

**Dipartimento di Scienze Chimiche e Geologiche
Università degli Studi di Modena e Reggio Emilia**

**Climate change and human impact
in a long-term perspective:
Palynology of Central Po Plain deposits
since the Lateglacial**



Eleonora Clò

PhD Course in
Models and Methods for Materials and Environmental Sciences
XXXIV Cycle – Academic Year 2020-2021

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TABLE OF CONTENTS

ABSTRACT	1
RIASSUNTO.....	2
ABBREVIATIONS.....	3
1 INTRODUCTION	4
1.1 STUDY AREA: LOCAL ENVIRONMENTAL SETTINGS	4
1.1.1 CURRENT CLIMATE AND LOCAL METEOROLOGICAL-HYDROLOGICAL DATA	5
1.1.2 NATURAL AND SEMI-NATURAL FLORISTIC COMPOSITION AND VEGETATION.....	7
1.1.3 AGROSYSTEM	12
1.2 PREHISTORIC AND HISTORICAL CONTEXT	17
1.2.1 ARCHAEOLOGICAL INTEREST OF THE AREA: THE TERRAMARA S. ROSA DI POVIGLIO.....	22
1.3 LATEGLACIAL TO HOLOCENE CLIMATE OSCILLATIONS IN NORTHERN ITALY	26
1.4 PALYNOLOGICAL STUDIES IN THE PO PLAIN	29
2 AIMS.....	34
2.1 RESEARCH TOOLS AND OBJECTIVES	34
2.2 MAIN TYPES OF BIOLOGICAL PROXIES CONSIDERED	36
2.2.1 POLLEN.....	37
2.2.2 NON-POLLEN PALYNOMORPHS (NPPs).....	40
3 MATERIALS AND METHODS	41
3.1 CORING	41
3.1.1 STRATIGRAPHY AND CHRONOLOGY OF THE CORES	43
3.1.2 POLLEN SAMPLING	53

3.2 POLLEN AND NPPs EXTRACTION	55
3.3 IDENTIFICATION AND COUNTS	56
3.4 DATA PROCESSING	57
3.5 DETECTION OF MOLECULAR BIOMARKERS	62
4 RESULTS	63
4.1 POLLEN	63
4.1.1 CONCENTRATION AND COUNTS	63
4.1.2 STATE OF PRESERVATION	63
4.1.3 FLORISTIC RICHNESS.....	64
4.1.4 GENERAL POLLEN SPECTRA AND MAIN SUMS	64
4.2 NON-POLLEN PALYNOMORPHS	65
4.3 POLLEN ZONES	67
4.3.1 POLLEN ZONE 1	68
4.3.1.1 POLLEN SUBZONE 1A	68
4.3.1.2 POLLEN SUBZONE 1B	68
4.3.2 POLLEN ZONE 2	68
4.3.2.1 POLLEN SUBZONE 2A	69
4.3.2.2 POLLEN SUBZONE 2B	69
4.3.3 POLLEN ZONE 3	69
4.3.3.1 POLLEN SUBZONE 3A	70
4.3.3.2 POLLEN SUBZONE 3B	70
4.3.3.3 POLLEN SUBZONE 3C	70
4.3.4 POLLEN ZONE 4	71
4.3.4.1 POLLEN SUBZONE 4A	71
4.3.4.2 POLLEN SUBZONE 4B	71
4.3.4.3 POLLEN SUBZONE 4C	72
4.4 SURFACE SOILS	76

5 DISCUSSION.....	79
5.1 TECHNICAL ASPECTS AND RESEARCH LIMITS	80
5.2 DISCUSSION ABOUT THE CHRONOLOGY	82
5.3 STATISTICAL PROCESSING TO DETECT FLORA AND VEGETATION TRANSFORMATIONS.....	87
5.3.1 PRINCIPAL COMPONENT ANALYSIS	87
5.3.2 MULTIVARIATE CURVE RESOLUTION-ALTERNATING LEAST SQUARES	92
5.3.3 CONSTRAINED INCREMENTAL SUMS OF SQUARES CLUSTER ANALYSIS (CONISS)	96
5.4 FLORA AND VEGETATION RECONSTRUCTION	103
5.4.1 FLORISTIC COMPOSITION	103
5.4.2 PALYNOLOGICAL INDEX OF ALLUVIAL TRANSPORT	105
5.4.3 <i>RIVULARIA</i> HETEROCYSTS IN THE STRATIGRAPHIC RECORD.....	111
5.4.4 MODERN POLLEN RECORDS	117
5.4.5 QUANTITATIVE RECONSTRUCTIONS OF VEGETATION	121
5.4.6 EVIDENCE FROM THE THREE CORES	127
5.4.6.1 N-S3 CORE.....	128
5.4.6.2 C-S1 CORE.....	140
5.4.6.3 F-S2 CORE	147
5.4.7 VEGETATION HISTORY AND LAND USE TRANSFORMATIONS IN THE LAST 19,000 YEARS	151
5.5 CONNECTED RESEARCH FOR DEEPENING PARTICULAR ASPECTS REGARDING THE TERRAMARE CULTURE	156
 6 CONCLUSIONS AND PERSPECTIVES	 160
6.1 THE LONG-TERM LANDSCAPE EVOLUTION	160
6.2 HUMANS AS SHAPING AGENT OF THE LANDSCAPE	163
6.3 A DEEPER LOOK INTO THE LAND USE OF THE TERRAMARA S. ROSA DI POVIGLIO	164
6.4 CONCLUSIVE REMARKS AND FUTURE PERSPETIVES	166
 REFERENCES	 168

ACKNOWLEDGEMENTS	205
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APPENDIXES

ABSTRACT

As a floodplain in which complex human–water systems with dynamic behaviors were established, the Po Plain is considered a key area for the interpretation of long-term relationship between human populations and the environment because of the strategic location between the Mediterranean and continental Europe. This research focuses on the ambitious aim of investigating local and regional environmental changes that occurred in the Po River floodplain as a twofold result of climate changes and human actions during the Holocene. To reach the goal, three terrestrial cores were drilled in the Central Po Plain at different distances from the Terramara S. Rosa di Poviglio, which has been investigated for more than 35 years thanks to the archaeological excavation directed by Maria Bernabò Brea, Mauro Cremaschi and, and in recent years, Andrea Zerboni. All authorizations to carry out the excavation and sampling has been released by the SABAP-BO (MiC) to the Dipartimento di Scienze della Terra “A. Desio” of the Università degli Studi di Milano. The cores were included in the SUCCESSO-TERRA Project (PRIN-20158KBLNB; P.I. M. Cremaschi, A. Zerboni – Università degli Studi di Milano). Concerning the different distances from the archaeological site at which the cores were drilled, it has been decided to name the sequences PVG N-S3 (Near-S3), PVG C-S1 (Central-S1) and PVG F-S2 (Far-S2). Pollen samples were taken throughout the depth of the cores but only the N-S3 core was analysed entirely (77 samples), while palynological analysis of the other cores was carried out for more recent levels according to the focus on the detection of vegetation changes during the Holocene (90 and 28 samples were analysed for the C-S1 and the F-S2 core, respectively). Problems with the reliability of radiocarbon dates influenced by the reservoir effect was attested. Chronology is still in a preliminary stage and will be updated soon with Optically Stimulated Luminescence and possible correlations with other cores in the study area.

Four main pollen zones describing events and flora and vegetation transformations were identified according to the cluster analysis and visual examination. Pollen spectra show consistent trends and possible correlations throughout the three cores with a long-term picture of large-scale vegetation changes. At the same time, the collection of the three cores at short distances from each other offers the great opportunity to investigate different features and local variations, among which the main evidence is the decrease in anthropogenic pressure at a greater distance from the settlement. Different statistical elaborations (Principal Component Analysis and Multivariate Curve Resolution-Alternating Least Squares) have provided consistent results which contributed positively to the discussion of the detailed information from pollen data. MCR-ALS has never been applied in Palynology and the results obtained reveal the potential of this method for palynological investigations. The application of statistical methods for quantitative reconstruction of vegetation from pollen data have been deepened at the University of Bergen (Norway).

According to the stratigraphy and the possible comparison with the main reference pollen records for the study area, the bottom of the cores could be probably intercepted most of the Lateglacial. Climatic events and the human footprint are certainly reflected in the pollen spectra as part of a single complex dynamic system, from times when climate and ecosystem dynamics were the main factors of vegetation changes to others in which human populations play an increasingly important role with a permanent and extensive impact on the environment up to the current condition.

Keywords

POLLEN, HOLOCENE, PALAEOENVIRONMENT, TERRAMARE, BRONZE AGE

RIASSUNTO

La Pianura Padana ha fatto da teatro a complesse relazioni dinamiche tra uomo ed ecosistema fluviale che sono le basi di una vera e propria rivoluzione culturale, sicuramente favorita dalla posizione strategica di questo territorio posto tra il Mediterraneo e l'Europa continentale. Questa ricerca si pone l'ambizioso obiettivo di indagare i cambiamenti ambientali avvenuti nella pianura alluvionale del fiume Po durante l'Olocene, come conseguenza di fattori climatici e azioni antropiche che hanno modificato il territorio a scala locale e regionale. A tal fine, tre carotaggi terrestri sono stati eseguiti a diverse distanze dalla Terramara S. Rosa di Poviglio, indagata da oltre 35 anni grazie a numerose campagne di scavo dirette da M. Bernabò Brea, M. Cremaschi, e negli ultimi anni A. Zerboni. Tutte le autorizzazioni allo scavo e al campionamento sono state concesse dal SABAP-BO (MiC) al Dipartimento di Scienze della Terra "A. Desio" dell'Università degli Studi di Milano. I carotaggi sono stati inclusi nel progetto SUCCESSO-TERRA (PRIN-20158KBLNB; coord. M. Cremaschi, A. Zerboni - Università degli Studi di Milano). I carotaggi sono stati nominati PVG N-S3 (Near-S3), PVG C-S1 (Central-S1) e PVG F-S2 (Far-S2) in accordo con le diverse distanze di campionamento dal sito archeologico. Campioni pollinici sono stati prelevati lungo tutte le carote ma solo la N-S3 è stata analizzata interamente (77 campioni), mentre l'analisi palinologica delle altre sequenze è stata effettuata sui livelli più recenti secondo l'obiettivo di indagare i cambiamenti della vegetazione durante l'Olocene (90 e 28 campioni rispettivamente per C-S1 e F-S2). La cronologia è ancora in una fase preliminare, alcune date al radiocarbonio sono state rifiutate per problemi di sovrastima riferibili all'effetto serbatoio, e presto sarà implementata con luminescenza otticamente stimolata e possibili correlazioni con altre sequenze campionate nell'area di studio.

Quattro zone polliniche sono state identificate in accordo con i risultati della cluster analysis e all'analisi visiva delle curve polliniche. Gli spettri pollinici ottenuti forniscono una dettagliata immagine dei cambiamenti della vegetazione su larga scala grazie alla presenza di caratteristiche coerenti e possibili correlazioni lungo tutte le sequenze. Allo stesso tempo, il campionamento dei tre carotaggi a breve distanza l'uno dall'altro permette di indagare evidenze locali, tra cui la principale è la diminuzione della pressione antropica a maggiore distanza dall'insediamento. Diverse elaborazioni statistiche (Principal Component Analysis and Multivariate Curve Resolution-Alternating Least Squares) hanno contribuito positivamente alla discussione delle informazioni ottenute dai dati pollinici. L'analisi multivariata MCR-ALS non è mai stata applicata in Palinologia e i risultati ottenuti rivelano le potenzialità di questo metodo per indagini palinologiche. L'applicazione di metodi statistici per la ricostruzione quantitativa della vegetazione da dati pollinici è stata approfondita presso l'Università di Bergen (Norvegia).

In accordo con la stratigrafia e il confronto con le principali sequenze polliniche di riferimento per l'area di studio, i livelli più profondi delle carote intercettano probabilmente la maggior parte del Tardoglaciale. Gli eventi climatici e impronta ecologica dell'influenza umana sull'ecosistema si riflettono sicuramente negli spettri pollinici come parte di un unico complesso sistema dinamico, da tempi in cui le dinamiche climatiche ed ecosistemiche erano i principali fattori dei cambiamenti della vegetazione ad altri in cui l'impatto delle popolazioni umane ha un ruolo sempre più permanente ed esteso sull'ambiente fino alla condizione attuale.

Parole chiave

POLLINE, OLOCENE, PALEOAMBIENTE, TERRAMARE, ETÀ DEL BRONZO

ABBREVIATIONS

AP = Arboreal Pollen

API = Anthropogenic Pollen Indicators

BRAIN = Botanical Records of Archeobotany Italian Network

C-S1 = Central-S1

CONISS = Constrained Incremental Sum of Squares

F-S2 = Far-S2

GSSP = Global boundary Stratotype Sections and Points

LGM = Last Glacial Maximum

LOVE = LOcal Vegetation Estimates

LPPI = Local Pastoral Pollen Indicators

LRA = Landscape Reconstruction Algorithm

MCR-ALS = Multivariate Curve Resolution-Alternating Least Squares

MNT = Montale

N-S3 = Near-S3

NAP = Non-Arboreal Pollen

NPPs = Non-Pollen Palynomorphs

OJC = *Olea*, *Juglans* and *Castanea*

OSL = Optically Stimulated Luminescence

PCA = Principal Component Analysis

PPEs = Pollen Productivity Estimates

PVG = Poviglio

REVEALS = Regional Estimates of VEgetation Abundance from Large Sites

RSA = Relevant Source Area

RSAP = Relevant Source Area of Pollen

S. Rosa di Poviglio = Santa Rosa di Poviglio

SABAP-BO (MiC) = Soprintendenza Archeologia, Belle Arti e Paesaggio per la città metropolitana di Bologna e le province di Modena, Reggio Emilia e Ferrara (Ministero della Cultura)

SS = Surface Soil

VG = large village, “Villaggio Grande” in Italian

VP = small village, “Villaggio Piccolo” in Italian

1 INTRODUCTION

1.1 STUDY AREA: LOCAL ENVIRONMENTAL SETTINGS

The Po Plain is the largest landscape physiographic unit of northern Italy. Extended between the Alps, the Apennines, and the Adriatic coast, it is the most extensive plain in Italy with a surface of approximately 46,000 km² and an altitudinal range that reaches a maximum of 200 m a.s.l. The flatlands of the Veneto and Friuli regions are included in the Venetian-Friulian Plain, although present-day Venetian and Friulian rivers don't flow into the Po River. Altogether, they effectively combine into a single plain.

The Po River is the longest Italian watercourse (652 km) and crossed the floodplain with a 74,970 km² catchment area; it flows eastward from the western Alpine down to the Adriatic Sea (Castaldini et al, 2019). Along its path, the Po River intercepts affluents running down from the Alps, in the north, and the Apennines, in the south; some of them are draining lakes of glacial origins (i.e., the lakes Maggiore, Como, Iseo, and Garda). The altitude range of the drainage basin spanning from approximately 4 m b.s.l. in the Polesine sub-region that corresponds in the eastern part with the Po delta, up to ca. 2100 m a.s.l. in the southern Piedmont province of Cuneo (Pian del Re, Monviso) where the Po River originates.

The current morphological and lithological features of the Po Plain are the results of the action of ice and rivers due to the alternation of glacial-interglacial periods, especially during the Last Glacial period and the progressive glacial retreat. The complexity of this area derives from the synergy among different overlapping natural processes, such as spatial displacements of the coastline, tectonic movements, sediment supply from both Alpine and Apennine slopes, and anthropic factors related to the long-standing connection of this territory with human populations that, especially during the Holocene, affected the morphogenetic system of the territory (Castiglioni, 1997). The depositional system presents only alluvial fans on the Apennine side, while to the Alpine side is often linked with sediment transport caused by glacial processes. Both torrential fans and true fluvioglacial outwash plains alternate and overlap; they flatten out towards the low plain, where gravels are replaced by silty/sandy sediments. These originate specific feature dividing the lower plain from the upper part called the "spring line" or "spring belt" (Castiglioni, 1997; Muscio, 2002), where the surface water of the mountain streams spring out again from the underground.

Original low undulations related to the alluvial nature Po Plain are completely flattened in the current landscape because of the intense deforestation actions and natural erosive processes that shaped the floodplain in a large extension of flat agricultural patches.

The study area is located in the Central Po Plain, south of the Po River, at about 40 km north of the Tuscan-Emilian Apennine margin, in the province of Reggio Emilia between the Crostolo and Enza rivers (Fig. 1). This territory has been shaped since the Late Pleistocene/Early Holocene by the Apennine watercourses developing alluvial megafans with their sediments (Cremaschi & Nicosia, 2012; Rosselli, Molinari, & Severi, 2016; Rossi et al, 2002; Valloni & Baio, 2009). The texture of these fans is mostly composed by gravel and fine-textured alluvial sediments occur at their top (Cremaschi & Nicosia, 2012; Cremaschi, Storch, & Perego, 2017). Several spring watercourses flow along the Enza alluvial fan (Brandolini et al, 2018).

In this context, flank depression areas are delimited by the alluvial ridges of the Enza and Crostolo that emerge from the flat floodplain. These lower and poorly drained areas of floodplains are known in fluvial geomorphology as backswamps, where deposits of fine silts and clays accumulates during flooding events (Brandolini & Cremaschi, 2018).

Poviglio is located upon the outer margin of the Enza alluvial fan, on an area topographically higher than the surrounding plain, which originates from the margin of the Apennine and extends to the northwards to the center of the Po Plain (Castiglioni & Pellegrini, 2001). A large depression area still characterized the northern portion of the Enza alluvial fan (Castiglioni et al, 1997; Marchetti, 2002), which was occupied by an extended swamp known as Valle di Gualtieri during the Middle Ages (Brandolini & Cremaschi, 2018; Cremaschi & Marchesini, 1978).

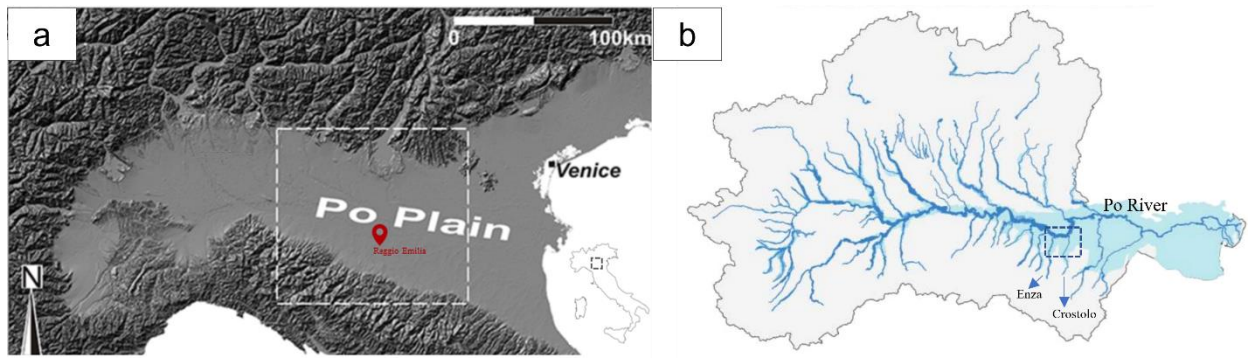


Figure 1. a) Digital terrain model of northern Italy illustrating the location of the study area (modified from Cremaschi et al, 2016); b) Main hydrographic network of the Po Plain.

Floodplains are complex human–water systems in which dynamic behaviors operated by both natural and human pressure are at the base of the development over time of different environmental conditions (Di Baldassarre et al, 2013). The long-last interaction between anthropogenic activities and natural resources usually affected the landscape development in fluvial environments, playing a crucial role in the onset of civilizations whose development usually based on the presence of fertile land and fresh water (Brandolini & Cremaschi, 2018). As a transition area between the Apennines and the Alps, the territory has always played a key role also because of its high biodiversity related to the habitat diversification, and its function as an ecological corridor. At the national level, the flora of Emilia-Romagna is very important both for the number of species and for the presence of endemic and relict species among them (Blasi & Biondi, 2017). All these aspects together with the strategic location midway between the Mediterranean and continental Europe, make the Po Plain a key area for the interpretation of long-term historical events and processes (Starnini, Biagi, & Mazzucco, 2017).

1.1.1 CURRENT CLIMATE AND LOCAL METEOROLOGICAL-HYDROLOGICAL DATA

The Modern Warm Period, 1950 AD to the present day, indisputably highlights the human overprint on global warm climate condition during the last 50 years (Margaritelli et al, 2016; Mensing et al, 2015), as clearly reported in IPCC special report: “*Human-induced warming reached approximately 1 °C (likely between 0.8 °C and 1.2 °C) above pre-industrial levels in 2017, increasing at 0.2 °C (likely between 0.1 °C and 0.3 °C) per decade (high confidence)*” (Masson-Delmotte et al, 2019).

The Po Plain has a special place in Europe because is in the southernmost part of the Central European phytogeographic region, whose boundary coincides with the ridge of the northern Apennines (Pignatti, 1979; Tomaselli, 1970). Therefore, this area is considered part of the temperate continental bioclimatic region (Rivas-Martínez, Penas, & Díaz, 2004), adjacent to the Mediterranean climatic system. The climate is characterized by significant temperature variations between cold winter and hot summer. Precipitations are moderate and occur the most in autumn and spring, while frequent atmospheric humidity peaks are responsible for the formation of thick fog during winter and muggy weather during summer.

From a meteorological point of view, record numbers were documented in the territory of Reggio Emilia in 2017. According to a study developed by the Geophysical Observatory of the UNIMORE Engineering Department (www.meteo.unimore.it), the weather station located at the San Lazzaro University campus indicated an average annual temperature of 14.7 °C, with a total rainfall of 586.9 mm. Daily extremes range from the lowest minimum temperature of -8.9 °C (recorded on January 7th), to the highest maximum temperature of 40.3 °C (reached on August 3rd). In this year, 89 days above 30 °C and 56 freezing days with a minimum temperature below 0 °C were recorded.

According to the values reported in the HydroMeteoClimate Report (*Rapporto Idrometeorologia*; ARPAE, 2021), the territory of Poviglio is characterized in the 2020 by a mean annual temperature of 14.4 °C and an annual precipitation sum of 794 mm. The availability of a long-term archive of climatic variability starting from the middle of the last century (1961-1990 with a good temporal continuity and data quality) reports a trend anomaly of 1.6 °C in average temperature and of 64 mm in precipitation (for regional values see Table 1). These anomalies are calculated as differences between the current value of the index and its average in the reference period, testifying longer and warmer summers, and shorter and less cold winters than in the past. The signal of the change in the pluviometric regime is more nuanced, even if it records strong irregularities between periods of heavy rain or intense thunderstorms and prolonged phases of drought.

Table 1. Regional average monthly values in 2020 and anomalies compared to the period 1961-1990 (ARPAE, 2021).

	GEN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Tmax (°C)	8.70	13.20	12.60	18.90	22.40	25.90	29.20	29.70	25.20	17.20	12.40	7.50	18.60
Tmin (°C)	0.50	2.30	2.60	5.80	11.00	13.90	16.00	17.50	13.40	8.00	5.00	2.10	8.20
Tmed (°C)	4.60	7.70	7.60	12.40	16.70	19.90	22.60	23.60	19.30	12.60	8.70	4.80	13.40
Prec (mm)	26.00	10.00	72.00	35.00	45.00	78.00	65.00	80.00	55.00	119.00	29.00	209.00	822.00
Anomaly Tmax (°C)	3.80	5.80	1.00	3.20	1.90	1.40	1.70	2.90	2.20	0.00	2.00	1.50	2.30
Anomaly Tmin (°C)	2.00	2.30	-0.10	-0.50	0.80	0.20	-0.10	1.60	0.40	-0.70	1.30	2.40	0.80
Anomaly Tmed (°C)	2.90	4.00	0.50	1.40	1.40	0.80	0.80	2.30	1.30	0.30	1.70	1.90	1.50
Anomaly prec (mm)	-47.00	-55.00	-10.00	-46.00	-28.00	12.00	14.00	9.00	-21.00	26.00	-79.00	130.00	-94.00

Regarding to the hydrological data (ARPAE, 2021), the average discharge of the Po River in 2020 was 1,383 m³/s, comparable with the average value of 1921-1970 (1,468 m³/s) and that of most recent years 2001-2019 (1,432 m³/s). The only significant anomalies occurred in April and November, when the average monthly rates were much lower than the average, and in October with values higher than the reference values (Fig. 2).

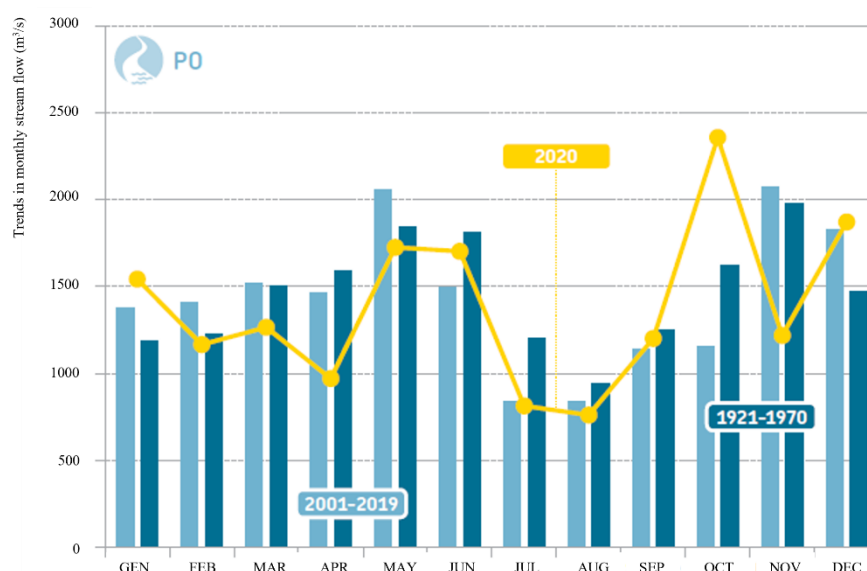


Figure 2. Po River, hydrometric section of Pontelagoscuro (FE). Average monthly flows of 2020 (yellow), of the period 1921-1970 (blue), and of the period 2001-2019 (light blue).

1.1.2 NATURAL AND SEMI-NATURAL FLORISTIC COMPOSITION AND VEGETATION

It is not easy to describe the Po Plain from a floristic and vegetational point of view because natural plant communities have been reduced or canceled from the territory. In fact, it represents the area that more than any other in Italy has undergone transformations because of an intense, capillary, and continuous human action over the long term. However, it is possible to describe potential vegetation in absence of anthropogenic disturbance through the integration of knowledge on surviving examples of lowland forests (e.g., Bosco Fontana, MN; and Bosco della Panfilia, FE), pollen records (Accorsi et al, 1999; Bosi et al, 2015, 2018; Cremaschi et al, 2016; Dalla Longa et al, 2019; Mercuri et al, 2012; Ravazzi et al, 2013; Valsecchi et al, 2006; Vescovi, Kaltenrieder, & Tinner, 2010) and climatic and pedological aspects (Segadelli et al, 2020).

Vegetation assemblages reflect mixed influences from the Central European phytogeographic region and the Mediterranean area. The boundary between these two regions is usually well marked along the Apennine ridge but, in the easternmost part of the region, the coastal vegetation occurs as a mix of Central European and euri-Mediterranean taxa (Ferrari, 1996). However, plants diversity of the Emilia-Romagna is primarily determined by the orography and five altitudinal vegetation bands are distinguished by the bioclimatic gradient in relation to the altitude gradient (Blasi, 2010; Fig. 3):

- **Alpine belt** of very limited extension **above 2000 m a.s.l.** The landscape consists of discontinuous primary grasslands with *Trifolium alpinum*, *Silene acaulis* subsp. *excapae*, and *Fetusa robustifolia*, together with plant communities dominated by mosses and lichens;
- **Subalpine (or boreal) belt** characterized by moors of *Vaccinium myrtillus* and *V. gaultherioides* above the timberline (**over 17000 m a.s.l.**). The extension of the moors is currently reduced compared to the potential due to the profound changes made by human activities with the consequent development of grazing areas dominated by *Nardus stricta*;
- **Mountain (or sub-Atlantic) belt** extends **between 900 and 1700 m a.s.l.** throughout the region. The landscape is characterized by forest communities dominated by *Fagus sylvatica*, with fir trees (*Abies alba* and *Picea abies*) alternate with bushes, grasslands, and crops. *Castanea sativa* woods is consider an anthropogenic landscape which replaced the beech forest especially at lower altitudes. Thickets or bushes of hygrophilous trees and shrubs (*Salix alba*, *S. purpurea*, *S. eleagnos*, *S. triandra*, *S. caprea*, and *Alnus glutinosa*) characterized wetlands and streams;
- **Sub-mountain (or sub-Mediterranean) belt** extends **below 800-900 m a.s.l.** The natural vegetation is represented by mixed deciduous forests (*Quercus cerris*, *Q. pubescens*, *Q. petraea*, *Ostrya carpinifolia*, *Carpinus betulus*, *Fraxinus ornus*, *Acer campestre*, *A. opulifolium*, *Sorbus torminalis*, and *S. domestica*) with mesophilic or thermophilic features in relation to topography and substrate. Hygrophilous thickets with *Salix alba*, *S. purpurea*, *Populus nigra*, and *Alnus glutinosa* are typical along watercourses. Abandoned agricultural land are well documented, and bushes, sparse shrubs and grasslands represent dynamic stages for the recovery of the forest cover;
- **Internal plain belt** is characterized by natural oak-hornbeam vegetation with *Quercus robur*, *Carpinus betulus*, and *Acer campestre*. However, the natural vegetation, confirmed by historical data and palynological research, has almost completely disappeared because most of the territory is profoundly modified by human activity. Natural riparian thickets consisting of *Populus alba*, *Quercus robur*, *Fraxinus angustifolia*, and *Ulmus* are relevant only along watercourses. The **coastal area** partly preserves the natural vegetation with mixed mesoxerophilous oak woods (composed by *Quercus robur*, *Carpinus betulus*, *Q. pubescens*, *Fraxinus ornus*, *Q. ilex*, and *C. orientalis*) and pine forests (with *Pinus pinea* and *P. pinaster*) of ancient cultural origin.

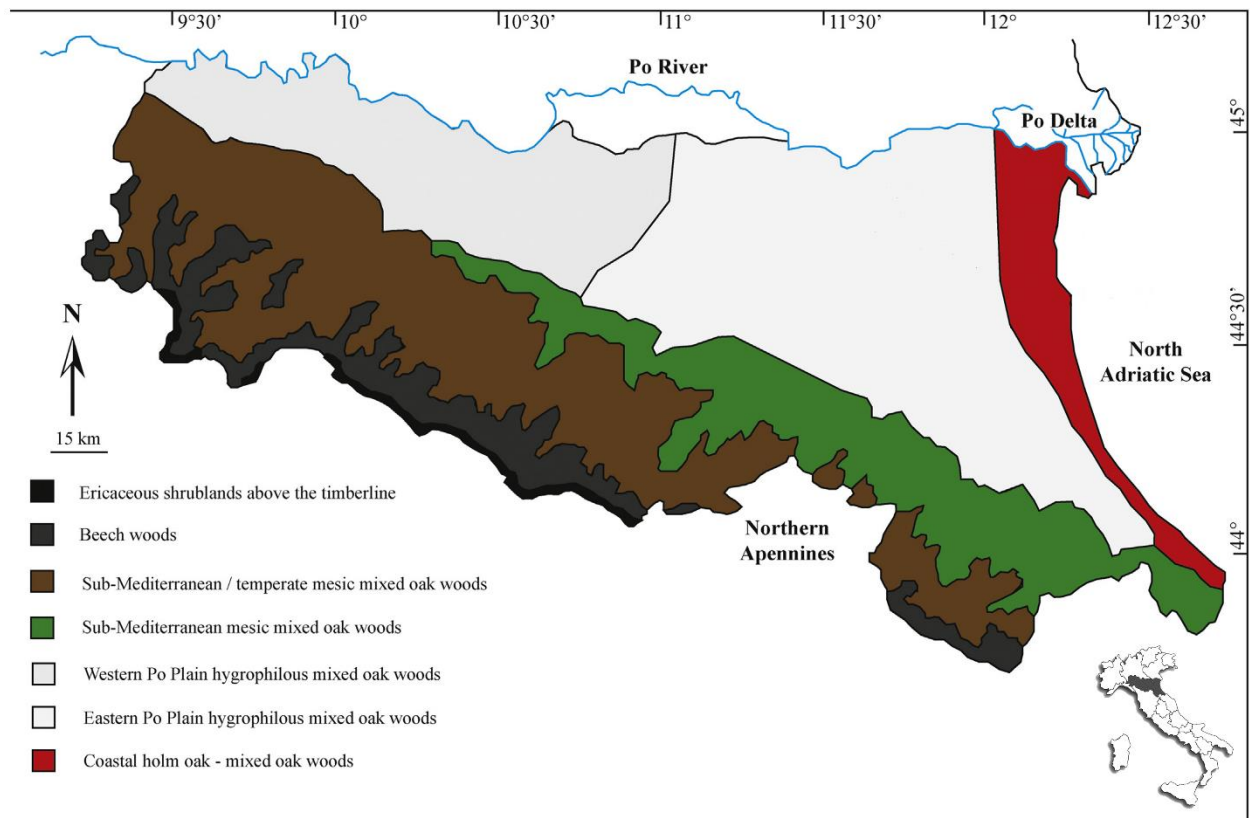
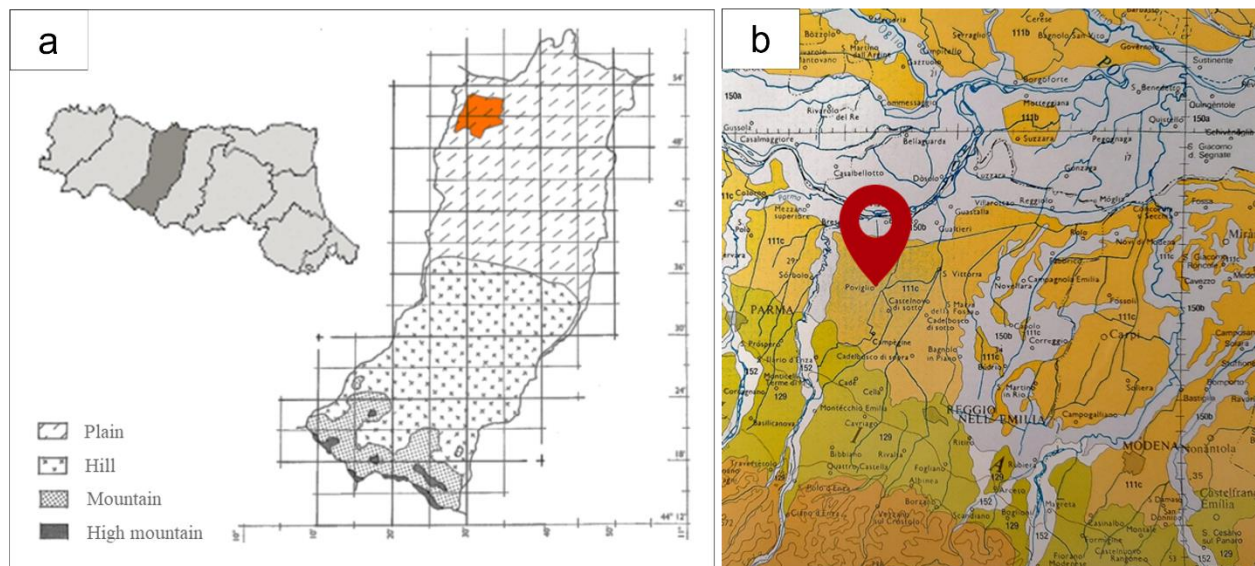
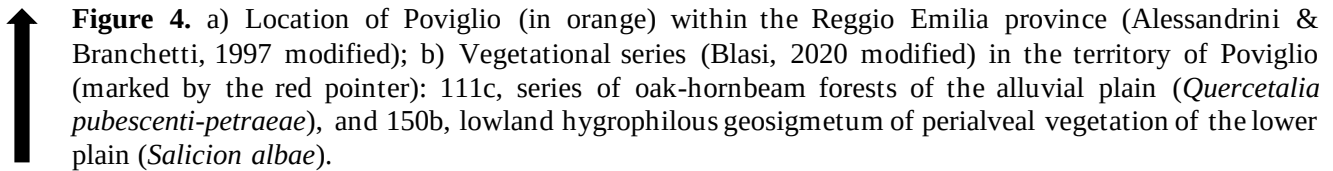


Figure 3. Vegetation zonation of the Emilia-Romagna Region of northern Italy based on Ferrari (1996) and partly redrawn from Cacciari et al (2020).

The territory of Poviglio is located in the central part of the plain and its mature vegetation corresponds to the phytosociological order *Quercetalia pubescenti-petraeae* Br.-Br. (1931), which borders the lowland hygrophilous geosigmetum of perialveal vegetation of the lower plain (*Salicion albae* Soó 1930 em. Moor 1958) and describes a mixed forest community of thermophilous deciduous species typical of alluvial deposits of clays, sands, and silts (Blasi, 2010; Ferrari, 1996; Fig. 4).



 **Figure 4.** a) Location of Poviglio (in orange) within the Reggio Emilia province (Alessandrini & Branchetti, 1997 modified); b) Vegetational series (Blasi, 2020 modified) in the territory of Poviglio (marked by the red pointer): 111c, series of oak-hornbeam forests of the alluvial plain (*Quercetalia pubescenti-petraeae*), and 150b, lowland hygrophilous geosigmatum of perialveal vegetation of the lower plain (*Salicion albae*).

The white oak (*Quercus pubescens* Willd.) is the most widespread and dominant tree. This series can be divided into a shrubby stage of the *Prunetalia spinosae* Tüxen 1962, mainly characterized by old man's beard (*Clematis vitalba* L.), dogwood (*Cornus sanguinea* L.), hawthorn (*Crataegus monogyna* Jacq.), European spindle tree (*Euonymus europaeus* L.), common privet (*Ligustrum vulgare* L.), rock cherry (*Prunus mahaleb* L.), black thorn (*Prunus spinosa* L.), dog rose (*Rosa canina* L.), and young arboreal species that can renew the forest, as in the case of field maple (*Acer campestre* L.). Shrub formations can be present, as well as in clearings and edges of deciduous oak woods, also in open areas as colonizing vegetation of abandoned pastures, fields, and river sediments (Ubaldi, 2008). The class *Festuco-Brometea* Braun-Blanquet & Tüxen ex Braun-Blanquet (1949) represents the herbaceous stages (Blasi, 2010) and includes dry grassland and steppe vegetation (Terzi, Di Pietro, & Theurillat, 2016).

The mixed mesic oak wood formed a wide vegetation belt throughout most of the region. The oak-hornbeam woodlands (*Querco-Carpinetum boreoitalicum* Pign. 1953) are considered the climax vegetation of the Po Plain, even if no trace remains in the southern Po Plain. It is physiognomically characterized by the dominance of pedunculate oak (*Quercus robur* L.) and hornbeam (*Carpinus betulus* L.), together with smooth-leaved elm (*Ulmus minor* Mill.), hop-hornbeam (*Ostrya carpinifolia* Scop.), *Acer campestre*, common ash (*Fraxinus excelsior* L.), and small-leaved lime (*Tilia cordata* Mill.). This wood changes its floristic composition based on the variations, even modest ones, of the morphology and structure of the soils and the depth of the aquifer (Blasi, 2010). The typical plant formations, the oak-hornbeam, is often recognizable with hygrophilous variants with southern ash (*Fraxinus angustifolia* subsp. *oxycarpa* (M. Bieb. ex Willd.) Franco & Rocha Afonso) and *Ulmus minor*.

Natural vegetation is preserved only in few areas, generally it is still spread near rivers and fresh-water habitats. Hygrophilous woods are represented at the mature stage by the *Salicetum albae* Issl. (1926) with woods subject to autumn and spring floods. The mature stage is represented by woods with white willow (*Salix alba* L.) and black poplar (*Populus nigra* L.), with black elder (*Sambucus nigra* L.) to form the shrub layer and creeping bentgrass (*Agrostis stolonifera* L.), common mugwort (*Artemisia vulgaris* L.), and stinging nettle (*Urtica dioica* L.) as the herbaceous component (Alessandrini et al, 2010; Blasi, 2010). In swampy environments, with water no longer subject to horizontal flow and dark soil, the dominance of *Salix* is progressively replaced by black alder (*Alnus glutinosa* (L.) Gaertn.).

Stagnant freshwater vegetation is distributed in a mosaic pattern. Starting from the deeper water zone, the following vegetation associations are identified:

- Associations of floating hydrophytes above and below the water surface characteristic of *Lemnetea* (*Lemnetum gibbae*, *Lemno-Spirodeletum polyrrhizae*, *Lemno minoris-Salvinietum natantis*, *Hydrocharitetum morsus-ranae*, *Ceratophylletum demersi*, *Lemno-Utricularietum vulgaris*, *Utricularietum neglectae*) with duckweed (*Lemna minor* L. and *L. gibba* L.), common duckmeat (*Spirodela polyrrhiza* (L.) Schleid.), floating watermoss (*Salvinia natans* L.), and water fern (*Azolla caroliniana* Willd.).
- Associations of rooting hydrophytes totally submerged or emerging with leaves and flowers (*Potametea*). *Nymphoidetum peltatae* dominated in shallow water by fringed water lily (*Nymphoides peltata* (S.G. Gmel.) Kuntze); *Nymphaetum albo-lutae* in calm and eutrophic waters with European white water lily (*Nymphaea alba* L.), yellow water lily (*Nuphar lutea* (L.) Sm.), and willow grass (*Polygonum amphibium* L.).
- Helophyte associations of *Phragmition*. Reeds of *Phragmitetum vulgaris* of shallow water; *Typhetum angustifoliae* and *Typhetum latifoliae* of deeper waters; *Scirpetum lacustris* of deep water; *Scirpetum maritimi* of surface water; hygrophilous grasslands of *Typhoides arundinacea* (L.) Moench.

- Associations of hygrophilous species of *Magnocaricion*. *Caricetum acutiformis* in wet meadows rich in organic substances; *Leucojo-Caricetum elatae* typical of long-flood wet meadows; *Holoschoeno-Juncetum subnodulosi* of wet meadows with short flooding.
- Long-flooded wet grassland associations of *Molinio-Arrhenatheretea*.
- White willow riparian woods (*Salicetum albae* Issl. 1926) subject to autumn and spring floods, with *Salix alba*, white poplar (*Populus alba* L.) and *Ulmus minor*, *Cornus sanguinea*, alder buckthorn (*Frangula alnus* Mill.), *Clematis vitalba*, and common hop (*Humulus lupulus* L.).
- Seasonally flooded hygrophilous woods belonging to the association *Clematido viticellae-Quercetum roboris*, consisting of *Quercus robur*, *Fraxinus angustifolia* subsp. *oxycarpa*, *Populus alba*, *Ulmus minor*, *Salix alba*, and *Acer campestre*.

The study area is recognized as having a **high naturalistic value**. Below will be described a Special Area of Conservation (Fontanili di Corte Valle Re) with 8 habitats of community interest, and an Ecological Rebalancing Areas (Oasi Ex Cave Corazza).

Fontanili di Corte Valle Re

The **Fontanili di Corte Valle Re** (<https://www.riservavallere.it/>) are included into the Natura 2000 protected areas network, the main tool of the European Union policy established under the Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora.

A nature reserve was established in this area in 1992 and the site was proposed as Sites of Community Importance (SCI) in 1995. Since 2019 it is designated as **Special Area of Conservation** (SACs; **code IT4030007** - National legal reference of SAC designation: DM 13/03/2019 - G.U. 79 03-04-2019) and extends for 877 hectares in plain between the municipalities of Campegine, Reggio Emilia and Sant'Ilario d'Enza (longitude: 10.5328; latitude: 44.7672). The site includes the *Riserva naturale regionale Fontanili di Corte Valle Re* and the *Area di Riequilibrio Ecologico Fontanili media pianura reggiana* (Formulario Natura 2000 del sito IT4030007, 2019 retrieved from <https://ambiente.regione.emilia-romagna.it/it/parchi-natura2000/rete-natura-2000/siti/it4030007>; Fig. 5).



Figure 5. a) Natura 2000 sites in the Province of Reggio Emilia – the municipality of Poviglio is marked by the red pointer; b) *Riserva naturale regionale Fontanili di Corte Valle Re* (green line) and *Area di Riequilibrio Ecologico Fontanili media pianura reggiana* (orange line) (Regione Emilia-Romagna, 2021).

The territory has an intensely agricultural connotation (with the dominance of arable land with wheat, corn, alfalfa, irrigated forage meadows and stable meadows) and often it is patches with the presence of numerous *fontanili* (“spring”) and canals with reeds and small riparian woods. Springs are phenomena related to the outflow of deep waters that are induced to rise to the surface (Muscio, 2002). The current springs are among the last remnants of a resurgence system that until a few decades ago dotted the Apennine margin along the alluvial fans of the main waterways. Today this type of environments has almost disappeared due to crop water requirements that have caused a drastic lowering of the aquifers. The clear water that comes out has a temperature between 11 and 17 °C throughout the year, favoring the development of vegetation even during winters with the formation of small clouds of steam and microhabitats with suitable conditions for the development of different plant associations (Regione Emilia-Romagna, 2021). Broadleaved pondweed (*Potamogeton natans* L.) is dominant in still water, especially in the central part of springs. Pond water-starwort (*Callitriche stagnalis* Scop.), fool’s-water cress (*Helosciadium nodiflorum* (L.) W.D.J. Koch) and watercress (*Nasturtium officinale* W.T. Aiton), together with *Lemna minor*, American waterweed (*Elodea canadensis* Michx.) and whorl-leaf watermilfoil (*Myriophyllum verticillatum* L.), expand to fully cover zones with reduced depth and speed of the water. Floating populations with long and thin leaves of horned pondweed (*Zannichellia palustris* L.), sago pondweed (*Stuckenia pectinata* (L.) Börner), hairlike pondweed (*Potamogeton trichoides* Cham. & Schltdl.), and opposite-leaved pondweed (*Groenlandia densa* (L.) Fourr.) dominate where the flow of water is faster. The riparian belt is characterized by helophytes, including loads, rushes, cattails, and marsh reeds. Woods, when present, are dominated by species that once covered the marshy lowlands of the plain, such as *Alnus glutinosa*, grey willow (*Salix cinerea* L.), *Frangula alnus*, and common buckthorn (*Rhamnus cathartica* L.).

There are **8 habitats of community interest**, of which 1 priority, cover about 15% of the site's surface (Table 2).

Table 2. Council Directive 92/43/EEC of 21 May 1992: habitat types and their extensions (Formulario Natura 2000 del sito IT4030007, 2019). The priority habitats are marked with an asterisk.

Code	Priority	Habitat types (Annex I)	Cover [ha]
3150		Natural eutrophic lakes with Magnopotamion or Hydrocharition -type vegetation	0.17
3260		Water courses of plain to montane levels with the Ranunculion fluitantis and Callitriche-Batrachion vegetation	0.29
3290		Intermittently flowing Mediterranean rivers of the Paspalo-Agrostidion	0.33
6430		Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels	0.18
6510		Lowland hay meadows (<i>Alopecurus pratensis</i> , <i>Sanguisorba officinalis</i>)	110.13
91E0	*	Alluvial forests with <i>Alnus glutinosa</i> and <i>Fraxinus excelsior</i> (Alno-Padion, Alnion incanae, Salicion albae)	0.17
91F0		Riparian mixed forests of <i>Quercus robur</i> , <i>Ulmus laevis</i> and <i>Ulmus minor</i> , <i>Fraxinus excelsior</i> or <i>Fraxinus angustifolia</i> , along the great rivers (Ulmenion minoris)	1.93
92A0		<i>Salix alba</i> and <i>Populus alba</i> galleries	17.22

There are no plant species of community interest but rare and/or threatened species. Among them, there are summer snowflake (*Leucojum aestivum* L.), marsh fern (*Thelypteris palustris* Schott), fineleaf waterdropwort (*Oenanthe aquatica* L.), southern succisella (*Succisella inflexa* (Kluk) Beck), marsh valerian (*Valeriana dioica* L.), *Zannichellia palustris*, *Groenlandia densa*, marsh seedbox (*Ludwigia palustris* (L.) Elliott), floating sweet-grass (*Glyceria fluitans* (L.) R. Br.), brookweed (*Samolus valerandi* L.), and tape grass (*Vallisneria spiralis* L.).

Animal species of community interest are present, such as European pond tortoise (*Emys orbicularis* L.), Italian crested newt (*Triturus carnifex* Laurenti), spotted weather loach (*Cobitis tenia* L.), hermit beetle (*Osmoderma eremita* Scopoli), and large copper butterfly (*Lycaena dispar* Haworth). Among fish, noteworthy is the presence of the Italian spring goby (*Knipowitschia punctatissima* Canestrini), an endemic threatened species of the Po Plain with very limited ecological requirements exclusive of the springs. At least 15 species of birds are reported, among which the little bittern (*Ixobrychus minutus* L.) nests in the territory, while the others frequent the site regularly outside the reproductive period or during migrations and wintering (e.g., golden plover (*Pluvialis apricaria* L.) and hen harrier (*Circus cyaneus* L.) (Regione Emilia-Romagna, 2021).

The **Oasi Ex Cave Corazza**, within the municipality of Poviglio, is an Ecological Rebalancing Areas (ARE) included in the network of protected areas of the Emilia-Romagna Region. Due to the presence of stagnant and underground water, it represents a wet environment that preserves the original features of the Central Po Plain. The area, extending for 7 hectares, is characterized by periodically mown meadows with different degrees of humidity, natural grasslands, reeds, flooded bushes dominated by poplars, white willow and common elm, and areas subjected to recent reforestation interventions. The peripheral marshy area, characterized by submerged soil, is dominated by reeds (*Phragmites australis* (Cav.) Trin. ex Steud.) and cattails (*Typha latifolia* L.). Along the borders there are willows, white poplars, pedunculate oak and other tree species typical of moisture soils and tolerant occasional flooding. Furthermore, the presence of important “ecotone” or transition areas, consisting of long rows of hedges, represent a precious refuge for many animals.

1.1.3 AGROSYSTEM

Human contributions to a radical changes and loss of biodiversity and soil it is increasingly recognizable from local to global scale. Today, the Po Plain is one of the most productive territories in Italy. Human environments have replaced the natural potential vegetation and intensive industrial agriculture is widespread throughout the plain. Lowland woods have been replaced by crops, urban and industrial areas, artificial poplar groves, and other forms of land use that have radically changed the landscape. At the same time as the increase in anthropogenic footprint throughout the plain and the diffusion of forms of intensive exploitation of cultivated areas, there is also the expansion of natural and semi-natural environments in inland and mountain/hilly territory, as a result of agricultural abandonment with subsequent recolonization by forest communities. About three quarters of the land use changes that occurred in Italy between 1960 and 2017 are due to this loss of agricultural areas due to urbanization or the abandonment of crops (ISPRA, 2018). The CORINE Land Cover Programme, coordinated by the European Environment Agency (EEA), started in 1985 specifically for the detection and monitoring of land cover changes across Europe (<https://land.copernicus.eu/pan-european/corine-land-cover>; EEA, 2018). At national level, data about the changing on land use and land cover are released in open access format on the ISPRA website (<https://www.isprambiente.gov.it/it/attivita/suolo-e-territorio/coprezza-del-suolo/corine-land-cover>) and represent a valid tool available to the national institutional and scientific community.

As shown in Table 3 (ISPRA, 2018), the herbaceous cover is very extensive in the Emilia-Romagna Region, covering 1,182,416 hectares within which herbaceous crops are the most developed.

Table 3. Land cover (hectares and percentages) in Emilia-Romagna Region, based on 2017 data (ISPRA, 2018 modified).

Artificial Surfaces and Constructions	Natural open spaces with little or no vegetation	Trees	Shrubs	Herbs	Wet environments	
221645.00	9728.00	767810.00	29628.00	1182416.00	34063.00	Hectares
9.87	0.43	34.20	1.32	52.66	1.52	Percentages

Analysing the subdivision of the three main land use classes at the regional level, it can be observed that the most developed land use is related to agricultural practices (66.63% of the regional territory; Table 4), and 'intensive crops' cover values around 39% of the territory (ISPRA, 2018).

Table 4. Main land use (hectares) in Emilia-Romagna Region, based on 2017 data (ISPRA, 2018 modified).

Urban	Agricultural	Natural	
125117.00	1496034.00	624139.00	Hectares
5.57	66.63	27.80	Percentages

The entire regional territory is subject to intensive agriculture of cereals (mainly wheat and corn, while rice cultivation has declined sharply compared to 50 years ago; Table 5a), fodder (especially *Medicago* and other legumes), horticultural crops (among which the cultivation of tomatoes is the most extensive; Table 5b) and widespread fruit production (Rosaceae-Prunoideae including pears, peaches, and apricots; Table 5c). In 2019, vineyards in Emilia-Romagna were increased by 2.5% compared to 2018. Reggio Emilia is confirmed as one of the provinces with the largest area planted with vineyards (15.6%) on the regional territory. There are also several animal farms (pigs and cattle) to produce meat and dairy products (Brasili & Boccaletti, 2020).

Table 5. Agricultural production in Emilia-Romagna (2018-2019; Brasili & Boccaletti, 2020 modified): a) cereals; b) horticultural crops; c) fruit trees.

a	Hectares		b	Hectares				c	Hectares	
	2018	2019		2018		2019			2018	2019
Common wheat	135552,00	115420,00	Garlic - shallot	498,00		461,00		Apple	5111,00	5079,00
Durum wheat	55086,00	65438,00	Asparagus	725,00	1,00	752,00	1,00	Pear	19206,00	18808,00
Barley	21858,00	20015,00	Basil		4,00		4,00	Peach	4952,00	4267,00
Corn	56447,00	51584,00	Chard	104,00	13,00	121,00	13,00	Nectarines	7221,00	6802,00
Sorghum	28289,00	22712,00	Artichoke	90,00		94,00		Plum	4216,00	4270,00
Oats	320,00	336,00	Carrot	2178,00		2264,00		Apricot	6265,00	6303,00
Rice	5478,00	5713,00	Cauliflower	162,00		172,00		Cherry	2173,00	2142,00
Total	303030,00	281218,00	Cabbage	54,00		42,00		Kiwifruit	4850,00	4842,00
			Savoy cabbage	47,00		50,00		Olive	3990,00	4157,00
			Cucumber	21,00	38,00	19,00	40,00	Total	57984,00	56670,00
			Onion	2540,00		2813,00				
			Watermelon	1014,00	19,00	1020,00	17,00			
			Bean - green bean	4600,00	6,00	4615,00	6,00			
			Broad bean	36,00		36,00				
			Fennel	146,00		146,00				
			Strawberry	230,00	53,00	235,00	61,00			
			Endive	161,00	20,00	123,00	23,00			
			Lettuce	1297,00	75,00	1278,00	131,00			
			Eggplant	92,00	28,00	88,00	30,00			
			Melon	1463,00	226,00	1311,00	230,00			
			Potato	5274,00		5172,00				
			Pepper	32,00	10,00	37,00	10,00			
			Pea	4992,00	1,00	5739,00	1,00			
			Tomato	244,00	101,00	135,00	93,00			
			Industrial tomato	24125,00		26461,00				
			Parsley	58,00	14,00	64,00	6,00			
			Chicory	847,00	14,00	802,00	14,00			
			Radish	7,00	6,00	5,00	6,00			
			Celery	149,00	4,00	134,00	4,00			
			Spinach	1454,00	1,00	1313,00	1,00			
			Valerian		2,00		2,00			
			Pumpkins - courgettes	1712,00	78,00	1856,00	101,00			
			Others		267,00		412,00			
			Total	54352,00	981,00	57358,00	1206,00			
				Field	Greenhouse	Field	Greenhouse			

Archaeological and historical sources reveal that the territory of Poviglio had a strong agrarian connotation since pre- and protohistorical times (Bernabò Brea & Cremaschi, 2004). The study area was densely settled during the Roman Period, when an organization into a rural system began, known by the Latin term of “centuriation” (Bottazzi, Bronzoni, & Mutti, 1995). At the beginning of the 1st century BC a large roman villa rustica occupied the territory and extended about 5000 m² with an agricultural-productive sector and of a residential part (Mutti, 2007). A large occupation continues until the 2nd century AD, and then, in a minor way, up to the 5th century AD. The collapse of the Western Roman Empire (5th century AD) coincided with a progressive waterlogging of large floodplain areas, which for centuries seems to have lost its vocation for agricultural practices converted in fishing and water transport by boat until the 10th century AD (Brandolini et al, 2018; Racine, 1986). The later Renaissance large-scale land reclamation works profoundly shaped the landscape turning the wetland environment into the arable land visible today.

However, to this day the territory continues to be poorly drained, and the aquifer reaches arable layer in winter months. The landscape surrounding the study area (Fig. 6) is characterized by non-irrigated arable land use for annually harvested non-permanent crops, including cereals (e.g., wheat, corn, and sorghum), forage crops (e.g., alfalfa), and tomatoes. The strong agrarian connotation of the territory is also evidenced by the presence of farmhouses and agricultural building, including the one with a large and airy barn dating back to the ‘30s of the 20th century which is located on the edge of the archaeological area of the Terramara S. Rosa di Poviglio. Surrounded by an agricultural context that dominates the landscape, the municipality of Poviglio is characterized by discontinuous urban fabric concentrated mainly near the city (Fig. 7).



Figure 6. Landscape surrounding the archaeological area of the Terramara S. Rosa di Poviglio. The circles magnify an artificial wetland (top left), the agricultural building (top right), and crops (alfalfa at the top, and tomato residues at the bottom). Images of 19th August 2021, E. Clò.

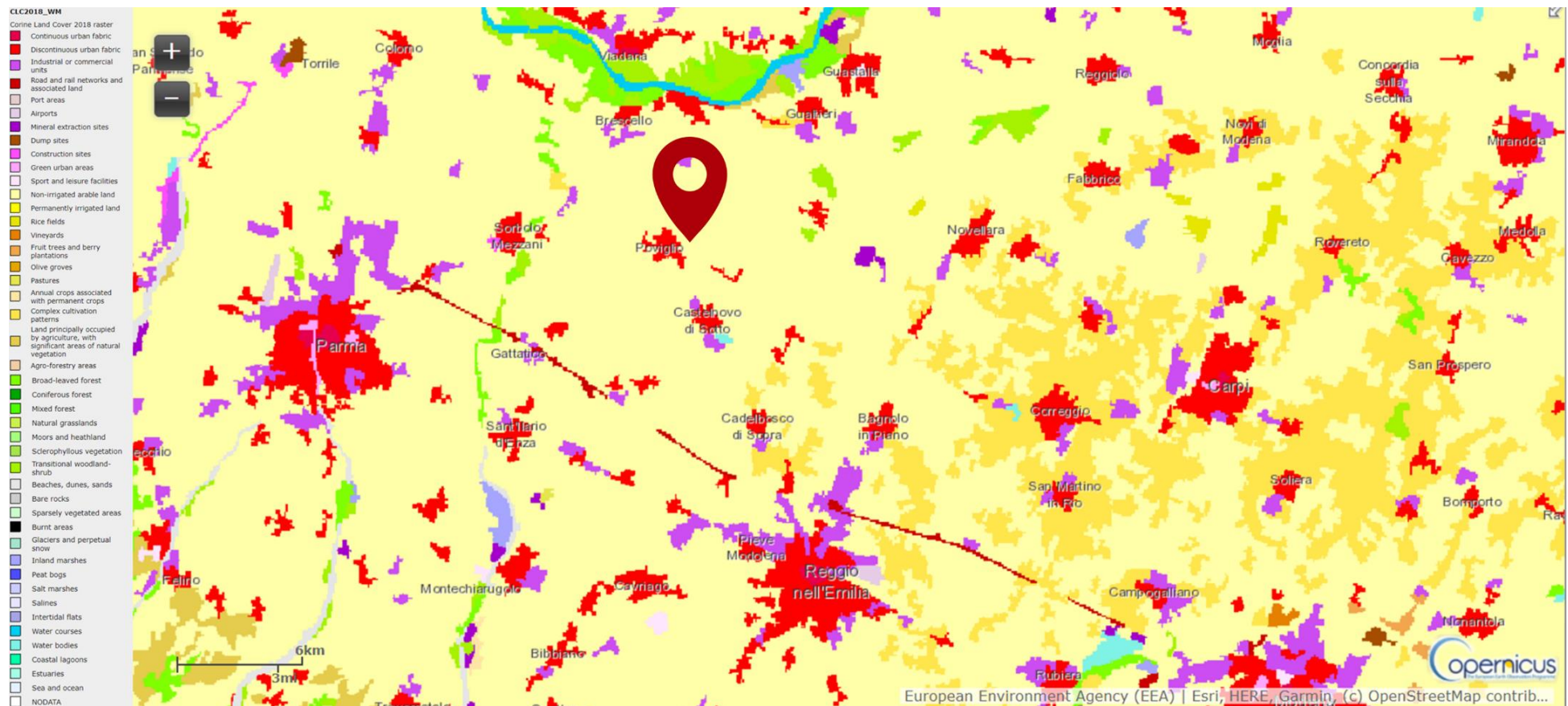


Figure 7. Image of the study area captured by CORINE Land Cover (CLC) 2018, Version 2020_20u. The municipality of Poviglio is marked by the red pointer.

Land expropriation for public reason

Starting from 1984, a research project on the site of the Bronze Age of S. Rosa in Fodico di Poviglio was carried out by the Superintendence for Archaeological Heritage of Emilia-Romagna and by the Department of Earth Sciences of the University of Milan, in agreement with the Municipality of Poviglio. The project, carried out for a long time in an informal way, was formalized in 2002. More recently, the Ministry of Cultural Heritage and Activities and Tourism, the General Direction of Antiquities and the Superintendence of Archaeological Heritage of Emilia-Romagna have expropriated much of the archaeological area for protection, research, and enhancement purposes (art. 95 and 97 of LD 42/2004).

Land consumption

Land consumption, land degradation and the loss of ecosystems functions continue in recent years in addition to the loss of natural vegetation. Soil consumption is the factor deriving from human action that has the greatest impact. This phenomenon involves the loss of natural resources because of the occupation of agricultural, natural, or semi-natural areas with the spread of artificial surfaces and the increasing density of buildings. The report on Land Consumption, Territorial Dynamics, and Ecosystem Services (ISPRA, 2020; Fig. 8), which provides an updated picture of the processes of land transformation on a national and local scale and analyses with particular attention the natural functions lost or threatened, reports land consumption in the territory of Poviglio in 2019 up to 493 hectares (11.3%) with an increase of 0.28 hectares compared to 2018.

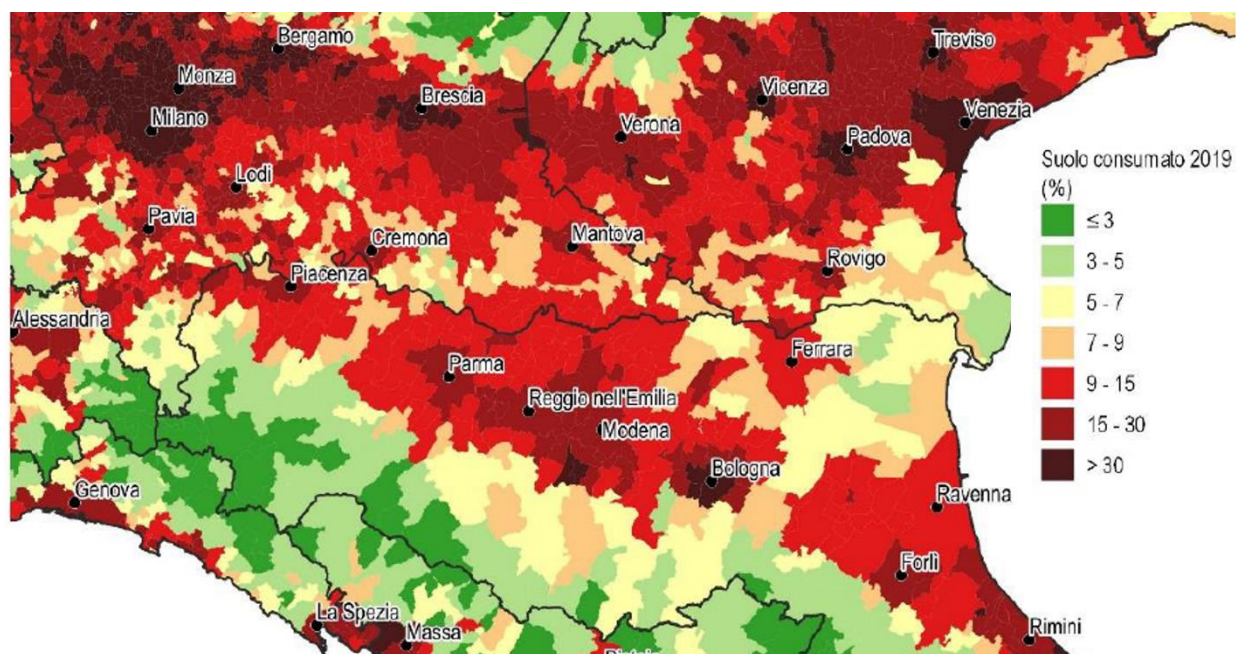


Figure 8. Land consumption in northern Italy, 2019 data (ISPRA, 2020 modified).

The speed of land consumption is still far from the European goals, which want to achieve sustainable land use to stop the process of land take by 2050 (European Union, 2016). The data confirm the critical land consumption in peri-urban and urban areas, where there is a continuous and significant spread of artificial surfaces, with an increase in density of buildings and decrease in agricultural and natural areas. The data confirm the advancement of phenomena such as urban dispersion and decentralization on the one hand and, on the other, the densification of urban areas that causes loss of natural areas within cities (ISPRA, 2020).

1.2 PREHISTORIC AND HISTORICAL CONTEXT

Gravettians and early Epigravettians

Human settlement locations have been related to the increased magnitude of glacial cycles and the occurrence of unstable climatic conditions since the Middle Pleistocene. Palaeolithic populations disappeared in large areas of continental Europe during the maximum extension of the ice sheets and large migrations took place through the corridors connecting the European regions (Hublin & Roebroeks, 2009). Biological, cultural, and social adaptations to the Late Pleistocene climate change of the Upper Palaeolithic human groups are not well understood yet. Although the absence of direct evidence, the petroarchaeological record suggests that the Great Adriatic Plain (GPP; a vast alluvial landscape composed by the Po Plain, the Venetian-Friulian Plain, and the Adriatic Plain) was systematically crossed by the Gravettians and the early Epigravettians hunter-gatherer groups, that could have seasonally settled along the Apennine belt, close to riverine environments in the alluvial plain and in Po River delta (Peresani et al, 2021). At the end of the LGM (corresponding to the collapse after 18 ka cal yr BP of the Alpine glaciers) the development of active riverine environments and new wetlands in the plain probably influenced human occupation along the river terraces, even if not yet detected.

Mesolithic

In the southern regions of Europe, the Mesolithic includes the development of Sauveterrian (Early Mesolithic) and Castelnovian (Late Mesolithic) cultures, from the beginning of the Holocene with a duration of more than 3000 years (Gobbo, 2010).

Mesolithic sites distribution spans all over the Emilian area, from the Apennines to the southern Po Plain (Biagi et al, 1980; Fontana, Ferrari, & Visentin, 2013), while no trace of Mesolithic evidence is documented in the Romagna area east of Bologna. Sites are present at different altitudes reflecting settlement strategies adopted by hunter-gatherers. Usually, the settlements are located close to rich ecological areas, such as wet environments with lithic raw materials sources, and in place that ensured a good control over the surrounding territory and an easy connection with watershed paths. Although the poor quality of the evidence mostly represented by lithic surface records, the distribution of the sites suggests the presence of small local groups which based their subsistence on different natural resources, which changed in relation to seasonal displacements.

Information about the Sauveterrian sites comes mainly from the plain (Collecchio near Parma; I.N.F.S., Casalecchio, and Cava Due Portoni near Bologna; Le Mose near Piacenza; Fontana, Ferrari, & Visentin, 2013, and references therein) and mid- and high-mountain sites, while in the hilly band the presence is less documented. Castelnovian sites also shows a greater presence in the plain (e.g., Riola and Stanga near Bologna; Gazzaro near Parma; Le Mose near Piacenza; Fontana, Ferrari, & Visentin, 2013, and references therein), and in the mountains.

Neolithic

The activities of human populations began to be a determining factor in shaping the natural setting during the Neolithic because of the strategic position of this area for economic and cultural exchanges (Cremaschi, 2000; Primas, 1997). The Neolithic is a moment of crucial importance for cultural history, when the transition from nomadic hunter-gatherers to more sedentary farmers was commonly triggered by the onset agriculture, which strongly changed the relationship between nature and human populations (Mercuri & Sadori, 2014). Technological, social, and economic aspects of prehistoric communities underwent profound changes and a complex process in this period, such as the domestication of plants and animals, the formation of permanent settlements even of considerable size, the production of objects in polished stone, a deep knowledge of ceramics, wood architecture, the exchange of raw materials and artifacts even over long distances reached also by navigation, new subsistence practices, and new ideologies and belief (Starnini,

Biagi, & Mazzucco, 2018). Subsistence economy based mainly on cultivations of cereals and legumes and on an early animal husbandry, which together provide an increasing food production and food independence to Neolithic people. Some evidence of deforestation is attested in the Po Plain. The decrease in forest cover was limited to small areas and the rapid regeneration of woods was favored by the instability and transience of the settlement (Cremaschi, 1990, 2000). In this context, shifting agricultural practices had minimal impact on the vegetation cover and were limited to the plain areas (Accorsi et al, 1999; Cremaschi & Nicosia, 2012).

The Early Neolithic sites (ca. 7550–7050/6450 cal yr BP) reflect short-period occupations in the Po Plain with a low impact on the local vegetation cover, and a preference for natural, open areas along the watercourses that provided a large range of natural resources, but also in well-sheltered positions to prevent river floods (Nisbet, 2013). Two cultural aspects are identified for the Early Neolithic in the Po Plain and are defined on the basis of their pottery forms and decorations also as groups or *facies* (Pearce, 2013; Starnini, Biagi, & Mazzucco, 2018, and reference therein): the Fiorano culture, whose distribution covers the eastern part of the Po Plain, corresponding to Emilia (e.g., Fiorano and Savignano near Modena), Veneto and north-western Tuscany regions, and the Vhò culture in Lombardy, part of Piedmont and western Emilia (e.g., Travo-Casa Gazza near Piacenza). Archaeobotanical records suggest that wild plants contributed to human subsistence together with domesticated cereals, pulses, and oil plants. Generally, barley, emmer, and einkorn were the main crop species, while pulses were poorly represented with lentil and pea (Rottoli & Castiglioni, 2009).

The chronology and the cultural context of the Middle and Late Neolithic sites (ca. 7050/6450–5450 cal yr BP) are still under debate. The Neolithic Square-Mouthed Pottery (SMP) culture (Bocca Quadrata; Ferrari, Mazzieri, & Steffè, 2006) is the most important culture extending from the Austrian Alps to central Tuscany, and from Piedmont and Liguria to Friuli (e.g., Palù di Livenza). There is not a clear picture of the further evolution of the crop spectra yet. However, archaeobotanical records suggest the introduction of poppy and a slightly increased cultivation of naked cereals and flax (Rottoli & Castiglioni, 2009). Furthermore, a significant part of the diet was represented by the collection of wild edible fruits, such as hazelnuts, grapes, and fruits of many Rosaceae (Pini, 2004; Rottoli & Castiglioni, 2009).

Chalcolithic (Copper Age)

The cultural context of northern Italy in the centuries between the end of the Neolithic Square-Mouthed Pottery culture and the beginning of the early Bronze Age is quite elusive. During the Copper Age (ca. 5450–4050 cal yr BP) until the Early Bronze Age contrasting situations of relationship between human groups and the environment coexist in the southern edge of the Po Plain. Sites still located in plain and forested context are attested (e.g., the sites of the Cultura del Vaso Campaniforme of S. Ilario and Rubiera-RE; Barfield, Cremaschi, & Castelletti, 1975), together with the occurrence of deforestation activities in some territories (as documented in the Rubiera Cave Corradini near Reggio Emilia; Cremaschi, 1997). Massive wood clearance through fire (*slash-and-burn*) is also documented all along the southern margin of the Po Plain and the adjoining Apennines (Cremaschi & Nicosia, 2012; Cremaschi et al, 2015). Among the archaeobotanical records, the first evidence of broomcorn millet and an increase in the use of cornelian cherry fruits and acorns may represent important innovations of the Chalcolithic (Rottoli & Castiglioni, 2009). During the Chalcolithic and the Early Bronze Age, an important shift in land management were adopted with the introduction of transhumant pastoralism (Cremaschi, Nicosia, & Salvioni, 2011)

Bronze Age

The Bronze Age is a prehistoric period that identifies civilizations using weapons, tools, and ornaments made with the copper-tin metal alloy (Guidi, 1988). On a large scale, the Bronze Age is the scene of new forms of economy and cultural, social, and political identity (Diamond, 2005; Harding, 2000; Kristiansen & Larsson, 2005; Peroni, 1997). In this context civilizations already belonging to the historical phase (eastern Mediterranean) coexisted with others without central power that had not yet adopted writing. Among the most evident consequences of the important improvements in knowledge, that triggered the evolution of complex forms of land use, there was the opening of the landscape characterized by treeless

lands for settlements and rural activities and shrubby lands for pastures, favoring the spread of semi-arid habitats as the most characteristic human environment (Mercuri et al, 2012; Ravazzi et al, 2020; Roberts et al, 2011).

In Italy, as in most of the European territory, this phase occurs during the last centuries of the 3rd millennium BC (ca. 4250 cal yr BP) until the beginning of the 1st millennium BC (ca. 2850 cal yr BP). The Bronze Age in northern Italy is generally divided following archaeological phases based on the technological, economic, and social development (Cremaschi & Gallinaro, 2021; Zamboni, 2021): *Early Bronze Age* (ca. 4250–3600 cal yr BP), *Middle Bronze Age* (ca. 3600–3275/3250 cal yr BP: BM1, 3600–3500 cal yr BP; BM2, 3500–3400 cal yr BP; BM3, 3400–3275/3250 cal yr BP), *Recent Bronze Age* (ca. 3275/3250–3100 cal yr BP), and *Final Bronze Age* (ca. 3100–2860 cal yr BP). But see also the Table 1 by Cardarelli in Mercuri et al (2015a).

In the Po Plain, the chronological interval in which the trajectory of the **Terramare culture** had developed spans from 3500 to 3120 cal yr BP and represents an original cultural phenomenon, which its own social model, land management, production, and commercial exchanges (Bernabò Brea & Cardarelli, 1997). This culture has developed for about 400 years with the simultaneous presence of more than 200 settlements and villages spread throughout the Emilia-Romagna Region at the acme period of this civilization (Bernabò Brea, Cardarelli, & Cremaschi, 1997). The role that the Terramare has assumed in European protohistory is well defined from a geographical and cultural point of view, as a strategic link between the Mediterranean and central Europe. This civilization has always represented an important reference of the Italian prehistory, although some long decades of crisis of the studies occurred from the first half of the 20th century until the '80s, when many new research fields have been developed. The origin of the term “*terramare*” is deeply rooted in the Emilian agricultural tradition of the 18th and 19th centuries. It derives from “*fertilizing lands*” (Cavedoni, 1864) with the features of small hills widespread throughout landscape of the Po Plain, often exploited as quarries of soil rich in organic substance. These fertile masses are stratified settlements of the Bronze Age that quarry excavations have strongly damaged, and sometimes destroyed. The sites are in the Central Po Plain (Fig. 9), especially in Emilia, from the Piacenza plain to the western edge of the Bologna area, with different concentrations throughout the territory. The cultural aspect of the terramare affects the whole territory between the high Mantuan plain and the Valli Grandi Veronesi area, while the southern border is marked by the Apennines. To the north, the territory occupied by the terramare populations is adjacent to the area characterized by the piles of Lake Garda, so much so that some authors speak of a pile dwelling-terramare culture (De Marinis, 1997)

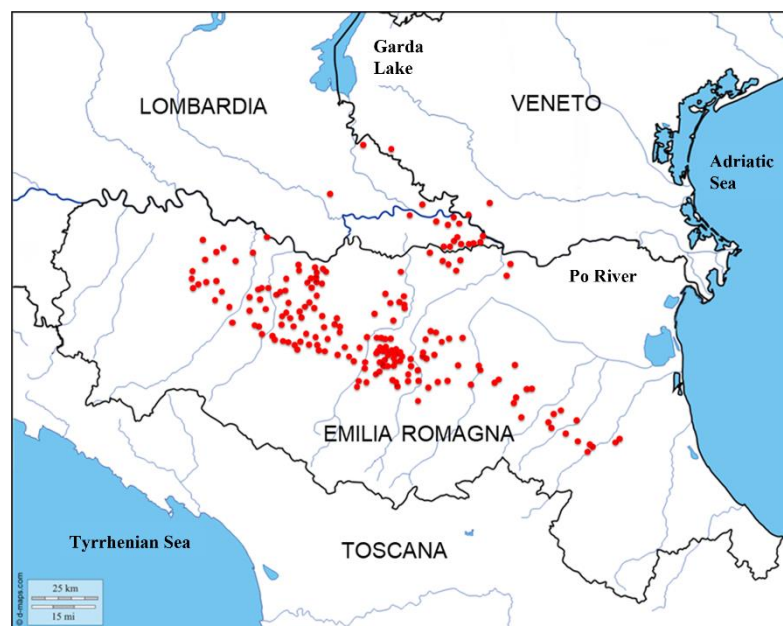


Figure 9. Map of the distribution of the settlements; modified from Bernabò Brea, Cardarelli, and Cremaschi (1997), and Cremaschi et al (2016).

In the Early Bronze Age, the territory was sparsely inhabited and until the beginning of the Middle Bronze Age (BM1) the villages belonging to the Terramare culture were more distributed north of the Po River. The colonization by these populations took place in an area characterized by the presence of forests already partially thinned out, as evidenced by the presence of microcharcoals at the base of the Poviglio and Montale sequences (Mercuri et al, 2006a; Ravazzi, Cremaschi, & Forlani, 2004). The central phase of the Middle Bronze Age (BM2) is of key importance for the development of this civilization that largely colonizes the territory with homogeneous settlements from structural and cultural point of view.

The settlements were usually characterized by a quadrangular shape, and they were surrounded by peripheral structures consisting of moats, embankments, and palisades (Bernabò Brea, 2009; Bernabò Brea, Cardarelli, & Cremaschi, 1997). Archaeological elements are distributed in a regular way, as can be seen from the alignments of postholes and other oriented wooden structures that denote a well-coded model of spaces use. The primary economy also seems to reflect a very specific structure, particularly connected to deforestation practices, intensive land use divided into forestry, agriculture and pastures, and management of water resources. Palynological records show a thin forest cover close to sites where, however, wet environments were common. Crops included several types of cereals (Cremaschi et al, 2016; Mercuri et al, 2015a; Ravazzi, Cremaschi, & Forlani, 2004), and the possible presence of intercropping with legumes (Mercuri et al, 2006a, 2006b). Among cereals, archaeobotanical records date the start of millet cultivation in the Po Plain to 3520–3360 cal yr BP, with the fully development of the Terramare culture (Filipović et al, 2020). Pastures, which seem to have had the same incidence as the cultivated areas, were mainly related to the presence of goats, sheep, cattle, and pigs.

Consequently, the territory underwent a depth transformation by the populations with massive deforestation actions, intensive cultivation on large scale, and the localized adaptation of the river network in the area surrounding the settlements. The presence of the moat around the settlements, in addition to a strictly defensive role, was necessary to allow a constant access to the river network to collect water and redistribute it in the cultivated fields through irrigation canals.

During the last phase of the Middle Bronze Age (BM3) a territorial reorganization was evident, determined by the abandonment of some villages, the establish of new ones, and the increase in size of others (Cardarelli, 2009; Mutti, 1993). The consistent demographic increase and the tendency to greater complexity in the economic, social, and political spheres became crucial in the Recent Bronze Age. The number of settlements dropped slightly, but the expansion of some of these reflects the demographic increase following the economic success witnessed by the exponential growth of metallurgical production. Archaeological data suggests a total population of 70,000 - 100,000 people in the Middle Bronze Age and 100,000 - 150,000 in the Recent Bronze Age (Cardarelli, 1997). The full development of this civilization seems to coincide with a slow change in climate towards cooler and more humid conditions, in accordance with the period of general cooling attested in the Alpine system (the Lobben glacier advance; e.g., Magny, 2004; Magny et al, 2010; Pelfini et al, 2014). At the beginning of the following period, the collapse of the Terramare culture (3150–3100 cal yr BP) was probably linked to the occurrence of different natural and social factors that favored the sudden abandonment of settlements and the collapse of the entire cultural system (Bernabò Brea & Cardarelli, 1997; Bernabò Brea, Cardarelli, & Cremaschi, 1997; Cardarelli, 1997; De Marinis, 1975; Pearce, 1998). It is therefore probable that people were not able to adapt to the new environmental/climatic conditions (one or more short dry episodes; Baroni et al, 2006; Cremaschi, Pizzi, & Valsecchi, 2006; Valsecchi et al, 2006), indicated as the Bronze Age Warm Period (BAWP). Regional climatic dynamics changed from a wet and cool phase, along which the civilization developed, to an arid and warm phase that accompanied its collapse (from recent studies on speleothems from Corchia in the Alpi Apuane: Regattieri et al, 2014, and from the Tana della Mussina cave: Regattieri et al, 2020; Tirabassi et al, 2020; Zerboni et al, 2020). Interdisciplinary research pointed out that the end of the Terramare culture cannot be satisfactorily explained by referring only to environmental causes and climatic oscillations, but it is also necessary to consider also social dynamics and the impact of intensive land use on natural resources (Cardarelli, 1997; Cremaschi, 2009a; Cremaschi et al, 2016).

Some traces of survival of these populations are present on the slopes of the Apennines (e.g., the site San Michele di Valestra survived the Terramare crisis and was continuously occupied throughout the Middle, Recent, and Final Bronze Ages, up to the Iron Age; Bietti Sestrieri, 1997; Cremaschi et al, 2018). A strong anthropic void is recognizable from an archaeological point of view in the Po Plain, particularly evident in the Emilian territory which remained depopulated until the Etruscan colonization of the 7th-6th century BC.

Iron Age

The Late Bronze and the Early Iron Age in the Po Plain (ca. 3100–2400 cal yr BP) show a wide range of variability and diversity. The Terramare culture seem to have provided a crucial background of traditions and technical skills for later population developments, starting from the 1st millennium BC, up to a centralization process south of the Alps that began at least in the 9th–8th centuries BC, in close parallel with the regions south of the Apennines (i.e., Etruria and Latium; Pacciarelli, 2016). Examples of discontinuity are documented between the 7th–6th centuries BC, but a new wave of settlement nucleation and exchange networks between the Mediterranean and central Europe took place in northern Italy after the mid-6th century BC (Zamboni, 2021).

Roman Period

In the 4th and 3rd centuries BC, the Central Po Plain was occupied by Veneti, Ligures and, various Celtic populations, with which the Romans had contacts especially for trades. By the end of the 3rd century BC, the Romans occupation was spread in almost all the Italian peninsula, including large parts of northern Italy that was then completely subject to Roman domination during the 2nd and 1st centuries BC with a continuous foundation of colonies and a network of important roads that allow the connection between the new towns and Rome (Bosi et al, 2020, and reference therein). Numerous luxurious *domus* testify the high level of civilization attained in northern Italy, and the strategic role of this territory for expansionist policies and protection of the northern boundaries. After Roman colonisation, deforestation, and drainage were carried out, shaping the plain in a highly productive area. Land subdivision practice (*centuriazione*) adopted by the Romans considered the morphological aspects of the territory to facilitate surface water flow-off and delimit the land assigned to Roman settlers for the agricultural improvement of the entire region (Giorgi, 2000). Archaeobotanical data from northern Italy show that the assemblage of food plants found in the Roman archaeological sites can be divided into a series of phases spanning nearly nine centuries of history (*“Romanization”/Republican* - 3rd to 1st century BC; *Imperial* - 1st to 2nd century AD; *Late Roman* - 3rd to 4th century AD; *Late Antiquity* - 5th to 6th century AD). Generally, a substantial continuity in the consumption of cereals and pulses were observed, together with new introductions of kitchen garden/aromatic species and fruits especially from Imperial times onwards (Bosi et al, 2020).

Middle Ages

The collapse of the Roman Empire was associated with a period of climatic instability that led to a progressive waterlogging condition of the Po Plain, related to frequent flood events reported in historical chronicles between the 6th and 7th centuries AD (Squatriti, 2010). A widespread reforestation and re-establishment of marshes occurred in large part of the territory, where a new economy reliant on pasture of pigs, hunting, and fishing in the marshes were established (Brandolini et al, 2018; Montanari, 1979). In this context, many sites were abandoned, and the Roman drainage system collapsed. In the Emilia-Romagna Region the first attempts to drain the wetlands is reported in historical documents starting from the late 8th century, but only from the 10th to the 13th centuries large actions of water management were promoted both by monasteries and by private landowners (Brandolini & Cremaschi, 2018; Curtis & Campopiano, 2014). According to historical–archaeological data, early medieval settlements (6th–10th centuries AD) were concentrated on fluvial ridges within the new palustrine landscape, where the topographically higher positions around the swampy meadows provided a strategic control of the waterways and the sustenance resources. The *castrum* represents the typical settling pattern of this period (Brandolini et al, 2018). Archaeobotanical records from key Mediaeval-Renaissance centers in northern Italy (from 13th century onwards) provided information about the domestic life, which involved a rich variety of fruits and flowers, together with many vegetables, aromatics, spices, medicinal, fibres, oil plants, cereals, and pulses (e.g., Bandini Mazzanti et al, 2005).

1.2.1 ARCHAEOLOGICAL INTEREST OF THE AREA: THE TERRAMARA S. ROSA DI POVIGLIO

The archaeological site of S. Rosa di Poviglio (Lat. 44° 52' 21" N; Long. 10° 34' 31" E), is a Middle-Recent Bronze Age settlement belonging to the Terramare civilization and it has been investigated for more than 35 years thanks to archaeological excavations directed by M. Bernabò Brea, M. Cremaschi and, in recent years, A. Zerboni. The excavation of the Terramara S. Rosa in Fodico di Poviglio (Reggio Emilia) began in 1984 and continues to this day thanks to the efforts of the institution that coordinates the operations, the Department of Earth Sciences “A. Desio” of the University of Milan, the collaboration of the Municipality of Poviglio and the Museum of the Terramara S. Rosa di Poviglio, and occasionally thanks to the economic contribution of private individuals. The excavation project is highly multidisciplinary, and it is one of the largest archaeological excavations of European prehistory and the longest-lived and most extensive archaeological excavation of the Bronze Age Terramare culture. Detail investigation is extended over a large portion the Terramara S. Rosa di Poviglio and includes archaeological structures and the area surrounding them (Bernabò Brea & Cremaschi, 2004; Cremaschi, 2004; Cremaschi & Pizzi, 2021; Mele et al, 2013).

The settlement lasted for most of the Bronze Age and abandoned at the so-called “Terramare crisis”. It was medium-large in size and covered approximately 7 hectares. The Terramara S. Rosa di Poviglio has been recorded in geographic and cadastral maps since the 19th century (Cremaschi, 1997, 2004), and the boundaries of the terramara are evident in aerial photos (Fig. 10), from which it is possible to distinguish the embankments surrounded two agglomerations closely interconnected: the small village (“Villaggio Piccolo” in Italian – VP) which is 1 ha in area and it represents the oldest settlement dating back to the Middle Bronze Age and, the large village (“Villaggio Grande” – VG) of the Recent Bronze Age with an area of 7 ha. The wise and complex management of the territory that allowed an exponential demographic increase is evident in this site, testified by the development over the two main centers VP and VG. The structures surrounding the site (moats, canals, and ditches) include a cremation cemetery 300 m East of the terramara (Cremaschi et al, 2012).

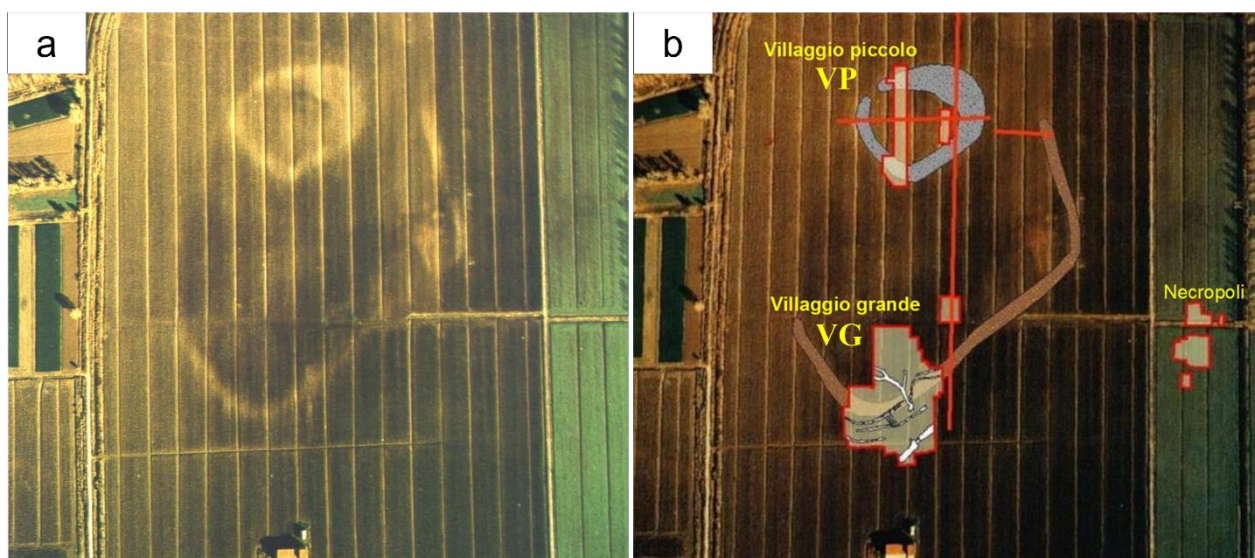


Figure 10. Terramara S. Rosa di Poviglio (RE): aerial photographs. a) The ramparts surrounding both the VP and VG are clearly visible on the aerial photograph taken soon after ploughing (lightly coloured strips sediments in contrast with the dark colours of the surrounding vertisols); b) The main archaeological features are indicated by labels: the small village (Villaggio Piccolo-VP) to the north, the large village (Villaggio Grande-VG) just below, and the cremation cemetery (Necropoli) on the right.

Many investigations have contributed to the geomorphological reconstruction of the area, especially through geophysical prospecting activities carried out starting from the 2008 excavation campaign to realize future developments of the archaeological project (Filini, 2015; Infurna, 2014; Mele et al, 2013). The apparent electrical resistivity map (Fig. 11; Giudici et al, 2021) clearly highlights the shape and the extension of VP and VG through the contrast between the areas corresponding to the alluvial sandy ridges on which the villages were located (more resistive), and deposits of fine silts and clays linked to flood events (less resistive) that fill a large depression area to the N of the site.

Geomorphological records suggests that this site was located near a palaeo-channel of the Po River that was active during the Bronze Age (Cremaschi, 2004).

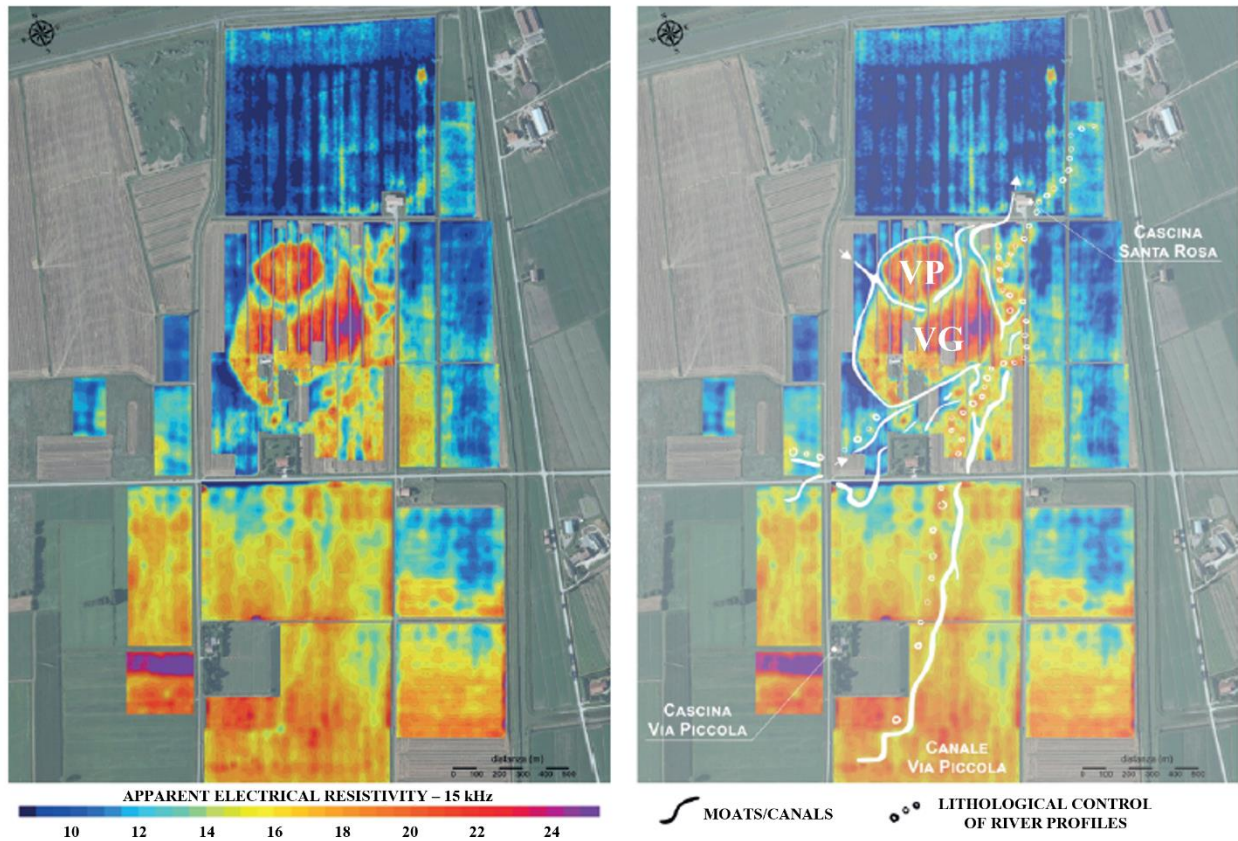


Figure 11. Map of the FDEM 15 kHz apparent electrical resistivity of the site Terramara S. Rosa di Poviglio and in its closest surroundings, illustrating the subsurface archaeological features; modified from Giudici et al (2021). Warm colours indicate high resistivity, while cool colours indicate low resistivity. The main archaeological features are indicated by labels.

Archaeological structures (rampart, moat, general shape of the settlement) have been directly investigated to the entire site, illustrating in detail both the infrastructure connection systems between the two villages, their fence, and, for the first time in the context of Terramare, a complex hydraulic system.

The archaeological deposits related to the VP are only partially preserved because they were largely removed by quarrying in the 19th century, while the archaeological deposits of the VG are preserved inside the earthen ramparts and form a small mound (Cremaschi, 2004). The well-preserved archaeological inhabitation structures inside the VG consist of regular rows of rectangular houses separated by roads (Bernabò Brea, Cremaschi, & Pizzi, 2003; Bianchi, 2004). During the Recent Bronze Age, the houses were no longer built as pile dwelling, but resting on the ground and therefore built with a less demanding in terms of timber (Bernabò Brea et al, 2009).

The two dwelling areas were surrounded by moats and bordered by a fence, which was later replaced by the earthen rampart built during the last phase of the settlement, and by complex hydraulic structures (Cremaschi & Pizzi, 2021; Cremaschi, Pizzi, & Valsecchi, 2006). Detailed information about the exploitation of water resources by the Terramare populations comes from this site, which present a complex and structured hydraulic system consisting of a peripheral moat, large water wells, and interconnecting ditches related to the collection and redistribution of water.

The **hydraulic system** was discovered at the southern edge of the VG close to the palisade and inside the peripheral moat (Cremaschi & Pizzi, 2006; Cremaschi, Pizzi, & Valsecchi, 2006; Pizzi & Cremaschi, 2004). Starting from the 1998, a network of large wells with a great structural complexity was discovered. With fourteen excavation campaigns carried out up to 2011, approximately 700 m² of the moat and the adjacent areas were investigated. More than sixty wells have been brought to light, together with a stretch of canal converging into the moat, and a couple of passages that crossed it. For the first time, therefore, the structures intended for water management have been explored from an archaeological point of view at the margin of a Terramare settlement, as never done before (Cremaschi & Pizzi, 2021). The water wells were excavated to reach sandy aquifer at the base of the archaeological deposit (Pizzi & Cremaschi, 2004) from the late Middle Bronze Age (about 3350–3280 cal yr BP) up to the Recent Bronze Age (3280–3120 cal yr BP). The frequent rearrangement of these structures is related to the purpose of following the water table level that clearly lowered during the final phase of occupation of the settlement (Cremaschi, Pizzi, & Valsecchi, 2006). In particular, the presence of wells inside the moat reflects the lack of water in this structure, and the need to find it at greater depths in gradually lowering aquifers. This data is also suggested by the discovery of a cluster of wells cutting one another, among which the last one to be dug is also the deepest. The local conditions of the aquifers near the Terramara S. Rosa di Poviglio were influenced by the water discharge of the Po River (Cremaschi, 2004), and it is therefore reasonable linking the lowering of aquifers at the decrease in flow of the river as an aridification episode of regional importance (Bernabò Brea, Cardarelli, & Cremaschi, 2018; Cremaschi, Pizzi, & Valsecchi, 2006; Cremaschi et al, 2018)

Archaeobotanical research

Over the last few decades, the knowledge on flora and vegetation in the context of the Terramara S. Rosa di Poviglio has greatly expanded, thanks to a substantial amount of palynological analysis (Cremaschi et al, 2016; Florenzano et al, 2021a; Furia, 2016-2017; Mercuri et al, 2021; Ravazzi, Cremaschi, & Forlani, 1992, 2004). Studies on seeds and fruits are less in number because of the scarce preservation of the remains (Chiapparelli et al, 2021), as well as for anthracological and xylotomic records (Rottoli & Motella, 2004).

Climatic oscillations and human overprints are preserved in pollen spectra as a single complex dynamic system. In particular, the extraordinary high-resolution of the sequences coming from the moats between the Villaggio Grande and the Villaggio Piccolo (the mean resolution may be estimated ca. 12 years per sample; Cremaschi et al, 2016) makes visible the key role of anthropogenic pressure in forest cover changes that had occurred during the Middle and Recent Bronze Age.

Palynological reconstruction shows fairly open vegetation composed mainly by riparian communities and oak woods. The latter presents the features that distinguish the *Quercus-Carpinetum boreoitalicum* Pign. (1953), with the dominance of oaks (in particular English oak) and hornbeams, patches by elms, ash trees, maples, limes, and perhaps firs and yews, depending on the humidity rate and the characteristics of the soil. This type of vegetation has been the scene of continuous transformation of plant cover and biodiversity, while some pollen taxa (e.g., *Tilia*) completely disappeared toward in changing composition communities. Open vegetation was widespread with an important role of synanthropic plants marking the presence of widespread human activities in the area, while the fluctuation of wetland indicators may be interpreted as hydrographic oscillations linked to climatic factor or human management of water resource. However, synchronous decline of hygrophilous trees (mainly *Alnus* and *Salix*) together with that of elm seems to be related to fast rate of water table decline during the Bronze Age. The dramatic decrease in woods, well documented at the top of each pollen record (Cremaschi et al, 2016; Ravazzi, Cremaschi, & Forlani, 2004), including oak and riparian woods as the nearly synchronous action on vegetation cover of human and climatic pressure.

Charcoals analysis suggests that the wooden structures of the settlements were mainly, if not exclusively, made up of oaks (Rottoli & Mottella, 2004). Most of the poles used by the population have diameters between 10 and 20 cm, suggesting the use of plants that are specially selected in young and probably coppiced woods (Rottoli & Mottella, 2004). New evidence in the area outside the VG of many elm charcoals shows a growth anomaly in cross section that can be attributed to the practice of defoliation; these elements suggest the use of this species for pastoral economy with a form of management and maintenance of these plants close to the site (Chiaffarelli et al, 2021). The elm is also well attested in the analyses of the VP (Rottoli & Mottella, 2004), although the practice of defoliation had not been documented.

The extension of deforested areas increased starting from the Middle Bronze Age up to the Recent Bronze Age, reducing the tree cover to ca. 20% (Cremaschi et al, 2016; Ravazzi, Cremaschi, & Forlani, 2004). Through the quantitative estimate of the extension of the area that best describes the vegetation represented by pollen spectra (Relevant Source Area-RSA; Sugita, 1994), it was described how large the area affected by deforestation was. Based on this algorithm, Ravazzi, Cremaschi, and Forlani (2004) established that during the Middle Bronze Age the deforested territory around the Terramara S. Rosa di Poviglio had a radius of 500 m, while in the Recent Bronze Age, it extended further, reaching a diameter of at least 4 km.

Economy was based on wood management not only for the supply of timber, but also for fruits of special cultural interest that could have been collected on the wild or from cultivated woody plants (e.g., *Corylus* and *Prunus*). *Olea*, *Juglans*, and *Castanea* are scarce documented in pollen diagrams, even if the latter shows a somewhat increasing continuous curve (Cremaschi et al, 2016). The finding of a chestnut charcoal may be indicative of the occasional presence of this species not far from the site even if not yet considered interesting by the population neither for the wood nor for the fruit (Chiaffarelli et al, 2021).

The role of *Vitis* in everyday life is controversial, although there is no doubt that this plant played an important role also for the Terramare people in the preparation of alcoholic drinks (Mercuri et al, 2006a). Pollen evidence suggests that some grapevine grew as part of the riparian communities near the moat. Appreciated and used by the population for the same reason of *Vitis* (Mercuri et al, 2006a), also *Cornus mas* should have been common in the landscape surrounding the site testified both as pollen and macroremains.

Crop fields were composed with a diversified set of cereals represented mainly by pollen from the *Avena/Triticum* and *Hordeum* groups. Traces of *Panicum* and *Secale* pollen in the Recent Bronze Age are index that crops probably increased in drought-tolerant variety during dryness or phases of water crisis. Despite the very low availability of macroremains, five species of cereals have been documented in the area outside the VG (i.e., *Hordeum vulgare*, *Triticum dicoccum*, *T. monococcum*, *T. timopheevii*, and *Panicum miliaceum*). It is known that millet cultivation spread during the Bronze Age in the Po Plain (Filipović et al, 2020), as a C4 species with short vegetative cycle and a low need of water, which can be sown in the same fields where other cereal crops have already been harvested and can be used in both human and animal diet (Chiaffarelli et al, 2021).

New pollen evidence from the filling of wells located at the edge of the moat of the Villaggio Grande (Florenzano et al, 2021a), not only testify the presence of cereal fields in the area as an already consolidated knowledge, but the high amount of cereals (up to ca. 6%) documented for a well located near the palisade, suggests that plant processing had occurred quite close to this point, or even the use of the well to receive waste of the processing of cereals. However, this is not confirmed by the macroremains that do not document the presence of cereal processing waste, perhaps because no combustion episodes occurred, and any unburned material has completely degraded (Chiaffarelli et al, 2021).

Other element that suggests breeding and grazing practices is the presence of Fabaceae pollen (e.g., *Astragalus*, *Lotus*, *Melilotus*, *Medicago*, and *Trifolium*), generally present in meadows and pastures, and which can be cultivated for forage in fields in rotation with cereals. The presence of legumes among the macroremains is particularly limited.

High values of Cichorieae were found especially considering the more recent chronologies. Relatively higher values characterized the pollen spectra from the North and East ditches (Ravazzi, Cremaschi, & Forlani, 2004) suggesting that pasturelands were prevalently distributed in those sectors of the site and that the food subsistence of this terramara should have been probably less based on animal breeding than it was

in other settlements (Mercuri et al, 2006a). However, the general increase in this pollen type marks the spreading of dry pastures favored by the change in land use as a response of the population of dryer climate conditions and a fall in soil fertility (Cremaschi, 2009a), which caused a reduction in extension (or the abandonment) of the fields.

1.3 LATEGLACIAL TO HOLOCENE CLIMATE OSCILLATIONS IN NORTHERN ITALY

Lateglacial

The term *Lateglacial* is informally used to indicate the phase of climatic transition which followed the LGM. The upper limit of the Lateglacial is now assigned an age of 11,650 cal yr BP (Gibbard & Head, 2000; Walker et al, 2009) in correspondence of an abrupt event coinciding with the beginning of the Holocene detectable in isotopic, palynological, and dendrochronological archives. Concerning the characterization of the beginning of the Lateglacial there was no unanimous agreement in the literature until recent years (Bini et al, 2004; Orombelli, Ravazzi, & Cita, 2005). Three different definitions have been used to identify the lower limit of the Lateglacial: a) most of the authors of central-western Europe have assumed as a limit the sharp climatic change which led to better climatic conditions marked by the start of Greenland Interstadial 1 (GI-1) at 14,700 cal yr BP (Giesecke et al, 2019; Johnsen et al, 1992, 1997; Steffensen et al, 2008); b) some authors have attributed a global valence to term *Lateglacial* and identified the transition from LGM to the present interglacial which spanning starting around 19,000 cal yr BP (in this case the lower limit of the Lateglacial is represented by the beginning of deglaciation at global scale; Lambeck et al, 2000; Orombelli, Ravazzi, & Cita, 2005; Ravazzi et al, 2007); c) others used it with a regional chronostratigraphic inference, identifying the onset of deglaciation at a local scale with consequent different chronologies of the stages. Currently there's no doubt it started with an interstadial (probably the GI-1) corresponding to the "Bølling-Allerød" at ca. 14,700 cal yr BP, after the Late Pleniglacial (18,000–14,700 cal yr BP) in NW Europe (Cohen & Gibbard, 2019). This is agreed upon by specialists in the Quaternary stratigraphic commissions of International Union of Quaternary Research (INQUA - SACCOM) and International Commission on Stratigraphy (ICS) and is published in official sites such as that of the International Commission on Stratigraphy (<https://stratigraphy.org/>).

Different types of natural archives and a wide range of techniques are now available to obtain climatic shifts record over time intervals about centuries or decades. These archives are represented by lake successions (with pollen data as proxy; Finsinger et al, 2006; Vescovi et al, 2007), dendrochronological series (Cremaschi et al, 2021; Frisia et al, 2005), speleothems (Regattieri et al, 2014, 2019, 2020; Tirabassi et al, 2020; Zerboni et al, 2020), and ice cores from polar caps (North Greenland Ice Core Project members, 2004). The latter compared with other sedimentary records have unparalleled temporal resolution and continuity. A key role in documenting abrupt climate changes of the Northern Hemisphere during the last glacial period is to be attributed to the two deep ice cores drilled at the beginning of the 1990s in central Greenland (GRIP and GISP2, respectively 3027 m and 3053 m long) with fully reliable climate archives back to 105 kyr BP, and the ice core from the North Greenland Ice Core Project (NGRIP, 3085 m ice thickness) from which they has been measured at very high resolution for water isotope ratios, dust, and impurity concentrations older than that found in central Greenland (Johnsen et al, 1997; North Greenland Ice Core Project members, 2004; Steffensen et al, 2008).

High-precision continuous water stable isotopes ratio ($\delta^{18}\text{O}$) from polar ice cores are commonly used as past temperature proxies (Masson-Delmotte, 2005). Measurements made on the GRIP ice core are considered a workable approach to the subdivision and correlation of the Lateglacial high-frequency climatic oscillation record in the Northern Hemisphere composed of two abrupt warmings interrupted by one cooling event (Orombelli, Maggi, & Delmonte, 2010; Steffensen et al, 2008; Walker, 2000). The Greenland Stadial 3 (GS-3) was followed by a short warm episode (GI-2) and a long interval of fluctuating isotopic temperature (GS-2) ending abruptly at the onset of the Bølling with the rise in temperature (about 7-8 °C in the mean annual temperatures) accompanied by a 40% increase in the methane concentration and a 100% increase in precipitation (GI-1; 14,700 cal yr BP; Orombelli & Ravazzi, 1996; Rasmussen et al,

2006). A rapid change from glacial temperature was attested during the Bølling characterized by mild conditions which declines irregularly (about 5 °C cooler) through the Allerød and a return to glacial values at the onset of the Younger Dryas (GS-1; at 12,900 cal yr BP) up to the onset of the present warm interglacial (Oronelli, Maggi, & Delmonte, 2010).

Holocene

The Holocene climate is characterized by millennial-scale climatic variability that has been observed in the Greenland Ice Cores and correlated with other marine and continental records showing similar patterns (Mayewski et al, 2004), side by side with shorter variations in cool and wet and hot and dry direction (Cremaschi, 2009a).

Since the beginning of the 20th century, the Holocene has been divided into five periods according to a biostratigraphic nature based on plant macrofossil records from Scandinavian peat bogs and pollen succession of central and northern Europe reflecting climatic changes (Mangerud et al, 1974; Sernander, 1908). However, vegetational response to climate change could reflect time transgression at global scale leading to temporal (and spatial) lags in the proxy records (Walker et al, 2009). This classification is based on radiocarbon dates and considers the different periods as chronozones whose limits are arbitrarily rounded to multiples of 500 years in conventional radiocarbon age (Cremaschi, 2000; Ravazzi, 2003): *Preboreal* (10,000–9000 yr BP), *Boreal* (9000–8000 yr BP), *Atlantic* (8000–5000 yr BP), *Subboreal* (5000–2500 yr BP), and *Subatlantic* (from 2500 yr BP onwards). See the chapter 1.4 PALYNOLOGICAL STUDIES IN THE PO PLAIN for further details.

Recently, a more globally applicable subdivision than those based on northern European records has been developed starting from the huge amount of worldwide increase in Holocene records. A new Holocene subdivision has been adopted (Walker et al, 2019), according to the former Holocene tripartite division (Walker et al, 2012) with boundaries at ~11.7, ~8.2, and 4.2 ka cal yr BP when global/near-global abrupt climatic events were occurred. A formal subdivision of the Holocene Series/Epoch was established into the Greenlandian, Northgrippian, and Meghalayan stages/ages and their corresponding Lower/Early, Middle, and Upper/Late subseries/subepochs supported by single GSSP (Global boundary Stratotype Sections and Points):

- *Greenlandian Stage/Age; Lower/Early Holocene Subseries/Subepoch* – The Greenlandian Stage/Age is the lowest stage of the Holocene Series/Epoch. A formal definition of the Pleistocene/Holocene boundary based on the Greenland NGRIP ice core was proposed due to the highly detail climatostratigraphic reference section. The beginning of the Holocene is clearly visible in the Greenland NGRIP2 ice core at the depth of 1492.45 m, where there is “the clearest signal of climatic warming” starts end marks the end of the last cold episode of the Pleistocene at 11,700 cal yr BP (Walker et al, 2009). A major change in atmospheric circulation regime and a temperature rise of $\sim 10 \pm 4$ °C were attested by many proxies at the onset of the Holocene (Buizert et al, 2014; Grachev & Severinghaus, 2005).
- *Northgrippian Stage/Age; Middle Holocene Subseries/Subepoch* – The Northgrippian Stage/Age is the second stage of the Holocene Series/Epoch whose beginning is marked by a change in trend from a period of generally rising temperature to a clear signal of climate cooling which occurs at ~8200 cal yr BP. The “8.2-ka climatic event” is located at 1228.67 m depth in the Greenland NGRIP1 ice core marked by low $\delta^{18}\text{O}$ values and a cooling of ~5 °C detected by the water isotope diffusion-derived temperature record (Gkinis et al, 2014). Several volcanic eruptions could have contributed to this event in synergy with the consequences of the North Atlantic cooling caused by the meltwater discharge after the deglaciation in North America (Cole-Dai et al, 2021).
- *Meghalayan Stage/Age; Upper/Late Holocene Subseries/Subepoch* – The Meghalayan Stage/Age is the highest subdivision of the Holocene Series/Epoch. The lower limit is defined by a GSSP in a speleothem from Mawmluh Cave (NE India) showing evidence of an abrupt reduction in precipitation at ~4200 cal yr BP (Rousseau et al, 2019), the “4.2-ka climatic event” with a global

expression but with different features across latitudes. Evidence of a dry period was documented in the Mediterranean and the Levant with possible regional climate patterns (Bini et al, 2019).

In recent years, the necessity of a new subdivisional scheme including the *Anthropocene Series/Epoch* has raged in the scientific community. The most quoted hypothesis attributes the beginning of the Anthropocene in the mid-20th century due to a stratigraphic signal of radiogenic fallout from thermonuclear weapons testing (Walker et al, 2019), even if GSSPs that define the end of the Holocene around 1950 AD have not been formally proposed yet.

Climate changes in the last 3000 years

Hydroclimatic variations featured the last 3000 years, during which periods of optimums and climatic deterioration are mixed (Di Rita et al, 2018a; Mensing et al, 2015; Sadori et al, 2016a), even if the subdivision is complicated by different palaeoclimatic interpretations (Margaritelli et al, 2016). However, it is well-established that one of the direct factors of climate variability and regional hydrological regimes affecting northern Europe and the Mediterranean area is the North Atlantic Oscillation (NAO; Bianchi & McCave, 1999; Bond et al, 2001; Di Rita et al, 2018a, 2018b; Hurrell, 1995; López-Moreno et al, 2011; Margaritelli et al, 2016; Marshall et al, 2002; Wanner et al, 2001). Understanding NAO index oscillations in different region of the Mediterranean area is often controversial and this makes it necessary to consider other proxy archives. Temperature and precipitation regime in the northern territories of the Mediterranean, on the borders of which the Po Plain is located, reflected a cool wet climate condition during phases of negative NAO and dry climate predominating during positive phases of the NAO (Giraudi et al, 2011; Piovesan & Schirone, 2000).

The Roman Warm Period, also called Roman Climatic Optimum (RCO), ca. 2050–1750 cal yr BP, refers to the warmest period of the last 2 kyr in western Mediterranean regions with average temperatures 2 °C higher than the values recorded during the last centuries (Margaritelli et al, 2020). Mild temperature characterized an exceptional climate stability during this period that coincide with the rise of Imperial Rome (1st–3rd century AD) (McCormick et al, 2012), although some authors agree on a considerable complexity in terms of regional and local different variations (e.g., Bini et al, 2020; Büntgen et al, 2011; Dermody et al, 2012). In the Late Roman Period, between the 3rd and 6th century AD, climate became less stable, and an unfavorable phase characterized by a general cooling phase (i.e., the so-called Migration Period or the Dark Age Cold Period; Büntgen et al, 2011; Christiansen & Ljungqvist, 2012). Hydro-geological imbalance occurred in the Po Plain with the occurrence of many flood events, which led to the progressive waterlogging of the territory (Bosi et al, 2018; Brandolini & Cremaschi, 2018; Cremonini, Labate, & Curina, 2013; Stefani & Vincenzi, 2005). Climatic conditions like those of the Roman Period are attested starting from the beginning of the 9th century AD (Büntgen et al, 2011).

Important climatic changes during the last millennium are registered by independent proxies. A well-defined rise in temperatures marks the beginning of the Medieval Climate Anomaly, also called Medieval Warm Period (MWP), ca. 1090–700 cal yr BP (Margaritelli et al, 2016), characterized by warm and mild climate with a thermal maximum of 0.3 °C more than the 20th century mean (Trachsel et al, 2012), and low frequency of precipitations across the western Mediterranean (Esper et al, 2007; Trouet et al, 2009). Following the MWP thermal maximum, precipitation increased and temperatures begin to drop reaching average minimums during the Little Ice Age (LIA), ca. 700–100 cal yr BP, the last rapid climatic change attested at a global scale and well recognizable in Mediterranean marine records (Christiansen & Ljungqvist, 2012; Fischer et al, 1998; Goudeau et al, 2015; Incarbona et al, 2010; Lirer et al, 2014; Margaritelli et al, 2016; Trachsel et al, 2012).

The subsequent Industrial Period, ca. 100 cal yr BP–present (Margaritelli et al, 2016), was characterized by the occurrence of a warm and humid climatic phase.

1.4 PALYNOLOGICAL STUDIES IN THE PO PLAIN

Vegetation transformation processes in the Po Plain are a highly topical issue, examined through numerous palynological research that provide comparisons on the composition and distribution of vegetation cover over the long term. A general, but at the same time local and detailed, description of the vegetation is available through the integration of several pollen records covering time periods from the Last Glaciation (Ravazzi et al, 2018) to the Holocene (Accorsi et al, 1999). Pollen data are available from every part of the territory, from the western part (Bertoldi, 1996; Caramiello, Siniscalco, & Arobba, 1996), the central plain (Ravazzi et al, 2013), to the eastern one (Cacciari et al, 2020; Rossi et al, 2021), together with evidence from the Apennines (Guido et al, 2020) and from the Alps (Ravazzi et al, 2007; Vescovi et al, 2007). However, the sedimentary conditions that characterize the plain make it difficult to obtain long-term continuous stratigraphic sequences, such as those widely studied from a palaeoenvironmental perspective in hilly and mountain settings (mainly lake environments and peat bogs; Joannin et al, 2013; Vescovi, Kaltenrieder, & Tinner, 2010; Vescovi et al, 2010), although with some exceptions especially for the eastern part of the Po Plain (Bianchini et al, 2022; Cacciari et al, 2017; Marchesini, Marvelli, & Lobietti, 2017; Ravazzi et al, 2006).

Together with palaeoenvironmental research, the information provided by palynological studies in archaeological sites largely increases the opportunity of investigating the extraordinary habitat diversity and cross-cultural development over the last millennia, from prehistory to modern times. Considering the key role that floodplains play in the development of civilization and cultural orientations based on the environmental context, on-site studies from a network of distributed archaeological sites are fundamental to disentangle the long-term impact of human population on vegetation transformations (Mercuri & Florenzano, 2019). However, it is not easy to obtain an overview of the research due to the fragmentary nature of literature on the location, chronology, culture, and archaeological contexts. BRAIN network is a useful instrument providing a reference list that helps to find references about Italian on-sites (archaeological) or near-sites (human-related environmental sites) studies. Thanks to availability of BRAIN database (<https://brainplants.successoterra.net/>), which has a free online access since 2015, an updated list of sites with palynological investigation is provide in Table 6 and the site distribution is plotted in Fig. 12.

Palaeoenvironmental data and information about the development of human-related environmental changes are also well detectable in off-site marine cores. The hydrology of the Adriatic Sea is seasonally controlled by winds and river inputs, among which the discharge from the Po River reflects a sediment source area including the Po Plain with regional vegetation changes occurring as the result of climate and human influences over a wide area (Combourieu-Nebout et al, 2013; Lowe et al, 1996; Mercuri et al, 2012).

Table 6. List of sites (main culture phase and geographical location), archaeological context, and chronology) with palynological investigation in the Center Po Plain (Emilia-Romagna Region). Cultures key: M=Mesolithic; N=Neolithic; Ch=Chalcolithic; B=Bronze Age; I=Iron Age; E-A=Etruscan-Archaic period; H=Hellenistic period; R=Roman Age; Ma=Middle Ages; Re=Renaissance; Mo=Modern age. Key colors: yellow=On-Sites; red=Off-Sites; green=Spot Records. To the Reference list, Mercuri et al (2015b), and references to original investigators and publications on The BRAIN network and database - https://brainplants.successoterra.net/References_List.html

Cultures	Name		Province	Latitude	Longitude	Meters a.s.l.	References
M	Forlì - Cantiere ANAS Via Ravennana	●	Forlì Cesena	44°14'24"	12°04'07"	30	Gobbo, 2011
M, N	Casalecchio di Reno	●	Bologna	44°29'00"	11°15'59"	61	Gobbo, 2011
M, N	Le Mose	●	Piacenza	45°02'22"	9°45'02"	61	Gobbo, 2011
N	Forlì - Via Navicella	●	Forlì Cesena	44°15'12"	12°05'11"	15	Gobbo, 2011
N	Splimberto - Via Marchionni	●	Modena	44°33'02"	11°01'12"	69	Gobbo, 2011
N	Travo - Via Sant'Andrea	●	Piacenza	44°51'48"	9°32'53"	176	Costantini & Costantini Biasini, 1998/1999; Gobbo, 2011
N	Riccione - Via Berlinguer	●	Rimini	43°59'48"	12°38'48"	12	Gobbo, 2011
N	FG Lugo near site	●	Ravenna	44°25'31"	11°55'17"	10	Torri et al, 2019
N, Ch	Parma - Via Guidorossi	●	Parma	44°47'08"	10°17'46"	57	Gobbo, 2011; Rottoli & Regola, in press
Ch	Imola - Cà di Guzzo	●	Bologna	44°22'01"	11°42'09"	48	Marchesini et al, 2011b
Ch	Cesena - Provezza	●	Forlì Cesena	44°11'02"	12°10'53"	26	Marchesini et al, 2011b
Ch	Forlimpopoli - Via Canalazzo	●	Forlì Cesena	44°11'00"	12°06'19"	30	Marchesini et al, 2011b
Ch	Faenza - Via Bisaura	●	Ravenna	44°17'23"	11°52'38"	34	Gobbo, 2011
B	Sant'Agata Bolognese - Viadotto Crocetta	●	Bologna	44°40'42"	11°10'10"	14	Marchesini et al, 2010c
B	Sant'Agata Bolognese - Montrione	●	Bologna	44°39'18"	11°06'56"	21	Marchesini et al, 2010c
B	Anzola Emilia - Terramara	●	Bologna	44°32'55"	11°11'32"	41	Marchesini & Marvelli, 2011d
B	Monte Castellaccio	●	Bologna	44°21'00"	11°42'00"	76	Bandini Mazzanti et al, 1996a, 1996b
B	Baggiovara - Opera Pia Bianchi	●	Modena	44°36'26"	10°52'18"	59	Mercuri et al, 2015; Montecchi et al, 2011
B	Terramara di Montale	●	Modena	44°34'34"	10°54'38"	71	Mercuri et al, 2006a, 2006b, 2019a
B	Noceto - Vasca Votiva Piccola	●	Parma	44°48'02.96"	10°10'19.35"	81	Aceti et al, 2009; Castiglioni et al, 2009; Rottoli & Castiglioni, 2009b
B	San Michele in Tiore - Monte Leoni	●	Parma	44°40'52"	10°13'10"	150	Ammerman et al, 1976; Pals & Voorrips, 1979
B	Terramara S. Rosa di Poviglio	●	Reggio Emilia	44°51'48.71"	10°34'00.79"	21	Cremaschi et al, 2016; Mercuri et al, 2019a; Ravazzi et al, 2004; Rottoli & Motella De Carlo, 2004
B, I	Casinalbo	●	Modena	44°35'00"	10°52'00"	60	Mercuri et al, 2015; Montecchi et al, 2014
I	S. Giovanni Persiceto - Via Imbiani	●	Bologna	44°37'57"	11°09'59"	23	Marchesini & Marvelli, 2010b
E-A	Bologna - Via Frassinago/Via Foscolo	●	Bologna	44°29'30"	11°19'53"	66	Marchesini & Marvelli, 2002a
E-A	Pianella di Monte Savino	●	Bologna	44°19'40"	11°24'20"	550	Bosi et al, 2004; Carra et al, 2005; Lopane et al, 1998; Luciani, 2004
E-A	Comacchio - Podere Belfiore	●	Ferrara	44°44'00"	12°07'05"	1	Marchesini & Marvelli, 2006e
E-A	Mirandola - Arginone	●	Modena	44°54'29.20"	11°13'5.99"	9	Accorsi et al, 1992b
E-A	Mirandola - Misera Vecchia	●	Modena	44°54'8.60"	11°11'46.29"	9	Accorsi et al, 1992c
E-A	Castelfranco Emilia - Forte Urbano	●	Modena	44°36'03"	11°02'42"	39	Marchesini et al, 2008e
E-A	Reggio Emilia - S. Claudio	●	Reggio Emilia	44°41'41"	10°37'28"	60	Accorsi et al, 1990a
E-A	Casale di Rivalta	●	Reggio Emilia	44°39'02"	10°34'20"	90	Accorsi et al, 1990b
E-A	Verucchio - Necropoli Lippi	●	Rimini	43°59'04"	12°25'07"	300	Marchesini & Marvelli, 2002c, 2002d
E-A	Stele Daunia del Museo di Cattolica	●	Rimini	43°57'48.32"	12°44'27.58"	7	Mercuri, 2019
E-A, R	Bologna - Via D'Azeglio	●	Bologna	44°29'19"	11°20'23"	38	Marchesini et al, 2010d
E-A, R, Ma	Modena - Area Novi Sad	●	Modena	44°39'2.84"	10°55'22.92"	34	Bosi et al, 2017b; Marchesini et al, 2017; Montecchi et al, 2017; Rinaldi et al, 2017
H, R	Casalecchio di Reno - Zona A	●	Bologna	44°29'01"	11°16'02"	67	Marchesini & Marvelli, 2009
R	Malalbergo - via Vita	●	Bologna	44°43'10"	11°31'59"	12	Marchesini & Accorsi, 1993
R	San Pietro in Casale - Maccaretolo	●	Bologna	44°43'09"	11°25'58"	12	Marchesini et al, 2003
R	Bentivoglio - Calcarata	●	Bologna	44°39'57"	11°26'09"	12	Marchesini & Marvelli, 2009
R	Altedo - Via Vita	●	Bologna	44°39'10"	11°28'20"	11	Marchesini & Marvelli, 2009
R	S. Giovanni Persiceto - Piazza del Popolo	●	Bologna	44°38'23"	11°11'21"	22	Marchesini & Marvelli, 2009
R	S. Giovanni Persiceto - Podere Opera	●	Bologna	44°36'52"	11°12'04"	25	Marchesini & Marvelli, 2009
R	S. Giovanni Persiceto - Via Mandria	●	Bologna	44°36'47"	11°12'01"	25	Marchesini & Marvelli, 2009
R	Calderara di Reno - San Vitale	●	Bologna	44°32'42"	11°18'04"	35	Marchesini & Marvelli, 2009
R	Casteldebbole	●	Bologna	44°30'58"	11°15'59"	53	Bandini Mazzanti et al, 1995; Marchesini & Marvelli, 2009
R	Medicina - Loc. Luogo Pozzo	●	Bologna	44°30'56"	11°36'48"	17	Marchesini & Marvelli, 2009; Marchesini et al, 2001a
R	Imola - Ex cinema Modernissimo	●	Bologna	44°21'18"	11°41'36"	52	Marchesini & Marvelli, 2004b
R	Portomaggiore - Gambulaga	●	Ferrara	44°44'25"	11°49'01"	2	Marchesini & Marvelli, 2006d
R	Carpi - Fossoli - Discarica AIMAG	●	Modena	44°49'08"	10°53'53"	23	Marchesini et al, 2008d
R	Modena - Cittanova	●	Modena	44°39'00"	10°50'00"	41	Rinaldi, 2010
R	Modena - Ex Cinema Capitol	●	Modena	44°38'41.22"	10°55'41.40"	34	Bosi et al, 2017a; Rinaldi, 2010; Rinaldi et al, 2013
R	Modena - Viale Amendola	●	Modena	44°38'0.12"	10°54'27.47"	34	Bosi et al, 2015a, 2019c; Rinaldi, 2010; Rinaldi et al, 2013
R	S. Antonio	●	Modena	44°34'26"	10°50'52"	82	Bertolani et al, 1995
R	Splimberto - Cava Ponte del Rio	●	Modena	44°33'03"	11°01'10"	43	Marchesini & Marvelli, 2002b
R	Montegabbio	●	Modena	44°30'48"	10°47'09"	350	Montecchi & Accorsi, 2010; Rinaldi et al, 2010
R	Fontanellato - Cannetolo	●	Parma	44°52'51"	10°08'51"	48	Marchesini & Marvelli, 2005b
R	Comacchio - Santa Maria in Padovetere	●	Ferrara	44°40'29.34"	12°07'18.11"	-1	Beltrame et al, 2019
R, R/Ma	Castel S. Pietro Terme - Ex cinema teatro Bios	●	Bologna	44°24'01"	11°35'28"	76	Marchesini & Marvelli, 2003
R, R/Ma	Modena - Palazzo Boschetti	●	Modena	44°38'46.21"	10°55'47.90"	34	Accorsi et al, 1999b
R, Ma	Parma - Piazza Garibaldi	●	Parma	44°48'05.49"	10°19'40.59"	55	Bosi et al, 2011, 2012a; Florenzano et al, 2012; Giachi & Lazzari, 2012; Guarnieri, 2012; Mercuri et al, 2012
R, Ma	Nonantola - Selva Zena	●	Modena	44°41'17"	11°03'51"	19	Rucco et al, in press
Ma	Sant'Agata Bolognese - Nuova Geovis	●	Bologna	44°41'10"	11°10'12"	17	Bosi et al, 2014; Marchesini, 2014; Marchesini & Marvelli, 2011c, 2014; Marvelli et al, 2014; Trocchi et al, 2014
Ma	Castel S. Pietro Terme - Piazza XX Settembre	●	Bologna	44°23'51"	11°35'23"	75	Marchesini & Marvelli, 2001
Ma	Fidenza - Via Bacchini	●	Parma	44°51'55"	10°03'36"	75	Marchesini & Marvelli, 2006g
Ma, Re	Cento - La Rocca	●	Ferrara	44°43'28"	11°17'12"	17	Marchesini & Marvelli, 2006f
Ma, Re	Carpi - Ex manifattura Loria	●	Modena	44°46'22"	10°53'11"	27	Marchesini et al, 2008d
Ma, Re, Mo	Cognetto	●	Modena	44°37'56"	10°52'12"	34	Accorsi et al, 1997a; Bandini Mazzanti et al, 2001a; Marchesini & Forlani, 2001; Marchesini et al, 2001b
Re	Ferrara - Giardino delle Duchesse	●	Ferrara	44°50'11.83"	11°37'06.19"	9	Bosi et al, 2006
Re	Ferrara - Porta Paola/Via Bologna	●	Ferrara	44°49'53"	11°36'58"	9	Marchesini et al, 2008b, 2008c
Re	Argenta - Via Vinaroia/Aeotti	●	Ferrara	44°37'55"	11°50'01"	4	Bandini Mazzanti et al, 1999; Forlani & Marvelli, 1999; Forlani et al, 1999; Mercuri et al, 1999
-	Modena Campi-52	●	Modena	44°37'59"	10°56'44"	34	Bosi et al, 2015b
-	San Lazzaro di Savena	●	Bologna	44°28'06"	11°25'22"	59	Vittori Antisari et al, 2016

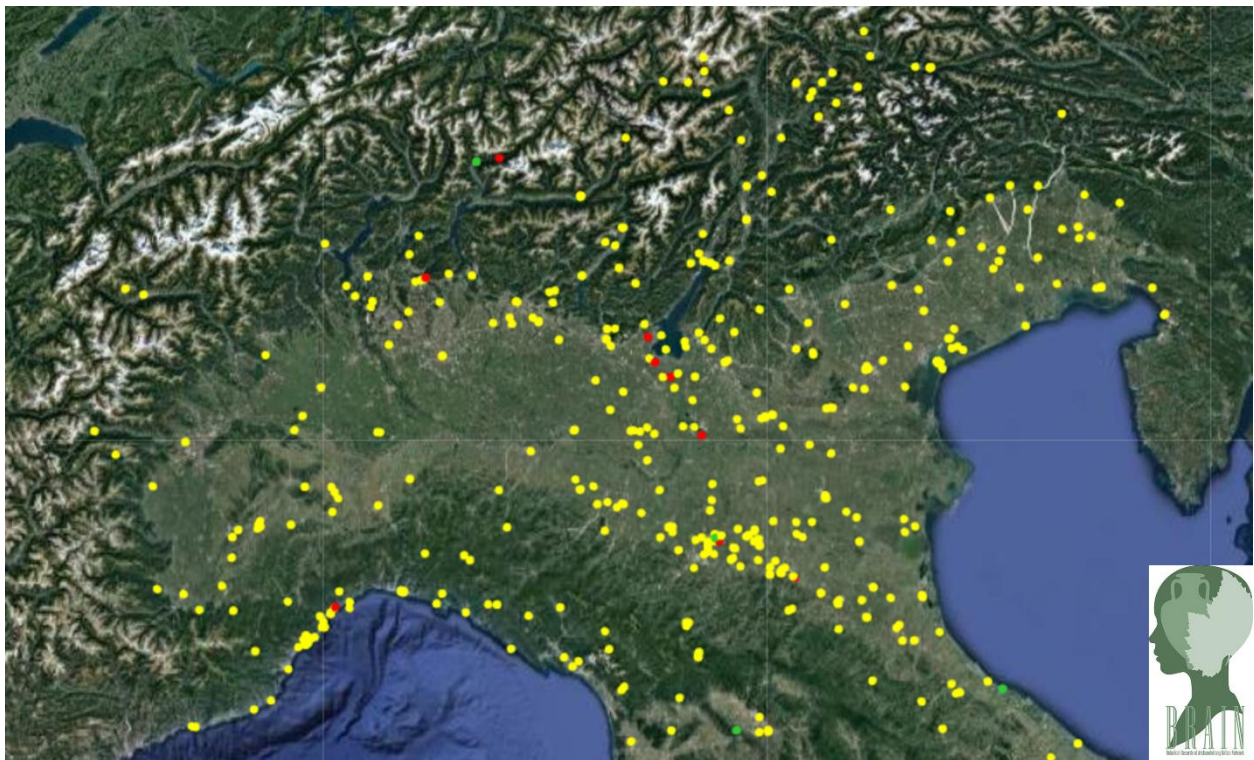


Figure 12. Distribution map of the sites in the Po Plain and in its surrounding hilly and mountain settings. Key colors: yellow=On-Sites; red=Off-Sites; green=Spot Records. From: The Brain network and database - <https://brainplants.successoterra.net>

Palaeoenvironment and vegetation history in the Central Po Plain

The Last Glaciation environmental history of the Po Plain is still poorly known (Ravazzi et al, 2012, 2018), and the spread of open habitats was influenced by edaphic and topographic factors and ecological disturbance, mainly related to the substantial reorganisation of the fluvial network occurred during the LGM. Open drylands characterized the north-alpine slope (Amman et al, 1989), while coniferous and birch forests survived the southern edge of the Alps where more complex biostratigraphic events are attested (Ravazzi et al, 2004).

Chronological control useful to correlate pollen records from reference sites are still scarce for the Late Pleniglacial. The presence of conifers (*Larix decidua*, *Pinus sylvestris*, *P. mugo*, *P. cembra*, *Picea abies*, *Juniperus* sp.) and some broadleaved trees (*Betula pendula*, *B. pubescens*, *Alnus viridis*, *Hippophaë rhamnoides*, *Salix* sp., *Rhamnus* sp.) at the end of the LGM is supported both by macroremains and pollen evidence from the Po Plain and at the eastern Alpine margin (Ravazzi et al, 2007). Large areas of the plain were subject to erosion and deposition processes not compatible with the presence of dense forest canopy. The percentage of forest cover describe from pollen data (AP = 30-50%) suggests the presence of spaced trees and xerophilous shrubs, alternating with steppes dominated by Poaceae, Asteraceae, Polygonaceae, Amaranthaceae, and *Artemisia* favored by the occurrence of fires that limited the extension of woods (Ravazzi et al, 2012). However, a progressive increase in the afforestation rate is evident in deglaciare areas mainly related to the expansion of pioneer vegetation, with birch trees, larch, and juniper (Lago Piccolo di Avigliana; Finsinger et al, 2006), and thickets of European Green Alder, willow, and larch (Ivrea; Schneider, 1978).

In the central-western Po Plain, knowledge on the palaeoenvironmental and palaeobotanical transformation during the **Lateglacial** is still scarce, due to the few lacustrine successions and radiometric dating available in alluvial environments (Ravazzi et al, 2007). Interaction between climate and vegetation during the Lateglacial is considered one of the most key moments in the history of the Alpine and Po Plain palaeoenvironment, during which the modern vegetation structures have been configured with the forest

biomes that have characterized the natural environment during the present interglacial, before extensive anthropogenic changes. During this time interval short and abrupt climatic events shaped the landscape of northern Italy. The central Po Plain in front of the Apennine margin was characterized by conditions of alluvial sedimentation with the formation of ephemeral meadows on silts and sands during the Bølling-Allerød interstadial. The woody component (*Pinus sylvestris*, *Picea*, *Hippophaë*) was present only in limited stable areas (Ravazzi et al, 2006, 2012), probably together with *Betula pendula* and *B. pubescens*. At the beginning of the interstadial there was a strong increase in the palaeoproductivity with accumulation of peat in lake and marsh, a sharp increase in the tree limit to about 1700 m a.s.l., an increase in forest cover and a decrease in the frequency of fires identified from low concentrations of charcoals even in the plain. In the second half of the interstadial, the spread of thermophilous broadleaved trees (*Tilia* sp., *Ulmus* sp., *Quercus* sp., *Fraxinus excelsior*, *Corylus*) led to the formation of mixed woods both in the lowland and on the hills that vary in composition in relation to edaphic conditions. The Bølling-Allerød interstadial was followed by a progressive decline in the afforestation rate and a long phase with steadily lower values of forest cover. These changes coincided with the beginning of the Younger Dryas cooling event. However, the decline in AP was moderate in lowland areas ($\Delta AP = -10\%$), and the forest cover was partially replaced by *Artemisia* and other light-demanding species typical of grasslands and steppes together with xerophilous shrubs.

The onset of the **Holocene** in northern Italy is marked by a sudden rise of warm temperate tree pollen abundance (Finsinger et al, 2006). The increase in thermophilous trees is documented also in pollen record from the Central Po Plain, even if with a poor pollen preservation (Mosi di Crema; Ravazzi et al, 2012). Vegetation transformations are not documented with short-term fluctuations, but of variations of centuries or millennia. The physiognomy of forests changed during the Holocene, and the biodiversity (as number of pollen taxa) increased from the Preboreal to the Subatlantic. From pollen records it is evident that in the first part of the Holocene vegetation changes were mainly related to climate oscillations, while the effects of human pressure were present only later, especially from the Subboreal onwards, when it is increasingly difficult to separate anthropogenic causes from environmental ones.

In the Preboreal the spread of forest was still limited compared to the open grasslands. In the plain *Pinus sylvestris* have dominated spectra, together with less significant values of *Abies* and *Picea*, as a result of long-distance transport from the Apennines where conifers prevailed (Accorsi et al, 2004; Marchesini, Marvelli, & Lobietti, 2017). Broadleaved woody plants were still very low, especially the hygrophilous ones almost exclusively represented by alder and sporadic presence of willow. Fluvial dynamics influenced the series of vegetation with the supply of sediments that prevented the spread of an even more structured forest. *Carpinus* was second to *Quercus* in the mixed oak wood composition in the plain, while the hills were already characterized by a greater extension of a more diversified deciduous forest with *Quercus*, *Tilia*, *Salix*, *Corylus*, *Carpinus*, *Alnus*, *Ostrya*, *Fagus*, and with refuge stations for *Castanea* and *Juglans*. No clear evidence of human presence is documented, even if pollen spectra from Emilia-Romagna are marked by slight anthropogenic indicators (i.e., ruderal pollen and cereals; Accorsi, Bandini Mazzanti, & Forlani, 1992; Accorsi et al, 1996) and repeated traces of fires (Vittori Antisari et al, 2016).

The first substantial change occurred in the Boreal. *Pinus sylvestris* was stationary in the hills and *Picea* raised its altitudinal limits especially in the northern Apennines. The plain became a patchwork of woody and open areas related to river environment. *Abies* and broadleaves trees suddenly spread, with high presence of *Tilia* that was second to *Quercus* throughout the region. Deciduous forests, even if they maintained limited extensions, were composed of a greater diversity with *Corylus*, *Quercus*, *Betula*, *Tilia*, *Ulmus*, *Carpinus betulus*, *Ostrya*, and *Fagus*, which was present within the oak wood with isolated specimens or in small groups. Increasing values of *Alnus* testify the spread of hygrophilous woods (Accorsi et al, 1996). From this chronozone, the mixed oak wood together with other broadleaved trees characterized the arboreal component, especially in the plain where pollen records document the spread of the *Querco-Carpinetum boreoitalicum* Pign. (1953).

Six pollen taxa characterized the pollen spectra through the region during the Atlantic: *Abies*, *Pinus*, *Quercus*, *Tilia*, *Corylus*, and *Alnus*. In this chronozone, the vegetation has reached maximum elevation limits, with the most stable distribution of the whole Holocene. *Abies* notably spread probably growing in the plain and as monospecific woods in the hills up to ca. 6000–5500 cal yr BP (Accorsi et al, 1999; Vescovi, Kaltenrieder, & Tinner, 2010). The forest cover in the plain was mainly represented by

mesophilous mixed wood, where *Quercus* and *Tilia* shared the leadership followed by *Carpinus*, *Ulmus*, and *Fraxinus*, the latest indicators of higher humidity. As a consequence of the climatic improvement towards warmer and more humid conditions, with availability of water in the soil, it is attested also the spread of plants properly of the riparian environment dominated by *Alnus* and *Salix* (Accorsi et al, 1996) and hygrophilous herbs such as Cyperaceae and *Typha*. *Ostrya* is less represented in pollen spectra than in the Boreal. *Corylus* was always widespread at the margin of the wood associated with Rosaceae, including *Crataegus*, *Prunus*, *Rosa canina*, and *Pyrus*. The increasing diffusion of *Castanea* and *Juglans*, the appearance of *Vitis* and the spread of *Corylus* may suggest increasing trend of human influence. New climatic conditions favored the occupation of new spaces by Neolithic populations and the introduction of agriculture and animal husbandry, favoring the presence of more fertile areas often near waterways. Evidence of human activities increases in pollen spectra that show clearer cereals records (consisting of *Hordeum* group and *Avena/Triticum* group), more abundant weeds, and other synanthropic plants.

In the Subboreal a cultural landscape began to spread throughout the region with the continuous increase in open areas in the plain, and evidence of cultivated plants valuable for edible fruits, timber, or other uses. However, some vegetation features of the Atlantic still characterized the landscape, especially the spread of alder. *Abies* remained confined to the mountains, leaving space for *Fagus* expansion both in the mountains and hills (Accorsi et al, 1999; Vescovi, Kaltenrieder, & Tinner, 2010). Important changes occurred also in the composition of the mixed oak wood with *Ulmus* that largely replaced *Tilia* in the hills and plain (Accorsi et al, 1999). The scattered presence of Mediterranean evergreens (e.g., *Quercus ilex*, *Olea*, *Phyllirea*) increased, probably as a result of warmer and dryer oscillations. The beginning of the Terramare culture and land exploitation since ca. 3550 cal yr BP in the plain was marked also by a dramatic fall of trees also in Adriatic marine cores (e.g., RF93-30; Mercuri et al, 2012). Wood exploitation created a new equilibrium in the oak woods in which *Carpinus betulus*, *Fraxinus* and *Corylus* gradually spread and occupied spaces left by oaks. A woodland management was also introduced by coppicing activities that are reflect in pollen records showing peaks of *Carpinus betulus* alternating with those of deciduous *Quercus*, or *Corylus*, or *Fraxinus* and *Ostrya* (Mercuri et al, 2006a, 2012). *Castanea*, *Juglans* and *Vitis* largely increased within a general spread of anthropogenic pollen indicators related to the spread of crops and pastures (Accorsi et al, 1999; Cremaschi et al, 2016; Mercuri et al, 2006a, 2006b, 2012, 2015a).

The plain was largely characterized by an open landscape in the Subatlantic, and forest consistency was at its regional minimum of the Holocene both in the plain and in the high-altitude belts. Pollen record from the Central Po Plain testifies Roman forest clearings (Ravazzi et al, 2013). However, forest cover increased in the hills with the spread of chestnut woods of anthropogenic nature that replaced the mixed oak wood and *Fagus* community. Pollen suggests that woodlands with chestnut and fir trees were largely distributed across the low slopes of the Apennines, and possibly some fringes grew near the plain (Bosi et al, 2015). *Ostrya*, which had never had an important role, began to spread in the hills. *Alnus* maintained some importance in the hills and mountains but in the plain it was replaced by *Salix*, which was probably favored by the anthropic selection. Wetlands and freshwater environments were spread everywhere (Bosi et al, 2015), and evidence of an early Middle Age phase of abandoning with an expansion of swamps and shallow organic ponds marked by Cyperaceae, *Sparganium*, and peaks of *Myriophyllum* (Bagnolo Lake pollen record; Ravazzi et al, 2013). In the Recent Phase (1950–1999 AD; according to Accorsi et al, 1999) a trend toward reforestation is documented in the pollen spectra from superficial soil. Both natural and cultivated plants contributed to this picture. The diversity of tree/shrubs currently cultivated in the region (e.g., for fruits and as ornamental plants) has increased with a largest spread of native and exotic plants: *Buxus*, *Castanea*, *Cupressus*, *Juglans*, *Olea*, *Prunus*, *Sorbus*, *Vitis*, *Morus*, *Cedrus*, *Aesculus*, *Robinia*, *Ailanthus*, *Calocedrus*, *Thuja*, *Ginkgo*, and *Amorpha* (Accorsi et al, 1996).

2 AIMS

2.1 RESEARCH TOOLS AND OBJECTIVES

General objective

Palynological data are used in a wide number of research fields and application studies including palaeoecology, palaeoclimatology, archaeology, and chronostratigraphic correlations (Izdebski et al, 2016). For the results obtained, these types of research are living a period of great growth methodologies and applications. Furthermore, the increasing interest in present and future climatic variations and the interactions with human activities and adaptations have led to the formulation of large-scale projects. Palynology contributes with both for the direct value of pollen data as proxies of environmental parameters (flora, vegetation, and landscape), and for secondary deductions about palaeoecological conditions, climate change, and human disturbance observing the vegetation transformation over time. Archaeological studies are increasingly supported by environmental investigations, especially concerned archaeobotanical studies aimed at reconstructing the choices of human populations in relation to the environment in which they lived. In particular, the response of natural vegetation to human pressure, as well as to climatic and environmental changes can be studied through pollen analysis, that also provide information about cultural evolution through the knowledge of botanical species present and used by people. Environmental features must have played a fundamental role on human choices especially in prehistoric times. At the same time, the landscape has been modified by different strategies and adaptations, mainly linked to the birth of agriculture which determined the presence of populations for a long time in the same territory.

The current scarce availability of studies that provide a continuous and long-term picture of the vegetation transformations in the Central Po Plain highlighted the need to carry out the research on which this thesis is based. Hence the need to broaden the knowledge regarding environmental transformations that occurred during the succession of cultural adaptation and economic subsistence, the diffusion of the complex phenomenon of agriculture, and the extensive transformation of the landscape up to modern times.

This thesis is part of an extensive palaeoenvironmental research program, which involved expertise in geoarchaeology, archaeobotany, archaeometry, archaeozoology, and anthropology cooperating with archaeologists in the study of the Terramare culture. The SUCCESSO-TERRA Project (PRIN-20158KBLNB; *Human Societies, Climatic/Environmental Changes and Exploitation/Sustainability of Natural Resources in the Po Plain during the Mid-Holocene. The case study of the Terramare culture*; coord. Mauro Cremaschi - Andrea Zerboni, Università degli Studi di Milano; <https://www.successoterra.net>) addresses the relationship between human populations and the environment in an interdisciplinary perspective, considering the bidirectional dynamics with which the climate has conditioned the environment and cultural adaptation, and human communities have shaped the landscape. In order to study environmental transformations that occurred during the Middle Holocene in northern Italy and in the Mediterranean area, the project investigates the relationship between climate and society during the Bronze Age. SUCCESSO-TERRA offered a great opportunity to define how climate and social contributions act in synergy to shape woods and fields during the development and collapse of the Terramare culture, pointing out the crucial point of challenges opened by the climate change in progress.

This research aims to contribute to the general program of the SUCCESSO-TERRA Project with a palynological investigation of three continuous off-site cores drilled at different distances north from the Terramara S. Rosa di Poviglio to obtain a picture of large-scale flora and vegetation transformations. However, the general purpose of this thesis is much more ambitious, addressing the study of the dynamics of vegetation on a long-time perspective, starting from the Lateglacial and with a special focus in investigating the landscape transformations occurred in the Central Po Plain related to both climatic factors and human activities during the Holocene.

This thesis deals with the study of botanical microremains (pollen and Non-Pollen Palynomorphs), which provide reconstructive elements on different palaeoenvironmental aspects that will be briefly examined in the following chapter. The study is based on 195 samples from three cores named N-S3, C-S1, and F-S2 collected in Fodico di Poviglio in the province of Reggio Emilia (the letters N, C, and F indicates their position with respect to the Terramare archaeological site: Near, Central, Far). In relation to their position right in the center of the plain, the cores represent continuous terrestrial archives which has received the airborne pollen from large distances, up to the slopes of the Apennines and the Alps, especially in some chronological phases when the landscape was largely open. In-depth studies were conducted on the observation of many pollen grains of secondary deposition (also called reworked pollen) in different levels of the sequences, to detect the occurrence of floods related to the sedimentary origin of the alluvial plain and at the base of the development of complex human–water systems in the study area.

Three surface soil samples were collected in the same area to obtain a picture of the pollen rain from current vegetation as useful reference model for the interpretation of the palaeoenvironmental pollen spectra.

As part of the research, a collaboration with the CNRS-LSCE (*Laboratoire des Sciences du Climat et de l'Environnement*) was established regarding molecular investigations aimed at isolation of miliacin (a molecular biomarker specific of *Panicum* and few other Poaceae) from the cores to improve the level of detail provided by the pollen data, integrating biomolecular technologies with botanical skills.

The PhD research project was divided into several work packages (Fig. 13) and involved in the first instance a phase of data collection, both bibliographic, territorial, and environmental, which were processed at the same time as the palynological analysis. Bibliographic research was carried out about archaeobotanical publications spanning from Lateglacial to the Holocene in the Po Plain, but also more generally throughout northern Italy. Both data referring to individual archaeological sites and off-site contexts (mainly lacustrine environments), and data from synthesis papers and review on the Emilia-Romagna Region and its borders were considered.

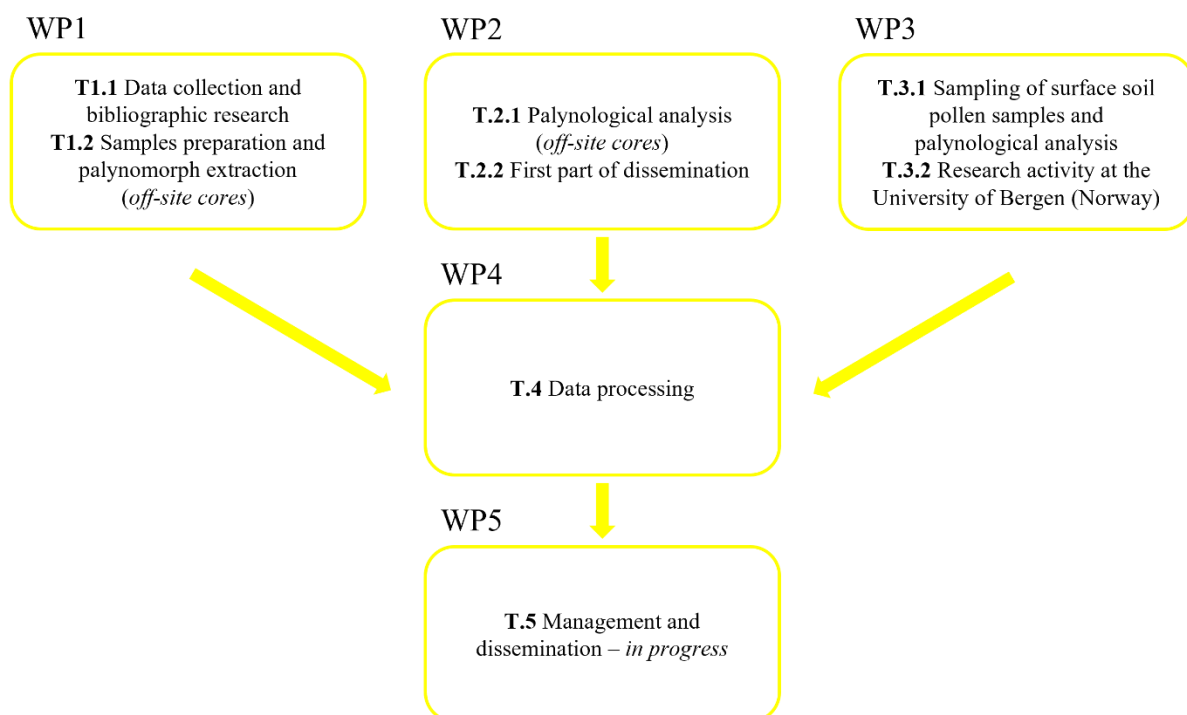


Figure 13. PERT chart of the research project.

Palynological analysis of pollen samples from the three off-site sequences and the surface soils was carried out to achieve the following purposes:

- to add an important contribution to the palaeoenvironment and palaeoclimatic reconstruction of the study area and its surroundings for the Lateglacial-Holocene chronological interval;
- to examine the floristic-vegetational variations and hypothesize about their causes;
- to reconstruct the evolution of human-plant relationships;
- to correlate and integrate the data emerging from the palynological analysis with the main reference biostratigraphic records from northern Italy.

Specific objectives

The time range selected is known to have hosted human groups from the Mesolithic to Neolithic, Bronze Age, and Iron/Roman cultures, so showing different pathways of land use and plant exploitation over the millennia. One of the key aspects of this thesis is to disentangle, whenever possible, phases of occupation and evolution of the landscape with the focus to the management of the territory during the Bronze Age in terms of harvesting edible fruits, creation of open spaces exploited for lawn and pasture, cultivation, and use of wood.

To do this is necessary to compare analyses both from on-site, showing evidence of local human activities, and off-site records, tracing palaeoenvironmental changes at regional scale driven mainly to climatic factors. For this reason, the location of the cores was based on the geophysical survey carried out by the Department of Earth Sciences “A. Desio” UNIMI, investigating the lithological differences in the sedimentary context and the relationship between the archaeological site and surrounding areas.

The new information obtained from palynological investigation on the three off-site cores were compared with on-site studies, already carried out by the Laboratory of Palynology and Palaeobotany UNIMORE (the host institution of this research activity). The skills to develop this aspect of the research were acquired during the period of research activities carried out at the University of Bergen. During the period spent abroad it was possible to set up and apply the Landscape Reconstruction Algorithm to the whole set of data available in order to evaluate the vegetation composition within the relevant source area of pollen of two sites of the Terramare culture (Terramara S. Rosa di Poviglio and Terramara di Montale) during the Recent Bronze Age, starting from the regional vegetation evaluation obtained from the off-site pollen records.

However, the main purpose of this research is to demonstrate the potential of the palynological method to provide information related to changes in vegetation not only in a general way and on a large scale, but also with a considerable degree of detail useful for distinguishing local features and distribution of vegetation in a limited space. The main hypothesis of this research is that the incidence of human impact decreases at greater distances from the settlement with a specific distribution of human activities around the influence of the terramara at least during the Bronze Age. This is the basis of the need to analyse three sequences at short distances from the archaeological site but always within the area of influence that was probably frequented daily by the population.

2.2 MAIN TYPES OF BIOLOGICAL PROXIES CONSIDERED

The first factor that negatively influences the development and evaluation of innovative and sustainable environmental policies is the cognitive incapacity to perceive large-scale and long-term changes. According to Hanski (2008), humans are able to perceive changes in small and familiar spaces during limited time intervals as a result of biological evolution, which magnifies the mismatch between the exponential growth of the extent of human impact and our limited perception of the world. Overcoming this obstacle, the palaeoecological approach considers past, present, and future not as autonomous units but in connection

with each other, in a *continuum* through which species and populations evolve (Rull, 2010).

The current conditions, therefore, are the result of the synergic action of ecological factors and biological evolution, with an impact that can be assessed in the present with the possibility of setting up correct environmental reconstructions and management plans (Desjardins, Friesen, & Jordan, 2020; Marignani et al, 2017). Different from ecological monitoring, that usually consider the time interval in which the same ecological conditions are involved (called ecological time or real time; Jackson, 2001), palaeoecology evaluations are the key to understand how, when, and why ecosystems have responded to perturbation factors and their possibility of resilience (Birks, 2012; Seddon et al, 2014).

Palynology is the science of palynomorphs, a general term which includes both plant and animal structures microscopical in size (e.g., pollen, spores, cysts, diatoms...), and palynological studies fit into this context allowing to detect the transformations of flora and vegetation due to climatic-ecological factors and cultural pressure (Dimbleby, 1985; Faegri, Kaland, & Krzywinski, 1989; Pearsall, 2000).

Pollen is certainly one of the most used and effective tools for the palaeoecological-palaeoclimatic studies of the Quaternary and to highlight anthropic transformations of the natural environment. However, more and more frequently, other remains found in the same preparations are being studied alongside pollen, namely “Non-Pollen Palynomorphs”, which enhance the reconstructive capacity of pollen.

2.2.1 POLLEN

Pollen grains are the principal object of the palynological analysis and its key role in palaeoenvironmental reconstructions depends upon four basic features:

- 1) the preservation of these structures in sediments due to the presence in the pollen walls of sporopollenin, a natural biopolymer extremely resistant to decay in certain sedimentary environments;
- 2) morphological characteristics that are specific to a particular genus or species of plant (e.g., shape, size, aperture number and location, ornamentation...) essential for identification (Forlani, 1986; Halbritter et al, 2018; Punt et al, 2007);
- 3) they are produced in vast quantities, especially by wind-pollinated plants, and are distributed widely from their sources;
- 4) they reflect the natural vegetation at the time of pollen deposition.

Palaeoenvironmental reconstructions through pollen analysis are based on the floristic list, consisting of the identified pollen taxa, the relative and absolute abundances, and vegetation structure and composition identified by assemblages of specific pollen taxa. Generally, pollen taxa are grouped into sums useful for environmental and land use reconstructions according to the local vegetation and general knowledge on botany and ecology.

Palynologists usually consider pollen percentages to measure changes in pollen assemblages even there is not a linear relationship with vegetation abundance (Berglund, 1991; Faegri & Iversen, 1989; Prentice & Webb, 1986). Starting from the awareness that pollen data from different sized sites provide information about vegetation at different scales (Berglund, 1973), the need for quantitative reconstruction of the relationships between pollen and vegetation has increased for a better understanding of the anthropogenic impacts on ecosystem dynamics. New theoretical studies have been developed to clarify the mechanism and factors that affect pollen representation of vegetation since the last two decades of the last century (Prentice, 1985; Sugita, 1994). The biological nature and the genetic-ecological factors of the species, first the pollen productivity related to the type of pollination and dispersal, must always be considered in pollen-vegetation models (Andersen, 1970; Davis, 1963; Mercuri, 2014; Parsons & Prentice, 1981; Prentice, 1985; Sugita, 1994, 1998).

Pollen productivity estimates (PPEs) might be influenced by biotic (e.g., genetics, spatial structure of vegetation, succession stages, competition, and disturbance), abiotic (e.g., geology, soil types, and climate), and anthropogenic factors (e.g., land use) and it could change through time and in different region or due to methodological differences (Broström et al, 2008). This parameter is one of the main inputs of the Landscape Reconstruction Algorithm (LRA) and its two models, REVEALS (Regional Estimates of VEgetation Abundance from Large Sites; Sugita, 2007a) and LOVE (LOcal VEgetation Estimates; Sugita, 2007b), useful in quantitative reconstruction of past vegetation to obtain robust and accurate estimate of local vegetation composition and the background (regional) pollen source. A large number of application in the LRA's two models REVEALS and LOVE have been used to reconstruct regional and local plant cover in Europe north of the Alps (Cui et al, 2013; Fyfe et al, 2013; Hjelle et al, 2018; Marquer et al, 2020; Mazier et al, 2015; Nielsen & Odgaard, 2010; Nielsen et al, 2012; Trondman et al, 2015), but studies about relative pollen productivities are only starting more recently in the Mediterranean area (Githumbi et al, 2021, and reference therein; Grindean et al, 2019).

Quantitative reconstruction of past landscape is still challenging, especially for palynologists who deal with areas rich in biodiversity in which long-lasting human activities have been a key role in shaping the mosaic landscape, as in the case of the Mediterranean (Mercuri & Sadori, 2014; Mercuri, Sadori, & Ollero, 2011; Roberts et al, 2011, 2019; Servera-Vives et al, 2018). Due to the complexity of such and other contexts, research are being carried out to extend and adapt the models (Githumbi et al, 2021, and Azuara et al, 2019 for coastal sites).

Pollen in archaeological sites

Palynology in archaeological sites (Dimbleby, 1985; Faegri, Kaland, & Krzywinski, 1989) deals with the study of pollen and other palynomorphs in anthropic contexts of the past. The potentiality of this science to obtain robust data derives from the application of a precise and standardize method starting from a correct sampling strategy up to the elaboration of the data in a strongly interdisciplinary perspective.

A detailed analysis of pollen spectra allows to link the change in vegetation to cultural evolution, identifying the main forms of human-plant interaction (Dimbleby, 1985; Faegri, Kaland & Krzywinski, 1989) which can occur in terms of exploitation of plant resources (e.g., selective harvesting and deforestation), cultivation and diffusion of plants of economic interest, breeding (with consequent selection of resistant species), and inhabited areas where spontaneous synanthropic plants win the competition with other species. Although the state of preservation maybe altered by many factors, first oxidation conditions and the use of fire by humans which influence the post-depositional decay.

Palynology applied in archaeological contexts is now considered a key tool for interpreting the cultural landscape (Mercuri, 2014; Mercuri et al, 2015b), human behaviors (Mercuri, 2008a) and their purposes such as changes in subsistence strategies, introduction or abandonment of crops, and intentional cutting of trees to open clearings for settlement, agricultural practices or to use timber for construction.

Palynology is one of the applicative aspects of Archaeobotany, an intrinsically interdisciplinary science that allows to reconstruct both the natural environment and the land use strategy together with the local people's knowledge, belief, and use of plant (Mercuri, 2008b, 2008c; Mercuri, Sadori, & Blasi, 2010; Mercuri et al, 2019; Pearsall, 2000; Sadori, Mercuri, & Mariotti Lippi, 2010; Wright, 2010), through the integration of ecology (plant-human dynamics) and ethnobotany (cultural uses of plants).

Human activities and environmental changes are co-evolutionary and adaptive processes that can be investigated through palynological and archaeobotanical investigation reflecting a series of land transformations that derived from the special combination of environment and culture (Dearing, 2006). The term *plant cultural landscape* refers to a geographical area with specific characteristics resulting from the combination of natural and anthropogenic factors (UNESCO, 2005): a mosaic of plant communities directly or indirectly influenced by human activities (Faegri, Kaland, & Krzywinski, 1989). The knowledge of the native flora, local vegetation, and crops typical of the territory allows to identify the role of human activities and how they have influenced the surrounding landscape (Behre & Jacomet, 1991; Mercuri, Sadori, & Blasi, 2010; Sadori, Mercuri, & Mariotti Lippi, 2010). Botanical analysis in archaeological contexts assumes that anthropogenic action, whether intentional or not, is the main way by which plants were transported within the site; therefore, the presence and the spatial distribution of botanical remains clearly reflect human behavior, the destination of an environment, and the function of archaeological structures

(Brinkkemper et al, 1999; van der Veen, 2007).

To investigate the development of an intrinsically complex cultural landscape in response to climate change or local environmental variations (Mercuri et al, 2012), it is necessary to examine primarily the pollen spectra relating to anthropogenic indicators (IA - Anthropogenic pollen Indicator; Behre, 1981, 1986; Brun, 2011), pollen taxa that testify to the presence of human populations and their activities. These plants can be divided into two main categories: cultivated/cultivable species (for food, medicinal, ornamental, ritual practices...) and grassland or wild synanthropic species (weeds, indicators of fallow fields and ruderal, meadow/pasture indicators) as secondary anthropogenic indicators sensu Behre (1990), and ubiquitous pollen taxa in Italian archaeological sites from Mercuri et al (2013a).

In addition, arboreal or woody plant (trees + shrubs + lianas = Arboreal Pollen-AP) reflects the forest cover of an area which can vary as result of change in climate (Berglund, 1986; Sadori et al, 2016b) but also by anthropic causes in the case of trees exploitation and wood management (Cremaschi et al, 2016; Mercuri et al, 2006a, 2015a). The increase in pollen spectra of olive (*Olea*), walnut (*Juglans*) and chestnut (*Castanea*) trees are another important indicator of the spread of human activities, which are reflected in the distribution of “cultural plants” gathered or cultivated since ancient times (‘OJC group’; Mercuri et al, 2013b and Florenzano et al, 2017). Among woody plants, *Vitis* (Mercuri et al, 2021) and *Corylus* (Aceti, Ravazzi, & Vescovi, 2009) may be other important cultural biomarkers together with *Cornus* (Mercuri et al, 2006a), *Prunus*, and other Rosaceae, possibly collected in the wild, managed, or cultivated.

Comparing on- and off-site pollen records

Pollen preservation in sediments is influenced by several factors, including the type of deposition, the nature of the archives, and the presence of human disturbance (Dimbleby, 1985; Hall, 1981; Traverse, 1988, 2007). Samples can be collected from almost every type of context (Cappers & Neef, 2012; Mercuri et al, 2015b), but natural archives, such as mires, raised bogs and lakes, are considered the best sampling points as often ensure a good preservation condition and a low level of anthropogenic influences, which allows to obtain a representative reconstruction of the surrounding area (Sugita, 1994; Sugita, Gaillard, & Broström, 1999).

In the last decade, more and more pollen studies have been carried out in archaeological contexts (on-site; Cremaschi et al, 2016; Dalla Longa, 2019; Florenzano et al, 2022; Mercuri et al, 2006a, 2006b, 2015b; Ravazzi et al, 2020; Stoddart et al, 2019; Vignola et al, 2021) or on sediments of marine and continental high-resolution coring (off-site; Bosi et al, 2018; Di Rita & Magri, 2019; Mensing et al, 2015; Ravazzi et al, 2013; Sadori, 2018; Sadori, Masi, & Ricotta, 2015; Vescovi, Kaltenrieder, & Tinner, 2010, and other references inserted later) focused on the development of landscape transformations that occurred under the pressure of natural/climatic or cultural events.

The integration of these two approaches was proposed by Mercuri (2014) to recognize the succession from simple to complex forms of resources exploitation from local site to region scale, and to be able to distinguish natural and anthropogenic contributions to environmental changes. The information from both records, different in terms of scale and resolution, can give useful evidence for a complete and detailed reconstruction of natural vegetation, surface processes, and the mechanisms, the time scale, and intensity of land use which have a key role in landscape transformations (Mercuri et al, 2019; Woodbridge et al, 2021). Palynological analyses of samples collected from stratigraphic sequences/trenches in settlement excavation (on-site) provide information about local space–time events in flora composition and vegetation cover changes, while off-site sampling is used to obtain a pollen representation over large areas (e.g., Colombaroli et al, 2008; Jahns, 2005; Marinova et al, 2012; Revelles et al, 2018; Sabato et al, 2015; Vanni  re et al, 2008; Vescovi et al, 2010; Weiberg et al, 2016). Further detail may emerge from analyses carried out in the area of influence of the site frequented every day by people (near-site; Mercuri et al, 2019). The comparison of different records gives a comprehensive vision of the territory and is therefore useful to obtain a picture of local and regional differences within the cultural landscape reconstruction (Boivin et al, 2016; Roberts et al, 2019), highlighting peculiarities and large discrepancies between different sites (van Amerongen, 2020; see also the multi-point and multi-site pollen sampling in Mercuri et al, 2015a: 237), and low influence or high impact in a given territory depending on the scale (space) and duration (time) of the human presence (Mercuri et al, 2019).

2.2.2 NON-POLLEN PALYNOMORPHS (NPPs)

The knowledge of non-pollen palynomorphs (remains of diaspores, cyanobacteria, green algae, rhizopods, fungi, invertebrates, and chormophytes; Miola, 2012) is increasingly complementary to pollen analysis by the fact that the pollen extraction method allows to isolate from the inorganic part of the sediments also other microfossils (Florenzano et al, 2012), which can therefore be found in the same palynological preparations (van Geel, 1986, 2001). NPPs analysis provides ecological information on a more local scale than pollen and adds detail about the natural or anthropic factors of landscape modification by associating them with certain events or activities (Miola, 2012).

The systematic study of NPPs in Quaternary sediments began in 1968 at the Institute for Biodiversity and Ecosystem Dynamics (IBED) in the University of Amsterdam (The Netherlands). With the studies of Bas van Geel it has begun to describe different types of palynomorphs and to name them, even if they were of unknown origin (van Geel, 1972, 1978); since then, the list of new palynomorphs is increasing, though many of them are not yet identified and the indicator-species approach (Birks & Birks, 1980) is difficult to apply. Given the growing use in palaeoenvironmental studies and to assess the current state of the art, Miola (2012) organized a list containing about 1400 NPPs described since 1972 to systematically reduce the differences in naming the same microfossils and increase the possibility of identifying new ones. The complete list of currently classified NPPs, with related references and a rich photo gallery, can be found in the “Non-Pollen Palynomorphs” online database, constantly updated by palaeoecologist L.S. Shumilovskikh, with the consultation of B. van Geel and F. Schlütz (http://nonpollenpalynomorphs.tsu.ru/NPP_Database.html).

Recent studies have confirmed the importance of these microfossils as useful elements for the interpretation of changes in ecological parameters at a local scale in stratigraphic archives, providing information on land use, presence of herbivores and any pastures, fires, erosion, and water quality (Cugny, Mazier, & Galop, 2010; Gelorini et al, 2011; McCarthy et al, 2018; Perrotti & van Asperen, 2019; Stivrins et al, 2019).

3 MATERIALS AND METHODS

3.1 CORING

Three terrestrial cores, research object of this thesis, were drilled in Fodico di Poviglio, in the province of Reggio Emilia (Emilia-Romagna Region, northern Italy), in 2018. The label PVG means “Poviglio”; the letters N C F indicates their position with respect to the Terramare archaeological site: Near, Central, Far (see below). The coordinates of the continuous stratigraphic sequences are = PVG N-S3: N44°52'27", E10°34'38"; PVG C-S1: N44°52'32", E10°34'42"; PVG F-S2: N44°52'38", E10°34'46" (Fig. 14). Their location was selected on geophysical surveys investigating lithological differences in the sedimentary context of the alluvial plain to identify a high-resolution archive for sedimentological, geochemical, and palynological investigations (Giudici et al, 2021; Mele et al, 2013).

Furthermore, three surface soils (PVG SS-A: N44°52'35.868", E10°34'33.362"; PVG SS-B: N44°52'31.966", E10°34'36.505"; SS-C: N44°52'31.966", E10°34'36.505"; Fig. 14) were collected in the same area in the summer of 2021, in order to obtain a picture of the pollen rain from current vegetation.

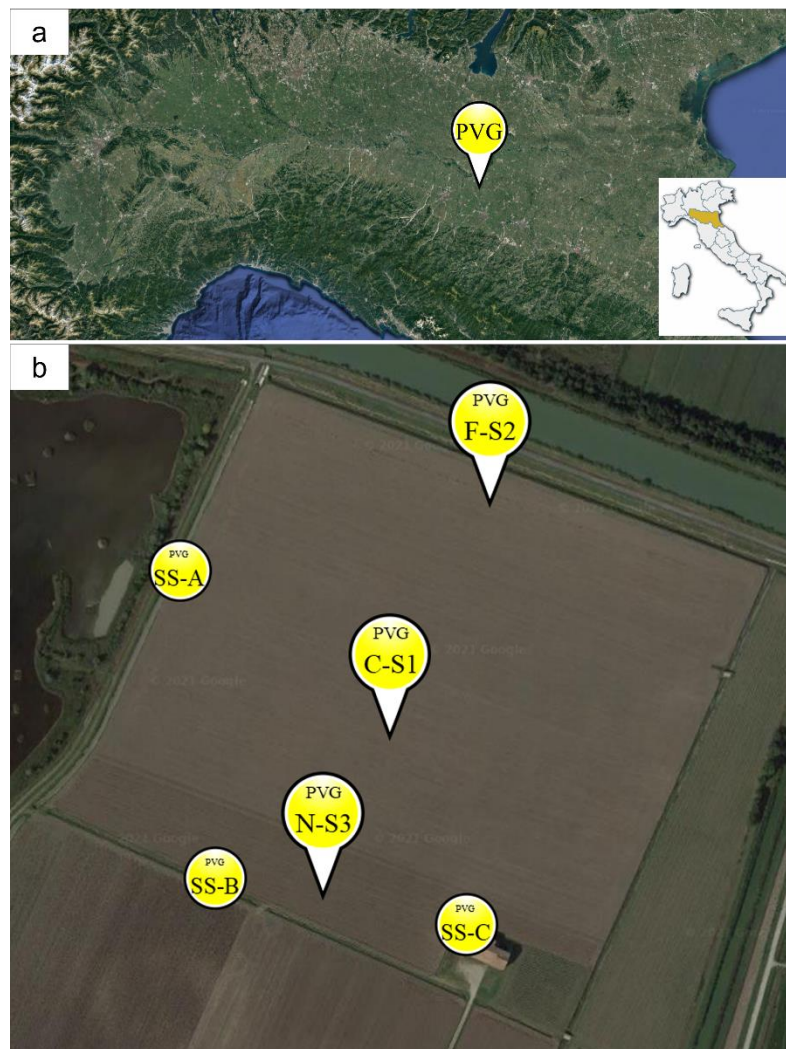


Figure 14. Study area: a) Satellite map (yellow pointer: PVG-Poviglio); b) Location of the cores (yellow pointers) and the surfaces soils (yellow dots). The basemaps are satellite images provided by Google Maps.

The study area has been under investigation for more than 35 years thanks to the archaeological excavation of the Terramara Santa Rosa di Poviglio starting in 1984 and continuing to this day. During the excavation campaign carried out in 2018 (23rd July – 2nd September; Excavation directors: Mauro Cremaschi - Andrea Zerboni; Zerboni & Cremaschi, 2018), the cores were collected in a S-N direction between the northern edge of the site (about 150, 320, and 525 meters from the VP–Villaggio Piccolo) and the southern bank of the Fiuma land reclamation canal (Fig. 15). Concerning the different distances from the archaeological site at which the cores were drilled, it has been decided to name the sequences PVG N-S3 (Next-S3), PVG C-S1 (Central-S1) and PVG F-S2 (Far-S2). The abbreviation PVG will be omitted in the text from this point onwards just for reasons of brevity.

All authorisations to carry out the excavation and sampling have been released by the SABAP-BO (MiC) to the Dipartimento di Scienze della Terra “A. Desio” of the Università degli Studi di Milano. The cores were included in the SUCCESSO-TERRA Project (PRIN-20158KBLNB – *Human societies, climate-environment changes and resource exploitation/sustainability in the Po Plain in the mid-Holocene: the Terramare culture*; Principal Investigator M. Cremaschi - A. Zerboni, Università degli Studi di Milano; <https://www.successtoterra.net>; Cremaschi et al, 2018).

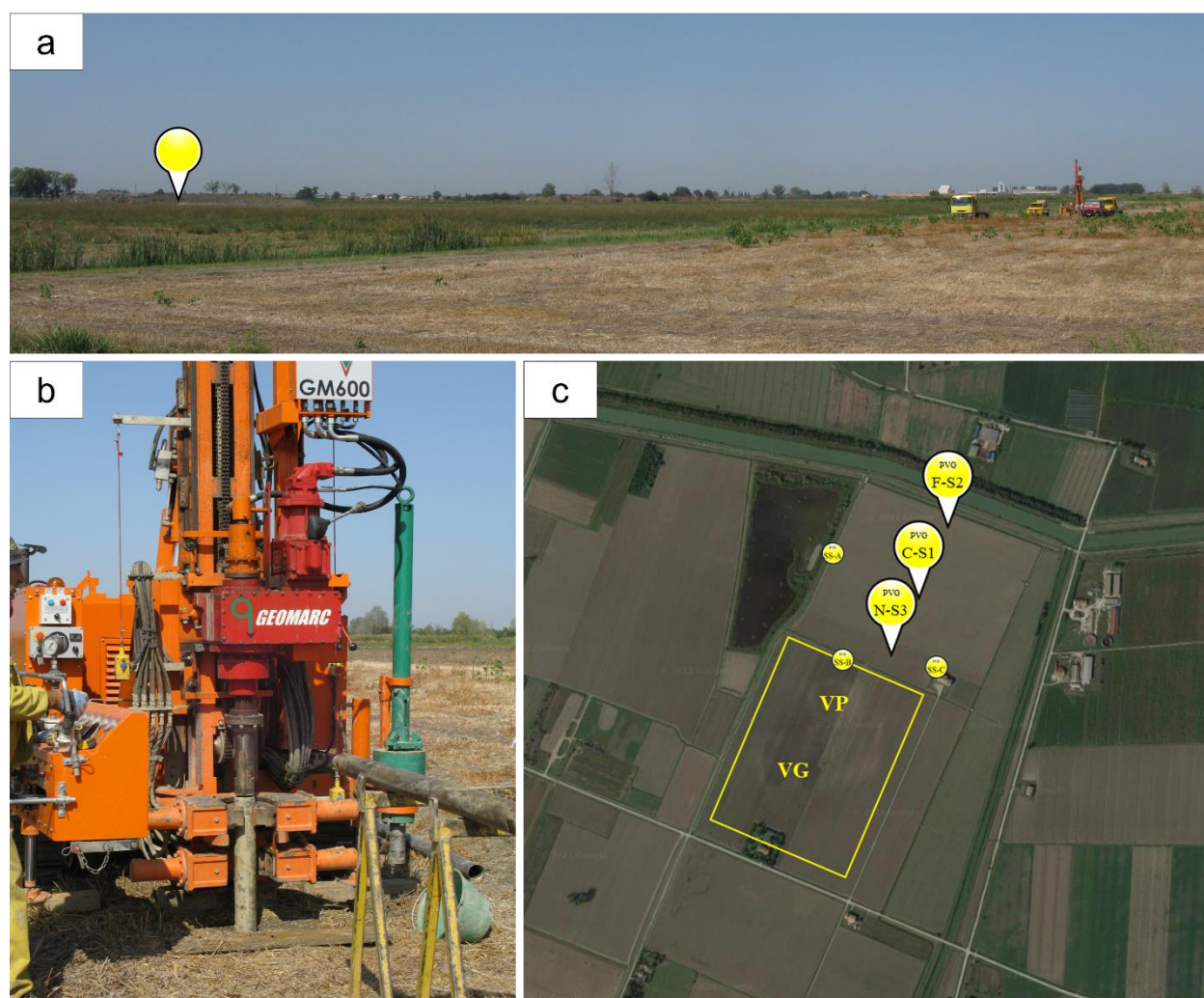


Figure 15. a) Landscape of the excavation campaign carried out in the summer 2018, the yellow pointer pinpoints the archaeological site; b) Corings operations were carried out by a medium-power hydraulic rotary probe GM 600 type, owned by the GEOPROVE S.n.c.; c) Locations of the three cores (PVG N-S3, PVG C-S1, and PVG F-S2) in the area N of the Terramara S. Rosa di Poviglio, which is highlighted by the yellow rectangle (VP-Villaggio Piccolo and VG-Villaggio Grande). The basemap is a satellite image provided by Google Maps.

3.1.1 STRATIGRAPHY AND CHRONOLOGY OF THE CORES

Many investigations have already contributed to the geomorphological reconstruction of the study area, in connection with the large excavation of the Terramara S. Rosa di Poviglio (Bernabò Brea & Cremaschi, 2004) and the cores already drilled which are distributed in SSW-NNE orientation up to the Po ridge in Rio Saliceto (Fig. 16).

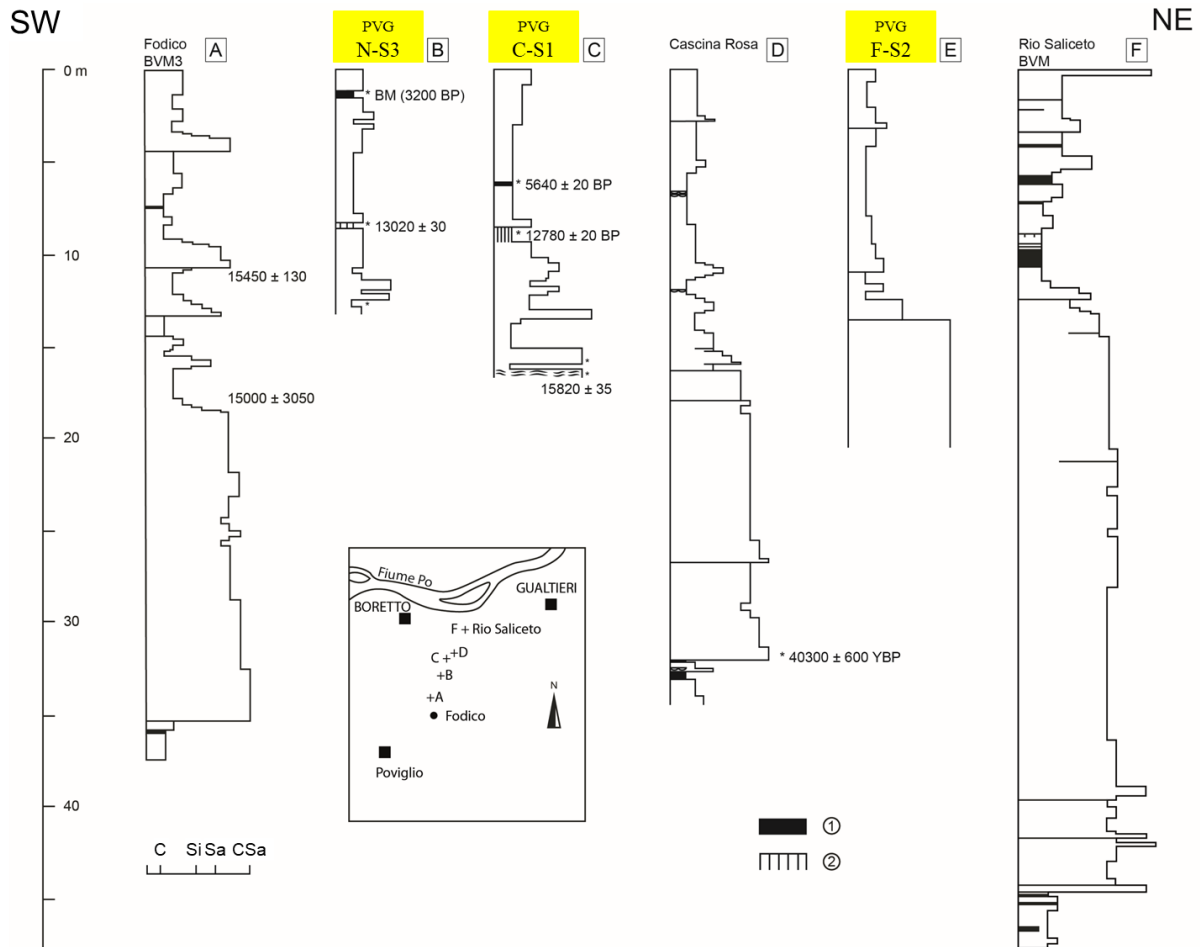


Figure 16. Cores available in the study area (Giudici et al, 2021 modified; Rosselli, Molinari, & Severi, 2016; Zerboni & Cremaschi, 2018). Key: C=clay; Si=silt; Sa=sand; CSa=coarse sand; 1=peat and organic sediments; 2=buried organic soils.

The stratigraphy of the cores considered in this study is very similar to that of the Cascina Rosa survey (Rosselli, Molinari, & Severi, 2016). The coarse sandy river deposits attributable to the Last Glacial Maximum are reached between 12 and 17 m depth (from S to N) and they decrease in number and texture in a S-N direction. The sediments above these sands are composed of alluvial clays and silts deposits, which are interspersed with buried soils and thin peat levels (Giudici et al, 2021; Rosselli, Molinari, & Severi, 2016; Zerboni & Cremaschi, 2018).

Detailed stratigraphic descriptions of the cores are reported in Tables 7-9, and the collection of pictures of each core is shown in Figures 17-19.

Geochemical analysis is still in progress.

Table 7. PVG N-S3: detailed stratigraphic description.

PVG N-S3				
Depth (cm)	Grain size	Colour	Field properties	Notes
0–50	Silty clay	5Y 3/2	Scarce brick fragments; scarce CaCO ₃ concretions	Agricultural horizon
50–110	Silty clay	5Y 4/2 with common mottles 2.5Y 6/6	Common CaCO ₃ concretions; scarce FeMn millimeter nodules	
110–130	Clay	5Y 3/1 with common mottles 10YR 6/6	Common FeMn nodules; scarce CaCO ₃ multi-millimeter concretions; common fragments of charcoal; scarce to common fragments of pottery	Archaeological level
130–210	Silty clay	Alternation of millimeter laminations 2.5Y 5/1 and laminations 10Yr 6/8	Common FeMn nodules; common CaCO ₃ concretions	
210–250	Clayey silt	5Y 6/1 with many mottles 10YR 6/8	Common FeMn nodules; scarce CaCO ₃ concretions in the lower part	
250–265	Clay	2.5Y 6/1 with common to scarce mottles 10YR 6/8	Common FeMn nodules; scarce CaCO ₃ concretions	
265–290	Clayey silt	5Y 6/1 with many mottles 10YR 6/8	Common FeMn nodules; scarce CaCO ₃ concretions	
290–370	Silty clay	Alternation of laminations 5Y 6/1 and 10YR 6/8	Scarce to common FeMn nodules; rare to very rare CaCO ₃ concretions	
370–385	Silty clay	Alternation of laminations 10YR 6/8 and 5Y 6/1	Common CaCO ₃ multi-millimeter concretions; scarce FeMn multi-millimeter nodules	
385–450	Silty clay	5Y 5/1 with many mottles 10YR 6/8	Scarce to rare CaCO ₃ concretions; scarce to absent FeMn nodules in the lower part	
450–615	Clay	10YR 6/1 to 10B 6/1 with mottles 10YR 7/8	Rare CaCO ₃ concretions; fragments of charcoal at 460 cm	
615–670	Clay	10BG 5/1 to 10BG 6/1 with common to scarce mottles 2.5Y 6/6	Scarce CaCO ₃ multi-millimeter concretions; FeMn nodules in the lower part	
670–785	Clay	Dense alternation of laminations 10BG 6/1 and 10YR 6/8, alternation of laminations 5GY 3/1 and 2.5Y 6/6 in the lower part	Scarce FeMn nodules in the upper part	
785–825	Silty clay	10B 6/1 with many mottles 2.5Y 6/6 and scarce mottles 5GY 3/1	Rare CaCO ₃ concretions; very rare FeMn nodules	
825–830	Silty clay	5B 7/1 with scarce mottles 2.5Y 6/6 and 10BG 2.5/1		
830–855	Clay	10BG 2.5/1 with millimeter laminations 10B 7/1 and scarce mottles 2.5Y 7/6	Rare CaCO ₃ millimeter concretions	
855–1080	Silty clay	Laminations 5B 6/1 to 5B 7/1 and 2.5Y 7/6 to 2.5Y 7/8 interspersed with laminations 10BG 2.5/1 to 10BG 4/1	Rare FeMn nodules; scarce CaCO ₃ concretions; organic laminations at 885, 910, 950–953, 985, and 990 cm	
1080–1095	Clay	10B 4/1 with evanescent laminations 10B 5/1 and common to scarce mottles 2.5Y 5/4	Common CaCO ₃ multi-millimeter concretions	
1095–1155	Silty clay	Alternation of multi-millimeter laminations 10YR 6/8 and 10B 6/1 (rarely 10B 4/1)	Rare fragments of charcoal	
1155–1180	Sandy clayey silt	10YR 6/8, not very evident laminations and scarce mottles 5GY 6/1		
1180–1185	Silty clay	5GY 6/1		
1185–1240	Silty clayey sand	5GY 6/1 with common mottles 2.5Y 6/8		
1240–1270	Clay	5GY 6/1 with common to scarce mottles 2.5Y 5/6, occasional organic levels 5B 2.5/1	Accumulation of CaCO ₃ concretions at 1260 cm	
1270–1300	Silty clay	5GY 6/1 with common to scarce mottles 2.5Y 5/6, 4 mm thick weak lamination 5B 2.5/1 at 1280 cm	Scarce CaCO ₃ multi-millimeter concretions from 1270 to 1275 cm	

Table 8. PVG C-S1: detailed stratigraphic description.

PVG C-S1				
Depth (cm)	Grain size	Colour	Field properties	Notes
0–60	Clayey silt	2.5Y 3/2	Scarce brick fragments	Agricultural horizon
60–80	Clayey silt	2.5Y 4/2 with scarce mottles 10YR 6/6	Scarce mollusc shell fragments	
80–140	Silty clay	2.5Y 4/3 with scarce to common mottles 10YR 6/6	Rare mollusc shell fragments; scarce CaCO ₃ millimeter concretions; rare FeMn nodules	
140–170	Silty clay	5Y 5/2 with many millimeter mottles 10YR 6/8 to 10YR 6/6	Common FeMn nodules; rare CaCO ₃ millimeter concretions	
170–205	Clay to clayey silt	2.5Y 4/2 with many mottles 10YR 7/8	Common CaCO ₃ millimeter concretions; scarce FeMn nodules	
205–260	Clayey silt to silty clay	2.5Y 4/2 with common mottles 10YR 7/8	Scarce to rare CaCO ₃ millimeter concretions; rare to scarce FeMn nodules	
260–300	Silty clay	2.5Y 4/2 to 2.5Y 5/3 with frequent mottles 10YR 5/6	Scarce CaCO ₃ millimeter concretions; scarce FeMn millimeter to multi-millimeter nodules	
300–400	Clay	2.5Y 4/3 to 2.5Y 4/2 with very abundant mottles 10YR 6/6 to 10YR 6/8	Scarce to common FeMn nodules; scarce to rare CaCO ₃ concretions	
440–460	Clay	5Y 5/1 with scarce mottles 10YR 5/8	Very rare CaCO ₃ concretions	
460–610	Clay	5Y 5/1 with very abundant mottles 10YR 6/8	Very rare CaCO ₃ concretions; very rare FeMn nodules	
610–670	Clay	5GY 5/1 with many mottles 10YR 6/8, accumulation of peaty material 5YR 3/2 at 645 cm (approx. 2 cm thick)	Very rare FeMn nodules; very rare CaCO ₃ concretions	
670–680	Clay	2.5T 3/2 to 10YR 3/6 with many mottles 5GY 5/1	Common CaCO ₃ multi-millimeter concretions	
680–710	Clay	10BG 5/1 with scarce mottles 10YR 4/4	Scarce CaCO ₃ concretions	
710–810	Clay	Alternation of laminations 10YR 4/6 (approx. 1–2 mm thick) and 10BG 6/1 to 10BG 4/1 (approx. 2–3 mm thick)	Scarce vegetal remains	
810–865	Clayey silt	10BG 4/1 with many mottles 10YR 4/6	Scarce CaCO ₃ concretions	
865–885	Clay	5GY 3/1 with scarce mottles 10YR 6/6	Scarce CaCO ₃ concretions	
885–915	Clay	5GY 3/1 with scarce mottles 10YR 6/6	Scarce CaCO ₃ concretions	
915–1025	Clayey silt	5GY 4/1 with many mottles 10YR 6/6	Scarce FeMn nodules	
1025–1065	Clayey sandy silt	5G 5/1 with very abundant mottles 10YR 6/8		
1065–1090	Silty sand	2.5Y 6/4 with common mottles 5GY 5/1 to 2.5Y 6/8		
1090–1120	Clayey sandy silt	5GY 5/1 with many mottles 10YR 6/8		
1120–1145	Sandy clay	5GY 5/1 with many mottles 10YR 6/8		
1145–1160	Clayey silt	5GY 5/1 with many mottles 10YR 6/8		
1160–1195	Silty sand	Alternation of laminations 2.5Y 6/4 and 5BY 5/1		
1195–1215	Sandy silt	2.5Y 6/2 with mottles 10YR 6/8 in the lower part		
1215–1300	Silty clay	Alternation of laminations 10YR 6/8 (approx. 1–2 mm thick) and 10BG 6/1 (approx. 2–3 mm thick)		
1300–1340	Medium/coarse sand	2.5Y 6/2		
1340–1400	Silty clay	10BG 6/1 with common mottles 10YR 6/8		
1400–1520	Clay	Alternation of laminations 10BG 6/1 (approx. 1–2 mm thick) and 10BG 5/1 (up to 5 mm) with scarce mottles 2.5Y 5/6	Fragments of charcoal scarce that increase downwards	
1520–1600	Medium/coarse sand	Weak laminated, 2.5Y 6/4 with scarce mottles 10BG 6/1 to 10YR 6/8		
1600–1610	Clay	Thin laminations 10Y 5/1 to 10BG 2.5/1	Scarce plant remains	
1610–1650	Medium/coarse sand	Weak laminated, 10Y 5/1 with centimeter peaty 5B 3/1 at 1630 and 1640 cm		

Table 9. PVG F-S2: detailed stratigraphic description.

PVG F-S2				
Depth (cm)	Grain size	Colour	Field properties	Notes
0–60	Silty clay	5Y 4/2	Scarce brick fragments	Agricultural horizon
60–145	Clay	5Y 5/2 with scarce mottles 10YR 6/6	Scarce mollusc shell fragments	
145–185	Clay	5Y 5/1 with common mottles 10YR 6/8	Scarce FeMn nodules; rare CaCO ₃ multi-millimeter concretions	
185–195	Clay	2.5Y 3/2 with common mottles 10YR 5/8	Common FeMn nodules and patinas; scarce CaCO ₃ millimeter concretions; very rare mollusc shell fragments	
195–280	Silty clay	Lamination between 230 and 280 cm, 2.5Y 5/1 with scarce to common mottles 10YR 6/8	Common FeMn millimeter to multi-millimeter nodules; common CaCO ₃ multi-millimeter concretions (accumulations at 230 and 260 cm)	
280–310	Clayey silt	2.5Y 5/1 with common to frequent mottles 10YR 6/8	Common to abundant FeMn nodules; scarce CaCO ₃ concretions	
310–410	Silty clay	10YR 6/8, alternation of laminations 10Y 6/1 and 10Y 5/1 in the lower part	Common to abundant CaCO ₃ concretions (accumulations at 345 and 390 cm); abundant FeMn multi-millimeter nodules	
420–795	Clay	10Y 6/1 with millimeter laminations 10Y 5/1 and common to abundant mottles 2.5Y 7/8	2/3 mm thick peat laminations at 420 and 497 cm; common CaCO ₃ concretions at 420, 495, 555, 630, 640, and 690 cm	
795–895	Silty clay	Strongly laminated, alternation of laminations 5GY 3/1 and 5B 5/1 with common mottles 2.5Y 7/8, clay accumulation 2.5Y 6/3 between 865 and 870 cm	Common CaCO ₃ concretions; scarce fragments of charcoal or vegetal remains	
895–940	Silty clay	Strongly laminated, alternation of laminations 5B 6/1 and 5B 5/1 with common mottles 2.5Y 7/8	Scarce fragments of charcoal or vegetal remains	
940–1000	Silty clay	Strongly laminated, 5B 6/1 with millimeter laminations 2.5Y 6/7	Scarce CaCO ₃ concretions; rare FeMn nodules	
1000–1090	Clayey silt	5B 7/1 with common to abundant mottles 10YR 7/8	Very rare CaCO ₃ concretions in the lower part	
1090–1130	Clay	2.5Y 6/6 with laminations 5B 4/1 to 5B 6/1	Rare CaCO ₃ concretion; rare fragments of charcoal	
1130–1170	Clay	2.5Y 6/6 with laminations not perfectly distinguishable	Rare CaCO ₃ concretion; rare fragments of charcoal	
1170–1220	Clayey silt, increase in sand in the lower part	5B 7/1		
1220–1250	Clay	5B 7/1 with scarce mottles 2.5Y 6/6	Rare fragments of charcoal	
1250–1350	Sandy clayey silt	5GY 6/1, approx. 1 cm thick weak lamination of medium/coarse sand at 1315, 1320, 1325, 1328, 1333, and 1339 cm		
1350–2000	Medium/coarse sand	5GY 3/1 to 4/1, centimeter laminations 5GY 3/1 a 5GYb 4/1 of coarse/medium sand and clayey sand laminations 5GY 6/1		

PVG N-S3
0.00 / – 5.00 m depth



PVG N-S3
– 5.00 / – 10.00 m depth



PVG N-S3
– 10.00 / – 13.00 m depth



Figure 17. Whole sequence of the N-S3 core, preserved into dedicated plastic boxes.

PVG C-S1
0.00 / – 5.00 m depth



PVG C-S1
– 5.00 / – 10.00 m depth



PVG C-S1
– 10.00 / – 15.00 m depth



PVG C-S1
– 15.00 / – 17.00 m depth



Figure 18. Whole sequence of the C-S1 core, preserved into dedicated plastic boxes.

PVG F-S2
0.00 / – 5.00 m depth



PVG F-S2
– 5.00 / – 10.00 m depth



PVG F-S2
– 10.00 / – 15.00 m depth



PVG F-S2
– 15.00 / – 20.00 m depth



Figure 19. Whole sequence of the F-S2 core, preserved into dedicated plastic boxes.

The dating of the sequences relies on two types of evidence: **i)** radiocarbon dates were obtained from organic sediments collected along the stratigraphic sequence of the cores (Table 10); **ii)** ceramic fragments found at 110-130 cm depth into the N-S3 core that have been attributed to the Middle Bronze Age (3200 yr BP) based on typological features. Problems with the reliability of the results were found for the radiocarbon dates carried out, as often occurred in establishing chronological sequences within the Terramara S. Rosa di Poviglio. In this floodplain context, samples of organic matter from buried soils and peaty sediments have often provided unacceptable dates because of their overestimation even by thousands of years (Cremaschi & Gallinaro, 2021). The origin of the overestimation has been attributed to the reservoir effect. The presence of bicarbonates dating back to the Late Pleniglacial in the groundwater (Dadomo & Martinelli, 2005; Gorgoni, Martinelli, & Sighinolfi, 1982) affects the results with more ancient ages in samples coming from levels permanently saturated and lowered by pumps only for the excavation period. It is possible that the same problem occurred with the dating done on the three cores. For this reason, some dates must be rejected (indicated with “R” in Table 10).

Accepted dates are consistent with core stratigraphy and compatible with palaeobotanical reconstruction. Correlations between the accepted dates of the cores were done in accordance with stratigraphic and sedimentary trends and pollen assemblage of the sequences. In this context, the pollen dating function was of additional value for chronology, based on the recognition of assemblages or zones (Davis, 1984) and the identification of these within pollen records from northern Italy (e.g., Vescovi et al, 2007, and references therein) and the Central Po Plain (Via Tolara; unpublished data). Furthermore, the occurrence of pollen of non-native plants in the upper part of the cores was considered as control point of the chronology. For further details see 5.2 DISCUSSION ABOUT THE CHRONOLOGY.

Waiting for the results from OSL technique, the main aspect discussed above played a key role in the elaboration of preliminary age-depth model by R Bchron v 4.7.6.

Table 10. AMS-¹⁴C ages for N-S3, C-S1, and F-S2. Calibration into calendar years (2σ range) was calculated with R Clam (R Core Team, 2020 and its integrated development environment, RStudio; RStudio Team, 2020), using the IntCal20 Northern Hemisphere ¹⁴C calibration curves (Reimer et al, 2020).

No. Lab.	Core	Depth (cm)	Dated material	Uncal ¹⁴ C age (years BP)	Cal ¹⁴ age (years BP)	Cal ¹⁴ age (years BC)	Accepted/ Rejected
LTL21117	N-S3	119-116	Bulk organic sediment	4329 ± 45	5025–4836 (94.9%)	3075–2886 (94.9%)	R
UGAMS 38057	N-S3	810	Bulk organic sediment	13,020 ± 30	15,740–15,450 (94.6%)	13,790–13,500 (94.6%)	A
LTL21118	C-S1	412-407	Bulk organic sediment	4503 ± 45	5315–4963 (95%)	3365–3013 (95%)	A
UGAMS 38057	C-S1	644	Soil organic matter	5640 ± 20	6485–6320 (94.6%)	4535–4370 (94.6%)	A
UGAMS 38059	C-S1	830	Bulk organic sediment	12,780 ± 20	15,340–15,140 (94.6%)	13,390–13,190 (94.6%)	A
UGAMS 38058	C-S1	1606	Bulk organic sediment	15,820 ± 35	19,170–18,970 (94.4%)	17,220–17,020 (94.4%)	A
LTL21119	F-S2	192	Bulk organic sediment	4976 ± 45	5885–5600 (94.9%)	3935–3650 (94.9%)	R

Calibration graphs of accepted dates are reported in Figure 20 (2σ range) and 21 (σ range).

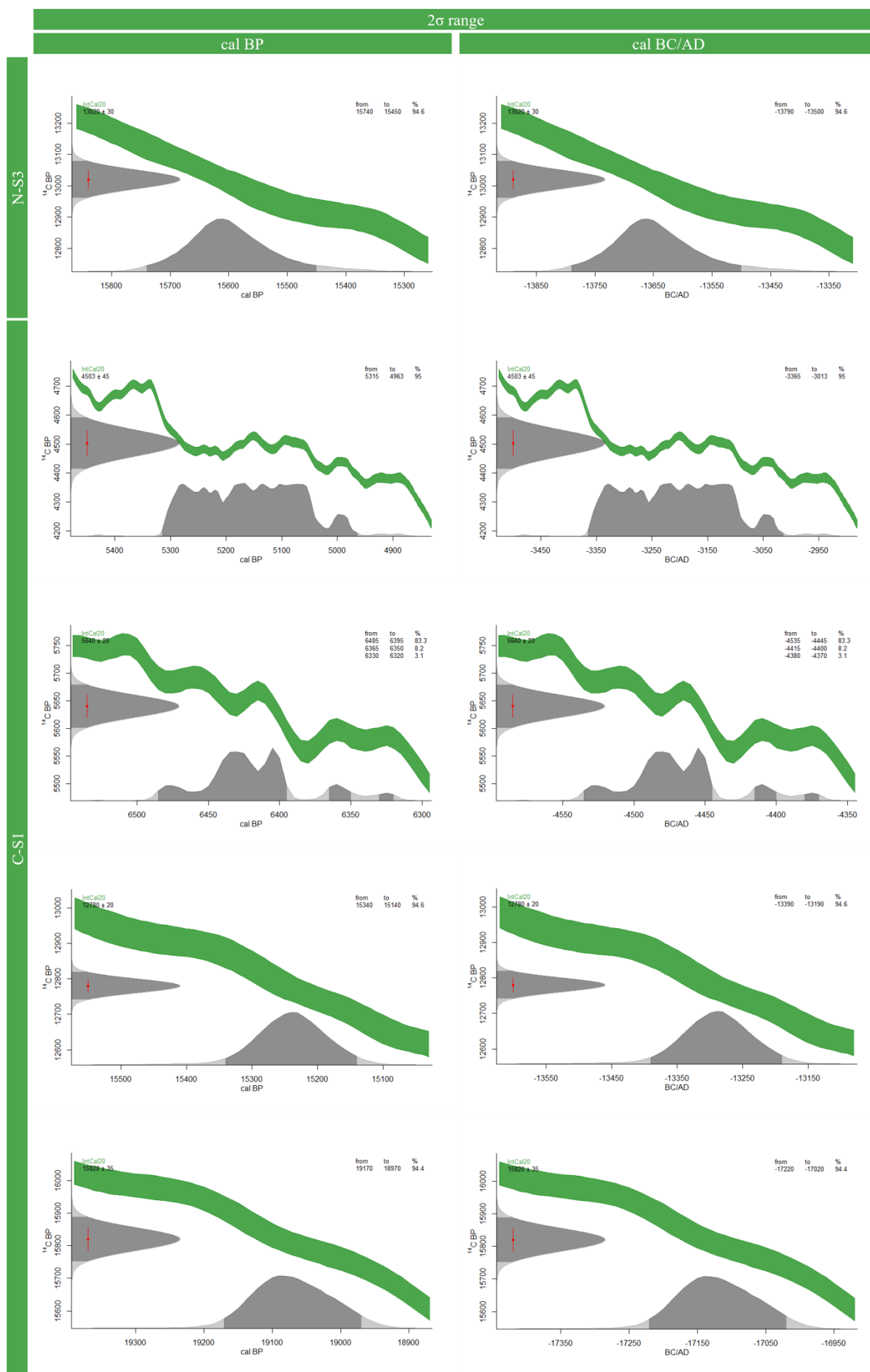


Figure 20. Calibration graphs of accepted dates (2 σ range).

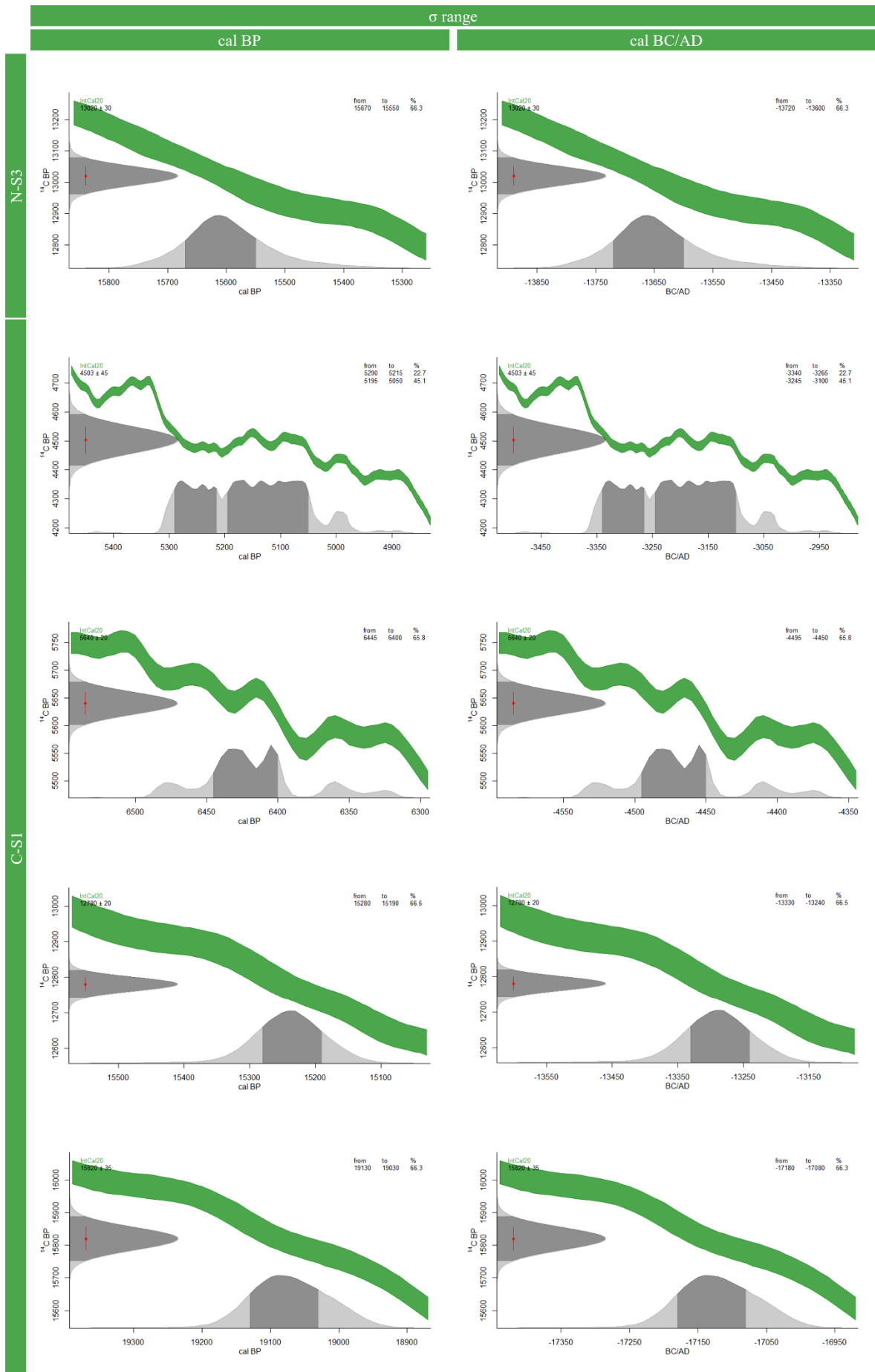


Figure 21. Calibration graphs of accepted dates (σ range).

3.1.2 POLLEN SAMPLING

Core pollen sub-sampling – A total of 292 pollen samples were collected (N-S3: 77 samples; C-S1: 150 samples; F-S2: 65 samples) at about 10-30 cm intervals (Fig. 22), according to the stratigraphy and archaeological phases. Pollen sampling of the F-S2 core was carried out at greater distance intervals due to the nature and granulometry of the sediment which determined the choice of some levels along the whole sequence. Pollen samples were taken throughout the depth of the cores, excluding the top levels of arable land. All samples were stored in a refrigerator to avoid perturbations and development of molds.



Figure 22. Pollen sampling by sterile disposable syringes, according to the method used in the Laboratory of Palynology and Palaeobotany UNIMORE.

Based on the stratigraphy and the dates obtained, it was decided to subject 195 samples to pollen extraction treatment according to the focus of the research on the detection of floristic/vegetational changes that may have developed in the Holocene. The N-S3 core was analysed entirely (77 samples) to obtain a complete and long-term reconstruction of the study area, while the first 90 and 28 samples were analysed from C-S1 and F-S2 core, respectively.

The list of samples considered in this thesis is shown in Table 11.

Table 11. List of pollen samples analysed with depth. Left: N-S3; Center: C-S1; Right: F-S2.

PVG N-S3				PVG C-S1				PVG F-S2	
Sample (No.)	Depth (cm)	Sample (No.)	Depth (cm)	Sample (No.)	Depth (cm)	Sample (No.)	Depth (cm)	Sample (No.)	Depth (cm)
1	45	40	412	1	61	46	534	1	73
2	55	41	421	2	71	47	544	2	88
3	65	42	431	3	81	48	555	3	121
4	79	43	441	4	90	49	565	4	155
5	89	44	451	5	98	50	575	5	186
6	99	45	461	6	110	51	585	6	192
7	103	46	471	7	121	52	595	7	220
8	113	47	481	8	134	53	605	8	249
9	120	48	491	9	146	54	615	9	281
10	124	49	525	10	155	55	625	10	310
11	128	50	555	11	166	56	635	11	341
12	138	51	587	12	177	57	645	12	372
13	147	52	616	13	188	58	655	13	397
14	158	53	646	14	199	59	665	14	410
15	168	54	678	15	210	60	676	15	440
16	178	55	707	16	223	61	685	16	469
17	188	56	738	17	238	62	696	17	498
18	198	57	768	18	250	63	705	18	532
19	203	58	798	19	263	64	715	19	563
20	214	59	830	20	276	65	725	20	591
21	224	60	845	21	288	66	735	21	621
22	235	61	861	22	299	67	745	22	651
23	245	62	893	23	310	68	755	23	680
24	258	63	921	24	320	69	765	24	711
25	268	64	953	25	324	70	774	25	740
26	278	65	983	26	330	71	785	26	771
27	288	66	1013	27	339	72	795	27	800
28	297	67	1045	28	350	73	805	28	830
29	303	68	1075	29	362	74	815		
30	313	69	1103	30	372	75	825		
31	323	70	1135	31	382	76	835		
32	334	71	1165	32	393	77	846		
33	344	72	1185	33	403	78	856		
34	354	73	1213	34	413	79	867		
35	365	74	1242	35	424	80	876		
36	375	75	1270	36	434	81	884		
37	385	76	1277	37	445	82	894		
38	395	77	1289	38	455	83	905		
39	402			39	465	84	915		
				40	475	85	925		
				41	485	86	935		
				42	495	87	945		
				43	505	88	955		
				44	515	89	964		
				45	525	90	972		

Surface soil sampling – The choice of the surface soils was based on the proximity to a wetland (A), cultivated fields (B), and an agricultural building (C) (Table 12).

Table 12. Surface soils: list of pollen samples.

PVG SURFACE SOILS	
Sampling “by cutting”	Sampling “by pinches”
SS-A	SS-Ap
SS-B	SS-Bp
SS-C	SS-Cp

Two different sampling methods were used (Florenzano et al, 2017):

1) *sampling “by cutting”* (Fig. 23): collection of ca. 2 cm thick portion of surface soils not covered by grass;

2) *sampling “by pinches”*: sub-samples of surface soil from several points over ca. 1 m² area (e.g., from forensic palynology; Horrocks et al, 1998).

The use of both sampling methods guarantees greater control of the pollen rain representativeness, which can be influenced by the sampling point.



Figure 23. Sampling “by cutting”.

3.2 POLLEN AND NPPs EXTRACTION

Samples were treated according to the routine method in use in the laboratory of Modena since the 1990s, which led to the concentration of palynomorphs after the elimination of the organic and mineral part of the sediment (Florenzano et al, 2012). The methodological protocol was imported and adapted from the Institute of Earth Sciences, Vrije Universiteit Amsterdam (PALICLAS project; Lowe et al, 1996; van der Kaars et al, 2001). About 1-2 g of sediment per sample was prepared, to each of which one *Lycopodium* spore tablet was added to calculate the pollen concentration, expressed as number of pollen grains per gram (p/g; Berglund, 1986). The sediment matrices were deflocculated with sodium pyrophosphate (Na₄P₂O₇·10H₂O 10% solution); it was necessary to extend this phase, up to a maximum of two days, to obtain greater efficiency given the high presence of clay which characterizes most of the samples. Each sample was filtered with a 7 µm nylon sieve and washed under running water. 10% hydrochloric acid was added to the residues to remove carbonates. After dehydration with glacial acetic acid, the samples were subjected to the classic acetolysis reaction (Erdtman, 1960), which involves the use of the acetolytic reagent (9:1 ratio of acetic anhydride and sulphuric acid) and a step in a water bath at 90° C for 10 minutes. The use of heavy liquid is the most critical phase of the treatment as it allows to concentrate palynomorphs even in poorly preserved contexts. After the addition of 40% hydrofluoric acid to eliminate silicates, the samples were washed in 98% ethanol, supplemented with alcohol and glycerin (1:1) and evaporated in an oven at 42° C for one night. The final residues were mounted on permanent slides in glycerol jelly for long-term preservation inside the Palinoteca of Modena.

3.3 IDENTIFICATION AND COUNTS

Pollen – Pollen identification was carried out under light microscope at 1000x magnification with the help of texts, scientific papers, keys, atlases (Beug, 2015; Faegri, Kaland, & Krzywinski, 1989; Moore, Webb, & Collins, 1991; Punt, 1976; Punt & Blackmore, 1991; Punt & Clarke, 1980-1991; Punt & Hoen, 2009; Punt, Blackmore, & Hoen, 1995; Punt et al, 2003-2009; Reille, 1992, 1995, 1998), and the reference pollen collection of Modena.

Pollen terminology agrees with Berglund and Ralska-Jasiewiczowa (1986), taxa denomination is in accordance with the keys and the botanical terminology follows APG IV (The Angiosperm Phylogeny Group, 2016) and The Plant List Version 1.1 (2013). The term “cf.” (= *confronta*, from Italian) indicates that the identification is probable but not sure. Pollen “*type*” and “*group*” refer to groups of plants with similar pollen from the morphological point of view, but which can belong to different Genera.

Two different morphologies of *Quercus* have been identified. Following Smit (1973), *Quercus robur/petraea* type groups pollen of deciduous oaks, named “broadleaved *Quercus*” in the text, and *Quercus ilex* is included in the *Quercus ilex* type.

Due to their archaeological and ethnobotanical importance, particular attention was paid to the identification of different types of Poaceae pollen grains, dividing them into morphological groups based on literature. The identification, although not always easy due to the great uniformity among genera and species, was based mainly on the criteria in Beug (1961) and Andersen (1979) with the correction factor for glycerol jelly (Faegri, Kaland, & Krzywinski, 1989). Pollen grains smaller than 37 µm (only few wild grasses are larger in size) with *annulus* diameters smaller than 8 µm were included into the wild grass group (Andersen, 1979). Among these, *Phragmites* was distinguishable with grain smaller than 26 µm and scabrate exine (Faegri, Kaland, & Krzywinski, 1989). Cereals (Cerealia type) were defined as larger than 37 µm according to Beug (1961). *Hordeum* group includes pollen size from 37 to 50 µm and mean *annulus* diameter 8-12 µm, while *Avena/Triticum* group includes pollen size larger than 50 µm and mean *annulus* diameter larger than 12 µm (Beug, 1961; Faegri, Kaland, & Krzywinski, 1989). The presence of *Triticum aestivum*/T. *spelta* and *Zea mays* (mean pollen size larger than 60 µm) was indicated according to Beug (2015). To distinguish *Panicum* several characteristics were considered according to Andersen (1979), Beug (1961, 2015), and Mercuri (1999): medium to large sized pollen grains (32-62 µm diameter), porus plus *annulus* mainly between 8 and 13 µm, and verrucate exine. As described in the literature, different species of *Panicum* and other genera (e.g., *Setaria* and *Echinochloa*) could be included in the same large-sized pollen type. For this reason, the term *Panicum* s.l. was used to indicate this pollen type which includes both cultivated millet (*P. miliaceum*) and wild grasses. *Secale cereale* was distinguished by oblong shape and the (sub-)apical position of the pore (Andersen, 1979; Faegri, Kaland, & Krzywinski, 1989).

Counts of at least 350 pollen grains per sample were performed for the N-S3 and C-S1 cores, except for sample 73 of the N-S3 core for which it was possible to count only 115 pollen grains. Counts of at least 200 pollen grains were carried out in samples from the F-S2 core. The state of preservation was noted as well as the frequency of reworked pollen grains. The count of saccate pollen grains includes both whole and fragmented pollen; however, the amount of one and the other have been kept separate in the elaboration. The presence of mono- and poly-specific pollen clumps was always noted (Mercuri, 2008c).

Non-Pollen Palynomorphs – Non-pollen palynomorphs (NPPs) were identified during the microscopic analysis to obtain a more detailed and local ecological interpretation. Only the presence was noted (+ = low; ++ = medium; +++ = high) for NPPs rarely observed.

Identification was based on atlases and publications (Carrión & Navarro, 2002; Cugny, Mazier, & Galop, 2010; Miola, 2012; van Geel, 2001; van Geel, Bohncke, & Dee, 1981; van Geel, Hallewas, & Pals, 1983; van Geel et al, 2003). According to the current international use, the NPPs mentioned in the literature before 2010 are indicated with the morphological type (“Type” followed by a progressive number) and the name of the taxon if identification could be suggested at different taxonomic levels (*Type No. System*, e.g., Type 61 *Mougeotia* cf. *gracillima*; van Geel, 1978). A new system, the “HdV-No. System” was adopted after the publication of the special issue on NPPs (Vegetation History and Archaeobotany Special Issue 19/5–6, 2010). The new identifications are identified by the acronym of laboratory in which they have been described followed by a progressive number (e.g., “HdV-x” indicates a morphological type identified in the Laboratory Hugo de Vries at Amsterdam, mostly from van Geel).

Particular attention was paid to the presence of *Rivularia* heterocysts (*Rivularia* type: van Geel, Hallewas, & Pals, 1983; HdV 170: Miola, 2012). A systematic quali-quantitative analysis of these structures was carried out on an entire slide for each sample of the N-S3 core (Taglini, 2019-2020; Zini, 2019-2020; Zini et al, 2021) and the first 20 samples of the C-S1 (Mazzola, 2020-2021). Heterocysts were divided into categories (Fig. 24) based on morphology (ellipsoidal or elongated) and the state of preservation of the sheaths (presence or absence). The systematic measurement of the body of the heterocysts allowed to evaluate the ratio between major and minor diameter (Md/md) that defines the morphological subdivision of the structures. The ellipsoidal shape includes heterocysts of almost spherical or spherical shape (very rare), while the elongated shape is named in this way because it presents a greater difference between the dimension of the major and minor diameters which characterizes the structure with a long and flattened aspect. Based on these considerations, the ratio between the diameters that establishes the threshold useful for the identification of the two morphologies was set at 1.6:

- $\frac{\text{Major diameter (Md)}}{\text{minor diameter (md)}}$ from 1 to < 1.6 = ellipsoidal heterocyst
- $\frac{\text{Major diameter (Md)}}{\text{minor diameter (md)}}$ from ≥ 1.6 to higher values = elongated heterocysts



Figure 24. Categories of *Rivularia* heterocysts identified: a) Ellipsoidal with sheaths (15x14 μm); b) Ellipsoidal without sheaths (10x8 μm); c) Elongated with sheaths (27x11 μm); d) elongated without sheaths (24x11 μm). The scale is 10 μm.

Photographs were taken of the most representative and best preserved palynomorphs using LEICA MC120 HD camera (see APPENDIXES, Figs. I-VII). The high number of photographs and the pollen diversity captured allowed the creation of a digital photographic atlas, which is archived at the LPP Laboratory in Modena as a reference tool for future palynological analysis of sites in the Po Plain.

3.4 DATA PROCESSING

Percentages, total concentration, and the number of pollen taxa (Floristic Richness) were calculated for each sample using Microsoft Office Excel. Pollen percentages were calculated over a Pollen Sum including all identified and unidentified pollen counted. Aquatic and wetland species were not excluded from the pollen sum, because a predominant effect of pollen related to wet environments (like in small mires or lakes) is not expected. The percentages of saccate pollen grains have been calculated in three distinct ways: a) percentage of whole plus broken pollen on the total sum of pollen grains; b) single percentage of whole and broken pollen on the total sum of pollen grains; c) single percentage of whole and broken pollen on the

total sum of specific pollen taxon to assess the incidence of fragmented pollen on the intact one. The percentages of reworked pollen grains, ferns, and other NPPs were calculated on the total sum of pollen grains plus themselves to allow a correct weighting of their presence (Berglund & Ralska-Jasiewiczowa, 1986).

The ratio between pollen percentages of woody plants (AP – Arboreal Pollen) and herbaceous plants (NAP – Non-Arboreal Pollen) was calculated, together with other main sums useful for environmental reconstructions, according to the local vegetation and landscape (Table 13; Behre, 1986; Cremaschi et al, 2016; Faegri, Kaland, & Krzywinski, 1989; Mazier et al, 2009; Mercuri et al, 2013a, 2013b; Pignatti, 1982).

Table 13. Main sums based on pollen taxa identified in the three cores.

Sum	Pollen taxa
Hygrophilous trees	<i>Alnus, Populus, Salix</i>
Hygrophilous herbs	<i>Scirpus</i> , Cyperaceae undiff., <i>Juncus</i> type, <i>Phragmites</i> , <i>Sparganium emersum</i> type, <i>Typha latifolia</i> type
Hydrophytes	<i>Lemna</i> , <i>Butomus umbellatus</i> , <i>Myriophyllum alterniflorum</i> type, <i>M. spicatum</i> type, <i>M. verticillatum</i> type, <i>Myriophyllum</i> undiff., <i>Hydrocharis morsus-ranae</i> , <i>Nymphaea alba</i> type, <i>Nuphar</i> , <i>Polygonum amphibium</i> type, <i>Potamogeton</i> , <i>Sparganium erectum</i> type
Plants of wet environments	Hygrophilous trees, hygrophilous herbs, hydrophytes
Saccate pollen grains	<i>Abies, Picea, Pinus</i>
Oak wood	<i>Carpinus betulus</i> , <i>Corylus avellana</i> , <i>Ostrya carpinifolia</i> / <i>Carpinus orientalis</i> , broadleaved <i>Quercus</i> , <i>Tilia cordata</i> , <i>T. platyphyllos</i> , <i>Tilia</i> undiff., <i>Fraxinus excelsior</i> type, <i>Acer campestre</i> type, <i>Ulmus</i> cf. <i>glabra</i> , <i>Ulmus</i> undiff.
OJC	<i>Olea europaea</i> , <i>Juglans regia</i> , <i>Castanea sativa</i>
Cereals	<i>Hordeum</i> group, <i>Panicum</i> s.l., <i>Secale</i> , <i>Avena/Triticum</i> group, <i>T. aestivum</i> / <i>T. spelta</i> , <i>Zea mays</i>
API	<i>Artemisia</i> , <i>Centaurea nigra</i> type, Cichorieae, <i>Trifolium campestre</i> type, <i>T. pratense</i> type, <i>T. repens</i> type, <i>Plantago</i> cf. <i>coronopus</i> , <i>Plantago</i> undiff., <i>Urtica dioica</i> type, <i>U. pilulifera</i> type, cereals
LPPI	Cichorieae, Asteroideae (<i>Anthemis</i> type, <i>Aster</i> type, <i>Carduus crispus</i> type, <i>Centaurea nigra</i> type, <i>Cirsium</i> , <i>Xanthium</i> type, Asteraceae undiff.), <i>Ranunculus</i> type, <i>Potentilla</i> type

Pollen diagrams, elaborated including percentage curves of single pollen types and sums, were drawn with TILIA and TGView (Grimm, 2004). Graphically, it was decided to isolate some pollen taxa from the relative sum by superimposing them on the curve (e.g., *Corylus* was separated from the curve of the mixed oak wood, as its spread is favored by the presence of animals - in particular, mammals - and by humans). Pollen diagrams were elaborated considering sums of pollen taxa belonging to the same genus or family and sharing the same ecological features. The same was considered also for elaboration and statistical analyses.

The cluster analysis was based on CONISS (Constrained Incremental Sum of Squares), on which zones and subzones were identified according to visual examination (Grimm, 2004).

The Principal Component Analysis (PCA) was elaborated with XLStat (Addinsoft, 2021).

Data Pretreatment – All variables were considered as percentages, including rare pollen taxa. The three cores were considered as three distinct datasets (N-S3: 92 variables-pollen taxa and 77 samples; C-S1: 100 variables-pollen taxa and 90 samples; F-S2: 70 variables-pollen taxa and 28 samples). The PCA was performed on the correlation matrix (Pearson).

The information obtained from the entire dataset was processed also under MATLAB® environment (MATLAB, 2019) through the graphical user-friendly interface related to the Multivariate Curve Resolution-Alternating Least Squares (MCR-ALS) algorithm (de Juan & Tauler, 2020; Jaumot, de Juan, & Tauler, 2015). Multivariate Curve Resolution methods allow to extract relevant information in a mixture system using a bilinear model decomposition of an experimental data matrix (D) in the matrices C and S^T containing pure profiles of components related to the concentration profiles (quantitative information) and the spectra (qualitative information), plus the residuals matrix: $D = CS^T + E$

Data Pretreatment – The whole data analysis considered all variables, including rare pollen taxa. A data pretreatment was performed with autoscaling, which results in a zero mean and unit variance of each variable.

MCR-Alternating Least Squares – Data from the three cores were arranged to include only one data matrix, with 195 row samples (however, the interface considered three different datasets: N-S3: 77; C-S1: 90; F-S2: 28) and 113 column variables (=total pollen taxa from the three cores). The concentration profiles achieved by MCR-ALS were plotted related to the depth of the cores. The choice of three components were determined by observing the eigenvalues representation; the total explained data variance was lower with the selection of two components, while no additional relevant environmental information was obtained with four components. The initial estimate of the S^T matrix was carried out by means of a purest variable detection method. Non-negativity was the only constrain selected both for concentration and spectra profiles. Normalization using the Euclidean norm was selected prior to starting the ALS optimization.

Quantitative reconstruction of past vegetation (Landscape Reconstruction Algorithm–LRA)

Information on the spatial distribution of past vegetation can be obtained from fossil pollen records by applying the Landscape Reconstruction Algorithm (LRA; Sugita, 2007a, 2007b). LRA (Fig. 25) has been developed to transform pollen percentage data to vegetation cover by a two-step approach, including the reconstruction of the regional vegetation (REVEALS; Sugita, 2007a), followed by the estimate of the local vegetation (LOVE; Sugita, 2007b). LRA allows to obtain estimates of vegetation abundance on local and regional scales (1 km² up to 5 km², and ca. 105 km², respectively).

Pollen counts reached for each core were considered acceptable for the application of the algorithm (even if the standard errors may be relevant with total pollen counts of 300-500 grains per sample; Sugita, 2007a). The most important parameter to pay attention in the quantitative reconstructions of past vegetation is pollen productivity estimates (PPEs) that can be calculated from modern pollen and vegetation data (Broström et al, 2008). The lack of a list of pollen productivity estimates (PPEs) for the study area highlighted the need to test many combinations of different parameters from several papers already published for northern Europe (e.g., Abraham, Oušková, & Kuneš, 2014; Githumbi et al, 2021; Kuneš et al, 2015, 2019; Mazier et al, 2012; Nielsen, 2004). To understand the most reliable set to use for the palaeoenvironmental reconstruction, the results obtained by the application of REVEALS on pollen data

from the surface soils were compared to the map of the land cover of the study area from the CORINE LAND COVER database. All CLC data layers are available on the EEA webpage: <https://land.copernicus.eu/pan-european/corine-land-cover/clc2018>. For the purpose of this study, a new list of pollen productivity estimates (PPEs) is proposed.

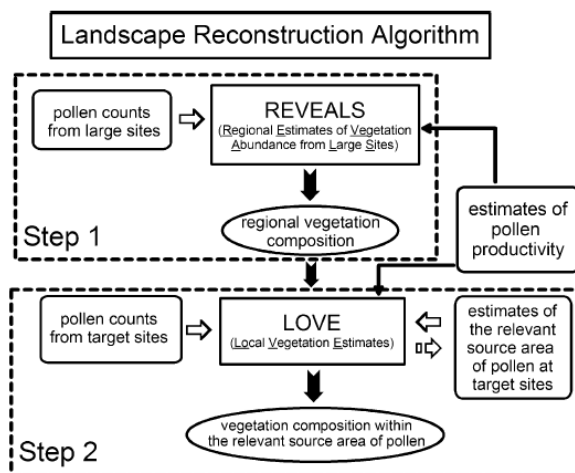


Figure 25. Framework of the Landscape Reconstruction Algorithm (LRA) proposed by Sugita (2007b). The application of REVEALS model (step 1) allows to obtain the reconstruction of regional vegetation composition by pollen counts from multiple large sites. The LOVE model (step 2) requires pollen counts from smaller and similarly sized sites and regional vegetation composition to estimates the relevant source area of pollen at target sites. Estimate of pollen productivity is a common input for both models.

The attempt to apply the REVEALS model (Regional Estimates of VEgetation Abundance from Large Sites; Sugita, 2007a), the first step of the LRA, at the pollen data from the three sequences has been made to estimates **regional vegetation composition**. However, chronological control of samples is critical for the application of LRA and the possibility to compare different sites, as in the case of the cores object of this research. For this reason, three different models were developed by applying REVEALS on each core within a 50 km radius from pollen sampling (Fig. 26 – point 1). The choice of the radius based on of the effective distance from the sampling point to the Apennine border. Since the sampling points are located in the central part of the Po Plain, the study area was considered in the model as a basin that captures the airborne pollen from large distances. The basin radius was chosen arbitrarily of 200 m, and the Prentice’s model (Prentice, 1985, 1988) for pollen records from bogs and fens was applied for affinity of deposition conditions. The Prentice model estimates pollen deposition at the center of a sedimentary basin, and it is appropriate for study sites where horizontal movement of pollen after deposition is negligible. The program REVEALS.v5.0.win64 (Sugita, unpublished) was used for regional vegetation reconstruction.

According to the pollen zones identified through the cluster analysis based on CONISS (Constrained Incremental Sum of Squares) that describe four main time windows with events and flora and vegetation transformations, the data of the three sequences relating to the same phase were combined to obtain quantitative information on the vegetation composition at a regional level (Fig. 26 – point 2). In this way, the cores were considered as different sampling points of the same basin with a radius of 200 meters.

In order to reduce the propagation of errors associated with the multiple steps in LRA, total pollen counts should be as large as possible (Sugita, 2007a). For this reason, in each core were selected the levels that intercept the final phase of the Terramara S. Rosa di Poviglio (starting from ~3200 yr BP) and pollen counts were combined into a new sum suitable to elaborate the regional vegetation estimate (Fig. 26 – point 3a). The LOVE model (Theory of quantitative reconstruction of vegetation II: all you need is LOVE; Sugita, 2007b), the second step of the LRA, was applied to two sites of the Terramare culture (Terramara S. Rosa di Poviglio and Terramara di Montale) with already available pollen data (Cremaschi et al, 2016; Mercuri et al, 2006a, 2006b) to obtain estimates of the **vegetation composition at local scale** (Fig. 26 – point 3b) with the LOVE.v5.1.win64 program (Sugita, unpublished).

Landscape Reconstruction Algorithm (LRA)

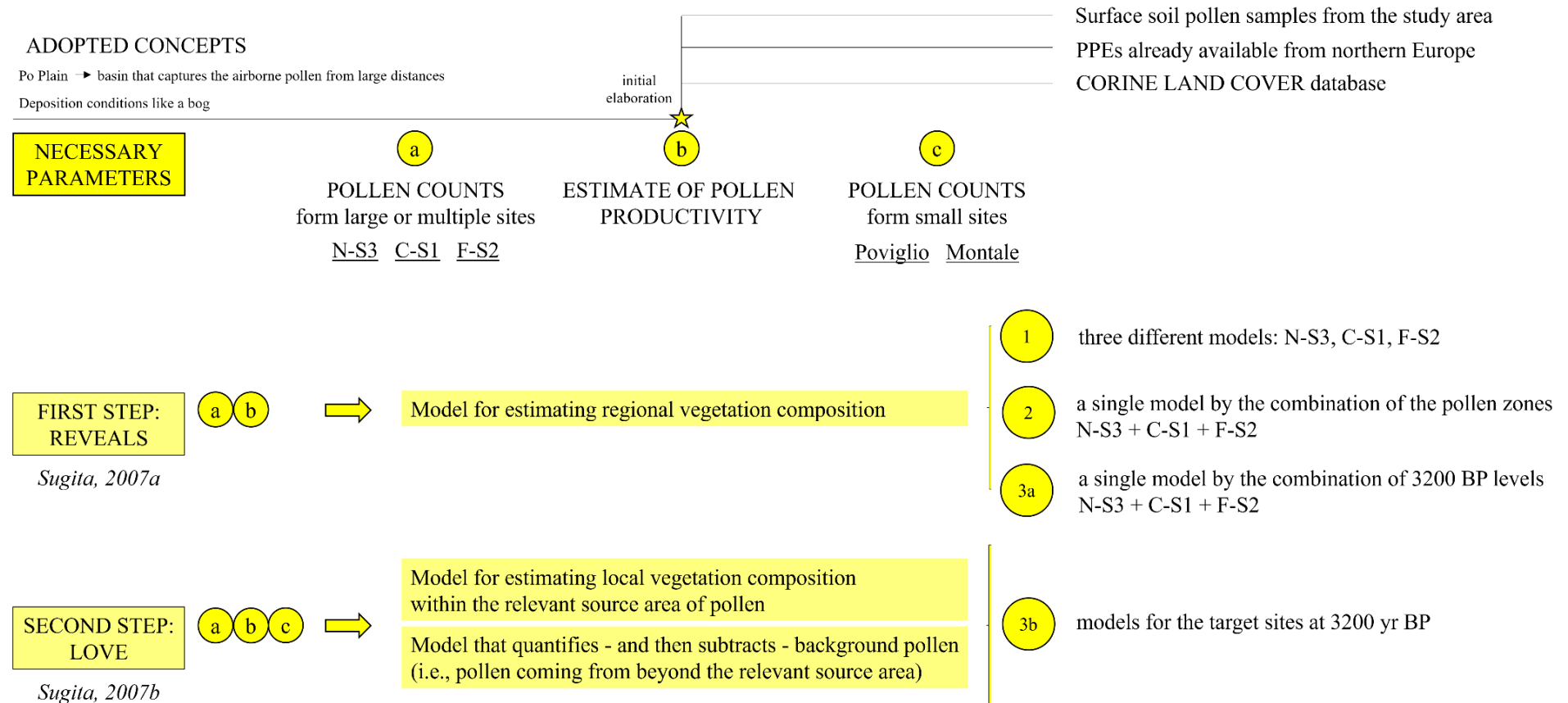


Figure 26. Flow chart of the Landscape Reconstruction Algorithm: general model adapted to the case study presented in this thesis. Key: letters = necessary parameters; numbers = types of elaborations carried out. The star marks the initial elaboration.

3.5 DETECTION OF MOLECULAR BIOMARKERS

The presence of molecular biomarkers specific for distinct vegetation types was investigated to improve the level of detail of the information provided by biological indicators in archaeological records, integrating biomolecular technologies with botanical skills (Brown & Brown, 2011). Biomolecular analysis was funded by a project FAR-DSV UNIMORE 2020 titled “*Molecular biomarkers from sedimentary archives to improve knowledge on agriculture and human impact: miliacine and dryness environmental conditions*” (P.I. Florenzano A. - Dip. Scienze della Vita UNIMORE; Partner: CNRS-LSCE). The investigation was focused on the detection of miliacin, a pentacyclic triterpene methyl ether (olean-18-en-3b-ol methyl ether), which is a molecular biomarker specific of *Panicum* and few other Poaceae in sedimentary archives (Bossard et al, 2013; Jacob et al, 2005, 2008).

The combined evidence of *Panicum* pollen and sedimentary miliacin could testify the local presence of the plant even in absence archaeocarpological records which often lack due to preservation issues.

It was necessary to collect new material from the three cores in summer 2020 to perform the biomolecular analysis. A selection of 31 samples related to Holocene chronology was made in correspondence with the previous pollen sampling and 1-2 cm thick sediment discs were taken for each sample (Fig. 27).

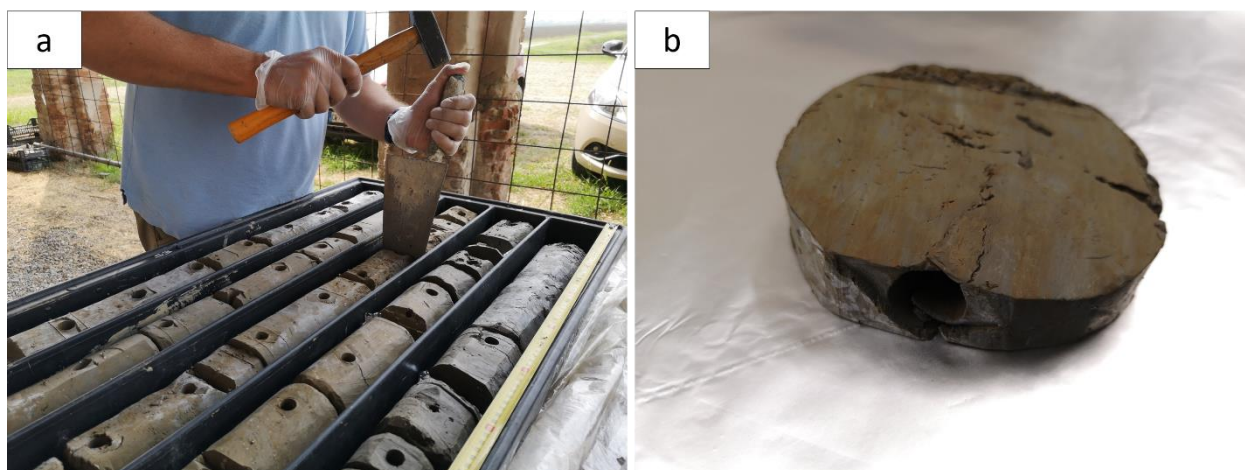


Figure 27. a) Subsampling phase for biomolecular analysis; b) A sediment disc corresponding to a previous pollen sampling marked by the hole left by the syringe.

Biomolecular investigations were commissioned to Dr. Jacob of the CNRS-LSCE (*Laboratoire des Sciences du Climat et de l'Environnement*), who was the first researcher (and currently the only one) to deal with the extraction of miliacin from archaeological sediments by developing an analysis protocol that guarantees the absence of contamination (Jacob et al, 2005). Samples were crushed to powder after being dried in an oven at 50 °C. A weighted amount of sample powder was plunged into a mixture of dichloromethane and isopropanol (2:1 v:v). Ultrasonication and centrifugation were carried out three times to ensure a maximum lipid extraction. Lipid extracts were then subjected to a rapid chromatographic separation in order to separate neutral, acidic, and polar compounds. Miliacin in the neutral fraction of lipid extracts was identified and quantified par Gas-Cromatography coupled to Mass-Spectrometry. 1µL was injected in splitless mode with the injector set at 280 °C. The gas chromatograph was equipped with a BPX5 column (60m, 0.32 mm id, 0.25µm phase). Helium was the gas vector (at 1.2 mL/min). The GC operating conditions were: temperature held at 80 °C for 1 min, then increased from 80 to 120 °C at 120 °C/min and 120 to 300 °C at 4 °C/min hold 10 minutes. The mass spectrometer was operated in electronic impact mode at 70 eV and scanned fragments from 50 to 650 amu. The structure of miliacin was assigned with authentic standards. Except from miliacin, other biomarkers of interest were identified with authentic standards or based on mass spectra and relative retention times.

4 RESULTS

This chapter presents data and some general observations about the whole set of samples. Pollen zones are described below. For details of the data, see Tables 14-16.

4.1 POLLEN

4.1.1 CONCENTRATION AND COUNTS

Pollen concentration is generally in the order of 10^4 , from 10^3 to 10^5 , usually showing a good amount of organic supply to the sediments. Average value is about 15,000 p/g in the N-S3 core, 20,000 p/g in the C-S1 core, and 18,000 p/g in the F-S2 core. The lowest concentration, 1056 p/g, is related to the N-S3 core (sample 73), while in the other two sequences the minimum values are 2104 p/g and 8110 p/g (sample 16 – C-S1 and sample 21 – F-S2). The highest concentration is present in the C-S1 core (175,327 p/g - sample 62), while the maximum values reached in the other two cores amount to 55,294 p/g (sample 61 – N-S3) and 43,381 p/g (sample 4 – F-S2).

All samples are polliniferous. A total of 66,087 pollen grains were counted. For each core it was possible to reach the established pollen sum, except for sample 73 of the N-S3 core with 115 pollen grains.

4.1.2 STATE OF PRESERVATION

The state of preservation of pollen grains is generally quite good and no relevant differences between pollen taxa, related to variety of specific composition and structure (Hall, 1981), have been observed. However, variability with different kinds of deterioration is usually present even within the same sample. Mechanical damages represent the main type of deterioration, characterizing partially broken, crumpled, or folded pollen grains, mainly related to the type of transport or post-depositional compaction of the sediment. Saccate pollen grains (*Abies* + *Picea* + *Pinus*) are particularly affected by this type of damage and they were usually observed as broken (mean values of the broken pollen on the total of saccate observed: N-S3: 69.5%; C-S1: 74.1%; F-S2: 73.8%). Damages related to different degrees of deterioration of the exine are also observed (Berglund & Ralska-Jasiewiczowa, 1986). Among these, pollen grains of light or dark color are present even within the same sample, together with pollen corroded, thinned, or thickened with some elements of the wall structure partially fused. However, these features did not prevent the punctual identification of pollen, as evident from the low percentage of unidentifiable pollen grains characterizing most of the samples (the average value is 3.4% for the N-S3 core; 1.6% for the C-S1 core, and 2.8% for the F-S2 core). They all may be considered coeval to the deposits, indicating different transport agents of the pollen input, and may help to understand better the deposit formation.

The presence of reworked pollen grains, resulting from the occurrence of alluvial phenomena, is variable along all the sequences, with the alternation of levels characterized by high percentages (maximum values: 76.5%, sample 66 – N-S3; 50.9%, sample 16 – C-S1; 24.2%, sample 9 – F-S2) and levels in which this type of findings has not been observed (as in the case of sample 5 of the F-S2 core), or they are scarce (minimum values: 0.8%, samples 8 and 5 – N-S3; 0.3%, samples 55, 7, 6, and 3 – C-S1). The average value is 18.1% (N-S3), 9.6% (C-S1), and 6% (F-S2).

The presence of clusters of pollen grains, called “pollen clumps”, was observed both consisting of a single pollen taxon and several taxa. Monospecific clusters have been observed mainly consisting of Cichorieae, Cyperaceae, and Poaceae wild grass group. Pollen clumps of *Sparganium emersum* type, *Trifolium* type, *Medicago*, broadleaved *Quercus*, *Artemisia*, Apiaceae, *Alnus*, *Salix*, *Aster* type, *Pinus*, *Amaranthaceae*, *Corylus*, *Stachys*, *Prunus*, *Potentilla* type, and reworked pollen grains have also been observed. The presence of some pollen clumps of indeterminable pollen grains was also reported.

4.1.3 FLORISTIC RICHNESS

A good number of pollen taxa composes the floristic list, with a decidedly lower abundance evident in F-S2 core further from the site (total amount: 136 – N-S3, 137 – C-S1, and 88 – F-S2; average values per sample: 35 – N-S3, 34 – C-S1, and 27 – F-S2). The greatest difference between samples is observed in the cores N-S3 and C-S1, in which the number of pollen taxa reaches a maximum of 48 (sample 23 – N-S3) and 47 (samples 49 and 39 – C-S1) to a minimum of 18 (sample 67 – N-S3; sample 32 – C-S1). In F-S2, the number of pollen taxa ranges from a maximum of 35 (sample 14 – F-S2) to a minimum of 16 (sample 4 – F-S2). The number of herbaceous pollen taxa is often higher (above 30 in the richest samples) compared to trees/shrubs (up to 20 taxa).

The presence of ferns (Pteridophyta) is testified by the identification of monolete and trilete spores (6 types of spores in total). Furthermore, the presence of Bryophyta is rarely attested.

4.1.4 GENERAL POLLEN SPECTRA AND MAIN SUMS

The ubiquitous and the most represented pollen taxa (i.e., present in at least half of the samples - the mean percentages of N-S3, C-S1, and F-S2 are reported) are limited number, compared to the overall pollen flora. Among them, there are 9 woody plants (*Alnus* – 10.7%, 9.4%, 9.2%; *Carpinus betulus* – 1.3%, 1%, 1.6%; *Corylus avellana* – 1.9%, 1.8%, 2.3%; broadleaved *Quercus* – 9.7%, 12.1%, 17.8%; *Fraxinus excelsior* type – 0.5%, 0.5%, 0.5%; *Abies* – 2.5%, 2.3%, 2.5%; *Pinus* – 9.6%, 7.7%, 5.3%; *Salix* – 3.6%, 4.4%, 7.1%; *Ulmus* – 2.3%, 2.3%, 1.8%) and 11 herbs (Amaranthaceae – 1.6%, 1%, 1%; *Aster* type – 0.7%, 0.8%, 0.6%; Cichorieae – 6.4%, 2.9%, 2.7%; *Scirpus* – 3.3%, 7.4%, 4.7%; Cyperaceae undiff. – 9.9%, 11.8%, 15.5%; *Plantago* – 1.8%, 1.5%, 1.4%; Poaceae wild grass group – 15.3%, 12.6%, 12%; *Hordeum* group – 0.8%, 0.9%, 0.6%; *Ranunculus* type – 0.8%, 1.2%, 0.7%; *Potentilla* type – 0.5%, 0.6%, 0.3%; *Sparganium emersum* type – 4.1%, 7.5%, 3.1%). In addition to these, other common pollen taxa among woody plants are *Ostrya carpinifolia*/*Carpinus orientalis* (0.3%, 0.3%, 0.2%), *Prunus* (0.3%, 0.4%, 0.2%), *Rosa* (0.2%, 0.1%, 0.1%), and *Vitis vinifera* (0.2%, 0.3%, 0.2%). All of these pollen taxa contribute to reconstruct the general forest cover in the area, together with Apiaceae (0.5%, 0.5%, 0.3%), *Artemisia* (1%, 0.9%, 0.3%), *Centaurea nigra* type (0.3%, 0.2%, 0.4%), *Brassica* type (0.3%, 0.2%, 0.1%), *Hornungia* type (0.3%, 0.2%, 0.2%), Caryophyllaceae (0.3%, 0.6%, 0.2%), *Trifolium campestre* type (0.4%, 0.3%, 0.2%), *Mentha* type (0.5%, 0.5%, 0.1%), and *Stachys* (0.4%, 0.2%, 0.2%) among herbaceous species representative of meadows.

Conventionally, the ratio between the percentages of woody plants (AP-sum of trees and shrubs) and herbs (NAP) has long represented quantitative changes in forest cover (Favre et al, 2008). On average, the forest cover described by pollen was low, typical of an open habitat, although there are many fluctuations in the forestation rate along the spectra (AP: 45.3% – N-S3, 44.0% – C-S1, and 49.8% – F-S2; NAP: 54.7% – N-S3, 56.0% – C-S1, and 50.2% – F-S2). However, AP percentages more than 60%, that may be indicative of closed canopy forest (Mitchell, 2005), are attested along the sequences (N-S3: 18/77 samples, C-S1: 25/90 samples, F-S2: 9/28 samples).

The AP percentage reaches maximum values of 79.4% (AP/NAP: 3.9; sample 35 – N-S3), 78.9% (AP/NAP: 3.7; sample 36 – C-S1), and 72.6% (AP/NAP: 2.7; sample 18 – F-S2) and minimum values of 4.3% (AP/NAP: < 0.1; sample 68 – N-S3), 7.7% (AP/NAP: 0.1; sample 32 – C-S1), and 16.9% (AP/NAP: 0.2; sample 28 – F-S2).

The forest cover was mainly represented by the mixed oak wood (16.4%, 18.3%, 24.5%), with dominance of broadleaved oak among trees and hazel among shrubs. The hygrophilous wood (14.3%, 13.8%, 16.2%) was represented by alder and willow, which identify the achievement of the climax community in a riparian vegetation succession. Woody plants consisted also by the conifer trees (here *Abies* + *Picea* + *Pinus*: 12.9%, 10%, 7.9%). The presence of *Olea*, *Juglans*, and *Castanea* pollen (OJC group), considered evidence of the evolution of the (arbori)cultural landscape, is sporadic in the sequences (0.2%, 0.1%, 0.2%).

Wet environments were widespread and covered mainly by hygrophilous herbs (17.6%, 27.1%, 23.5%) with the dominance of Cyperaceae and *Sparganium emersum* type, while the presence of hydrophytes was

usually scarce. Anthropogenic Pollen Indicators-API (11%, 7.3%, 6.3%) and other synanthropic plants were important markers of the development of human activities along the sequences. Among these Cichorieae and *Plantago* are dominant and cereals pollen is almost ubiquitous (0.9%, 1.3%, 0.8%) in the spectra. The occurrence of Local Pastoral Pollen Indicators-LPPI (9%, 5.8%, 5%), here represented by Asteroideae (1.4%, 1.2%, 1.2%), Cichorieae, *Ranunculus* type, and *Potentilla* type, is also attested as indication of local grazing activities.

Monolete and trilete spores were observed along all the sequences always with low percentages (1.4%; 0.7%; 0.4%). Among these, it is possible to identify spores of *Asplenium*, *Botrychium*, *Ophioglossum*, *Polypodium*, *Pteridium*, and *Trichomanes* type. A single *Sphagnum* spore was observed in sample 12 of the C-S1 core.

Reworked pollen grains are common along the sequences (18.1%, 9.6%, 6%), and include mainly saccate pollen (2.6%; 0.4%; 0.4%), *Normapolles* type, and *Classopollis*.

4.2 NON-POLLEN PALYNOMORPHS

The concentration of Non-Pollen Palynomorphs is generally attested in the order of 10^3 with an average value of about 1100 npp/g in the N-S3 core, 755 npp/g in the C-S1 core, and 1100 npp/g in the F-S2 core. The state of preservation is good although sometimes partially whole remains were observed (especially in the case of large structures). A total of 14 types of microremains were observed and identified as algae (Chrysophyceae statospore, *Pseudoschizaea* - NN 61, Dinoflagellate cysts - HdV 703, *Mougeotia*, *Rivularia* type - HdV 170, Unknown - HdV 225, and *Zygnema* type - HdV 314), fungi (*Chaetomium* - HdV 7, *Glomus* - HdV 207, *Sordaria* - HdV 55, *Sporormiella* - HdV 113, Unknown - HdV 361), animalia (*Trichuris* - HdV 531), and protozoa (*Arcella* - HdV 352).

Rivularia type (HdV 170) in the N-S3 core

The presence of *Rivularia* heterocysts is highly variable throughout the core, from the complete absence of these structures in many levels to the maximum value of 94 heterocysts in sample 58. This is reflected in heterocyst concentration that fluctuates throughout the sequence, from a minimum of 18.2 h/g in sample 27 (without considering the samples in which these structures are absent) to a maximum of 4115.3 h/g in sample 58, while the average value was 265.9 h/g.

The percentages of *Rivularia* type, strictly dependent and correlated to local vegetation, have different values throughout the core. Sample 53 has the lowest percentage of 0.1%, while the highest percentage of 13.6% is documented in sample 58. Considering the whole sequence, the average value is 1.6%.

The heterocysts are usually characterized by an excellent state of preservation of the cell body with the integrity of the wall and a well-defined morphology, which has always allowed the identification of these structures. A highly variable feature is the presence or absence of sheaths surrounding the trichome, not always easily identifiable due to organic and inorganic particles that sometimes obstructed the observation of these structures. A certain variability of the presence/absence of the sheaths is usually visible within the same sample (Fig. 28a).



Figure 28. N-S3 core bar charts: a) Presence of *Rivularia* heterocysts with and without sheaths; b) Presence of ellipsoidal and elongated *Rivularia* heterocysts.

The total number of cells without sheaths exceeds that of sheathed cells (366 and 270, respectively). This is especially evident in some samples, such as sample 3 (with 16 heterocysts without sheaths and 1 heterocyst with sheaths; subsequently the ratio between the two forms is reported), sample 58 (88/6), sample 32 (13/2), and sample 29 (25/6). However, the opposite situation is also present in other samples, such as sample 11 (with no heterocysts without sheaths and 28 heterocysts with sheaths), sample 51 (0/15), sample 47 (1/23), and sample 30 (1/9).

The morphology and size of the heterocysts also show variability. Very small cells are observed in sample 25, in which two heterocysts have major diameter (Md) of 5.9 μm and minor diameter (md) of 4.4 μm . Very large heterocysts are observed in samples 30 and 49, with a Md of 29.5 μm and a md of 17.7 μm . Elongated and ellipsoidal heterocysts are present in almost equal quantities throughout the sequence (315 and 321 heterocysts, respectively; Fig. 28b). However, some samples are characterized by the prevalence of one morphology. For instance, samples 47 and 58 have a greater value of ellipsoidal heterocysts compared to the elongated ones (19/4 and 69/25, respectively), while in samples 11 and 38 the elongated shape is more abundant than the ellipsoidal morphology (24/4 and 22/8, respectively).

Rivularia type (HdV 170) in the C-S1 core

The presence of *Rivularia* type is very variable, although always very low counts of these remains characterize the samples of the C-S1 core, from a minimum of 0 heterocysts (samples 20 and 12) up to a maximum of 8 heterocysts (sample 6). Except for the samples in which no heterocysts were observed, the concentration shows a minimum of 16.9 h/g in sample 4 and a maximum of 178.2 h/g in sample 2. The mean value is 79.5 h/g.

The percentages of *Rivularia* type spanning from the lowest value of 0.1% (samples 10, 8, and 4), and the highest percentage of 1.7% in sample 18. Considering all the samples, the average value is 0.6%.

The state of preservation of the heterocysts is good and homogeneous. Furthermore, a greater abundance of heterocysts with sheaths differentiates this core from the previous one, with a total number of 53 heterocysts with sheaths and 11 without sheaths (Fig. 29a).

Ellipsoidal heterocysts are more abundant compared to the elongated ones (49 and 15 heterocysts, respectively; Fig. 29b). However, some samples are characterized by the prevalence of elongated heterocysts, such as sample 2 with 4 elongated and 2 ellipsoidal heterocysts.

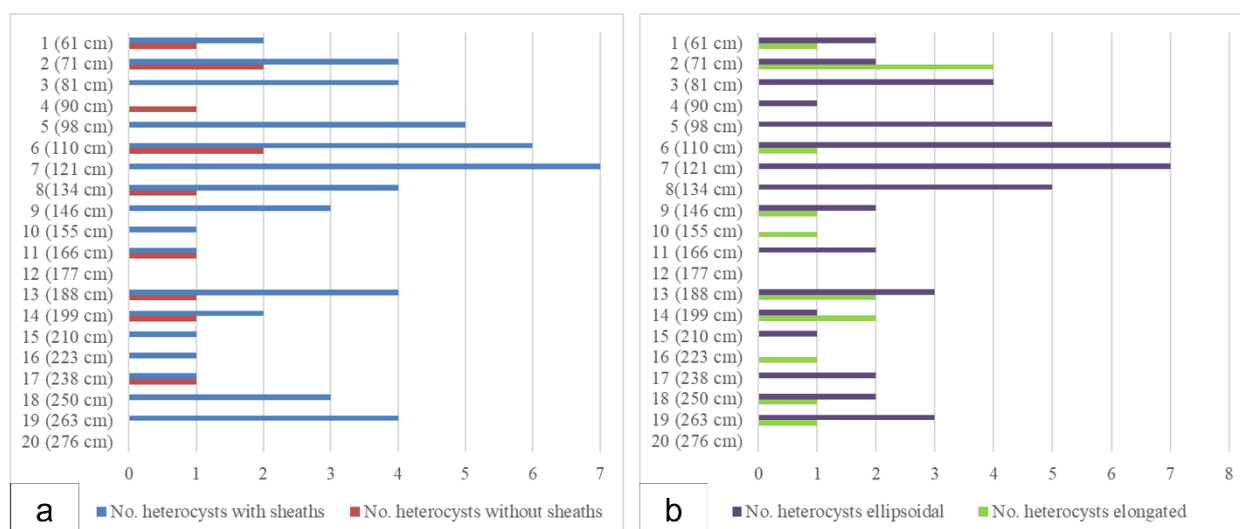


Figure 29. C-S1 core (samples 20-1) bar charts: a) Presence of *Rivularia* heterocysts with and without sheaths; b) Presence of ellipsoidal and elongated *Rivularia* heterocysts.

4.3 POLLEN ZONES

Four main pollen zones were recognized and labeled with the core name followed by a numerical code from 1 to 4, sorted from the most ancient to the recent chronology. The first pollen zone is represented only in N-S3, while the second pollen zone was identified in N-S3 and C-S1. The last two pollen zones were identified in all the cores. The zones were further subdivided into subzones indicated with the letters (a, b, etc. from the bottom to the top). However, there is a margin of uncertainty in establishing zone boundaries due to chronological uncertainties.

A general description of pollen zones and subzones is given below, starting from the bottom of the sequences. Subsequently, a systematic description is reported in the Tables 14-16. Similarities between the subzones are firstly described, then followed by dissimilarities to highlight environmental features on more local level. Unless otherwise specified, the pollen percentages reported represent the mean value of the

zone/subzone, in order to avoid possible bias due to the over-representation of a single sample during the interpretation. Pollen taxa with average values $\geq 0.5\%$ are mentioned for the N-S3 and the C-S1 cores, while the threshold value for the F-S2 core was set at 0.3% based on the proportion to the pollen sum. However, rare pollen taxa particularly significant from a vegetational point of view are also reported.

4.3.1 POLLEN ZONE 1

N-S3: 77-68, 1289-1060 cm

Pollen concentration has the lowest value (ca. 5500 p/g) while the reworked pollen percentage is the highest (31.5%), which together are index of a high deposition of matter diluting pollen. Accordingly, a relatively high value of *Pinus* is attested (18.9%), also found as fragments and broken grains (representing the 51.4% of *Pinus* pollen). Besides pine, *Picea* (3.6%) and *Abies* (2%) are represented among conifers. Forest cover also consists of hygrophilous wood (3.4%), represented by *Salix* (1.8%) and *Alnus* (1.6%), and of the oak wood components (2.9%) among which broadleaved *Quercus* (0.9%) and *Corylus* (0.8%) are dominant.

However, herbaceous pollen taxa exceed the wood component (AP: 32.7%; NAP: 67.3%). Poaceae wild grass group is dominant (26.4%). Wet environments also including hygrophilous herbs consisting mainly of Cyperaceae (10%). Cichorieae (7%), *Artemisia* (3%), *Plantago* (2.4%), and other pollen taxa included in the API group are well represented the pollen assemblage (API group: 14.6%). Among them, cereals are 1%. Amaranthaceae have significant values too (2.7%).

Zone 1 is subdivided into two subzones.

4.3.1.1 POLLEN SUBZONE 1A

N-S3: 77-72, 1289-1175 cm

Subzone 1a is distinguished by high values of *Pinus* (24.6%), *Picea* (5.4%), *Abies* (2.9%), and significant percentages of *Salix* (2.7%). Among herbs, *Mentha* type (1.4%), *Stachys* (0.8%), and *Ranunculus* type (1.2%) characterize the lower part of this subzone, while significant presence of Cichorieae (9.2%) and other Asteraceae (1.9%) is documented. Poaceae wild grass group (15.2%) and Cyperaceae (9.5%) are present.

4.3.1.2 POLLEN SUBZONE 1B

N-S3: 71-68, 1174-1060 cm

The significant rise in the Poaceae wild grass group (43.3%) is accompanied by a decline of tree percentages (e.g., *Pinus*: 10.3%). *Betula* (0.6%) and *Juniperus* type (0.7%) are often documented. This subzone also exhibits an increase in Amaranthaceae (3.7%) and *Artemisia* (4.6%) values, while Cichorieae (3.7%) decrease.

4.3.2 POLLEN ZONE 2

N-S3: 67-57, 1059-753 cm; C-S1: 90-74, 972-810 cm

Pollen concentration become higher (ca. 22,600 p/g; ca. 12,000 p/g) while the reworked pollen grains have lower values (14.2%; 12.7%) than in the previous zone. The ratio between AP (28.4%; 25.5%) and NAP (71.6%; 74.5%) marked the greater diffusion of grasslands. *Pinus* (20%; 17.2%) has values like the previous

zone and the percentage of fragmented pollen grains remains almost unchanged (51.3%; 35.7%). A slight drop of *Picea* (2%; 0.1%) and *Abies* (0.7%; 1.2%) was observed. The broadleaved woods continued to be not widespread in the area, but the record is almost continuous. *Alnus* (1.4%; 1.5%) and *Salix* (1%; 0.9%) characterized the hygrophilous wood showing some fluctuations in this zone (2.4%; 2.4%). As regards the mixed oak wood (2.4%; 2%), the dominant elements remain broadleaved *Quercus* (1.1%; 0.6%) and *Corylus* (0.7%; 0.9%). *Betula* is present (0.5%; 1.1%).

Poaceae wild grass group is dominant among herbaceous pollen taxa (33.6%; 25.7%), together with plants related to wet environments that in this zone are still composed of Cyperaceae (13.8%; 16.3%) but also by an important presence of *Sparganium emersum* type (4.8%; 11.9%). *Artemisia* (3.4%; 3.5%), Cichorieae (3.3%; 1.9%), and other Asteraceae (2.6%; 2.3%) maintain significant values.

Zone 2 is subdivided into two subzones.

4.3.2.1 POLLEN SUBZONE 2A

N-S3: 67-64, 1059-937 cm; C-S1: 90-82, 972-889 cm

This subzone is marked by a rise in the percentages of the tree taxa, especially *Pinus* (20.8%; 23%). *Picea* increases and reaches significant values in N-S3 (3.2%), while *Juniperus* type peaks at the bottom of the C-S1 subzone (1.5%). Poaceae wild grass group decreases in the N-S3 but increases in C-S1 (33.6%; 24.1%). Cichorieae (5.5%, 1.6%) and other Asteraceae (3.5%; 1.1%) show higher values in N-S3 than in C-S1.

4.3.2.2 POLLEN SUBZONE 2B

N-S3: 63-57, 936-753 cm; C-S1: 81-74, 888-810 cm

A drastic decrease in the reworked pollen is documented (7%; 8%). Simultaneously with a slight decline of *Pinus*, broadleaved *Quercus* shows a growing trend in this subzone. Poaceae wild grass group increases with fluctuations (33.7%; 27.6%). *Artemisia* (2%; 5.2%) and other Asteraceae (2.1%; 3.7%) show higher values in C-S1 compared to N-S3. Cichorieae also decrease significantly in N-S3 (2.1%).

4.3.3 POLLEN ZONE 3

N-S3: 56-29, 752-300 cm; C-S1: 73-18, 809-244 cm; F-S2: 28-12, 830-356.5 cm

Forest cover has largely increased in this zone, such that the trend held constant in the first two zones has reversed and the woody component (AP: 59.2%; 51.8%; 51.1%) exceeds the herbaceous one (NAP: 40.8%; 48.2%; 48.9%). The mixed oak wood become dominant (25.7%; 24.2%; 26.6%) and other woody plants start to be significant components in addition to broadleaved *Quercus* (16.3%; 15.9%; 19.6%) and *Corylus* (2.2%; 2.2%; 2.1%). Among these, *Ulmus* (4.2%; 3.5%; 2.7%), *Carpinus betulus* (1.2%; 1.1%; 1%), *Fraxinus excelsior* type (0.9%; 0.7%; 0.6%), and *Tilia* (0.8%; 0.5%; 0.4%) begin to characterize the spectra. *Prunus* increases (0.4%; 0.5%; 0.3%) probably taking space within the oak wood. The hygrophilous wood is represented by high values throughout the zone (24%; 16.9%; 14%) and continues to be composed of *Alnus* (19.9%; 13%; 10.9%) and *Salix* (4%; 3.9%; 3.1%). Concerning the riparian vegetation, it is necessary to note the increase in *Vitis* pollen (0.2%; 0.4%; 0.3%). Concurrently with the expansion of the broadleaved woods, there is a drastic drop of *Pinus* (5.1%; 5.9%; 6.3%) and *Picea*, whose presence become rare, while *Abies* grows gradually (2.8%; 2.9%; 2.9%). Among the conifers, the presence of fragmented pollen grains is significant (*Pinus*: 75.5%; 78.1%; 68.4% - *Abies*: 89.6%; 91.8%; 93.7%).

Among the herbs, Cyperaceae (13.7%; 19.8%; 23.3%) become prevalent on Poaceae wild grass group (7.8%; 8.8%; 8.4%) and, together with *Sparganium emersum* type (7.7%; 7.6%; 3.6%), testifies a rather widespread wet environment, which is confirmed also by the significant increase in *Rivularia* heterocysts reaching the highest abundance in all sequences (2%; 1.4%; 1.5%). According to this, the API group has the lowest values of the sequences in this zone (3.3%; 4.3%; 5.5%).

A significant increase in spores of the mycorrhizal fungus *Glomus* is documented starting from this pollen zone (2.6%; 1.7%; 2.1%).

Zone 3 is subdivided into three subzones.

4.3.3.1 POLLEN SUBZONE 3A

N-S3: 56-52, 752-601.5 cm; C-S1: 73-53, 809-600 cm; F-S2: 28-24, 830-695.5 cm

The main feature of the subzone 3a is the strong increase in the total tree pollen percentage (AP: 40.6%; 39.4%; 33%). This increase is almost entirely due to broadleaved *Quercus* (13.7%; 12.7%; 11.8%) together with the hygrophilous wood (dominated by *Alnus*: 8.1%; 8.5%; 2.8%), although the latter spread later compared to the mixed oak wood – the delayed diffusion of the hygrophilous wood is particularly evident in the F-S2. The oaks drop sharply in the upper part as a result of the colonization of wet environments (trees and herbs). A significant growth of *Abies* is also attested (3.9%; 2.6%; 4.2%). The significant rise in the tree percentages is accompanied by a profound decline in the values of Poaceae wild grass group (15.2%; 13.1%; 12.5%), Cichorieae (0.6%; 0.6%; 0.8%), and *Artemisia* (0.1%; 0.4%; 1.2%). *Ranunculus* type (0.8%; 1.9%; 0.5%) and *Plantago* (1.1%; 1%; 0.8%) increase. Among the hygrophilous herbs, Cyperaceae (23.2%; 26.5%; 35.1%) show high values and *Sparganium emersum* type (8.2%; 10.9%; 6.9%) is significant too.

4.3.3.2 POLLEN SUBZONE 3B

N-S3: 51-43, 601.4-436 cm; C-S1: 52-35, 599-418.5 cm; F-S2: 23-18, 695.4-515 cm

This subzone is marked by a rise in the ratios of reworked pollen (17.7%; 12.8%; 10.1%). The increasing trend of forest cover continues reaching maximum percentages throughout the entire records (AP: 68.2%; 65.8%; 64.9%). Broadleaved *Quercus* (19.6%; 24.1%; 29.4%) spreads together with the mixed oak wood. In particular, a strong increase in *Ulmus* (8.1%; 7.6%; 5.2%) is attested. *Fagus* is present with greater continuity. The percentages of *Prunus* are also starting to increase (0.7%; 0.7%; 0.3%). *Alnus* especially spreads in N-S3 (22.7%). *Vitis* has higher rates in C-S1 (0.5%). Hygrophilous herbs decrease (9.8%; 14.6%; 14.8%), while the API group increases (4.8%; 5.9%; 6.2%).

4.3.3.3 POLLEN SUBZONE 3C

N-S3: 42-29, 435-300 cm; C-S1: 34-18, 418.4-244 cm; F-S2: 17-12, 514-356.5 cm

Reworked pollen slightly decreases (9.9%; 12.2%; 5%). Broadleaved *Quercus* (15.1%; 11%; 16.3%) and *Ulmus* (2.8%; 2%; 2%) show a sharp decline in favor of a new expansion of wet environments (hygrophilous trees, reaching the maximum percentages throughout the whole sequences: 28.9%; 23.7%; 21.4%; hygrophilous herbs: 25.8%; 29.1%; 26.8%). The other components of the mixed oak show a more constant trend in the N-S3. *Fagus* is well attested (0.7%; 0.5%; 0.3%).

4.3.4 POLLEN ZONE 4

N-S3: 28-1, 299-45 cm; C-S1: 17-1, 243-61 cm; F-S2: 11-1, 356.4-73 cm

A new growth trend of the API group characterizes this zone with the highest percentages compared to the whole sequence (18.2%; 15%; 7.6%). Among these, it is particularly representative the increase in cereals which reach high percentages (1.5%; 1.9%; 0.9%) together with Cichorieae (12.9%; 10.1%; 4.7%), and *Plantago* (2.3%; 1.7%; 0.8%). Cyperaceae (13.4%; 19.7%; 15.3%) and Poaceae (11.6%; 11.8%; 17.7%) still have an important role among herbaceous plants, followed by Amaranthaceae (2.2%; 2.2%; 1.8%), and *Sparganium emersum* type (1.3%; 2.8%; 2.2%). Hydrophytes are well attested.

The landscape is more open related to the drop of the forest cover (AP: 42.5%; 37.1%; 47.9% - NAP: 57.5%; 62.9%; 51.1%). Broadleaved *Quercus* (9.7%; 10.9%; 15.2%), together with *Corylus* (2.3%; 1.4%; 2.6%) and *Carpinus betulus* (2.2%; 1.5%; 2.4%), mainly characterizes the mixed oak wood, which continues to be the main component of the forest cover (17.5%; 15.2%; 21.3%). The hygrophilous wood thinned out near the site (13.1%; 14.9%; 19.7%) and, while *Salix* increased (4.8%; 9.7%; 13.2%), a slight decrease in *Alnus* values was observed (8.3%; 5.2%; 6.5%). Conifers (*Pinus*: 6.8%; 4.1%; 3.7% - *Abies*: 3%; 1.4%; 2%) maintain lower values than the broadleaved component and the most part of their pollen grains are broken (*Pinus*: 70.7%; 86.9%; 72.4% - *Abies*: 87.5%; 84.6%; 67.5%).

Among the presence of the NNPs component, maximum values of *Glomus* (5.9%; 4.9%; 6.5%) together with a high ratio of *Pseudoschizaea* (2.4%; 0.6%; 1%) are documented in this pollen zone.

Zone 4 is subdivided into three subzones.

4.3.4.1 POLLEN SUBZONE 4A

N-S3: 28-15, 299-163 cm; C-S1: 17-15, 243-204.5 cm; F-S2: 11-10, 356.4-295.5 cm

Reworked pollen exhibits a profound increase reaching the maximum values of the upper levels (37.4%; 41.1%; 15.8%). *Pinus* (10.6%; 9.9%; 8.1%) and *Abies* (4.9%; 3.3%; 3.6%) increase. Broadleaved *Quercus* continues to drop slightly, although higher values are attested in the F-S2 (11.8%; 10.6%; 20.6%). *Carpinus* (2.6%; 2.3%; 1.4%), *Corylus* (3.6%; 3%; 3.8%), and *Ostrya carpinifolia/Carpinus orientalis* (0.4%; 1%; 0.5%) increase. *Rosa* and *Prunus* have significant percentages in N-S3 (respectively, 0.4% and 0.6%) and in C-S1 (respectively, 0.5% and 1.2%). *Vitis* is almost ubiquitous (0.4%; 0.8%; 0.5%) and *Juglans* is well attested (0.2%; 0.4%; 0.5%). Plants of wet environments are replaced by the API group (12.1%; 17.8%; 8.6%), among which an increase in cereals pollen is evident in N-S3 (1%) and in C-S1 (1.5%). Among them, *Avena/Triticum* group is significant in C-S1 (0.4%), while the punctual presence of *Panicum* s.l. is attested both in N-S3 and C-S1.

4.3.4.2 POLLEN SUBZONE 4B

N-S3: 14-6, 162-94 cm; C-S1: 14-10, 204.4-150.5 cm; F-S2: 9-8, 295.4-234.5 cm

A decrease in reworked pollen is documented at the bottom of the subzone (7.4%; 6.7%; 13.2%). The decreasing trend of forest cover continues (AP: 28%; 35.3%; 32.7%) simultaneously with a significant increase in Amaranthaceae (3.5%; 3%; 5.5%) and the API group (28.8%; 24.1%; 18.2%), of which the major component is represented by Cichorieae (23.4%; 19.2%; 13.8%) and cereals (1.8%; 1.2%; 2.1%). Among them, *Avena/Triticum* group is significant in the N-S3 (0.3%) and F-S2 (0.7%), while the punctual presence of *Panicum* s.l. is attested in C-S1. *Ranunculus* type reaches the maximum values in C-S1 and F-S2 (1.1%; 2%; 2.1%), while Caryophyllaceae peak at the top in C-S1 (4%). *Nymphaea alba* type is significant in N-S3 (0.4%), while *Nuphar* shows high values in F-S2 (1.2%).

4.3.4.3 POLLEN SUBZONE 4C

N-S3: 5-1, 93-45 cm; C-S1: 9-1, 150.4-61 cm; F-S2: 7-1, 234.4-73 cm

The mixed oak wood grows slightly in N-S3 (13.1%) and F-S2 (21%), while not recovering in C-S1 (13.2%). *Salix* reaches the maximum percentages throughout the whole sequences (10.4%; 14.7%; 19.5%). Hygrophilous herbs peak at the bottom of the subzone in N-S3 (30.1%) and C-S1 (33.6%), while they show a continuous increase in F-S2 (21.2%). The increase in the API group is attested at the top of the subzones (16.2%; 13.2%; 4.4%), characterized by the spread of Cichorieae (11.6%; 5.3%; 2.4%) and cereals (2.4%; 2.4%; 0.8%). Pollen of *Zea mays* is present in the most recent levels of the C-S1 (0.1%).

Table 14. PVG N-S3: summary of zone and subzones. Selected pollen taxa ($\% \geq 0.5$) for each zone and changes characterizing the subzones are reported.

PVG N-S3										
Zone	No. of samples	Depth (cm)	AP		NAP		Subzone	No. of samples	Depth (cm)	Notes
			Pollen taxa	%	Pollen taxa	%				
N-S3 1	10 (77 - 68)	1289 - 1060	<i>Pinus</i> <i>Picea</i> <i>Abies</i> <i>Salix</i> <i>Alnus</i> broadleaved <i>Quercus</i> <i>Corylus</i>	18.9 3.6 2 1.8 1.6 0.9 0.8	Poaceae wild grass group Cyperaceae Cichorieae <i>Artemisia</i> Amaranthaceae <i>Plantago</i> other Asteraceae Brassicaceae <i>Mentha</i> type <i>Ranunculus</i> type <i>Hordeum</i> group <i>Sparganium emersum</i> type <i>Stachys</i> <i>Trifolium</i> type Apiaceae	26.4 10 7 3 2.7 2.4 1.8 1.2 1.1 1 0.9 0.9 0.7 0.7 0.5	N-S3 1a	6 (77 - 72)	1289 - 1175	• <i>Pinus</i>, <i>Picea</i>, and <i>Abies</i> high; • Broadleaved <i>Quercus</i> significant; • <i>Salix</i> significant; • <i>Juglans</i> peaks at the top; • Cichorieae and other Asteraceae increase; • Poaceae wild grass group, Amaranthaceae, Brassicaceae, <i>Mentha</i> type, <i>Stachys</i>, and <i>Ranunculus</i> type decrease; • Cyperaceae high.
							N-S3 1b	4 (71 - 68)	1174 - 1060	• <i>Pinus</i>, <i>Picea</i>, and <i>Abies</i> decrease; • <i>Betula</i> and <i>Juniperus</i> type significant; • <i>Ostrya carpinifolia</i>/<i>Carpinus orientalis</i> and <i>Tilia</i> increase, while broadleaved <i>Quercus</i> and <i>Fraxinus excelsior</i> type decrease; • <i>Alnus</i> and <i>Salix</i> decrease; • <i>Castanea</i> presence at the bottom; • Poaceae wild grass group high; • <i>Artemisia</i> and Amaranthaceae increase; • Cyperaceae peak at the top; • Cichorieae and other Asteraceae decrease.
N-S3 2	11 (67 - 57)	1059 - 753	<i>Pinus</i> <i>Picea</i> <i>Alnus</i> broadleaved <i>Quercus</i> <i>Abies</i> <i>Corylus</i> <i>Betula</i>	20 2 1.4 1.1 1 0.7 0.7 0.5	Poaceae wild grass group Cyperaceae <i>Sparganium emersum</i> type <i>Artemisia</i> Cichorieae other Asteraceae Amaranthaceae <i>Plantago</i> <i>Hordeum</i> group <i>Mentha</i> type Apiaceae Brassicaceae	33.6 13.8 4.8 3.4 3.3 2.6 1.2 1.2 0.6 0.6 0.5 0.5	N-S3 2a	4 (67 - 64)	1059 - 937	• <i>Pinus</i>, <i>Picea</i>, and <i>Abies</i> increase; • Broadleaved <i>Quercus</i> increases while <i>Carpinus</i> decreases; • <i>Alnus</i> increases; • <i>Rosa</i> significant; • Cichorieae, <i>Artemisia</i>, other Asteraceae, and <i>Mentha</i> type increase; • Poaceae wild grass group and Cyperaceae decrease.
							N-S3 2b	7 (63 - 57)	936 - 753	• <i>Pinus</i> and <i>Picea</i> decrease; • <i>Betula</i> increases; • Almost continuous presence of broadleaved <i>Quercus</i>, <i>Carpinus</i>, <i>Corylus</i>, and <i>Ostrya carpinifolia</i>/<i>Carpinus orientalis</i>; • <i>Salix</i> increases; • Poaceae wild grass group, Cyperaceae, <i>Sparganium emersum</i> type, and <i>Ranunculus</i> type increase; • <i>Artemisia</i>, other Asteraceae, Cichorieae, Amaranthaceae, Brassicaceae, <i>Mentha</i> type, and <i>Hordeum</i> group decrease; • Other Rosaceae significant; • <i>Cannabis</i> presence at the top; • Reworked pollen grains decrease.
N-S3 3	28 (56 - 29)	752 - 300	<i>Alnus</i> broadleaved <i>Quercus</i> <i>Pinus</i> <i>Ulmus</i> <i>Salix</i> <i>Abies</i> <i>Corylus</i> <i>Carpinus</i> <i>Fraxinus excelsior</i> type <i>Tilia</i>	19.9 16.3 5.1 4.2 4 2.8 2.2 1.2 0.9 0.8	Cyperaceae Poaceae wild grass group <i>Sparganium emersum</i> type <i>Plantago</i> Cichorieae Amaranthaceae <i>Ranunculus</i> type <i>Typha latifolia</i> type	13.7 7.8 7.7 1.3 0.9 0.6 0.6 0.5	N-S3 3a	5 (56 - 52)	752 - 601.5	• <i>Pinus</i> decreases while <i>Abies</i> increases; • Broadleaved <i>Quercus</i>, <i>Corylus</i>, <i>Tilia</i>, <i>Fraxinus excelsior</i> type, and <i>Ulmus</i> increase; • <i>Alnus</i> increases; • <i>Fagus</i> presence; • Poaceae wild grass group, Cichorieae, <i>Artemisia</i>, and other Asteraceae decrease; • <i>Plantago</i>, <i>Ranunculus</i> type, and <i>Trifolium</i> type significant; • Cyperaceae high, <i>Sparganium emersum</i> type, <i>Sparganium erectum</i> type, and <i>Typha latifolia</i> type peak at the top.
							N-S3 3b	9 (51 - 43)	601.4 - 436	• All the components of the mixed oak wood increase; • <i>Alnus</i> peaks at the bottom while <i>Salix</i> decreases at the top; • <i>Fagus sylvatica</i> increases; • <i>Prunus</i> increases; • Cichorieae and <i>Plantago</i> increase; • Poaceae wild grass group, Cyperaceae, and <i>Sparganium emersum</i> type decrease; • Amaranthaceae, Apiaceae, other Asteraceae, Brassicaceae, and <i>Stachys</i> significant; • Reworked pollen grains increase.
							N-S3 3c	14 (42 - 29)	435 - 300	• Broadleaved <i>Quercus</i> and <i>Ulmus</i> decrease while <i>Carpinus</i> increases and the other oak wood components remain steady; • <i>Salix</i> increases; • <i>Fagus sylvatica</i> increases; • <i>Prunus</i> and <i>Vitis</i> significant; • Poaceae wild grass group, Cichorieae, other Asteraceae, and <i>Plantago</i> decrease; • Cyperaceae, <i>Sparganium emersum</i> type, <i>Sparganium erectum</i> type, and <i>Typha latifolia</i> type increase; • <i>Hordeum</i> group significant; • Reworked pollen grains decrease.
N-S3 4	28 (28 - 1)	299 - 45	broadleaved <i>Quercus</i> <i>Alnus</i> <i>Pinus</i> <i>Salix</i> <i>Abies</i> <i>Corylus</i> <i>Carpinus</i> <i>Ulmus</i> <i>Tilia</i> <i>Ostrya carpinifolia</i> / <i>Carpinus orientalis</i>	9.7 8.3 6.8 4.8 3 2.3 2.2 1.9 0.6 0.5	Cyperaceae Cichorieae Poaceae wild grass group <i>Plantago</i> Amaranthaceae <i>Sparganium emersum</i> type <i>Hordeum</i> group <i>Ranunculus</i> type other Asteraceae <i>Potentilla</i> type Apiaceae Brassicaceae Caryophyllaceae <i>Centaurea nigra</i> type <i>Trifolium</i> type <i>Mentha</i> type	13.4 12.9 11.6 2.3 2.2 1.3 1.2 1 0.9 0.8 0.7 0.7 0.6 0.6 0.5	N-S3 4a	14 (28 - 15)	299 - 163	• <i>Pinus</i> and <i>Abies</i> increase; • Broadleaved <i>Quercus</i> and <i>Fraxinus excelsior</i> type decrease, <i>Ulmus</i> decreases at the top while <i>Carpinus</i>, <i>Corylus</i>, and <i>Ostrya carpinifolia</i>/<i>Carpinus orientalis</i> increase; • <i>Alnus</i> and <i>Salix</i> decrease; • <i>Fagus</i> significant; • <i>Juglans</i>, <i>Rosa</i>, <i>Prunus</i>, and <i>Vitis</i> significant; • API group increases (cereals: <i>Hordeum</i> group, <i>Avena/Triticum</i> group, <i>Panicum</i> s.l.); • Poaceae wild grass group, Amaranthaceae, Apiaceae, other Asteraceae, Brassicaceae, Caryophyllaceae, <i>Mentha</i> type, <i>Ranunculus</i> type, and <i>Potentilla</i> increase; • Cyperaceae and <i>Sparganium emersum</i> type decrease; • Reworked pollen grains increase.
							N-S3 4b	9 (14 - 6)	162 - 94	• <i>Pinus</i> and <i>Abies</i> decrease; • <i>Ostrya carpinifolia</i>/<i>Carpinus orientalis</i> increases while the other components of the mixed oak wood decrease; • <i>Alnus</i> and <i>Salix</i> decrease at the top; • <i>Fagus sylvatica</i> decreases; • <i>Rosa</i> and <i>Prunus</i> significant; • <i>Vitis</i> decreases; • Cichorieae and cereals increase, while <i>Plantago</i> decreases; • Amaranthaceae and <i>Cannabis</i> high; • <i>Nymphaea alba</i> type significant; • Reworked pollen grains decrease.
							N-S3 4c	5 (5 - 1)	93 - 45	• Broadleaved <i>Quercus</i> peaks at the bottom and <i>Corylus</i> decreases; • <i>Salix</i> increases; • Cichorieae decrease, while cereals and <i>Plantago</i> increase; • Cyperaceae and <i>Sparganium emersum</i> type peak at the bottom.

Table 15. PVG C-S1: summary of zone and subzones. Selected pollen taxa (% ≥ 0.5) for each zone and changes characterizing the subzones are reported.

PVG C-S1										
Zone	No. of samples	Depth (cm)	AP		NAP		Subzone	No. of samples	Depth (cm)	Notes
			Pollen taxa	%	Pollen taxa	%				
C-S1 2	17 (90 - 74)	972 - 810	<i>Pinus</i> <i>Alnus</i> <i>Abies</i> <i>Betula</i> <i>Corylus</i> <i>Juniperus</i> type <i>Salix</i> <i>broadleaved Quercus</i>	17.2 1.5 1.2 1.1 0.9 0.9 0.6	<i>Poaceae</i> wild grass group <i>Cyperaceae</i> <i>Sparganium emersum</i> type <i>Artemisia</i> <i>other Asteraceae</i> <i>Cichorieae</i> <i>Hordeum</i> group <i>Typha latifolia</i> type <i>Mentha</i> type <i>Amaranthaceae</i> <i>Plantago</i> <i>Apiaceae</i> <i>Panicum</i> s.l. <i>Caryophyllaceae</i> <i>Ranunculus</i> type	25.7 16.3 11.9 3.5 2.3 1.9 1.8 1.5 1.3 1.1 0.9 0.8 0.8 0.6 0.6	C-S1 2a	9 (90 - 82)	972 - 889	<i>Pinus</i> high and <i>Abies</i> increases; <i>Betula</i> and <i>Juniperus</i> type decrease; <i>Corylus</i> significant and broadleaved <i>Quercus</i> increases at the top; <i>Alnus</i> and <i>Salix</i> increase; <i>Poaceae</i> wild grass group high; <i>Cichorieae</i>, <i>Artemisia</i>, <i>other Asteraceae</i>, <i>Mentha</i> type, and <i>Ranunculus</i> type increase; <i>Cyperaceae</i>, <i>Sparganium emersum</i> type, <i>Typha latifolia</i> type, and <i>Amaranthaceae</i> decrease.
							C-S1 2b	8 (81 - 74)	888 - 810	<i>Pinus</i> decreases while <i>Abies</i> increases; <i>Betula</i> significant; <i>Corylus</i> significant, broadleaved <i>Quercus</i>, and <i>Ulmus</i> increase; <i>Poaceae</i> wild grass group high; <i>Cichorieae</i>, <i>Artemisia</i>, <i>other Asteraceae</i>, <i>Hordeum</i> group, <i>Panicum</i> s.l., <i>Apiaceae</i>, <i>Brassicaceae</i>, and <i>Mentha</i> type increase; <i>Sparganium emersum</i> type and <i>Typha latifolia</i> type increase; <i>Cannabis</i> presence; - Reworked pollen grains decrease.
C-S1 3	56 (73 - 18)	809 - 244	<i>broadleaved Quercus</i> <i>Alnus</i> <i>Pinus</i> <i>Salix</i> <i>Ulmus</i> <i>Abies</i> <i>Corylus</i> <i>Carpinus</i> <i>Fraxinus excelsior</i> type <i>Prunus</i> <i>Tilia</i>	15.9 13 5.9 3.9 3.5 2.9 2.2 1.1 0.7 0.5 0.5	<i>Cyperaceae</i> <i>Poaceae</i> wild grass group <i>Sparganium emersum</i> type <i>Plantago</i> <i>Ranunculus</i> type <i>Cichorieae</i> <i>Amaranthaceae</i> <i>Potentilla</i> type <i>Apiaceae</i> <i>Hordeum</i> group <i>other Asteraceae</i> <i>Trifolium</i> type <i>Sparganium erectum</i> type	19.8 8.8 7.6 1.5 1.3 1 0.7 0.6 0.5 0.5 0.5 0.5	C-S1 3a	21 (73 - 53)	809 - 600	<i>Pinus</i> decreases and <i>Abies</i> increases; - Broadleaved <i>Quercus</i> initially increases but decreases at the top, while <i>Corylus</i>, <i>Carpinus</i>, <i>Tilia</i>, <i>Fraxinus excelsior</i> type, and <i>Ulmus</i> increase; <i>Alnus</i> and <i>Salix</i> increase; <i>Fagus sylvatica</i> increases; <i>Prunus</i> significant; <i>Cyperaceae</i> high; <i>Ranunculus</i> type and <i>Plantago</i> increase; <i>Poaceae</i> wild grass group, <i>Cichorieae</i>, <i>Artemisia</i>, <i>other Asteraceae</i>, <i>Hordeum</i> group, and <i>Panicum</i> s.l. decrease; <i>Cyperaceae</i> high, <i>Sparganium emersum</i> type peaks at the top, while <i>Typha latifolia</i> type decreases.
							C-S1 3b	18 (52 - 35)	599 - 418.5	- All the components of the mixed oak wood increase; <i>Alnus</i> and <i>Salix</i> remain steady; <i>Fagus sylvatica</i> increases; <i>Prunus</i> and <i>Vitis</i> increase; <i>API</i> group, <i>Potentilla</i> type, and <i>Rumex</i> increase; <i>Poaceae</i> wild grass group, <i>Cyperaceae</i>, and <i>Sparganium emersum</i> type decrease; <i>Amaranthaceae</i>, <i>Apiaceae</i>, <i>other Asteraceae</i>, and <i>Brassicaceae</i> significant; - Reworked pollen grains increase.
							C-S1 3c	17 (34 - 18)	418.4 - 244	- Broadleaved <i>Quercus</i> and <i>Ulmus</i> decrease, while the other oak wood components remain steady; <i>Alnus</i> and <i>Salix</i> increase; <i>Prunus</i> significant; <i>Vitis</i> peaks at the top; <i>Cyperaceae</i>, <i>Sparganium emersum</i> type, <i>Sparganium erectum</i> type, and <i>Typha latifolia</i> type increase; <i>Cichorieae</i>, <i>Plantago</i>, <i>Trifolium</i> type, and <i>Amaranthaceae</i> peak at the top; - Reworked pollen grains decrease.
C-S1 4	17 (17 - 1)	243 - 61	<i>broadleaved Quercus</i> <i>Salix</i> <i>Alnus</i> <i>Pinus</i> <i>Carpinus</i> <i>Abies</i> <i>Corylus</i> <i>Ulmus</i>	10.9 9.7 5.2 4.1 1.5 1.4 1.4 0.5	<i>Cyperaceae</i> <i>Poaceae</i> wild grass group <i>Cichorieae</i> <i>Sparganium emersum</i> type <i>Amaranthaceae</i> <i>Plantago</i> <i>Caryophyllaceae</i> <i>Ranunculus</i> type <i>Hordeum</i> group <i>other Asteraceae</i> <i>Brassicaceae</i> <i>Centaurea nigra</i> type <i>Potentilla</i> type <i>Apiaceae</i>	19.7 11.8 10.1 2.8 2.2 1.7 1.5 1.5 1.4 1 0.6 0.6 0.5	C-S1 4a	3 (17 - 15)	243 - 204.5	<i>Pinus</i> and <i>Abies</i> increase; - Broadleaved <i>Quercus</i> and <i>Ulmus</i> decrease, while <i>Carpinus</i>, <i>Corylus</i>, and <i>Ostrya carpinifolia</i>/<i>Carpinus orientalis</i> increase; <i>Alnus</i> and <i>Salix</i> decrease; <i>Fagus</i> significant; <i>Juglans</i> and <i>Fraxinus ornus</i> significant; <i>Rosa</i>, <i>Prunus</i>, <i>Vitis</i>, and <i>Humulus</i> significant; <i>API</i> group increases (cereals: <i>Hordeum</i> group, <i>Avena/Triticum</i> group, <i>Panicum</i> s.l.); <i>Poaceae</i> wild grass group, <i>Amaranthaceae</i>, <i>Apiaceae</i>, <i>other Asteraceae</i>, <i>Caryophyllaceae</i>, <i>Mentha</i> type, <i>Ranunculus</i> type, and <i>Potentilla</i> increase; <i>Cyperaceae</i> and <i>Sparganium emersum</i> type decrease and <i>Myriophyllum</i> significant; - Reworked pollen grains increase.
							C-S1 4b	5 (14 - 10)	204.4 - 150.5	<i>Pinus</i> and <i>Abies</i> decrease; - Broadleaved <i>Quercus</i> slightly increases while the other components of the mixed oak wood decrease; <i>Salix</i> peaks at the bottom; <i>Fagus sylvatica</i> decreases; <i>Prunus</i> significant; <i>Vitis</i> decreases; <i>Platanus</i> presence at the top; <i>Cichorieae</i> increase while <i>Avena/Triticum</i> group, <i>Trifolium</i> type, and <i>Plantago</i> decrease; <i>Amaranthaceae</i>, <i>Caryophyllaceae</i>, and <i>Ranunculus</i> type significant; <i>Cannabis</i> presence almost continuous; - Reworked pollen grains decrease.
							C-S1 4c	9 (9 - 1)	150.4 - 61	- Broadleaved <i>Quercus</i> and <i>Ulmus</i> decrease, while <i>Carpinus</i> increases; <i>Salix</i> increases; <i>Cyperaceae</i> and <i>Sparganium emersum</i> type peak at the bottom; <i>API</i> group initially decreases but peaks at the top; - Cereals include <i>Zea mays</i>.

Table 16. PVG F-S2: summary of zone and subzones. Selected pollen taxa (% ≥ 0.3) for each zone and changes characterizing the subzones are reported.

PVG F-S2										
Zone	No. of samples	Depth (cm)	AP		NAP		Subzone	No. of samples	Depth (cm)	Notes
			Pollen taxa	%	Pollen taxa	%				
F-S2 3	17 (28 - 12)	830 - 356.5	broadleaved <i>Quercus</i> <i>Alnus</i> <i>Pinus</i> <i>Salix</i> <i>Abies</i> <i>Ulmus</i> <i>Corylus</i> <i>Carpinus</i> <i>Fraxinus excelsior</i> type <i>Tilia</i> <i>Prunus</i> <i>Vitis vinifera</i>	19.6 10.9 6.3 3.1 2.9 2.7 2.1 1 0.6 0.4 0.3 0.3	Cyperaceae Poaceae wild grass group Sparganium emersum type Plantago Cichorieae other Asteraceae Amaranthaceae Hordeum group Ranunculus type Trifolium type Artemisia Potentilla type Sparganium erectum type Apiaceae Brassicaceae Caryophyllaceae Centaurea nigra type	23.3 8.4 3.6 1.8 1.4 0.7 0.6 0.6 0.6 0.6 0.5 0.5 0.4 0.3 0.3 0.3	F-S2 3a	5 (28 - 24)	830 - 695.5	• <i>Pinus</i> decreases while <i>Abies</i> increases; • Broadleaved <i>Quercus</i> initially increases but decreases at the top, while <i>Corylus</i>, <i>Carpinus</i>, <i>Fraxinus excelsior</i> type, <i>Tilia</i>, and <i>Ulmus</i> increase; • <i>Alnus</i> and <i>Salix</i> increase at the top; • Cyperaceae high; • Cichorieae increase and sharply decrease; • <i>Ranunculus</i> type and <i>Plantago</i> increase, <i>Trifolium</i> type and <i>Potentilla</i> type significant; • Poaceae wild grass group, Amaranthaceae, other Asteraceae, Brassicaceae, Caryophyllaceae, <i>Artemisia</i>, and <i>Hordeum</i> group decrease; • Cyperaceae and <i>Sparganium emersum</i> type high.
							F-S2 3b	6 (23 - 18)	695.4 - 515	• <i>Pinus</i> and <i>Abies</i> decrease and <i>Picea</i> peaks at the bottom; • The oak wood component increase but <i>Ostrya carpinifolia</i>/<i>Carpinus orientalis</i> decreases; • <i>Alnus</i> and <i>Salix</i> increase; • <i>Fagus sylvatica</i> peaks at the top; • <i>Rosa</i>, <i>Prunus</i>, and <i>Vitis</i> significant; • Cichorieae, <i>Plantago</i>, <i>Hordeum</i> group, <i>Rumex</i>, Apiaceae, and <i>Ranunculus</i> type increase; • Cyperaceae and <i>Sparganium emersum</i> type decrease; • Reworked pollen grains increase.
							F-S2 3c	6 (17 - 12)	514 - 356.5	• Broadleaved <i>Quercus</i>, <i>Ulmus</i>, <i>Corylus</i>, and <i>Fraxinus excelsior</i> type decrease, while the other oak wood components remain steady; • <i>Alnus</i> and <i>Salix</i> increase; • <i>Fagus sylvatica</i> increases; • <i>Vitis</i> peaks at the top; • Cyperaceae, <i>Sparganium emersum</i> type, <i>Sparganium erectum</i> type, and <i>Typha latifolia</i> type peak at the bottom; • Cichorieae, <i>Centaurea nigra</i> type, and Amaranthaceae peak at the top; • Brassicaceae and <i>Mentha</i> type significant; • Reworked pollen grains decrease.
F-S2 4	11 (11 - 1)	356.4 - 73	broadleaved <i>Quercus</i> <i>Salix</i> <i>Alnus</i> <i>Pinus</i> <i>Corylus</i> <i>Carpinus</i> <i>Abies</i> <i>Fraxinus excelsior</i> type <i>Juglans regia</i>	15.2 13.2 6.5 3.7 2.6 2.4 2 0.4 0.3 0.3	Poaceae wild grass group Cyperaceae Cichorieae Sparganium emersum type Amaranthaceae Ranunculus type other Asteraceae Plantago Centaurea nigra type Hordeum group Nymphaea alba type Typha latifolia type Apiaceae Avena/Triticum group Urtica	17.7 15.3 4.7 2.2 1.8 1 0.8 0.8 0.7 0.6 0.5 0.4 0.3 0.3 0.3	F-S2 4a	2 (11 - 10)	356.4 - 295.5	• <i>Pinus</i> and <i>Abies</i> increase; • Broadleaved <i>Quercus</i> decreases while <i>Corylus</i> increases; • <i>Alnus</i> and <i>Salix</i> decrease; • <i>Fagus</i> significant; • <i>Juglans</i>, <i>Fraxinus ornus</i>, and <i>Rhamnus</i> significant; • <i>Vitis</i> significant; • API group increases but cereals decrease; • Poaceae wild grass group, Amaranthaceae, Apiaceae, other Asteraceae, and <i>Ranunculus</i> type increase; • Cyperaceae increase and <i>Nymphaea alba</i> type significant; • Reworked pollen grains increase.
							F-S2 4b	2 (9 - 8)	295.4 - 234.5	• <i>Pinus</i> and <i>Abies</i> decrease; • Broadleaved <i>Quercus</i> and <i>Corylus</i> decrease, while <i>Fraxinus excelsior</i> type increases; • <i>Fagus sylvatica</i> decreases; • <i>Juglans</i> significant; • Cichorieae and cereals increase, while <i>Trifolium</i> type, <i>Plantago</i>, and <i>Urtica</i> decrease; • Amaranthaceae high; • <i>Ranunculus</i> type significant; • Cyperaceae increase, <i>Typha latifolia</i> type and <i>Nuphar</i> significant; • Reworked pollen grains decrease.
							F-S2 4c	7 (7 - 1)	234.4 - 73	• Broadleaved <i>Quercus</i>, <i>Carpinus</i>, and <i>Corylus</i> increase; • <i>Salix</i> increases; • <i>Juglans</i> significant; • <i>Morus</i> cf. <i>nigra</i> presence at the top; • Cyperaceae and <i>Sparganium emersum</i> type increase; • API group initially decreases but peaks at the top.

4.4 SURFACE SOILS

In this paragraph the results obtained from the palynological analysis of the three surface soils sampled by cutting (PVG SS-A, PVG SS-B, PVG SS-C) and one surface soil sampled by pinches (PVG SS-Cp) are described. The analysis of the latter became necessary due to the over-representation of an entomophilous pollen taxon (*Echium vulgare* type) observed in the corresponding superficial soil sampled by cutting. This probably occurred because of the interception of an anther in the soil, also testified by the presence of monospecific clusters. *Echium vulgare* type was not considered in the pollen sums and its percentages were calculated on the total sum of pollen grains plus themselves to obtain a correct weighting of their presence (Berglund & Ralska-Jasiewiczowa, 1986).

High pollen concentration characterizes the surface soils (48,000 p/g on average) showing a good organic composition. The lowest concentration, 39,000 p/g, concerns the SS-A, while the maximum value is present in the SS-C (55,000 p/g).

The state of preservation of pollen grains is generally quite good, although deteriorated pollen grains have sometimes been observed. Post-depositional factors may have sometimes altered the state of preservation of pollen, among which mechanical damages are the most common with the presence of partially broken, crumpled, or folded pollen grains. However, the percentage of unidentifiable pollen grains is generally low (1.6% on average), as well as the presence of reworked pollen grains (1% on average).

A total of 75 pollen taxa were identified (48 on average in each surface soil sample). The pollen diversity relative to herbaceous species almost doubles the wood component (52 pollen taxa in relation to 23 pollen taxa). The floristic list ranged from 43 pollen taxa (SS-A and SS-B) up to 49 (SS-C) and 55 (SS-Cp) pollen taxa. The presence of trilete spores is attested.

Almost half of the pollen taxa identified are ubiquitous, indicating a not very diversified landscape. Among them there are 7 woody plants (*Alnus* – 0.5%, 0.8%, 3.1%, 2.5%; *Ostrya carpinifolia*/*Carpinus orientalis* – 0.3%, 0.3%, 0.3%, 0.8%; *Castanea sativa* – 0.3%, 0.8%, 0.3%, 0.8%; broadleaved *Quercus* – 1.9%, 3.4%, 4.2%, 4.3%; *Fraxinus excelsior* type – 1.6%, 0.6%, 0.6%, 0.5%; *Pinus* – 1.3%, 3.1%, 2.2%, 2.3%; *Salix* – 4.8%, 1.7%, 2.2%, 2.5%) and 20 herbs (Amaranthaceae – 8.6%, 9.0%, 6.4%, 5.8%; Apiaceae – 1.1%, 2.3%, 0.8%, 1.3%; *Artemisia* – 0.3%, 1.7%, 0.6%, 1.3%; *Centaurea nigra* type – 0.3%, 0.8%, 0.3%, 0.5%; Cichorieae – 18.2%, 17.2%, 9%, 8.8%; other Asteraceae – 1.6%, 1.7%, 2.8%, 2.8%; Brassicaceae – 2.1%, 2%, 2.2%, 2.3%; Caryophyllaceae – 0.3%, 0.6%, 1.7%, 0.5%; Cyperaceae – 11%, 6.5%, 3.1%, 3%; *Trifolium* type – 0.8%, 0.6%, 0.3%, 0.5%; *Mentha* type – 1.3%, 0.3%, 0.8%, 0.8%; *Plantago* – 1.1%, 4.2%, 18.5%, 7.5%; Poaceae wild grass group – 30.7%, 30.8%, 22.4%, 29.8%; *Hordeum* group – 1.6%, 1.4%, 2%, 2.3%; *Polygonum aviculare* type – 0.3%; 0.3%, 0.3%, 1.5%; *Ranunculus* type – 1.3%, 0.6%, 1.1%, 0.5%; other Rosaceae – 0.3%, 0.3%, 0.8%, 0.3%; *Solanum nigrum* type – 1.3%, 0.8%, 0.3%, 1%; *Sparganium emersum* type – 0.5%, 0.6%, 0.3%, 1%; *Urtica* – 0.3%, 0.6%, 0.8%, 1.8%). There are also other pollen types which characterize the spectra, among them there are broadleaved taxa (*Carpinus betulus* – 0%, 0.3%, 0.3%, 0.3%; *Corylus avellana* – 0.8%, 0%, 1.4%, 1.8%; *Ulmus* – 0%, 0.8%, 1.7%, 0.8%), evergreen components of the Mediterranean vegetation and here probably ornamental plants (*Quercus ilex* type – 0.3%, 0.3%, 0%, 0.5%), annual crops (*Medicago* – 0.3%, 0%, 0.3%, 0.3%; *Avena/Triticum* group – 0%, 0.3%, 1.7%, 0.8%), and other herbaceous species representative of meadows and uncultivated fields (other Fabaceae – 0.3%, 0%, 1.7%, 0.5%; *Potentilla* type – 0.5%, 0.3%, 0%, 1%), or wet environments (*Typha latifolia* type – 0.8%, 0%, 0.3%, 0.3%).

The systematic comparison between the surface soils and the three cores about the pollen taxa reported above is presented in the Table 17.

Table 17. List of selected pollen taxa and their average values in the surface soils, N-S3, C-S1, and F-S2. “-” means absence.

Taxon	Surface soils	N-S3	C-S1	F-S2
<i>Alnus</i>	1.7	10.7	9.4	9.2
<i>Carpinus betulus</i>	0.2	1.3	1.0	1.6
<i>Corylus avellana</i>	1.0	1.9	1.8	2.3
<i>Ostrya carpinifolia/Carpinus orientalis</i>	0.4	0.3	0.3	0.2
<i>Castanea sativa</i>	0.5	0.0	0.0	-
broadleaved <i>Quercus</i>	3.4	9.7	12.1	17.8
<i>Quercus ilex</i> type	0.3	-	-	-
<i>Fraxinus excelsior</i> type	0.8	0.5	0.5	0.5
<i>Pinus</i>	2.2	9.6	7.7	5.3
<i>Salix</i>	2.8	3.6	4.4	7.1
<i>Ulmus</i>	0.8	2.3	2.3	1.8
Amaranthaceae	7.4	1.6	1.1	1.0
Apiaceae	1.4	0.5	0.6	0.3
<i>Artemisia</i>	0.9	1.0	0.9	0.3
<i>Centaurea nigra</i> type	0.5	0.3	0.2	0.4
Cichorieae	13.3	6.4	2.9	2.7
other Asteraceae	2.2	1.0	0.9	0.8
Brassicaceae	2.2	0.6	0.4	0.3
Caryophyllaceae	0.8	0.4	0.6	0.2
Cyperaceae	5.9	13.1	19.1	20.2
<i>Medicago</i>	0.2	0.0	0.0	0.0
<i>Trifolium</i> type	0.5	0.5	0.4	0.4
other Fabaceae	0.6	0.0	0.0	0.0
<i>Mentha</i> type	0.8	0.5	0.5	0.1
<i>Plantago</i>	7.8	1.8	1.5	1.4
Poaceae wild grass group	28.4	15.3	12.6	12.0
<i>Hordeum</i> group	1.8	0.8	0.9	0.6
<i>Avena/Triticum</i> group	0.7	0.1	0.1	0.1
<i>Polygonum aviculare</i> type	0.6	0.0	0.0	0.0
<i>Ranunculus</i> type	0.9	0.8	1.2	0.7
<i>Potentilla</i>	0.5	0.5	0.6	0.3
other Rosaceae	0.4	0.1	0.1	-
<i>Solanum nigrum</i> type	0.9	0.0	0.0	-
<i>Sparganium emersum</i> type	0.6	4.1	7.5	3.1
<i>Typha latifolia</i> type	0.3	0.3	0.4	0.3
<i>Urtica</i>	0.9	0.1	0.1	0.2

Pollen data clearly shows that the current forest cover is not extensive at all (15.5% on average; maximum value in SS-A: 12%; minimum value in SS-Cp: 20%) and the resulting landscape is mainly open with an agricultural vocation.

Woody plants, mainly single specimens that dot the landscape, are mainly broadleaved trees of the mixed oak wood (4.5%, 5.4%, 8.4%, 8.5%) with the dominance of oaks and hazel. Pollen related to plants that characterize the vegetation of higher altitudinal belts (here *Abies*, *Pinus*, *Fagus sylvatica*, and *Castanea sativa*), indicating long distance pollen transport favored by the open landscape, have been observed (total average: 3%). Among conifers, pollen grains of plants used for their ornamental value have also been observed (e.g., *Cedrus* and *Juniperus* type). As for the OJC group, *Olea* pollen is not present in surface soils and *Juglans regia* is present only in one sample (OJC group: 0.3%, 0.8%, 0.6%, 0.8%). *Vitis vinifera* pollen has been documented only in the soil SS-B). The proximity to a wetland and the presence of an artificial canal that delimits the study area are identified in the diagram by the occurrence of hygrophilous trees (5.3%, 2.5%, 5.6%, 5%), among which willow and alder are dominant while poplar is documented only in the soil SS-C. The presence of hygrophilous herbs is particularly attested in soils SS-A and SS-B sampled near two ditches on the edge of cultivated fields (12.3%, 7.1%, 3.9%, 4.3%). Hydrophytes are poorly documented by the presence of *Polygonum amphibium* type (0.3%, 0.3%, 0%, 0%). Anthropogenic Pollen Indicators-API (22.5%, 26.8%, 33.6%, 23.3%) and other synanthropic plants are the components that most characterizes the landscape. For example, Cichorieae and *Plantago* are dominant among weeds favored by human land use. Pollen of *Polygonum aviculare* type is documented everywhere and shows significant percentages in the SS-Cp soil that was sampled near the agricultural building. Cereals is almost ubiquitous with high percentages (1.6%, 1.7%, 4.2%, 3%). *Zea mays* has only been observed in SS-C.

A high amount of Non-Pollen Palynomorphs was observed during the pollen analysis. Most of these remains are represented by spores of coprophilous fungi (here *Sordaria*, *Sporormiella*, and *Chaetomium*, probably from manuring practices), arbuscular mycorrhizal fungi index of soil erosion (e.g., *Glomus*), and heterocysts of *Rivularia* type.

5 DISCUSSION

Vegetation dynamics spanning at least the last 15,000 years and the development of the cultural landscape with clear implications from local to regional scale will be discussed in this chapter aiming at understanding the ecosystem responses to different climate and human pressures in the study area.

The discussion will be organized in several parts based on key elements that emerged from the results of the palynological analysis:

- the relevance of some technical aspects related to both the intrinsic features of pollen samples, such as the amount of organic supply in sediment, pollen concentration, the state of preservation of the palynomorphs, and the methodological approach, which together allowed to obtain a huge amount of new information about flora and vegetation of the Central Po Plain;
- the awareness of clarifying from the beginning the possible limits of this research mainly related to the chronology of the sequences;
- the possibility to delineate four main pollen zones that identify regional or sub-regional pollen assemblages with common features in the three cores which reflect general environmental changes also present in the main reference records for the study area;
- the opportunity to highlight the more local aspects characterizing the cores obtained through the subdivision of pollen zones into subzones useful to identify differences on local plant distribution; this is certainly one of the central aspects of this research based on a first aim of investigating the extent of the anthropogenic impact on the environment in the levels that intercept the Bronze Age settlement related to the Terramare culture;
- the importance of obtaining further information about differences between both cores and samples in terms of plant composition through the application of different statistical analyses;
- the attempt to apply the Landscape Reconstruction Algorithm to transform pollen percentages to vegetation cover by accounting for differences in pollen productivity and dispersal among species;
- the potentiality to discriminate climatic evidence from the anthropic ones through the observation of arboreal pollen curves which reflect natural vegetation dynamics and the sudden and irreversible modeling action of human activities on the landscape;
- the effort to carrying out palynological analysis from three continuous terrestrial cores collected from an unusual context for this type of studies, which traditionally require sampling locations with relatively constant sedimentation; these continuous records allow to observe environmental changes in a floodplain landscape and provide a high detail about possible evidence of fluctuating water tables and consequences in the vegetation structure and dynamics;
- the need to observe the modern pollen rain to have reference local spectra obtained from different surface soil samples that provide an important source of information for interpreting and understanding the palaeoenvironmental records;
- the opportunity to reflect on how much human needs have upset and controlled the development of the environment, what is the natural vocation of the territory, and what type of landscape is best to preserve considering actions from a sustainable perspective useful for future generations.

5.1 TECHNICAL ASPECTS AND RESEARCH LIMITS

The palynological analysis from three terrestrial continuous cores collected in the province of Reggio Emilia (N Italy) provides a multitude of new data, with 100% of samples characterized by a good pollen content, although with some differences related to the chronology, different sedimentation conditions, and post-depositional disturbances of the material. The pollen preservation allowed to complete the analytical part with a good level of identification, although pollen grains with different types of deterioration were observed in the same samples resulting in a low level of taxonomic resolution of the deteriorated grains. However, selective deterioration of thin exine pollen grains do not seem to be very relevant. For example, the over-representation of Cichorieae that sometimes occurred, especially in some more ancient and more recent levels, is not a result of selective deterioration and it is not correlated to low pollen concentration which, on the contrary, shows an increasing trend in the same levels. The concomitant presence of other taxa referable to open environments and activities possibly related to grazing indicates a selection due to natural/climatic and anthropogenic factors rather than a selective corrosion of pollen grains (Florenzano et al, 2015). Indeed, the cichory herbs can be considered an important indicator of natural open habitats or environments influenced by human activities that may have produced the clearing of vegetation. According to the double role of these herbs as dry-resistant vegetation (ecologic value) and as important pastureland or grazing indicators (economic value) in archaeological contexts (Florenzano, Mercuri, & Carter; 2013; Mercuri et al, 2010), their increasing trend in the upper part of the pollen spectra may testify environmental changes towards climatic aridity and human impact in the last three millennia (Mercuri et al, 2012). Data on indeterminable pollen grains, which are almost always scarce, can be another useful criterion to evaluate the reliability comparability of pollen spectra. Pollen grains difficult to determine or not identifiable have higher values in the terminal part of all sequences with a range of percentages between 4% and 6% (Fig. 30). An important parenthesis will be dedicated to the presence of reworked pollen grains which is common in the spectra indicating the arrival of fluvial erosion sediments in the area that has often been subject to floods and swamps affecting pollen concentration with the dilution of the material (Fig. 30).

Considering the floristic-vegetational features and, as far as possible, the chronological data, a total of four main pollen zones describing flora and vegetation transformations were identified. The general pattern of the plant assemblage described by each zone is extremely similar and easily distinguishable in all the cores, providing a long-term pictures of large-scale vegetation changes. At the same time, the great potentiality of this research is based on the original sampling approach adopted for the collection of the three cores at short distances with the aim to identify more local environmental changes. This new approach applied on sequences with a long-term chronology offers the great opportunity to investigate different features and local variations, here identified by the pollen subzones, especially evident in the upper part of the diagrams and easily connected with anthropogenic activities.

These technical aspects are key concepts to be considered in the evaluation of the whole potential of the environmental reconstructions of the study area. The following paragraphs discuss the evidence of natural and anthropogenic environments that emerged from the palynological analysis with the ambition to provide new information about the evolution of the Po Plain. A main ambition is to distinguish between the response of plant formations to climatic-environmental conditioning and the response to anthropic pressure as processes that led to the consolidation of the current landscape. The pollen image obtained from the cores ranges from times when climate and ecosystem dynamics were the main factors of vegetation changes, to other times in which anthropogenic activities played an increasingly important role with a permanent and extensive impact on the environment. As regards the samples considered, please note that only the N-S3 core has been analysed entirely, while the others have been considered in particular for Holocene sediments, according to the focus of the research. The most recent phases are not present in the spectra because the surface levels of arable land cannot be included in pollen analyses. Datings are still being completed by Optically Stimulated Luminescence to limit the problems with the reliability of radiocarbon dates influenced by the reservoir effect, as often verified in chronological sequences within the Terramara S. Rosa di Poviglio (Cremaschi & Gallinaro, 2021).

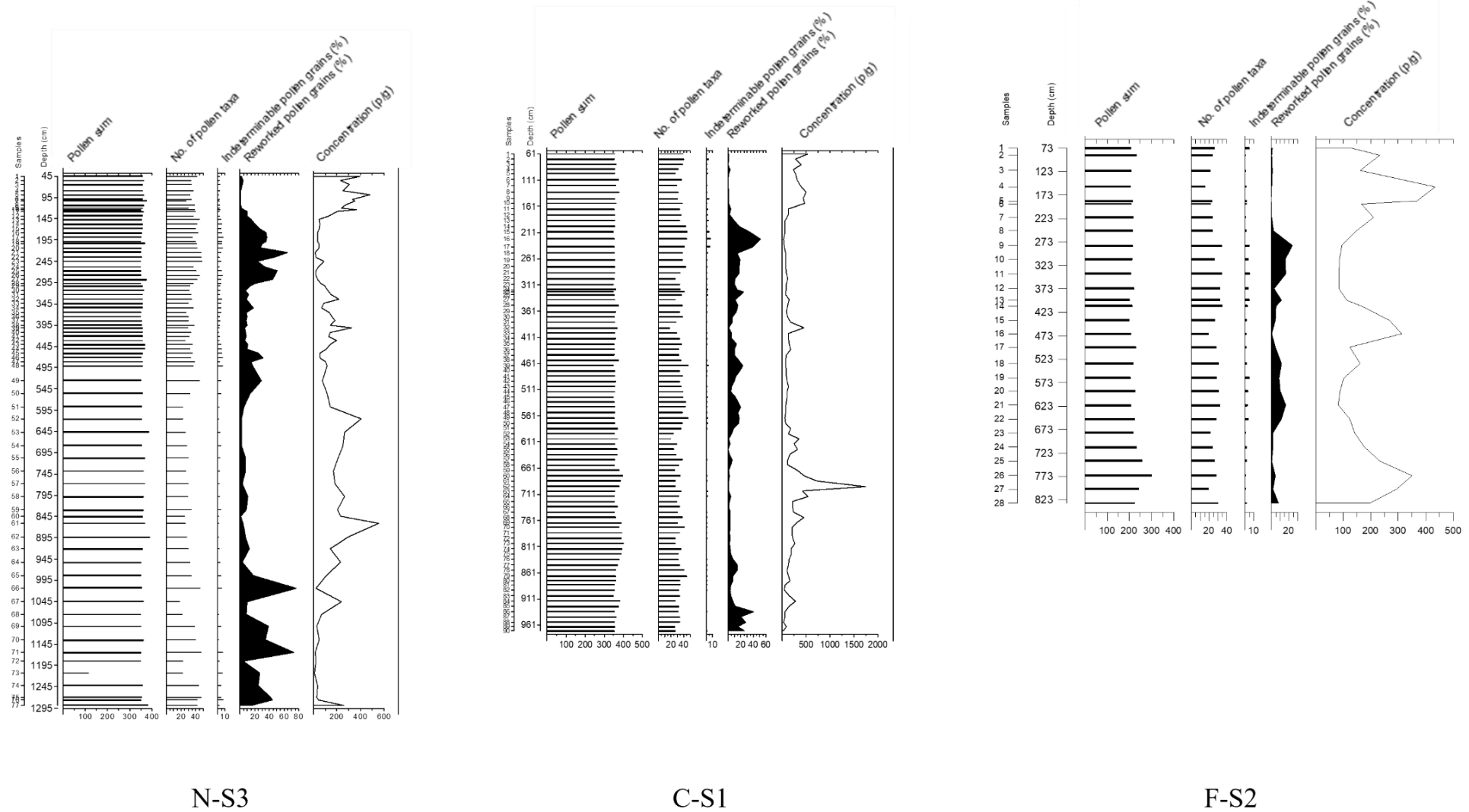


Figure 30. Synthetic pollen diagrams of N-S3, C-S1, and F-S2 cores useful to analyse the concentration and the state of preservation of the pollen material. The pollen sum obtained, the amount of indeterminable pollen grains, the number of observed pollen taxa (floristic richness), and the presence of reworked pollen were also entered for each sequence.

5.2 DISCUSSION ABOUT THE CHRONOLOGY

This chapter aims to highlight the main aspects that emerged from the analysis of the chronology of the three sequences.

Regarding the stratigraphy and sedimentology of the cores, the transition from coarse sandy fluvial deposits to alluvial deposits of clays and silts is marked. This represents the transition from Upper Pleistocene sedimentation of the Po palaeoriverbed to Holocene floodplain sedimentation.

Available radiocarbon dates (**13,020 ± 30 uncal yr BP** at 810 cm for N-S3 and **12,780 ± 20 uncal yr BP** at 830 cm for C-S1) allow for better identification of this interval before the beginning of the Lateglacial, despite their limitations in use.

As already stated, radiocarbon dating performed in the study area highlights numerous problems with the reliability of the results in establishing chronological sequences in a floodplain context because of the “hardwater effect” or “reservoir effect” related to the presence of old water into the aquifers (Cremaschi & Gallinaro, 2021, and references therein; Dadomo & Martinelli, 2005; Gorgoni, Martinelli, & Sighinolfi, 1982). This problem has been verified in radiocarbon dates from Holocene levels permanently saturated with water lowered by pumps during the period of the excavation campaign (VP/VG moat; Cremaschi & Gallinaro, 2021) and it is possible that radiocarbon dates of the cores may also be affected to this problem. The complete list of both accepted and rejected dates is shown in Table 10 in 3.1.1 STRATIGRAPHY AND CHRONOLOGY OF THE CORES.

However, the accepted dates are not always consistent with the interpretation of the pollen data based on existing knowledge of vegetation changes. This is the case for dates referable to the Lateglacial (see above). Both for the N-S3 and the C-S1 core there is a similar date (**13,020 ± 30 uncal yr BP - 15,740–15,450 cal yr BP** for N-S3 and **12,780 ± 20 uncal yr BP - 15,340–15,140 cal yr BP** for C-S1), which falls in a cold and arid climatic phase. The pollen spectra show an open and steppe vegetation. This is referable to the Oldest Dryas cooling event that is compatible with the radiocarbon date, or to the Younger Dryas that is compatible with the subsequent irreversible expansion of thermophilous trees that characterized then the beginning of the Holocene. However, even if the pollen assemblage may be also compatible with a Younger Dryas cool and dry phase, these dates cannot be rejected from a stratigraphic point of view and, for this reason, they have been considered in the elaboration of the age-depth model of the cores.

The presence of these two coeval radiocarbon dates strengthens the information, but at the same time may also be an effect of the same overestimation given the proximity of the cores. In this case, although difficult to demonstrate, the possibility to quantify the reservoir correction by an age offset in terms of about 2000 years for both the radiocarbon dates may be suggested. This is the first time such an assessment has been attempted for the Po Plain, and in general on terrestrial samples ascribable to alluvial plain contexts where reservoir correction is usually not applied. However, on the sidelines of this proposal there is the awareness that further chronological supports are necessary to confirm this hypothesis. In this case, pollen data does not provide any certainty, but they can only provide an indication to examine the order of magnitude of the overestimation.

Age-depth models

Waiting to obtain new dates using radiocarbon and OSL techniques, preliminary age-depth models were developed for each core (Figs. 31-33) based on a total of five radiocarbon dates, an archaeological date, and many pollen evidence used to derive control points for correlation with other records available in the study area (for further details see Tables 18-20).

For the sections of the cores where direct dating is missing, the correlation with marker layers from the other cores and stratigraphic series already studied in the same area has been applied. Correlations between three cores are supported both by stratigraphic and sedimentary trend and pollen assemblages. In the case of the N-S3 core, the radiocarbon date $15,820 \pm 35$ uncal yr BP of the C-S1 core was correlated at the bottom by contiguity.

Ceramic fragments found at 110-130 cm depth into the N-S3 core have been attributed on the base of the typology to the Middle Bronze Age. It was possible to correlate the same age to the other cores by comparison of the pollen assemblage.

A further correlation was done with a pollen series collected in the Municipality of Castelnuovo di Sotto (RE), about 5 km from the Terramara S. Rosa di Poviglio, in correspondence with the east bank of a palaeoriverbed located in “Via Tolara”. This series spans a chronology from the Copper Age (with a radiocarbon date available: 3890 ± 25 uncal yr BP - 4411–4245 cal yr BP) to the Roman Period. According to the stratigraphy and comparison between the pollen records, it was possible to correlate this sequence with the upper part of N-S3 (for further detail see chapter 5.4.6 EVIDENCE FROM THE THREE CORES – N-S3 *Pollen Zone 4*), C-S1, and F-S2.

Pollen evidence provided a valid support to the developments of the age-depth models, with comparison of pollen assemblages from northern Italy and identification of non-native plants as control points of the chronology.

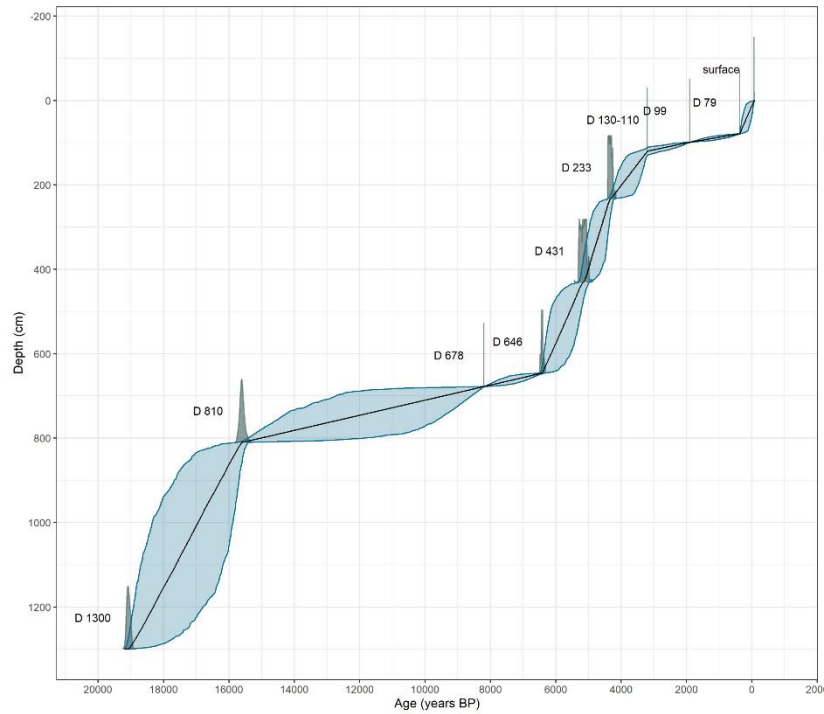


Figure 31. Age-depth model of the N-S3 core showing the probability distributions for ^{14}C dates calibrated using the IntCal20 Northern Hemisphere ^{14}C calibration curves (Reimer et al, 2020) and other control points. The interpolated model is represented as a solid black line and its 95% confidence interval as a blue band. R Bchron v 4.7.6

Table 18. N-S3: list of uncal ^{14}C dates (in black), archaeological dates (in red), stratigraphic correlations to layers with radiocarbon dates (in blue), and pollen evidence (in green).

ID (cm depth)	Ages	Notes	References
D 79	374 yr BP	The rapid decrease in hygrophilous herbs can be related to the large-scale land reclamation works (Bonifica Bentivoglio, 1576 AD)	Brandolini & Cremaschi, 2018
D 99	1900 yr BP	The high percentages of cereals (6.4%) can be related to the presence of a Roman “villa rustica” with its own agricultural production area	Brandolini et al, 2018; Mutti, 2007
D 130-110	3200 yr BP	Ceramic fragments	
D 233	3890 $\pm$ 25 uncal ^{14}C yr BP	Stratigraphic correlation with Via Tolara (US 4)	Unpublished data; see chapter 5.4.6.1 CORE N-S3 - Pollen Zone 4
D 431	4503 $\pm$ 45 uncal ^{14}C yr BP	Stratigraphic correlation with C-S1 (412-407 cm)	
D 646	5640 $\pm$ 20 uncal ^{14}C yr BP	Stratigraphic correlation with C-S1 (644 cm)	
D 678	8200 yr BP	<i>Abies</i> and <i>Fagus</i> expansion started contemporaneous with major climatic changes occurring during the 8.2 kyr event	Finsinger & Tinner, 2006; Tinner & Lotter, 2001
D 810	13,020 $\pm$ 30 uncal ^{14}C yr BP		
D 1300	15,820 $\pm$ 35 uncal ^{14}C yr BP	Stratigraphic correlation with C-S1 (1606 cm)	

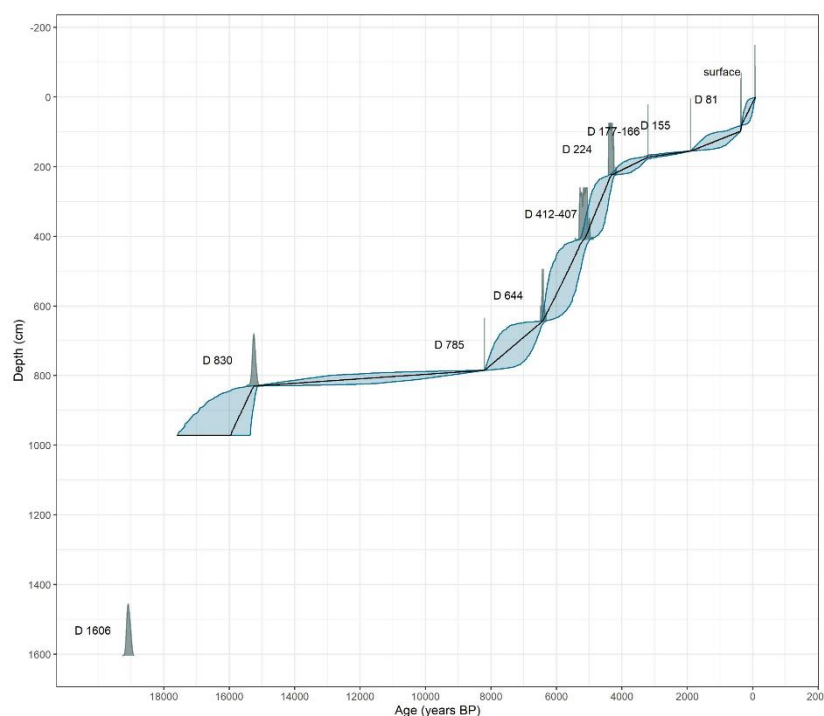


Figure 32. Age-depth model of the C-S1 core showing the probability distributions for ^{14}C dates calibrated using the IntCal20 Northern Hemisphere ^{14}C calibration curves (Reimer et al, 2020) and other control point. The interpolated model is represented as a solid black line and its 95% confidence interval as a blue band. R Bchron v 4.7.6

Table 19. C-S1: list of uncal ^{14}C dates (in black), stratigraphic correlations to layers with radiocarbon dates (in blue), and pollen evidence (in green).

ID (cm depth)	Ages	Notes	References
D 81	350 yr BP	<i>Zea</i> pollen suggests the introduction in the study area of this non-native plant. Historical sources documented the introduction in the region between the end of the 16 th century and the first half of the 17 th century	Cazzola, 1991
D 98	374 yr BP	The rapid decrease in hygrophilous herbs can be related to the large-scale land reclamation works (Bonifica Bentivoglio, 1576 AD)	Brandolini & Cremaschi, 2018
D 155	1900 yr BP	<i>Platanus</i> pollen suggests the introduction in the study area of one of the shade plants common in gardens of Roman villas	Rosati et al, 2015
D 177-166	3200 yr BP	Stratigraphic correlation with N-S3 (130-110 cm)	
D 224	3890 $\pm$ 25 uncal ^{14}C yr BP	Stratigraphic correlation with Via Tolara (US 4)	Unpublished data
D 412-407	4503 $\pm$ 45 uncal ^{14}C yr BP		
D 644	5640 $\pm$ 20 uncal ^{14}C yr BP		
D 785	8200 yr BP	<i>Abies</i> and <i>Fagus</i> expansion started contemporaneous with major climatic changes occurring during the 8.2 kyr event	Finsinger & Tinner, 2006; Tinner & Lotter, 2001
D 830	12,780 $\pm$ 20 uncal ^{14}C yr BP		
D 1606	15,820 $\pm$ 35 uncal ^{14}C yr BP		

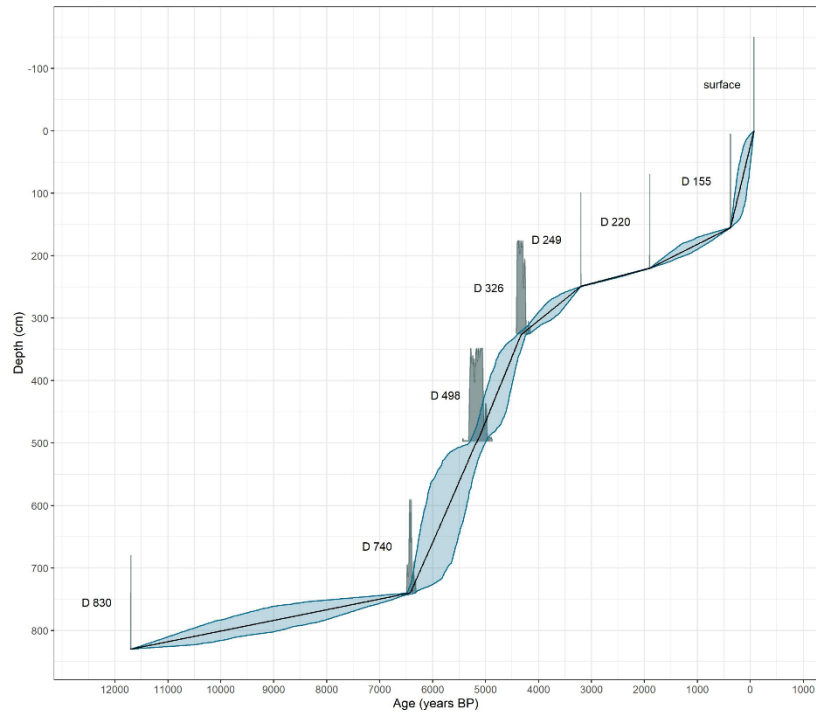


Figure 33. Age-depth model of the F-S2 core showing the probability distributions for ^{14}C dates calibrated using the IntCal20 Northern Hemisphere ^{14}C calibration curves (Reimer et al, 2020) and other control point. The interpolated model is represented as a solid black line and its 95% confidence interval as a blue band. R Bchron v 4.7.6

Table 20. F-S2: list of stratigraphic correlations to layers with radiocarbon dates (in blue), and pollen evidence (in green).

ID (cm depth)	Ages	Notes	References
D 155	374 yr BP	The rapid decrease in hygrophilous herbs can be related to the large-scale land reclamation works (Bonifica Bentivoglio, 1576 AD)	Brandolini & Cremaschi, 2018
D 220	1900 yr BP	The percentages of cereals can be related to the Roman occupation of the area and the development of a rural system	Brandolini et al, 2018; Mutti, 2007
D 249	3200 yr BP	Stratigraphic correlation with N-S3 (130-110 cm)	
D 326	3890 $\pm$ 25 uncal ^{14}C yr BP	Stratigraphic correlation with Via Tolara (US 4)	Unpublished data
D 498	4503 $\pm$ 45 uncal ^{14}C yr BP	Stratigraphic correlation with C-S1 (412-407 cm)	
D 740	5640 $\pm$ 20 uncal ^{14}C yr BP	Stratigraphic correlation with C-S1 (644 cm)	
D 830	11,700 yr BP	<i>Pinus</i> dominates the pollen assemblage, as a result of long distance transport from the Apennines to the open grasslands which were spread in the plain during the Lateglacial-Holocene transition	Accorsi et al, 1999; Mercuri et al, 2012

5.3 STATISTICAL PROCESSING TO DETECT FLORA AND VEGETATION TRANSFORMATIONS

Statistical elaborations were carried out to better understand the relationships between the data obtained from pollen analyses of the three cores, the relevance of pollen taxa, and their correlation. All the statistical approaches have provided consistent results which contributed positively to the discussion supporting the detailed information obtained by the analysis of pollen data. Principal Component Analysis, Multivariate Curve Resolution-Alternating Least Squares, and cluster analysis are the statistical analyses considered and they will be discussed separately in this chapter.

5.3.1 PRINCIPAL COMPONENT ANALYSIS

PCA is a frequently used multivariate technique for data compression, exploration, and interpretation of the variance sources present in a multivariate dataset. The results obtained from the analysis carried out on each single sequence (Figs. 34-36) make possible the easier graphical representation and interpretation of the data variance. The attempt to elaborate the PCA considering the three sequences as a single dataset was also made. However, this analysis proved to be ineffective for the data interpretation as the components obtained apparently do not have a clear ecological-environmental connotation and the distribution of the samples in the PCA space does not seem to follow a clear temporal subdivision. This result supports the initial hypothesis of considering the three sequences as single sites characterized by local differences.

The chronology and vegetational trends in the near-site core; N-S3 (92 variables-pollen taxa; 77 samples)

The first PC explains 9.23% (F1) of the total variance, the second PC explains 7.88% (F2).

— The first PC has high loadings for many arboreal pollen (e.g., broadleaved *Quercus*, *Alnus*, *Fraxinus excelsior* type, *Tilia*, *Ulmus*, *Corylus avellana*, and *Fagus sylvatica*) together with herbaceous pollen taxa related to wet environments (e.g., *Sparganium emersum* type and *Phragmites*), while low loadings correspond to xerophytes and light-demanding herbs (e.g., *Amaranthaceae*, *Helianthemum*, *Artemisia*, other *Asteraceae*, *Poaceae* wild grass group, and *Mentha* type) together with arboreal pollen from medium-long transport (e.g., *Picea* and *Betula*). The first component separates pollen spectra along a forestation gradient with different humidity condition, from an “open landscape” to a “forested environment”.

— The second PC has high loadings for some arboreal pollen too (e.g., *Corylus avellana* and *Carpinus betulus*) together with *Vitis vinifera*, *Prunus*, ruderal-synanthropic pollen taxa, and herbivory indicators (e.g., *Centaurea nigra* type, *Amaranthaceae*, *Plantago*, *Rumex*, *Potentilla*, *Trifolium* type, and *Ranunculus* type), while pollen taxa related to wet conditions have low loadings (e.g., *Cyperaceae* and *Sparganium emersum* type). The second component probably separates pollen spectra along a humidity gradient, from “wet conditions” to “arid conditions”.

The connotations of the first two components together determine the presence of an inverse anthropic pressure gradient in quadrants II and IV, from “more anthropic pressure” to “less anthropic pressure”.

Scores are arranged uniformly in the four quadrants, even if most of the samples have high scores for PC1. However, samples position in PCA space is homogeneous respect to the depth of the core. This feature makes three large groups distinguishable which could be indicators of different chronological phases.

— The first group of samples corresponds to the bottom part of the core characterized by open landscape dominated by pioneer species. This samples intercept the Late Pleniglacial and the whole Lateglacial according to reference pollen records from the Po Plain (Ravazzi et al, 2007, 2012; Vittori Antisari, 2016).

— The second group of samples corresponds to chronological phases related to a forest consistency increasing over time from the begin of the Holocene up to the Atlantic phase. Some samples respond positively to the second component, in agreement with short-period human occupations in the study area with a low impact on the local forest cover.

— The third group of samples corresponds to the upper part of the core and describes a progressive anthropic pressure on the landscape with the dominance of synanthropic plants typical of xeric environments favored by the continuous human pressure and changes in soil compositions. This vegetation change is in accordance with the overview of the Emilia-Romagna Region starting from the Subboreal

(Accorsi et al, 1999). This set of samples can be divided into two main parts distinguished mainly by the forestation gradient that decreases and changes in biodiversity in the more recent samples.

Woods and cereal fields in the central core; C-S1 (100 variables-pollen taxa; 90 samples)

The first PC explains 8.98% (F1) of the total variance, the second PC explains 6.21% (F2).

— As in the core described above, the first PC has high loadings for many woody plants (e.g., broadleaved *Quercus*, *Fagus sylvatica*, *Alnus*, *Ulmus*, and *Vitis vinifera*), while most of the herbs have low loadings (e.g., Poaceae wild grass group and *Typha latifolia* type). The first component clearly separates pollen spectra along a forestation gradient (from an “open landscape” to a “forested environment”).

— Herbaceous pollen taxa contribute most to the second PC with high loadings. Among these variables, primary indicators of human activities (e.g., *Zea mays*, *Avena/Triticum* group, and *Hordeum* group) together with other synanthropic plants (mainly Cichorieae and *Convolvulus*) present highest loadings. A high contribution is also represented by some hydrophytes (*Lemna* and *Hydrocharis morsus-ranae*), while hygrophilous herbs have low loadings (*Sparganium emersum* type, *Typha latifolia* type, and Cyperaceae). The second component probably separates pollen spectra along an anthropic pressure gradient (from “less anthropic pressure” to “more anthropic pressure”), which is even more pronounced in quadrant II and IV even for the C-S1 PCA space.

A large number of the samples have relatively low scores for PC2.

A distribution of the samples in PCA space relating to the core depth is appreciable also in this case and reflect different chronological phases in a very similar way to that already described above.

— The first group is isolated in the third quadrant and correspond at the end of the Late Pleniglacial and the Lateglacial.

— The second group of samples is more dispersed along the first component, reflecting the increase in the deciduous wood at the begin of the Holocene and a forested monotonous landscape attested during the Atlantic phase. However, it can be observed that within this group some samples tend to separate vertically as they are more influenced by the second component, as index of human presence within a landscape which maintains its natural connotation.

— The third group of samples corresponds to the upper part of the core that could be divided in three parts based on the progressive increase in the anthropic pressure attested by the introduction of non-native species, the increase in crops, and the opening of the landscape.

Less anthropogenic pressure in the core far from the site; F-S2: 70 variables-pollen taxa; 28 samples

Lower pollen counts and a greater sampling distance are the two main factors that probably influenced the resolution of the core causing some loss of information resolution. However, the result obtained from this analysis agrees with the general image obtained for the two sequences described above.

The first PC explains 11% (F1) of the total variance, the second PC explains 10.34% (F2).

— The first PC presents high loadings for some woody plants (e.g., broadleaved *Quercus*, *Ulmus*, and *Tilia*), while herbaceous plants generally show low loadings (e.g., Poaceae wild grass group and other Asteraceae). The first component places pollen spectra along a forestation gradient (from an “open landscape” to a “forested environment”).

— Most of the variables have relatively low loadings for the second PC (among which *Avena/Triticum* group has the lowest values), while the greatest contribution to this component is provide by *Artemisia*, *Panicum* s.l., *Secale*, *Sparganium emersum* type, and *Celtis*. The second component does not seem to describe a clearly identifiable gradient from the vegetational point of view, even if an anthropic pressure gradient can be attributed also in this case (from “less anthropic pressure” to “more anthropic pressure”).

Most of the samples are distributed along the first component according to the change of the landscape during the Holocene, from a condition with larger forest cover to a progressive opening of the woods. The two samples most characterized by the second component correspond the last and the first sample of the pollen sequence that both reflect an open environment from a more natural condition influenced by climatic events to a human-shaped landscape. The same chronological phases described above have also been identified for this PCA space (Figs. 34-36 reported the same colors for the chronological phases identified).

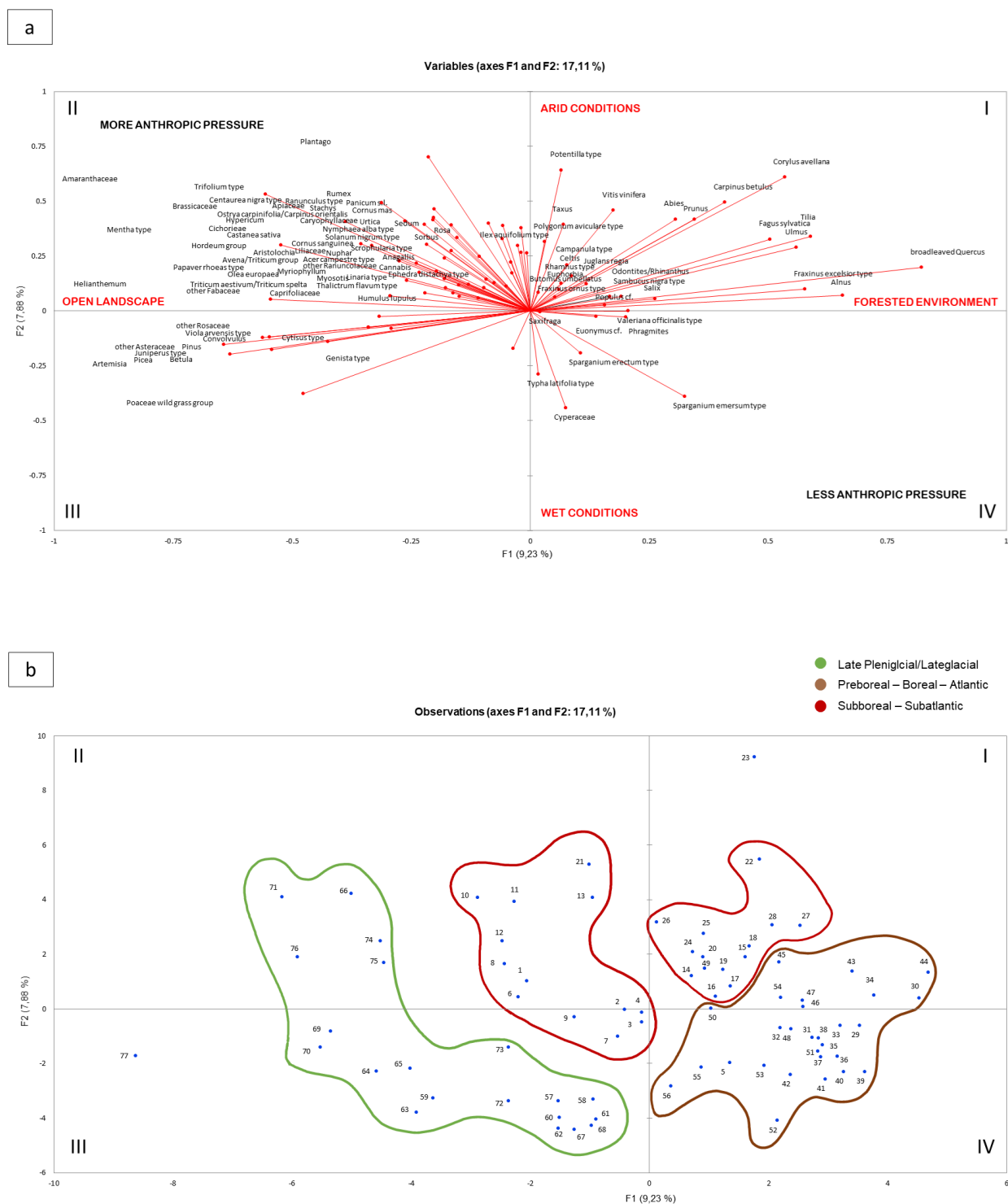


Figure 34. Principal Component Analysis (PCA; elaboration: XLStat) for the N-S3 core: a) Loadings plots: contribution of each variable to determine principal components direction; b) Scores plot: samples position (colored per chronology) in PCA space.

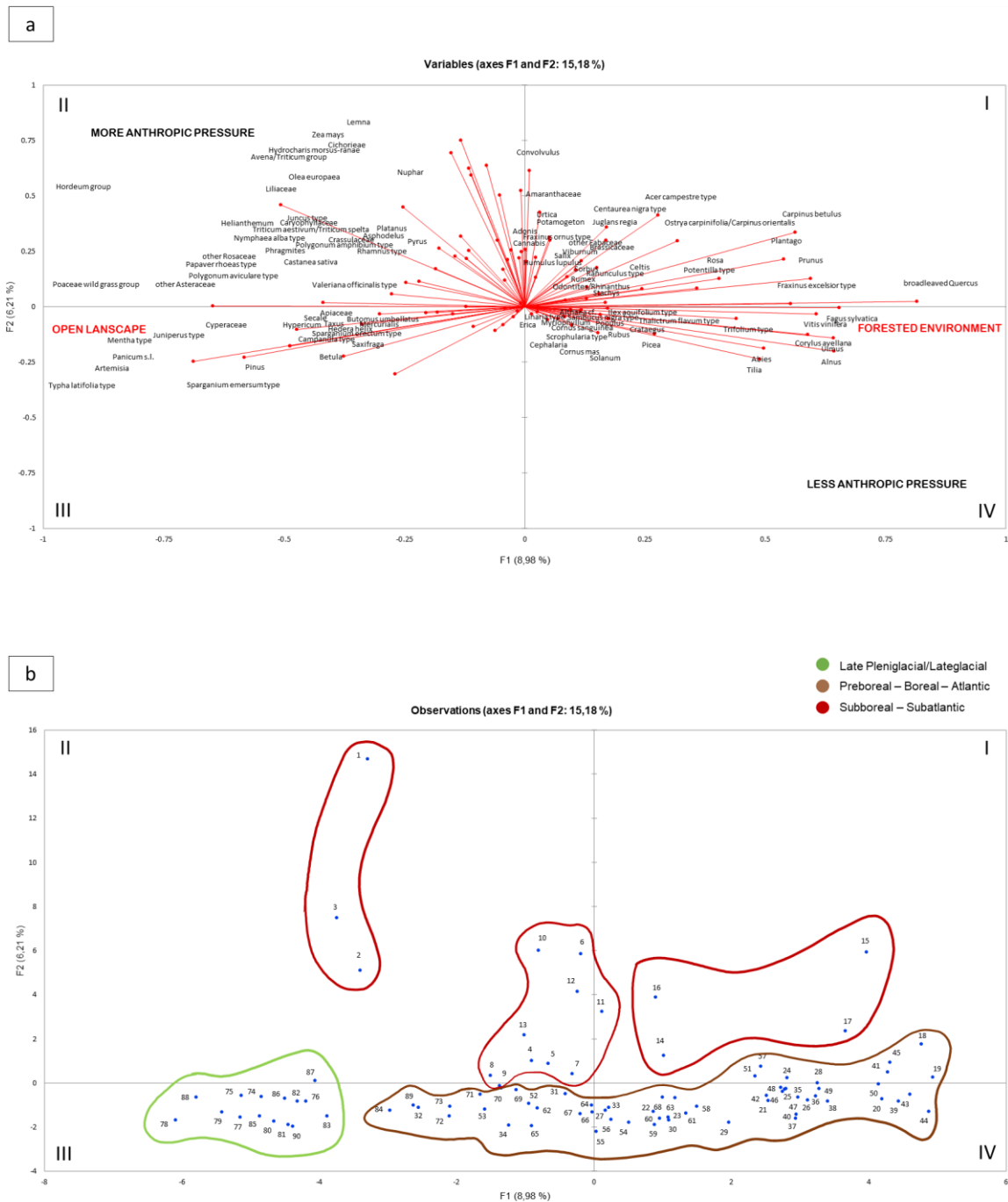


Figure 35. Principal Component Analysis (PCA; elaboration: XLStat) for the C-S1 core: a) Loadings plot: contribution of each variable to determine principal components direction; b) Scores plot: samples position (colored per chronology) in PCA space.

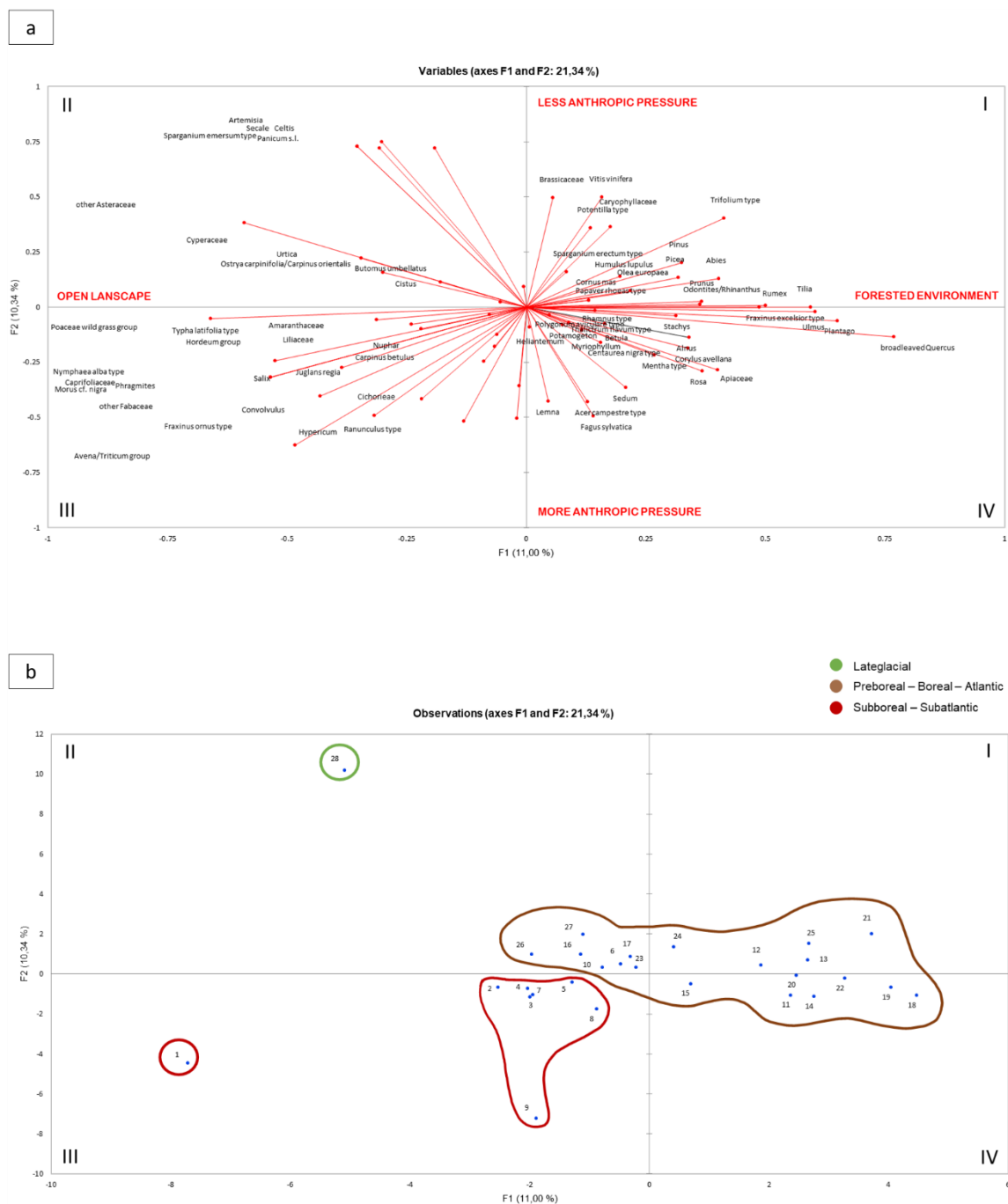


Figure 36. Principal Component Analysis (PCA; elaboration: XLStat) for the F-S2 core: a) Loadings plot: contribution of each variable to determine principal components direction; b) Scores plot: samples position (colored per chronology) in PCA space.

5.3.2 MULTIVARIATE CURVE RESOLUTION-ALTERNATING LEAST SQUARES

Multivariate Curve Resolution method allows to obtain a bilinear model decomposition showing the quantitative information of the concentration profiles and the qualitative information related to spectra profiles of the resolved components optimally fitting the experimental data matrix (de Juan & Tauler, 2020; Jaumot, de Juan, & Tauler, 2015). MCR were developed initially for the analysis of chemical processes monitored spectroscopically but it is increasingly applied to the resolution of environmental data sets during the last few years. This multivariate analysis has never been applied in Palynology and the results obtained here reveal the potential of this method also for environmental investigations from pollen data.

This processing includes the pollen data from the three cores previously arranged in a single data matrix of 195 row samples (N-S3: 77; C-S1: 90; F-S2: 28) and 113 column variables (arboreal pollen taxa: 1-46; herbaceous pollen taxa: 47-113). The percentage of explained variance achieved by MCR-ALS using three components and non-negative constraints is 33.7% (see Fig. 37 for the ASL optimization).

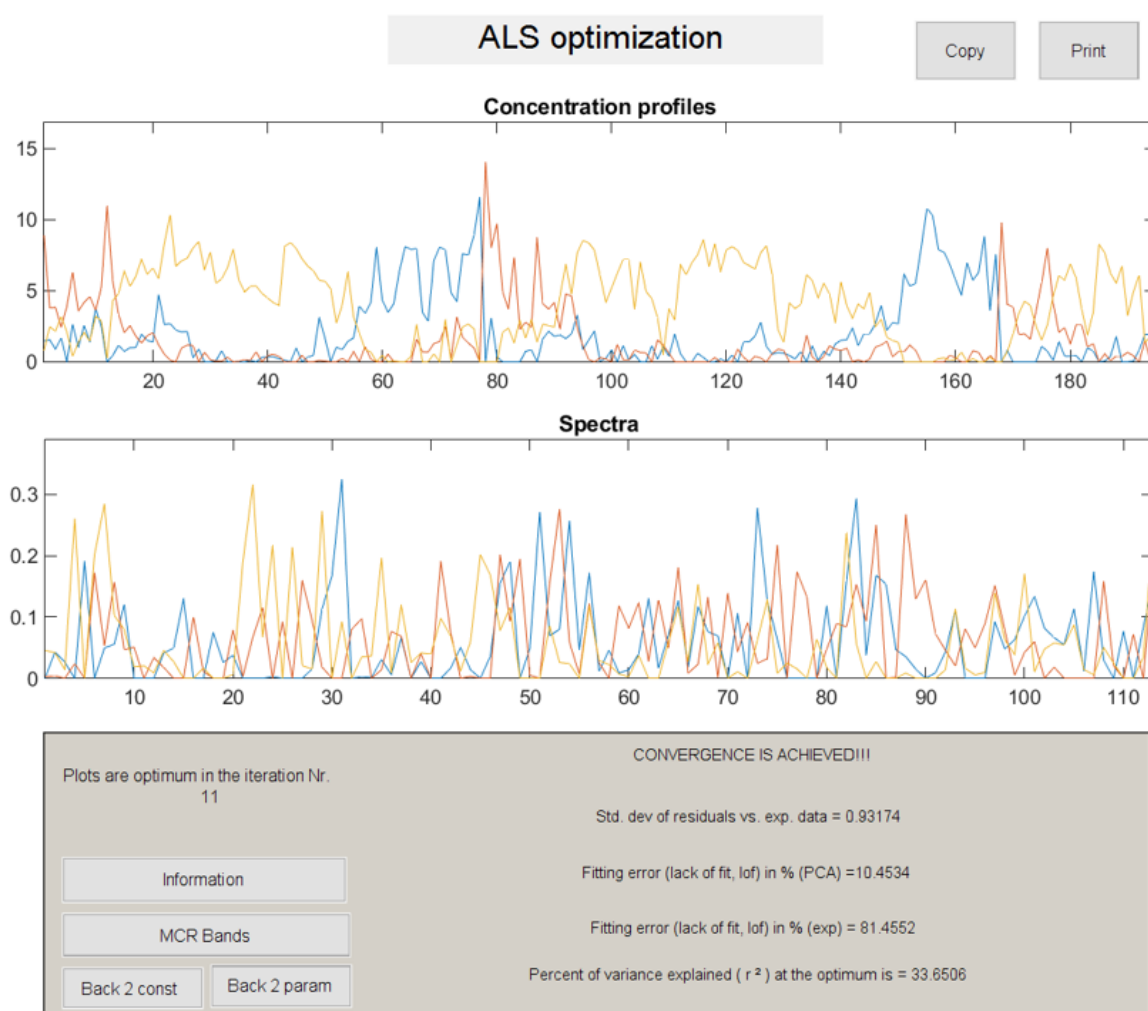


Figure 37. Multivariate Curve Resolution-Alternating Least Squares results window.

Concentration and pure spectra profiles of the resolved components show consistent vegetation changes at comparable depths among the cores and reflect general features of the whole study area (Figs. 38-39).

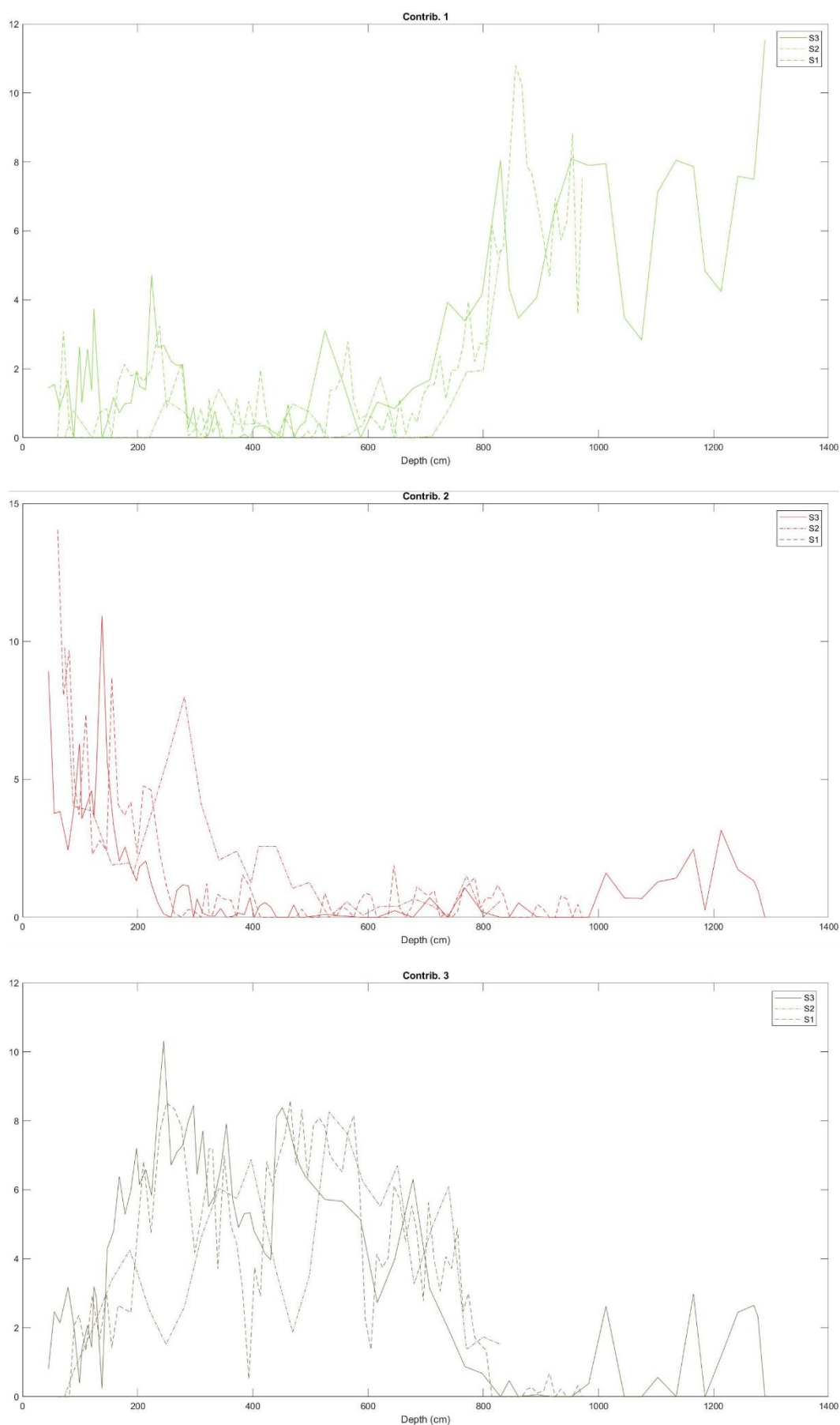


Figure 38. Concentration profiles (C) of the three components describing spatial (see the key to identifying cores) and temporal (the cores are sorted according to depth) distribution of the pollen spectra. The y-axis gives the relative concentrations obtained for each of the ALS-resolved component.

The three resolved components represent different vegetation assemblages, which could be used as a reference for different time range spanning from the Late Pleniglacial/Lateglacial to Holocene phases.

Components are identified as follows:

(i) The first component describes the vegetation formations typical of the reference pollen records from the Po Plain during the Late Pleniglacial/Lateglacial, which best represents the samples at the bottom of each core. This pollen assemblage is mostly represented in the N-S3 core in accordance with the a priori choice to investigate only this core entirely including all the deepest levels, while it characterizes fewer samples of the C-S1 core and only the last sample of the F-S2 core. The larger contributions from *Pinus* and *Betula* among phanerophytes reflect the presence of coniferous and mixed forests with birch trees present in stable areas of the low hills/high plain and is likely to be associated with a medium-long distance pollen transport. Related to the herbaceous plants, this profile indicates a steppe environment and meadow vegetation with light-demanding and pioneer herbs (e.g., Poaceae wild grass group, *Artemisia*, other Asteraceae, and Amaranthaceae) and some pollen taxa characterizing wet environments probably related to the unstable condition due to the occurrence of periodic flooding of the nearby river which could determine a temporary marshy landscape with local ponds (e.g., *Mentha* type-possibly referable to *Mentha aquatica*, *Typha latifolia* type, and *Panicum* s.l.).

(ii) The second component describes an environmental pattern with a larger contribution of plants associated with human activities. Among them, primary indicators (plants cultivated in fields) together with secondary indicators (weeds) consisting in adventives (non-native plants introduced with agricultural practices) and apophytes (native plants favored by human land use). This profile characterizes the more recent levels which probably defines the Subboreal when a cultural landscape began to appear throughout the Region. Overall, the S^T matrix describes an open landscape characterized mainly by cereal pollen and other synanthropic pollen taxa including *Urtica*, which is present in nutrient-rich soil such as grazed areas and settlements, and Cichorieae which could be related to pasturelands together with Amaranthaceae, Asteraceae, Fabaceae, Brassicaceae, Ranunculaceae, and Liliaceae. Wet environments are testified also by this component which suggests water-saturated conditions by the contribution of aquatic plants (mainly *Lemna* and *Nymphaea alba* type) and hygrophilous herbs (Cyperaceae), which could testify the presence of hydraulic structures related to the Terramare settlement or marshy landscape with local ponds. Trees also reflect cultural changes, with the introduction of species (*Platanus* and *Morus*) and the management and selection of others (e.g., *Salix*).

(iii) The third component describes a more monotonous landscape in which the trees contribution is dominant according to regional pollen record spanning from the Preboreal-Boreal to the Atlantic phase. Forest cover is mainly characterized by the elements of the mixed oak wood, which all give high contributions. In particular, broadleaved *Quercus*, *Corylus avellana*, *Carpinus betulus*, *Tilia*, *Fraxinus excelsior* type, and *Ulmus* show the highest concentration together with *Alnus*. In addition to hazel, other trees suitable for fruits also seem to have a key role within the landscape, like *Vitis*, *Prunus*, and *Rosa*. *Plantago* presents the highest concentration among herbs, together with synanthropic, ruderal plants, and Local Pastoral Pollen Indicators (e.g., *Rumex*, *Potentilla* type, *Ranunculus* type, and *Trifolium* type). According to Deza-Araujo et al (2021), the determination of *Plantago* pollen at genus level, as in the case of this dataset, may hamper or even prevent the recognition of human impact because *Plantago* type has both adventive constituents strongly related to land use (e.g., *P. lanceolata* type and *P. major* type) but also apophytes that occur in natural environments (e.g., *P. coronopus* type). However, the state of preservation of pollen grains does not always allow the accurate identification of the pollen type, especially in pollen samples from archaeological sites where depositional and post-depositional conditions are generally unfavorable for pollen preservation, and an effort in identification could favor the insertion of errors in the analysis. For this reason, the expert interpretation of the data on the set of pollen curves as the best choice in some contexts. All the species of this genus are recurrent with ecological features related to compaction of sediments due to trampling (Mercuri et al, 2013a), reflecting the presence of human groups and herbivore herds since the Neolithic.

5.3.3 CONSTRAINED INCREMENTAL SUMS OF SQUARES CLUSTER ANALYSIS (CONISS)

The cluster analysis was carried out on the three cores considering the same pollen taxa of the previous two statistical elaborations (Figs. 40-45). A good characterization of the samples emerges from the cluster analysis that divides the sequences into large chronological intervals including almost the same samples as the PCA and the MCR. Within these zones it was possible to identify pollen subzones, from which dissimilarities emerge based on local conditions. Zones and subzones were identified according to visual examination and comparison between the cores. The results obtained have already been described in detail in the paragraph 4.3 POLLEN ZONES.

Statistical elaborations carried out on the three pollen sequences show a general similarity between the cores, all of which can be divided into the same large chronological intervals based on significant changes in the vegetation that influenced the entire study area. Each core is however well distinguishable from the others for local flora and vegetation information, while differences in pollen sampling and sedimentation rate certainly influence the detail obtained for each sequence.

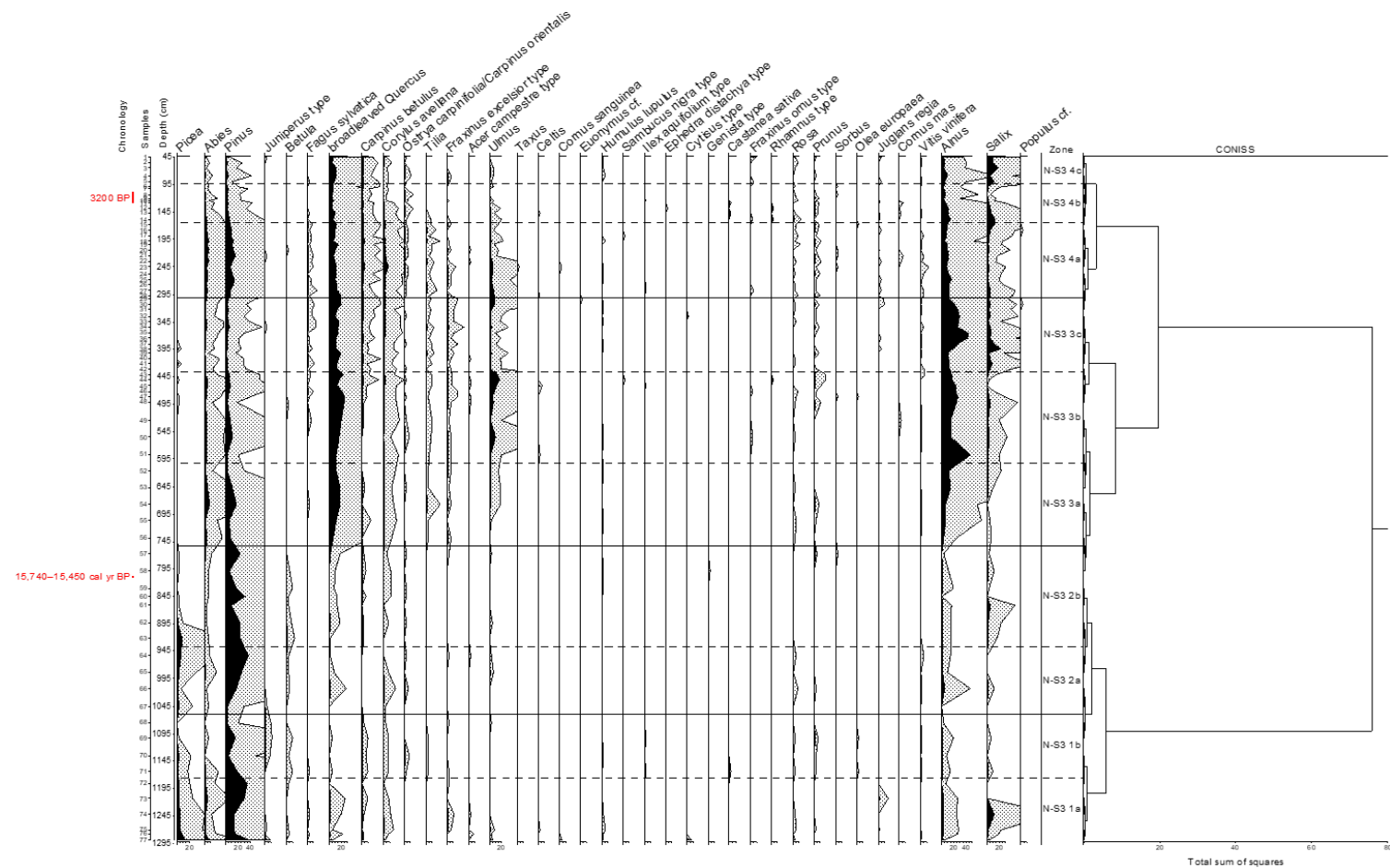


Figure 40. N-S3 core: percentage pollen diagram of woody plants and cluster analysis. Empty curves represent 10% exaggeration.

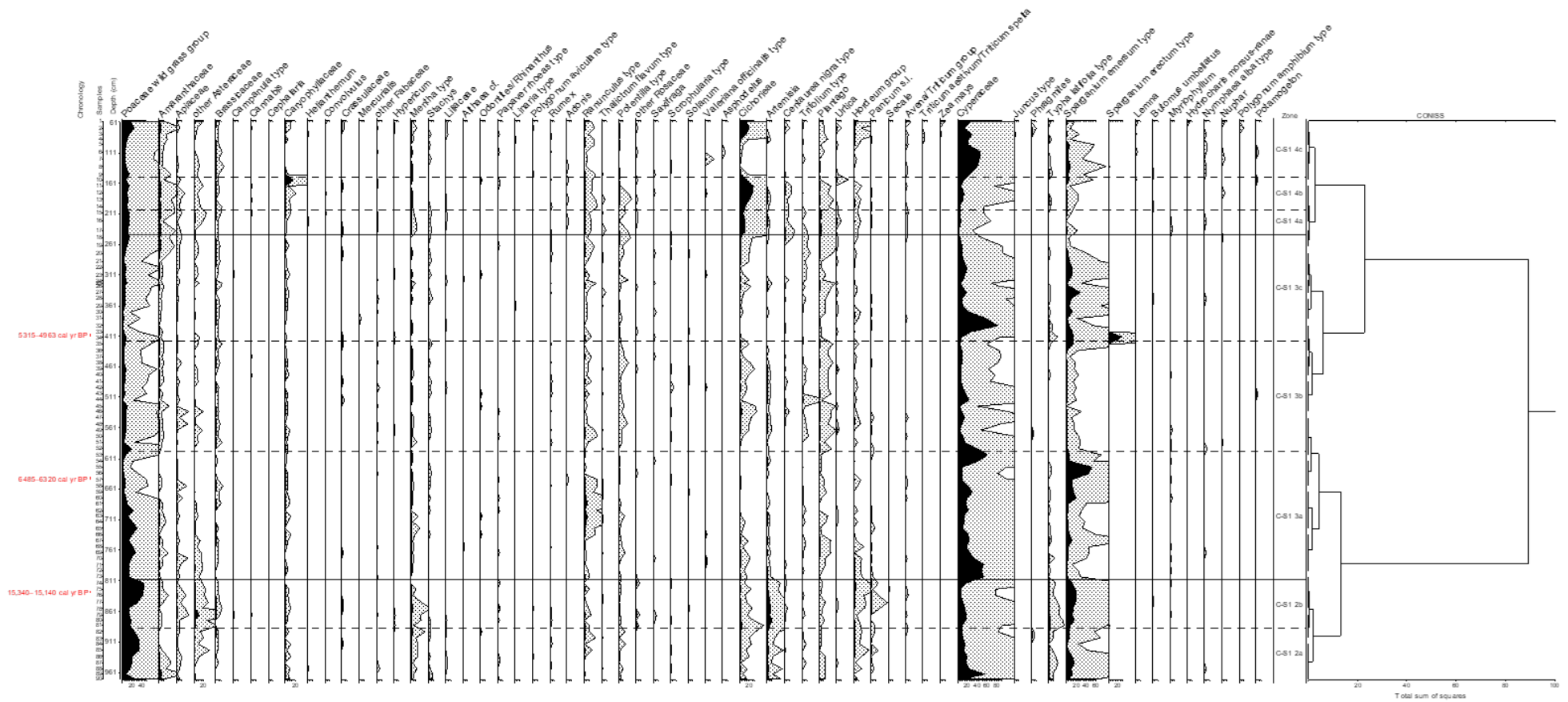


Figure 43. C-S1 core: percentage pollen diagram of herbaceous plants and cluster analysis. Empty curves represent 10% exaggeration.

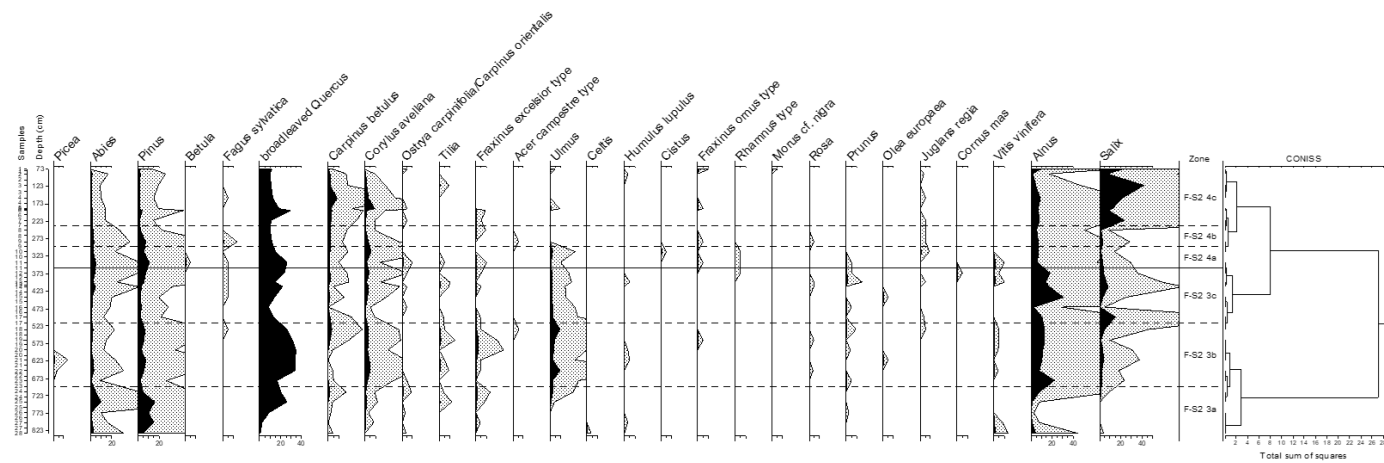


Figure 44. F-S2 core: percentage pollen diagram of woody plants and cluster analysis. Empty curves represent 10% exaggeration.

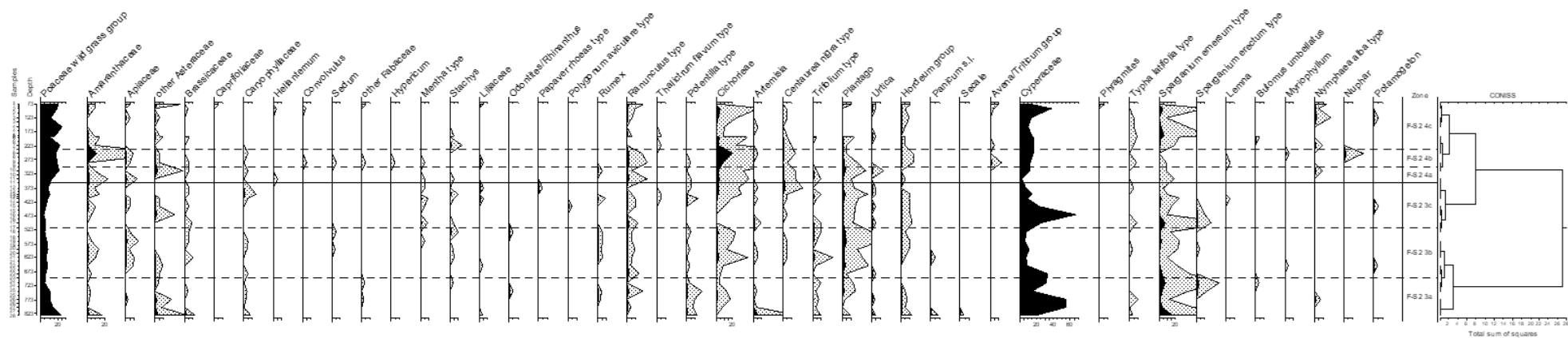


Figure 45. F-S2 core: percentage pollen diagram of herbaceous plants and cluster analysis. Empty curves represent 10% exaggeration.

5.4 FLORA AND VEGETATION RECONSTRUCTION

5.4.1 FLORISTIC COMPOSITION

How is vegetation represented in pollen records? Pollen records reflect a mixture of communities and/or successional stages. Continuous efforts in refinements the description of pollen morphology and image recognition allow identification at increasingly lower taxonomic level, but the taxonomical detail of identification varies between authors and largely depends on the pollen preservation. As poor taxonomic resolution may influence the effectiveness of pollen records to track plants and vegetation dynamics (Deza-Araujo et al, 2021), possible interference on pollen dispersal from vegetation structure, and differential pollen representation can also influence the interpretation in terms of floristic richness (Odgaard, 1999). For these reasons, the total number of pollen taxa recorded differs substantially from the floristic richness of the pollen source area, and the nonlinear relationship between floristic richness and pollen taxa richness may be used in attempts to estimate past floristic richness from fossil pollen assemblages. *Palynological richness*, the number of pollen types per sample at a standard count sum (Birks & Line, 1992), is the most widely accepted diversity index for pollen data, even if it does not consider pollen production and dispersal bias. The interpretation of palynological richness as a record of past biodiversity is currently unresolved (Birks, 2013; Giesecke, Amman, & Brande, 2014; van der Knaap, 2009), and requires a clear understanding of the relationship between pollen as the proxy, and the environmental parameter (vegetation, land use, climate) that it represents (Davis et al, 2013a, 2013b).

Pollen analysis from the three cores documents the presence of a fair number of pollen taxa from woody species which were present in the study area and its boundaries characterizing the forest cover with solitary trees, tree groves, patches, and closed forest depending on the chronological phases. Many pollen types can easily be referred to past and current vegetation series of the region (for details see 1.1.2 NATURAL AND SEMI-NATURAL FLORISTIC COMPOSITION AND VEGETATION), and main sums useful for environmental reconstructions are elaborated according to a physiognomic analysis with different detail degrees (see Table 13).

Forest tree species and populations have evolved to adapt to the environment in which they grow, with different climate, soil conditions, and factors of disturbance (e.g., fires). Forests responses to climate change are mostly studied at community level. However, analyses at population or community levels could underestimate individual trees responses that may vary in complex dynamic forest (Levine et al, 2016). The response of trees to climate variability is the key to understanding current and future forest dynamics and to plan sustainable forest management that faces increasing demands and disturbances with profound effects on the health, diversity, productivity, and resilience of forest ecosystems (European Environment Agency, 2018). In order to have a clearer indication of changes in ecological and climatic conditions, a comparative examination of the pollen list with the current flora and vegetation of the study area was carried out through the use of flora checklists and literature on vegetation series (Alessandrini & Branchetti, 1997; Blasi, 2010; Pignatti, 1982; Pignatti, Guarino, & La Rosa, 2017-2019; The Plant List, 2013).

The floristic list obtained is proposed in the Table 21.

 **Table 21.** Pollen list of woody plants identified and most common species from flora of the Central Po Plain and of the Apennine-Alpine margin included in pollen types. Nomenclature follows Pignatti (1982). Asterisks mark the species present in the study area during the Late Pleniglacial/Lateglacial (Ravazzi et al, 2007).

Family	Pollen type	Species
Adoxaceae	<i>Sambucus nigra</i> type <i>Viburnum</i>	<i>Sambucus nigra</i> L. <i>Viburnum lantana</i> L. <i>Viburnum opulus</i> L.
Aquifoliaceae	<i>Ilex aquifolium</i> type	<i>Ilex aquifolium</i> L.
Araliaceae	<i>Hedera helix</i>	<i>Hedera helix</i> L.
Betulaceae	<i>Alnus</i>	<i>Alnus glutinosa</i> (L.) Gaertn. <i>Alnus incana</i> (L.) Moench * <i>Alnus viridis</i> (Chaix) DC.
	<i>Betula</i>	<i>Betula pendula</i> Roth <i>Betula pubescens</i> Ehrh. * <i>Betula nana</i> L.
	<i>Carpinus betulus</i> <i>Corylus avellana</i>	<i>Carpinus betulus</i> L. <i>Corylus avellana</i> L.
	<i>Ostrya carpinifolia</i> / <i>Carpinus orientalis</i>	<i>Ostrya carpinifolia</i> Scop.
Cannabaceae	<i>Celtis</i> <i>Humulus lupulus</i>	<i>Celtis australis</i> L. <i>Humulus lupulus</i> L.
Celastraceae	<i>Euonymus</i> cf.	<i>Euonymus europaeus</i> L.
Cistaceae	<i>Cistus</i>	<i>Cistus salvifolius</i> L.
Cornaceae	<i>Cornus mas</i> <i>Cornus sanguinea</i>	<i>Cornus mas</i> L. <i>Cornus sanguinea</i> L.
Cupressaceae	<i>Juniperus</i> type	<i>Juniperus communis</i> L. <i>Cupressus sempervirens</i> L.
Ephedraceae	<i>Ephedra distachya</i> type	<i>Ephedra major</i> Host <i>Ephedra distachya</i> L.
Ericaceae	<i>Erica</i>	<i>Erica arborea</i> L. <i>Erica carnea</i> L.
Fabaceae	<i>Cytisus</i> type <i>Genista</i> type	<i>Cytisus sessifolius</i> L. <i>Genista tinctoria</i> L.
Fagaceae	<i>Castanea sativa</i> <i>Fagus sylvatica</i> broadleaved <i>Quercus</i>	<i>Castanea sativa</i> Mill. <i>Fagus sylvatica</i> L. <i>Quercus robur</i> L. <i>Quercus pubescens</i> Willd. <i>Quercus cerris</i> L. <i>Quercus petraea</i> (Matt.) Liebl.
Juglandaceae	<i>Juglans regia</i>	<i>Juglans regia</i> L.
Malvaceae	<i>Tilia cordata</i> <i>Tilia platyphyllos</i>	<i>Tilia cordata</i> Mill. <i>Tilia platyphyllos</i> Scop.
Moraceae	<i>Morus</i> cf. <i>nigra</i>	<i>Morus nigra</i> L.
Oleaceae	<i>Fraxinus excelsior</i> type <i>Fraxinus ornus</i> type <i>Olea europaea</i>	<i>Fraxinus excelsior</i> L. <i>Fraxinus angustifolia</i> Vahl <i>Fraxinus ornus</i> L. <i>Olea europaea</i> L.
Pinaceae	<i>Abies</i> <i>Picea</i> <i>Pinus</i>	<i>Abies alba</i> Mill. <i>Picea abies</i> (L.) H. Karst. <i>Pinus sylvestris</i> L. <i>Pinus cembra</i> L. <i>Pinus mugo</i> Turra <i>Pinus nigra</i> J.F. Arnold
Platanaceae	<i>Platanus</i>	<i>Platanus hybrida</i> Brot.
Rhamnaceae	<i>Rhamnus</i> type	<i>Rhamnus catharticus</i> L.
Rosaceae	<i>Crataegus</i> <i>Prunus</i> <i>Pyrus</i> <i>Rosa</i> <i>Rubus</i> <i>Sorbus</i>	<i>Crataegus monogyna</i> Jacq. <i>Crataegus oxyacantha</i> L. <i>Prunus spinosa</i> L. <i>Prunus avium</i> L. <i>Prunus mahaleb</i> L. <i>Pyrus communis</i> subsp. <i>pyraster</i> (L.) Ehrh. <i>Pyrus communis</i> L. subsp. <i>communis</i> <i>Rosa canina</i> L. <i>Rubus ulmifolius</i> L. <i>Rubus canescens</i> DC. <i>Rubus caesius</i> L. <i>Sorbus torminalis</i> L.
Salicaceae	<i>Populus</i> <i>Salix</i>	<i>Sorbus aria</i> L. <i>Populus alba</i> L. <i>Populus nigra</i> L. <i>Populus tremula</i> L. <i>Salix alba</i> L. <i>Salix triandra</i> L. <i>Salix caprea</i> L. <i>Salix cinerea</i> L. <i>Salix purpurea</i> L. <i>Salix eleagnos</i> Scop.
Sapindaceae	<i>Acer campestre</i> type	<i>Acer campestre</i> L.
Taxaceae	<i>Taxus</i>	<i>Taxus baccata</i> L.
Ulmaceae	<i>Ulmus</i>	<i>Ulmus minor</i> Mill. <i>Ulmus glabra</i> Huds.
Vitaceae	<i>Vitis vinifera</i>	<i>Vitis vinifera</i> L.

5.4.2 PALYNOLOGICAL INDEX OF ALLUVIONAL TRANSPORT

The need of writing this paragraph starts from the observation of many pollen grains of secondary deposition (also called reworked, recycled, or rebedded pollen) in different levels of the sequences. Sometimes they constitute the major portion of the pollen-and-spore assemblages recovered. The occurrence of this type of remains represents at the same time a nuisance during the analyses and an intriguing opportunity to get further palaeoenvironmental information. The problem of reworked pollen and spores is not a new one (Ananova, 1960; Davis, 1961; Erdtman, 1954; Iversen, 1936; Muller, 1959, and many others) and it is not surprising their abundance in contexts such as the one considered because of the transport is to be attributed to floods that frequently occur in alluvial plains whose sedimentary origin is determined by fluvial inputs. In the Po Plain, they have been commonly observed by Ravazzi, Cremaschi, and Forlani (2004) and by Mercuri et al (2015a). This type of palynomorphs, that occurred into stratigraphically younger deposits, are largely attributed to erosion phenomena of rocks in the source area of the parent plants and later redeposition in a different sedimentation area (Streel & Bless, 1980). Usually, a homogeneous assemblage of palynomorphs from different sources and chronology is related to different distances of transport as well as the times of redeposition (Jones, 1958). A detailed analysis of these remains could therefore provide important clues on the location of the source areas of sediments and the watercourse that deposited them. Furthermore, the amount of reworked pollen and spore could be regarded as a proxy for flood magnitude (Brown, Carpenter, & Walling, 2007) because any increase in the erosion of sedimentary rocks is linked to a larger transport of secondary plant microfossils to the basin of deposition (Stanley, 1966). In marine contexts, high percentages of reworked plant microfossils occurred in sediments formed during times of continental glaciation as a consequence of increased erosion related to base-level lowering (i.e., the change in gradient between the process of erosion and the process of deposition during glacial period; Stanley, 1965). Reworking phases, characterized by peaks of reworked palynomorphs, can be related to phases of subglacial abrasion and they are particularly frequent in fluvio-glacial deposits during the last two glacial Terminations reflecting deglaciation phases (Guiter et al, 2008; Pini, Ravazzi, & Donegana, 2009).

Recycled plant microfossils could be quite easily discriminated against the primary Pleistocene and Recent pollen and spores with objective criteria related to morphological features, among which the flat size, the dark color, or the degree of stain acceptance related to changes in exine-chemistry during the reworking process of plant microfossil. However, morphological criteria alone may not be enough for the identification of the reworked component, at least in some circumstances affected by massive reworking (Pini, Ravazzi, & Donegana, 2009), and a further detection of levels could be done by the covariance estimation between pollen grains belonging to Pliocene–Early Pleistocene extinct taxa (which must be considered reworked for sure) and pollen grains of doubtful origin.

The following morphological criteria were applied to distinguish reworked pollen palynomorphs (for details see Traverse, 1988 and Stanley, 1966):

- a brown or light-yellow color is usually distinguishable, or grains appear considerably darker than most of the other grains in primary deposition, even if such difference in color is partly still visible after acetolysis;
- the coalescence of inner wall surfaces as a consequence of compression of the remains;
- ornamentation and sculpture on the surface of the pollen are affected by the surface abrasion and they are not well distinguishable.

Many secondary pollen grains and other palynomorphs with different morphological features were observed along the sequences. The main identified forms can be referred to Dinoflagellate cysts, which mark a large chronological range from the Late Triassic to present. These remains were usually identified together with circumpollid pollen generically called *Corollina* (synonym of *Classopollis*; Traverse, 1988) that first appears during the Ladinian stage of the Triassic and characterizes gymnosperms until mid-Cretaceous time, and triporate pollen (collectively called *Normapollis*) that first appears and diversifies as the basic form of dicot pollen in Cenomanian about the middle of Cretaceous (Traverse, 1988). Altogether, this palynomorph assemblage could testify that the reworking probably took place mainly from Cretaceous deposits. The age-range considered is consistent with the Cretaceous Flysch formations of northern Italy

(Boccaletti et al, 1980; Marroni et al, 1992; Rosselli, Molinari, & Severi, 2016) that characterize extensively the basins of the Apennine watercourse within the territory of Parma and Reggio Emilia province (e.g., Enza River). The distribution of the palaeoriverbeds during the Bronze Age indicates that the study area has been located between the area of influence of the Po and the Apennine rivers that drain the territory (Cremaschi, 1997 Figs. 45-46). However, it is not easy to distinguish whether this Apennine palynofacies flowed into the Po River before being deposited, as already pointed out by Ravazzi, Cremaschi, and Forlani (2004) and Cremaschi et al (2016).

The percentages of reworked pollen, dinocysts, and reworked trilete spores are often in phase along all the sequences (Figs. 46-48), suggesting a possible common origin of these items. The abundance of these remains is usually concurrent to a drastic drop in pollen concentrations, which together are index of a high deposition of matter diluting pollen and point to a possible bias to the pollen record in which the vegetation cover at the time of sedimentation, the effect of erosional processes, and the long-distance pollen transport could be contribute to the pollen assemblage. Among these, the intake of fragmented saccate pollen taxa (e.g., *Pinus* and *Abies*) as pieces of sacchi and corpora usually reaches values that exceed the well-preserved pollen of the same type (Figs. 46-48). The preservation of saccate pollen types is usually more susceptible to fragmentation than other smaller types under unfavorable depositional conditions and high percentages of fragments imply an input of water current transport and alluvial deposits carrying down pollen from higher vegetation belts, especially if present together with high values of secondary palynomorphs.

As well as the low concentrations of pollen and the large amount of reworked and broken pollen provide useful information on the occurrence of alluvial events, the succession of different stages of vegetation and the presence of wet environment bioindicators reflect new conditions established as result of the accumulation of organic material, the increase in water level, and the degree of moisture in the soil.

In the diagrams (Figs. 46-48) it is possible to observe the spread of hygrophilous herbs (mainly Cyperaceae and *Sparganium emersum* type) as the first colonization following the moments of greater fluvial contribution, and the establishment of hygrophilous woods testifies the recovery of local stable hydrological conditions. The data is not surprising because the relationship between woody and herbaceous plants occupying the same habitat is relative and a prevalence of wetland herbs is usually observed during phases of constant flow and supply of water quantities that favored their spread at the edges of the watercourse. When the flow slows down, usually with lowering of the water level, the banks of the rivers become occupied by woody plants that reaches the banks, preventing the reeds and cattails from growing. On the contrary, the hydrophytes curve attests the presence of lentic aquatic habitats, like canals, ponds, or temporary pools but does not seem to be linked to the trend of the other parameters considered for the description of an environment subject to temporary flooding.

Among the Non-Pollen Palynomorphs, the presence of *Pseudoschizaea* (Scott, 1992 - also known as *Concentricystis*; Christopher, 1976), indicates a terrestrial environment with moments of stagnation of water and moments of desiccation. These cysts have been usually related to freshwater marshes (Milanesi et al, 2006; Rossignol, 196) and their presence indicates soil erosion (Pantaleón Cano et al, 1996) and variation (decreasing) of water level due to drier conditions (Carrión & Navarro, 2002). Considering the palaeoenvironmental indicator values, the most abundant presence of these remains in samples characterized also by high percentages of reworked pollen suggests the occurrence of small and temporary stretches of water following water level variation because of hydrological events which alter the local drainage patterns. In this case, the presence of *Pseudoschizaea* can also be considered an excellent bioindicator useful for the correlation of the three cores, as the presence of these remains is attested starting from 3b pollen subzones of each sequence.

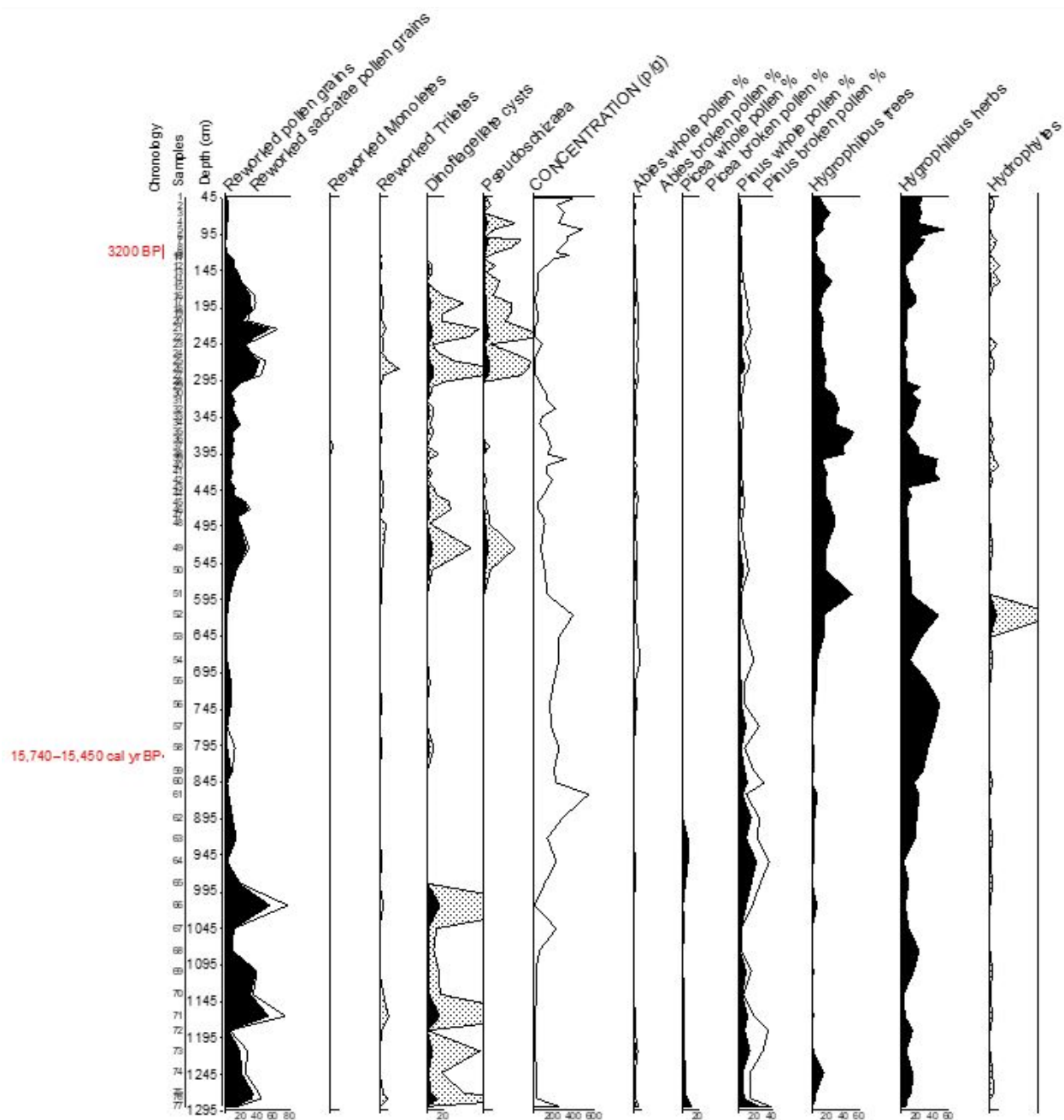


Figure 46. N-S3 core - palynological index of alluvial transport: parameters considered for the description of an environment subject to temporary flooding. Empty curves represent 10% exaggeration.

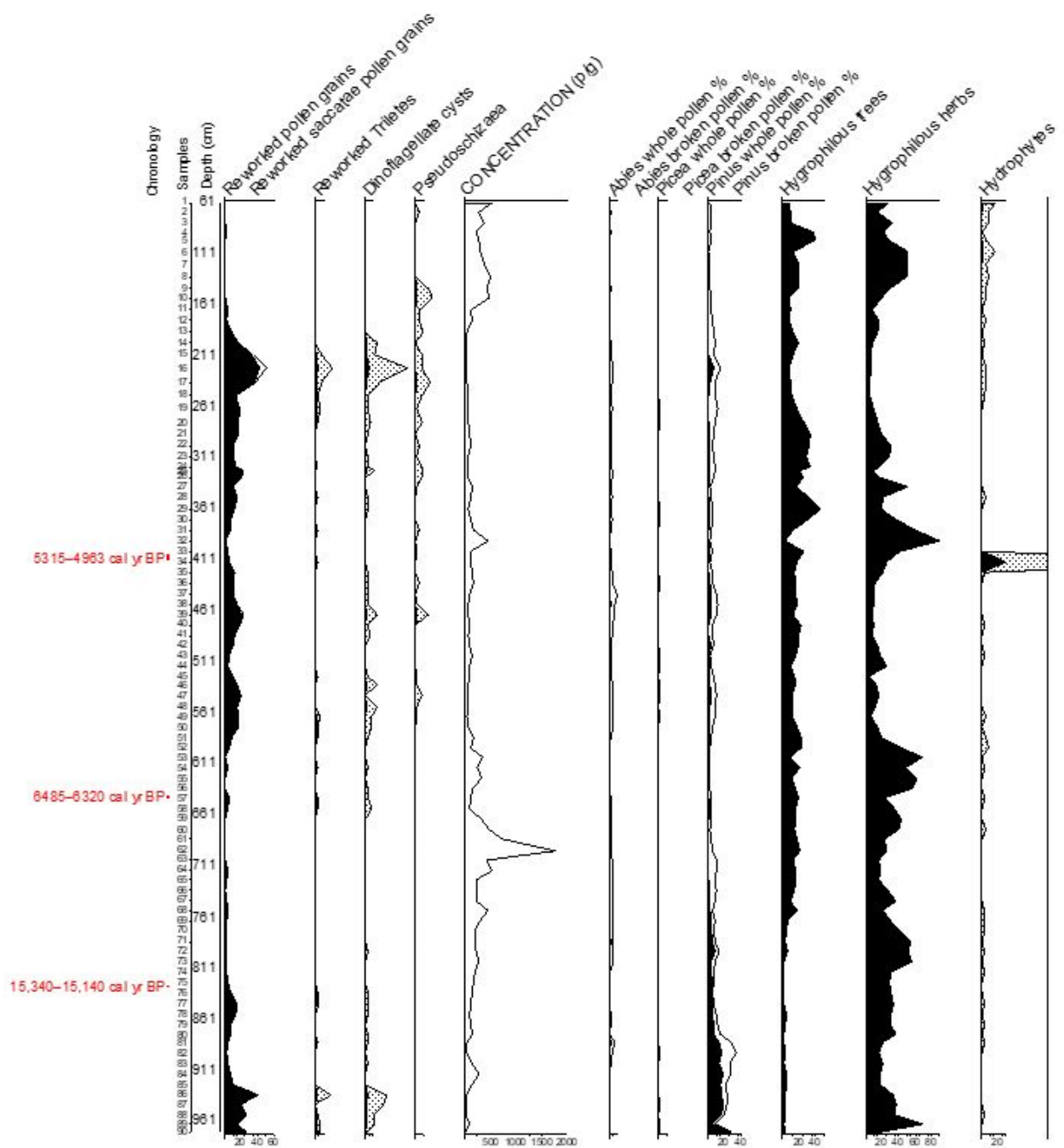


Figure 47. C-S1 core - palynological index of alluvial transport: parameters considered for the description of an environment subject to temporary flooding. Empty curves represent 10% exaggeration.

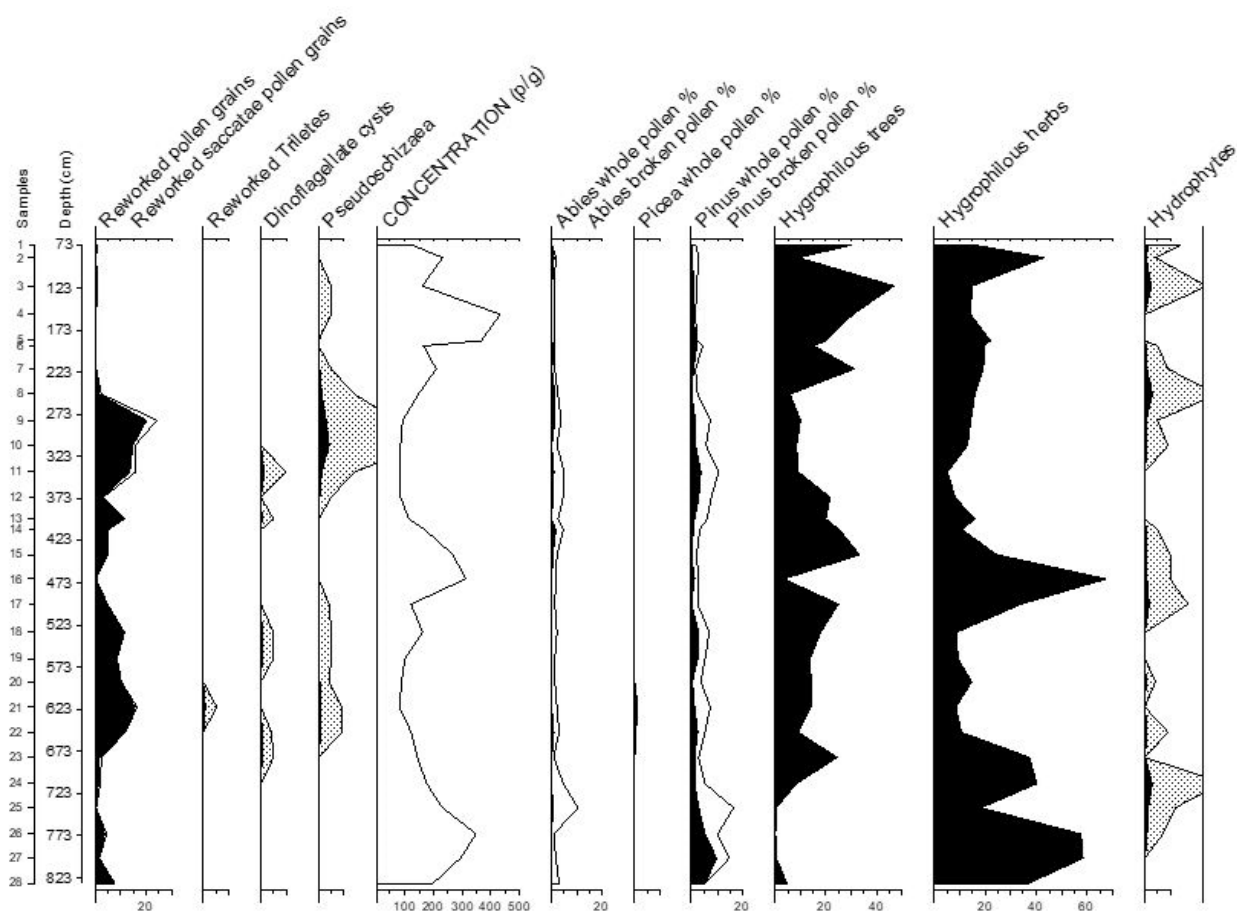


Figure 48. F-S2 core - palynological index of alluvial transport: parameters considered for the description of an environment subject to temporary flooding. Empty curves represent 10% exaggeration.

The ratio between the pollen in primary deposition (Ppd) and reworked pollen (rP) can be used as an index of the influence of river events on the sedimentation processes ($P_{pd/r}$; Ravazzi, Cremaschi, & Forlani, 2004 – in Italian “ $P_{nr/r}$, Polline_{non rimaneggiato/rimaneggiato}”). For applying this index to the three sequences, it was decided to invert the two terms ($P_{r/pd}$) for graphic reason, because of the presence of levels in which secondary deposition pollen grains were not observed (Fig. 49).

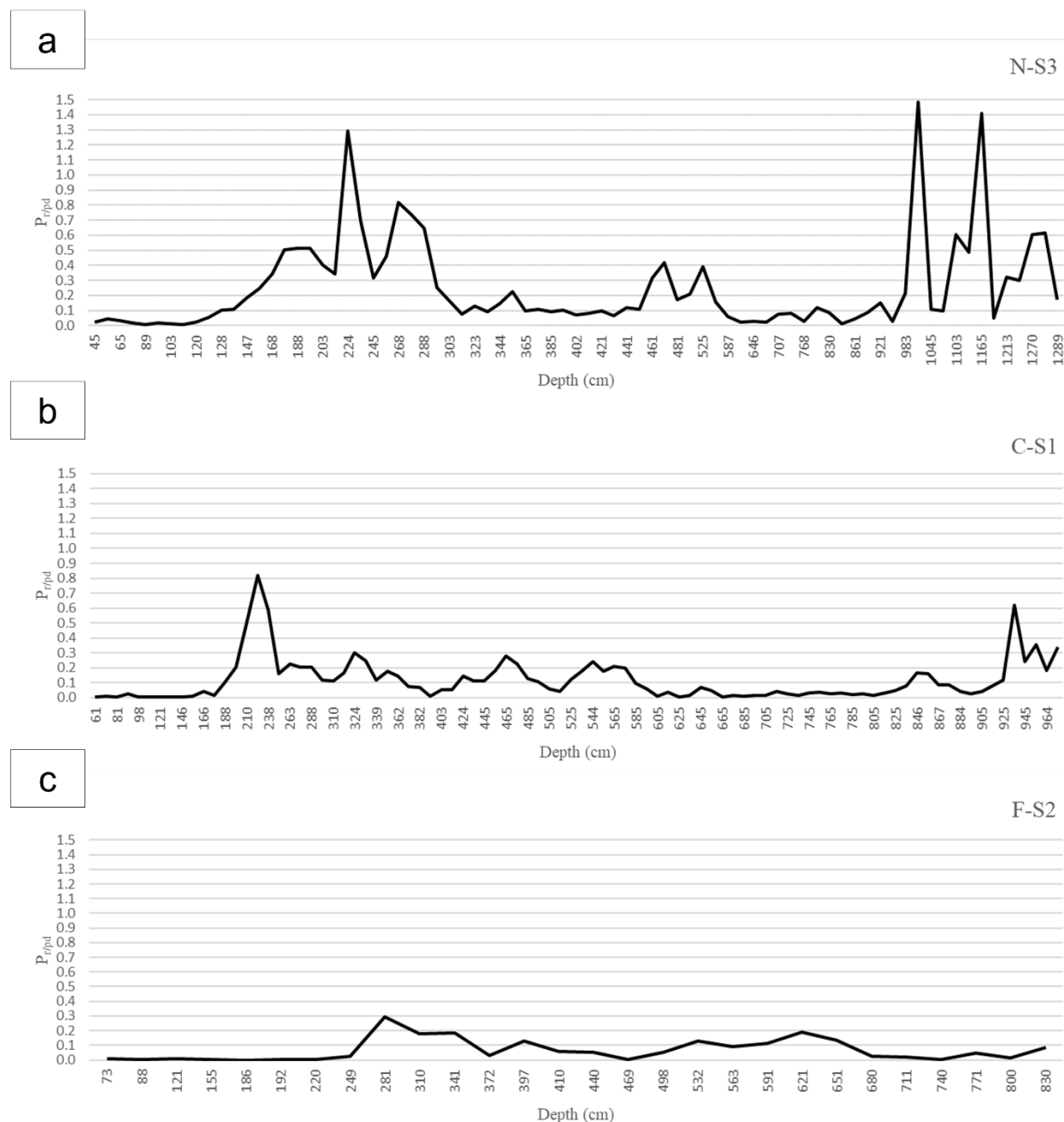


Figure 49. Ratio ($P_{r/pd}$) between the pollen count of reworked pollen and pollen in the primary deposition along the three sequences: a) N-S3; b) C-S1; c) F-S2. The values for each sample are reported, without any reference to the chronology or correlation between the cores. The same scale has been maintained to facilitate image viewing.

The presence of many fluctuations in this ratio is in accordance to the alluvial origin of the study area and the three sequences show similar trends as they are part of the same sedimentary basin. However, maximum values reached by the ratio are not the same in the three sequences. The higher values in the N-S3 core could be probably justify to a greater distance from the palaeoriverbed covered by alluvial fans during alluvial phases resulting in the deposition of sediments that can no longer be transported due to the reduction of the carrying capacity of the flow (Jain et al, 2014).

The higher the index value, the better is possible to suggest the occurrence of intense flood events in selected levels. Setting 0.5 as the minimum alluvial index threshold (based on the evidence that the amount of detected reworked grains reach the 50% of the amount of not-reworked pollen grains), at least two major flood events may have influenced the territory starting from the Late Pleniglacial/Lateglacial. The first event, or more likely a series of events in closely succession, is identifiable at the bottom of the sequences N-S3 and C-S1, with high amount of reworked palynomorph consequent to the glacier erosion and re-deposition of sediments in the lowland during the last deglaciation phase.

The second extensive succession of alluvial events is observed in the N-S3 in the levels preceding the Terramara S. Rosa di Poviglio (archaeological levels intercept pollen samples 11-8). This sedimentary feature agrees with the geomorphological evidence of the Central Po Plain related to the Subboreal period, when fine-textured alluvial deposits buried the distal margin of the alluvial fans and the soils developed on them (Cremaschi & Nicosia, 2012; Cremaschi, Storch, & Perego, 2017). Reflecting the general image of the study area, also the last peak of the $P_{r/pd}$ ratio of the other two cores could probably be referred to the same chronological phase. Actually, the index peaks show a well-expressed correlation between the three cores showing an increase in thickness of the more recent deposits in a northerly direction.

A decreasing trend of the $P_{r/pd}$ ratio is documented at the top of the stratigraphic succession. A similar situation was found in the pollen sequence of the moat located in the northern part of the Terramara S. Rosa di Poviglio (Ravazzi, Cremaschi, & Forlani, 2004). An active and continuous connection between the moat and the river network is documented up to the Middle Bronze Age, when a progressive reduction of river supplies began. Rapid and extensive flood events are not documented by pollen data for the post-Bronze Age levels in these cores. Unstable hydrogeological conditions are documented in the surrounding area after the collapse of the Roman Empire (5th century AD) with the expansion of vast swamp basins at the northern fringe of the Enza alluvial fan until the 10th century AD with the beginning of channelization and reclamation works that increased between the 12th and the 13th centuries (Brandolini & Cremaschi, 2018). However, the territory of Poviglio is located on an area topographically higher than the surrounding plain called “Valle di Gualtieri” (Brandolini et al, 2018; Castiglioni et al, 1997; Marchetti, 2002), and this is the reason for the data reported above related to the scarce presence of reworked pollen in the most recent levels of the cores.

5.4.3 RIVULARIA HETEROCYSTS IN THE STRATIGRAPHIC RECORD

The records observed in the cores from Poviglio have great interest for their general palaeoecological implication and for their peculiar morphology.

The life cycle of *Rivularia*, and more generally of cyanobacteria, is still little known. In fact, information available derives from studies on blooms with the rapid proliferation of populations and the formation of clearly visible colonies in freshwater or marine water systems (Hieronymus et al, 2021), and on genera of cyanobacteria that are toxic or harmful to ecosystems (Sukenik, Quesada, & Salmaso, 2015). Generally, processes of cell division or differentiation occur in response to environmental changes, such as the presence and quantity of nutrients and light irradiation, or internal factors related to catabolism and anabolism.

The optimal growth conditions and the development of blooms are found in spring and summer, periods in which usually the supply of nutrients is greater, together with high irradiation and optimal temperatures of at least about 25 °C (Hense & Beckmann, 2006). The first limitation to the growth of vegetative cells is

given by the lack of some nutrients following the rapid proliferation of the colonies that requires and consumes a large quantity of substances, the main one being nitrogen. Colonies respond by forming heterocysts, as cells that specialize in fixing nitrogen for the entire filament. The fixed nitrogen is then transferred to the vegetative cells of the trichome, while the heterocyst receives the photosynthates for its own metabolism from the adjacent cells (Hense & Beckmann, 2006). Each new heterocyst is formed in response to environmental or internal changes in the colony, as in the case of habitats rich in combined nitrogen (in proteins, nucleic acids, and other organic compounds) for prolonged periods, or a reduced effectiveness of the heterocysts (Whitton & Mateo, 2012). Other elements that influence the development of these structures are potassium, molybdenum, magnesium, calcium, and iron, fundamental in the functioning of these cells and the lack of which stimulates heterocystic differentiation (Sinclair & Whitton, 1977). For this reason, colonies grown over several years show residual heterocysts below the terminal and functioning one. In *Rivularia* a new heterocyst can develop above the one already present, which tends to collapse and undergoes apoptosis (Pasqua, Abbate, & Forni, 2019). In rare cases, intercalary heterocysts may also develop to obtain higher nitrogen fixation levels (Whitton, 1987).

The cell wall of the heterocyst is thick, robust, and clearly visible under the light microscope. It is composed of peptidoglycan or murein, pectic substances, and hemicelluloses. The outer layer is made up of phospholipids, lipopolysaccharides, and proteins, while the intermediate layer is about 10 nm thick and has murein that shapes the structure and provide mechanical protection. The inner layer is adjacent to the plasmalemma. The cell wall also stores compounds useful for shielding UV rays and has pores for the outward secretion of mucilage, the main component of the sheath which is composed of about 50% of complex polysaccharides with functions of adhesion to the substrate, movement, and protection from dehydration (Pasqua, Abbate, & Forni, 2019). The thickness of the wall protects the nitrogenase enzyme, which catalyzes nitrogen fixation reactions, from the inhibition given by oxygen which cannot penetrate inside the cell. This characteristic, combined with the possible calcification of the wall, allows the conservation over time of the heterocysts (Tappan, 1980).

In modern contexts, *Rivularia* is analysed together with other nitrogen-fixing microfossils to recognize eutrophication processes and the relative increase in the quantities of organic nutrients, nitrogen, and phosphorus generated by human activities (Stancheva et al, 2013). Furthermore, some species are invasive in many geographical areas, reflecting pollution conditions and lower water quality (El-Adl & Bream, 2016). It is possible to know the relationships between species of Rivulariaceae and their habitats, as well as their presence in palaeoenvironmental samples allows to reconstruct environmental contexts and changes on a long-time scale. The cell wall is the structure that mainly allows heterocysts to be preserved.

Rivulariaceae were documented in sediments from the Pliocene (5.332 - 2.588 million years ago) onwards. Many Pleistocene deposits (between 2.58 million years ago and 11,500 years ago) show cyanobacterial-like structures (Whitton & Mateo, 2012). Data on the presence and concentration of *Rivularia* in Quaternary sediments, combined with information on vegetation and pollen counts, allows the evaluation of hydrogeological transformation, trophic conditions, and changes in ecosystems caused by natural or anthropic factors (Carrión & Navarro, 2002).

Data on concentrations and percentages of *Rivularia* heterocysts from the N-S3 core describe a non-constant trend, reflecting different, and sometimes rapid, changes in ecological conditions in millennia of deposit.

The presence along the whole core of *Rivularia* heterocysts is index of a eutrophic environment strongly dependent on mild temperatures, humidity, or the direct presence of water. High amount of these remains in the diagram may suggest the occurrence of high concentration of nutrients (organic phosphorus and combined nitrogen) which favored the proliferation of colonies. The waning availability of nitrogen, the most consumed nutrient during bloom formations, generates the need to develop heterocysts to allow colonies to survive. Therefore, different presence of *Rivularia* heterocysts is first the indication of the oscillations of nutrients in the water, related to a decrease in the concentration of nitrogen following a eutrophic condition that allowed the large development of the colonies. The great variability of the presence/absence of sheaths denotes a different state of preservation of the remains due to post-depositional disturbances and soil compaction, which can lead to the loss of the less resistant structural part because of its mucilaginous composition.

The presence of heterocysts with different morphologies has never been investigated until the attempt made in this thesis to divide the findings into two main groups. Heterocysts of different morphology, not attributable to different species based on current knowledge, are observed in all samples, and in the most recent levels a homogeneous distribution of heterocysts is documented.

This investigation leads to the formulation of two questions at the basis of the interpretation of the data:

- Could the presence of different heterocyst's morphologies be an indication of the contemporary presence of different species of *Rivularia*?
- Could the presence of different species be linked to rapid changes in environmental conditions?

However, these questions have not yet been answered. The comparison of modern case studies and in-depth morphological analysis of these structures could be useful to improve *Rivularia* taxonomic identification, but no examples have been found yet.

Trend of Rivularia heterocysts in the cores

Observing the *Rivularia* type trend along the entire sequence of the N-S3 core (Fig. 50), it is possible to observe an almost total absence of heterocysts in the deeper levels (pollen zones 1 and 2), between 1289 cm (sample 77) and 830 cm (sample 59). This data, together with the image obtained from the pollen spectra, reflects the scarce presence of *Rivularia* colonies that could be related to the transition from glacial climatic conditions during the Late Pleniglacial/Lateglacial. In this case, the limiting factor is probably the temperature which, even in spring and summer, does not reach suitable conditions for the development of cyanobacterial colonies. However, the presence of heterocysts in some samples (e.g., 0.4% - samples 61) may suggest the occurrence of different conditions in some levels, such as the increase in temperature levels during warmer phases.

Sample 58, which has the highest concentrations and percentage of *Rivularia* of the entire sequence (4115.4 h/g and 13.6%) may intercepts the beginning of the transition from Lateglacial to Holocene, when the rise in temperatures and the increase in moisture concentrations have reached favorable conditions for colonies development. After this peak, the percentages of *Rivularia* type fluctuate up to recent levels, reflecting the different supply of nutrients (and water) deriving both from environmental factors, such as flood events of the nearby Po River, and anthropogenic activities especially related to pastures and cultivations with consequent modification of the trophic conditions of the soils and water regulation. The trend of *Rivularia* in pollen zone 3 reflects a chronological interval characterized by mild temperatures and high levels of humidity, with marked fluctuations. This phase returned the highest values of heterocysts and probably embraces the cooler phase of the Early Holocene and the wetter phase of the Middle Holocene. Only the deeper samples of the C-S1 intercept this phase, during which higher values of *Rivularia* type are documented also in this sequence testifying the occurrence of wetter phase followed by levels characterized by less water availability (Fig. 51).

Particular attention was paid to the levels that intercept the presence of the Terramare settlement (samples 11-8 N-S3 core). The trend of *Rivularia* reflects an initial high availability of nutrients compatible with a local eutrophic condition which was probably favored by human activities, cereals cultivation, and pastures which were probably quite widespread in the territory (*Rivularia* type: 3.1% - sample 11). Then, a decrease in the percentages was documented (2.2% - sample 10) up to the absence of heterocysts (samples 9 and 8), which support the hypothesis of the collapse of this civilization at a time of water crisis and soil depletion due to the continuous exploitation of natural resources by the population over a long period of time. The scarce supply of nutrients and the spread of arid conditions continue even after the abandonment of the settlement, reflecting the difficulty of local environmental recovery (absence of heterocysts - sample 7).

The amount of *Rivularia* in the C-S1 core is lower than the values observed in coeval phases in the N-S3 (first 31 samples). The reason of this difference may be related to the position of the cores with respect to the archaeological site. The N-S3 core is closer to the site than the C-S1, and it was collected near the moat located outside the settlement. The moat, characterized by an almost stable water level, was rich in organic substance (also because presumably the population threw vegetable waste into it; Florenzano et al, 2021a) that provide nutrients for the cyanobacteria colonies. The comparison of these data highlights a lower anthropogenic pressure in the C-S1 core (lower contribution of nitrates and other substances) and a lower proximity to wet environments necessary for the development of the colonies. However, the decline in the

percentages of *Rivularia* is also documented in the C-S1 core starting from sample 12, which, in accordance with the correlation of the two cores based on the pollen record, could correspond to the last phases of the Terramare settlement in Poviglio.

In the most recent levels, the presence of *Rivularia* may be a good indication of an environment constantly influenced by anthropogenic activities, agriculture, and livestock, responsible for a continuous supply of nutrients and water in the soil.

Comparison with pollen curves

The trend of *Rivularia* heterocysts has been compared with the main pollen curves of hygrophilous trees, hygrophilous herbs, and hydrophytes (Figs. 50-51). This comparison supports and integrates pollen data about the establishment of different conditions influencing the formation of wet environments plant successions. The close relationship between the *Rivularia* and plants of wet environment denotes the importance of the direct presence of water or soils saturated with moisture for the development of colonies. The curve of the hygrophilous trees, here dominated by *Alnus* and *Salix*, closely follows the trend of *Rivularia* and corresponding peaks are often visible. *Alnus* and *Salix* need high atmospheric humidity for their development, together with high nitrogen concentrations (Houston Durrant, de Rigo, & Caudullo, 2016; Kuzovkina, 2005). The simultaneous growth tendency of these plants and heterocysts indicates the presence of suitable conditions to common development. In particular, the beginning of the gradual and constant growth of hygrophilous trees starts just after the level that has the peak of *Rivularia* (sample 58 N-S3). This data testifies and confirms the increase in temperatures and precipitation at the beginning of the Holocene that led the increase in concentration humidity and favored the development of deciduous forests, together with the development of colonies of cyanobacteria. On the contrary, the trend of hygrophilous herbs and hydrophytes presents many peaks opposite to those of *Rivularia*. The result is not surprising because the abundance of herbaceous plants is usually related to phases of constant flow and supply of water that allows to this populations to cover the edges of the watercourse, the same ecological niche necessary for the development of *Rivularia* (especially evident in sample 5 of the N-S3, in which the absence of *Rivularia* correspond to a peak of hygrophilous herbs). When the flow slows down, sometimes with lowering of the water level, the banks of the rivers are occupied by woody vegetation preventing the reeds and cattails from growing and favoring the proliferation of *Rivularia* in shallow water.

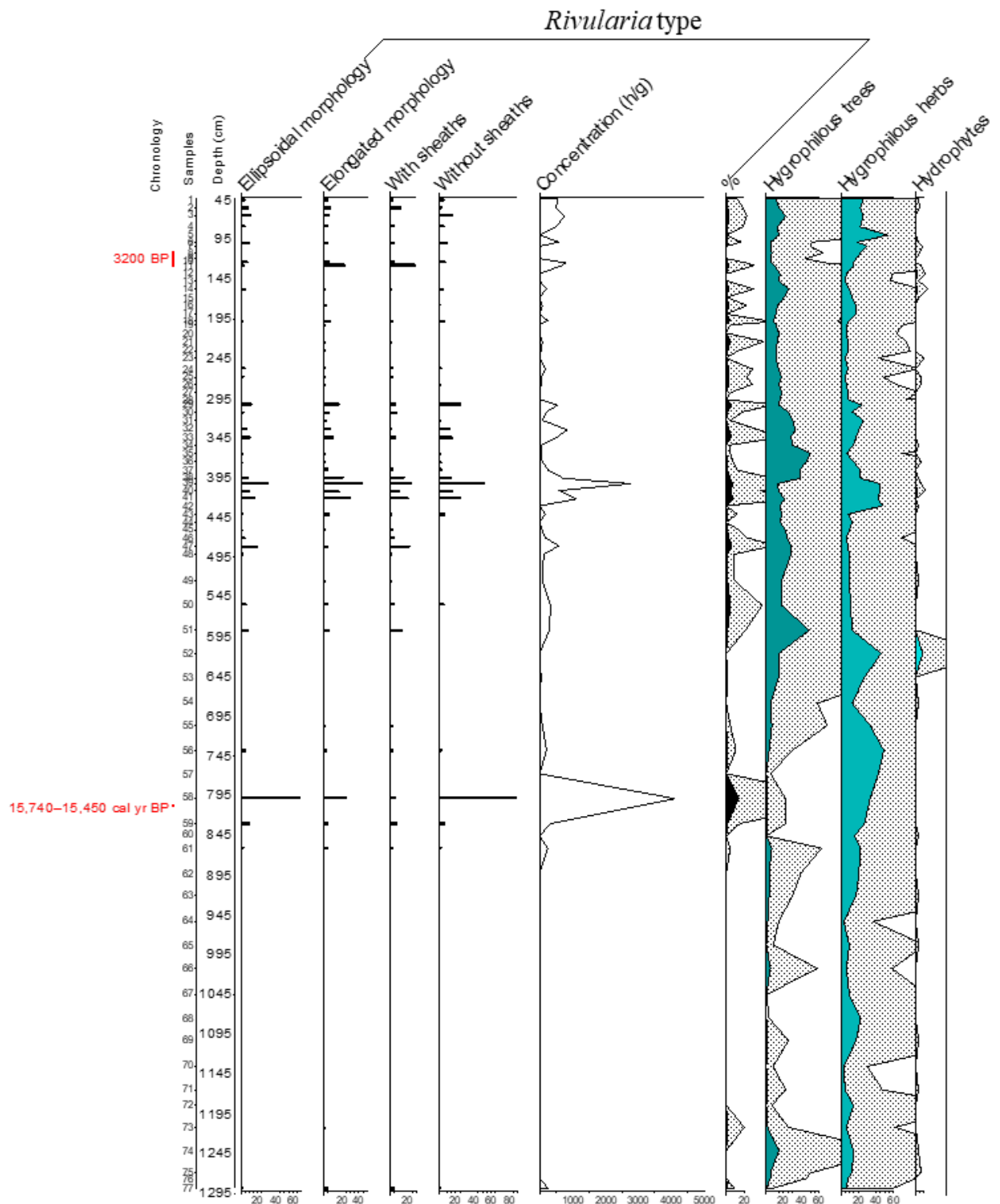


Figure 50. N-S3 core - *Rivularia* type (heterocysts morphology, presence/absence of sheaths, concentration (h/g), and percentages) and pollen sums of wet environments. Empty curves represent 10% exaggeration.

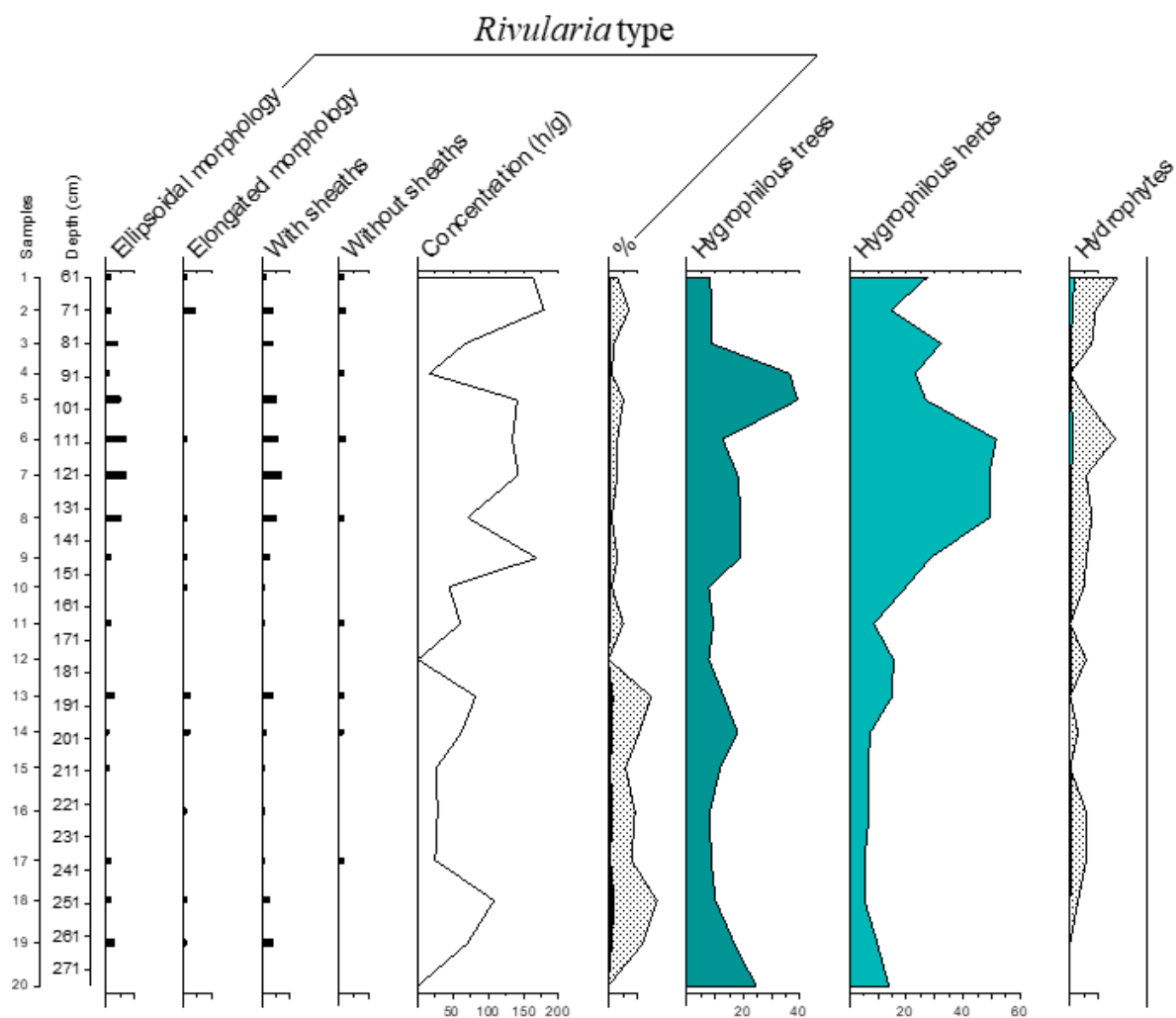


Figure 51. C-S1 core – *Rivularia* type (heterocysts morphology, presence/absence of sheaths, concentration (h/g), and percentages) and pollen sums of wet environments. Empty curves represent 10% exaggeration.

5.4.4 MODERN POLLEN RECORDS

Palynologists often use surface soil pollen samples because the reference to modern pollen assemblages is of particular interest to disentangle the relationships between pollen observed in a sediment sample and the presence of the source plants. Quaternary fossil pollen records can be more easily interpreted through the comparison with modern pollen samples that provide an invaluable research tool as a basic reference (modern analogues). The comparative approach can be based on the relationship between pollen as the proxy and the associated environmental parameters such as vegetation, land use, and climate (Davis et al, 2013a, 2013b, 2020). This approach requires a good calibration between pollen deposition and vegetation with a precise knowledge on how current flora and vegetation are reflected in the pollen spectra. Furthermore, an exciting challenge is the prediction of the future dynamics and changes in vegetation that can be addressed through the integration of different actuo- and archaeo-/palaeo-palynological approaches (Sadori et al, 2013). The current pollen rain can be investigated both through aerobiological monitoring with the use of artificial pollen catchers and through the analysis of surface soils and moss polsters in which the pollen rain is trapped (Gaillard et al, 1992; Heim, 1971; Hicks & Birks, 1996; Hjelle, 1997; Mazier et al, 2006). The study of pollen rain in surface soil samples allows to observe the average composition of about the last ten years of deposition (according to Accorsi et al, 1999) and provides useful data to refer to for the interpretation of palaeoenvironmental samples from the same territory.

Complex agroecosystem patterns in the Po Plain: what do different samples show?

The over-representation of *Echium vulgare* type observed in PVG SS-C testifies the interception of flowers or remains of anther fragments due to the presence of many monospecific clusters composed of this pollen type. High values of pollen derive from a short dispersal distance from the parent plants of this entomophilous species. In fact, plants of *Echium vulgare* L. have been documented within a 10 meters radius around the sampling point (Fig. 52). Probably due to the abundance of this species in the area, the analysis of the sample taken by pinching (PVG SS-Cp) has only reduced the representativeness of this pollen type and high percentages have been documented the same. Both the samples taken with different sampling method will be considered in the qualitative analysis of the current pollen rain without considering *Echium vulgare* type within the pollen sum (Fig. 53). *Echium vulgare*, common in uncultivated lands and dry grasslands (Pignatti, 1982), can be considered a good marker of current pollen rain as it has never been observed in the palaeoenvironmental samples of the cores.

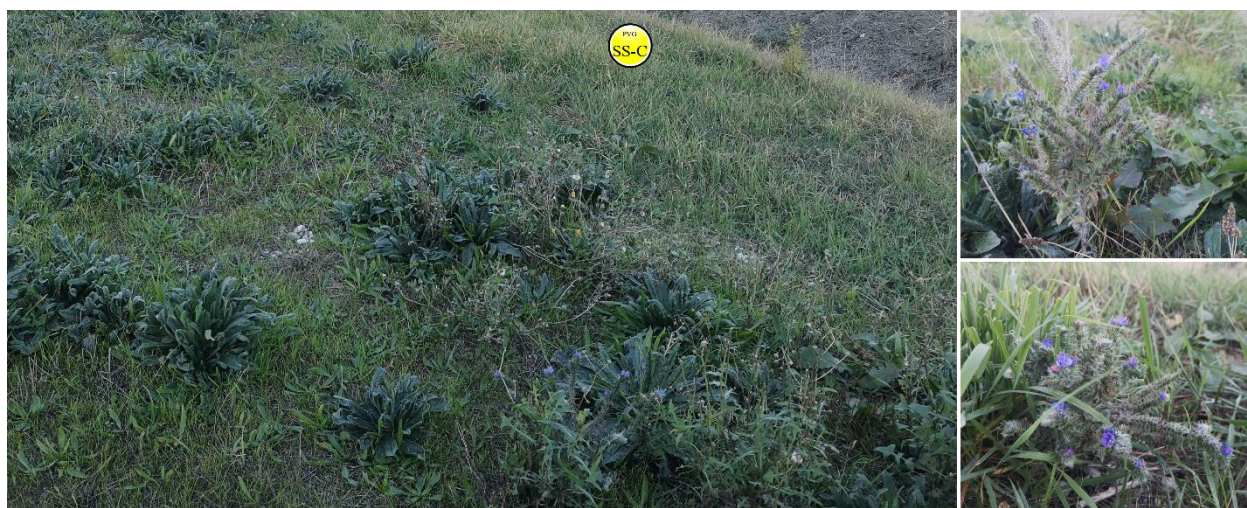


Figure 52. Presence of numerous *Echium vulgare* flowering plants near the PVG SS-C sampling point. Images of 26th October 2021, E. Clò.

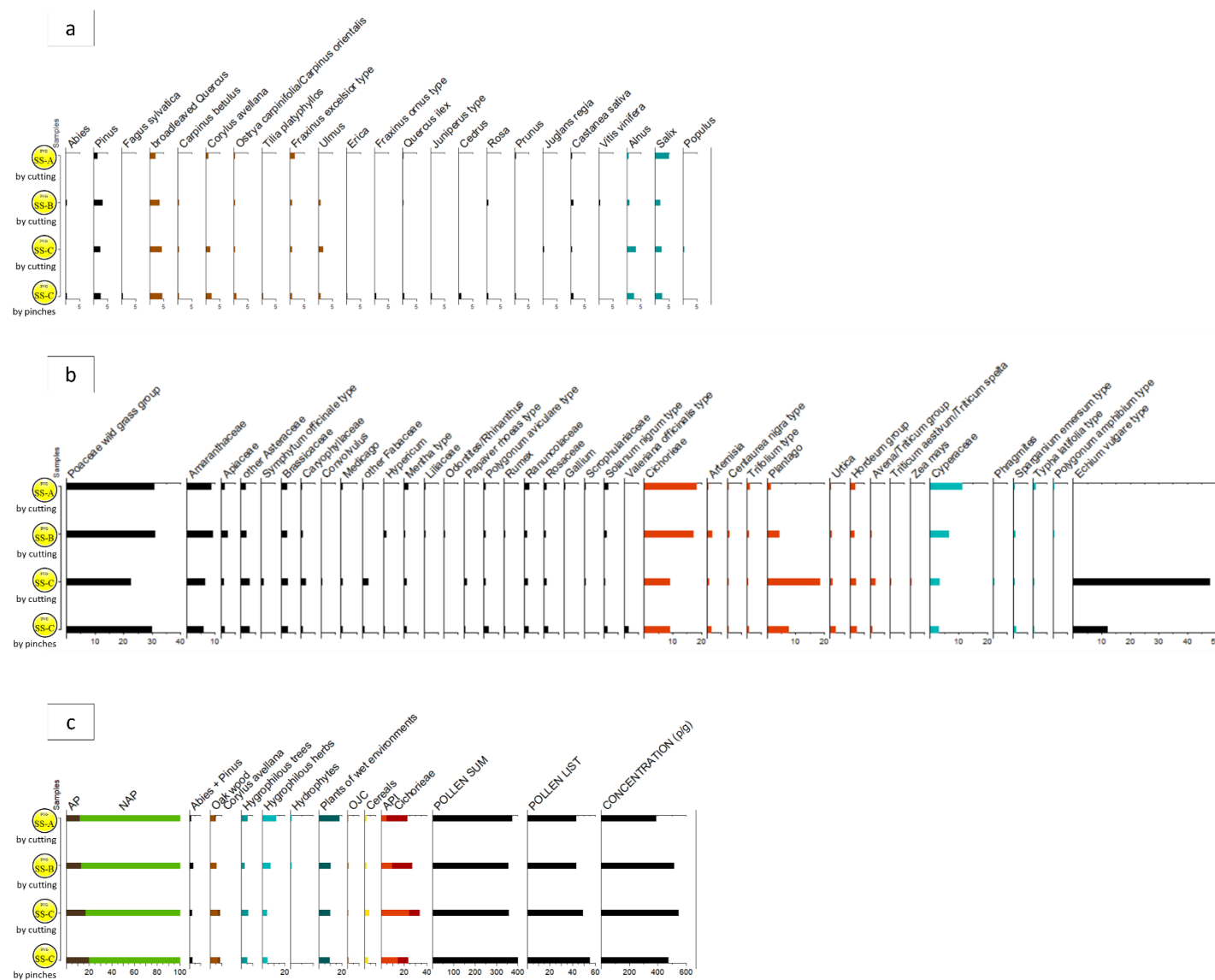


Figure 53. Superficial soil samples pollen percentages: a) Arboreal Pollen (AP); b) Non-Arboreal Pollen (NAP); c) selected pollen sums and pollen concentration. *Echium vulgare* type is excluded from the pollen sum.

The pollen spectra obtained from the surface soil samples reflect the presence of a mosaic of habitats with the prevalence of human environments over the natural ones from which it is possible to perceived how strong has been the anthropogenic imprint on the landscape of the Po Plain. In accordance with the current land cover of the territory, pollen data testify an open landscape (AP average value in SSs of PVG = 15.5%) with solitary trees, hedges among cultivated fields, and thickets of broadleaved trees. In general, this feature is well documented in sites located in the internal plain belt in the Po Plain from data available in the **Eurasian Modern Pollen Database** (EMPD, version 2; Chevalier et al, 2019; Davis et al, 2020; Fig. 54; Table 22), to whom pollen counts were provided by the Laboratory of Modena-UNIMORE.



Figure 54. Map of the surface soil samples pollen data available for the Central Po Plain: Rubiera-1 pollen sample, and Goito-4 pollen samples. Poviglio is marked by the red pointer. Modified from EMPD online map-based viewer (<https://empd2.github.io>).

Table 22. List of surface soil pollen samples from Rubiera and Goito; retrieved from <https://doi.pangaea.de/10.1594/PANGAEA.909130>.

Site	Longitude	Latitude	Elevation	Context	Description	References
Rubiera	10.794213	44.6535	48	Arable	Cornfield	Unpublished data
Goito	10.666111	45.221666	27	Arable	Permanent pasture	Unpublished data
	10.664444	45.223055	27	Arable	Permanent pasture	Unpublished data
	10.664444	45.222777	27	Arable	Cornfield	Unpublished data
	10.66728	45.220844	27	Orchard	Kiwi plantation	Unpublished data

Forest cover always has very low values (AP: Rubiera = 30%, Goito = 9.6% - average value), even if they can often be influenced by different ecological conditions and types of land use, especially tree crops, which are reflected on a specific parcel of territory near the sampling points.

Plants of wet environments are not so widespread in the area except near ditches, canals, and artificial wetlands. Pollen of plants of wet environments characterizes above all the spectrum of the PVG SS-A, sampled near an artificial wetland connected to a big canal that delimits the study area. The willow is dominant among the hygrophilous trees probably because it is kept or planted by human for ornamental reason (this feature is also documented at Rubiera; *Salix*: PVG = 2.8%, Rubiera = 1.2%). The presence of hydrophytes is poorly documented in the PVG pollen spectra except for the presence of *Polygonum amphibium* which, however, can appear both as a rooted hydrophyte with floating leaves and as a rhizomatous geophyte.

Cereal pollen testifies cultivation of barley, wheat, and corn based on pollen morphology and supported by local evidence of these crops in the area (cereals average value in SSs of PVG = 2.6%). However, cereal pollen grains are never abundant in pollen spectra according to their pollination mode (most of them are autogamous plants), the low amount of pollen production, the large volume, and the high weight of pollen which further influenced dispersion and transport (cereals: Rubiera = 6.9%, Goito = 1.3% - average value).

Vegetable and forage crops are also documented in pollen spectra as part of the agrarian activities. The main ones are the cultivation of tomatoes, whose pollen type (*Solanum nigrum* type) always has significant values in the pollen spectra of Poviglio (0.9% on average), and alfalfa (*Medicago sativa*: 0.2%). Both these cultures were observed in the surrounding area at the time of sampling.

The spread of grasses and other perennial species is favored by this agricultural system. Among these, synanthropic plants are always well documented in the pollen spectra. *Plantago*, as a significant bioindicator of trampled areas and soil compression, has the highest values (up to 18.5% in SS-C) in the sample collected near the rural building where it exceeds the value of Cichorieae (up to 18.2% in SS-A). Cichorieae are usually dominant in the pollen rain of arid or semi-arid environments (Horowitz, 1992) as pioneer plants in uncultivated lands describing environments that had developed under a long-time human pressure (Florenzano et al, 2015). High values of Cichorieae are documented mostly in Poviglio (13.3% on average), while the percentages are lower in the other superficial soils (Rubiera = 6.7%, Goito = 3.2% - average value). Elevated frequencies of Amaranthaceae (average value in SSs of PVG = 7.4%) are also correlated with agricultural landscapes, human disturbance, and fertilizer rates.

The high presence of coprophilous fungi, documented in all superficial soils but particularly abundant in PVG SS-B, are also related to fertilization practices applied to restore the essential nutrients to the soil after they have been depleted to improve crops growth and productivity.

In addition to annual crops, viticulture is an important component of the local economy. In the province of Reggio Emilia, viticulture is an ancient agricultural activity widespread in every part of the territory, except for the high mountain areas, thus representing the most important agricultural crop. Currently, the wine production is based on some main varieties among which the group of “*Lambrusco*” occupies a large part of the total vineyard cultivated. Here, *Vitis* pollen was observed only in the SS-B with very low percentages (0.3%). Generally, the rare presence of *Vitis* in pollen spectra and the exponential decrease in *Vitis* pollen accumulation at greater distances from the vineyard have been proven (Turner & Brown, 2004). However, only one pollen grain was observed on a pollen count too low to estimate the abundance of *Vitis*. *Vitis vinifera* L. is a creeper species and wild plants grew in hygrophilous woods, next to the ditch and to the river. Therefore, the wild origin of the observed pollen grain cannot be excluded due to the local environmental features. Similarly, *Vitis* pollen is not documented in the other superficial soils of the Po Plain which were not collected from within or around a vineyard.

The values of OJC group (only *Juglans* and *Castanea* in the surface soils of the Po Plain) are low in current pollen rains. The presence of *Juglans* in Italy is related to sparse specimens or small groups of trees grow near cultivated areas and along river shores, walnut plantations (pure or mixed), and as part of the urban flora (Ferrazzini et al, 2007; Mercuri et al, 2013b; Pelleri et al, 2020). *Juglans* pollen is present only in PVG SS-C (0.3%), as well as low percentages are documented in Rubiera (0.5%), while higher values are represented in Goito (1.4% on average). *Castanea* pollen was observed in all the surface soils samples collected in Poviglio (0.5% on average). Long-distance transport of this pollen is well-known but it represents a minor part of the airborne regional rain (Rubiera = 1.5%, Goito = 0.1% - average value) even if chestnut woods are common in the hills since the development of “chestnut landscape” dates to around 800-700 cal yr BP, when actions of propagation and transplanting strongly influenced the distribution of this species, only declining in modern times (Conedera et al, 2004; Mercuri et al, 2012).

Still regarding to long-distance pollen transport, the high productivity and easy dispersion of *Pinus* pollen is reflected in its significant presence of current pollen assemblage for the entire study area (PVG = 2.2%, Rubiera = 10.3%, Goito = 1.8%). *Abies* and *Fagus sylvatica* also identify higher vegetation belts.

Pollen from most ornamental plants which are planted in private gardens, avenues, and urban parks (e.g., *Quercus ilex* type, *Juniperus* type, and *Cedrus*) was observed even if always in low percentages.

Forest cover in the Central Po Plain has no longer reached the pollen percentages attested in the levels prior to the Bronze Age when mixed oak woods were spread in the region (AP = 65% - mean value from Accorsi et al, 1999). Pollen spectra testify the succession of open environments with different connotation resulting from both climatic and anthropogenic factors, that over time have led to the development of **the current landscape showing the lowest forest cover of the entire Holocene**. The results of the palynological analyses already carried out in previous studies show that large environmental transformations of this territory, mainly related to the forest cover and agrosystem development, have occurred during the Bronze Age (starting from the Middle Bronze up to the Recent Bronze Age with AP percentages around 15-20%; Cremaschi et al, 2016; Florenzano et al, 2021a; Mercuri et al, 2006a, 2015a; Ravazzi, Cremaschi, & Forlani, 2004) and then continued during the following phases (Iron Age and Roman Period = 17.4%; Florenzano et al, 2021a).

Regarding to the herbaceous component, the presence of Cichorieae is significant both in the current and past pollen spectra with comparable values starting from the Bronze Age (PVG SSs = 13.3%; N-S3 = 22.7%, samples 14-8 average value; C-S1 = 20.6%, samples 14-11 average value; F-S2 = 13.8%, sample 9-8 average value). This could be interpreted with a double significance according to different types of land uses. In archaeological contexts Cichorieae are among the most important indicators grazing and dry pastures that may correspond to both a land use change under dryer climate conditions and the abandonment of the fields (Cremaschi et al, 2016; Florenzano, Mercuri, & Carter, 2013; Florenzano et al, 2015; Mercuri et al, 2010). Today they have a clear ecological value as pioneer plants resistant to drought common in the agricultural landscape spread throughout the Po Plain. According to this, the trend of Cichorieae pollen is well documented also in off-site records starting from the last three millennia as a marker of the spread of dry grassland during increasing climate aridity and human impact (Mercuri et al, 2012).

5.4.5 QUANTITATIVE RECONSTRUCTIONS OF VEGETATION

REVEALS

The Landscape Reconstruction Algorithm (LRA; Sugita, 2007a, 2007b) application enables to transform pollen percentages into vegetation cover and thus allows a more profound discussion about changes in flora and vegetation composition and the transformation from more natural environments to cultural landscapes. In the growing perspective of models for the quantitative reconstruction of the vegetation starting from pollen data, with the increase in applications especially in northern Europe where the application is practical and realistic (Bunting et al, 2005; Cui et al, 2013; Fyfe et al, 2013; Githumbi et al, 2021; Hjelle et al, 2018; Marquer et al, 2020; Mazier et al, 2015; Nielsen & Odgaard, 2010; Nielsen et al, 2012; Trondman et al, 2015), the main purpose of development of this chapter is the application of the LRA (Sugita, 2007a, 2007b) to pollen data from contexts never tested before.

Since the study area is located at the southern border of continental Europe, a selection of PPEs from boreal/temperate Europe were used for all the pollen taxa, excluding the PPEs values of *Carpinus orientalis* and *Castanea sativa* from studies in the Mediterranean area (Table 23).

Table 23. List of pollen productivity estimates (PPEs) and their relative standard errors (SEs) chosen for the quantitative vegetation reconstruction of the study area. The term “Chenopodiaceae” has been adopted instead of “Amaranthaceae” in this chapter for consistency with the reference papers.

Plant taxa	PPE	SE	Reference
<i>Picea</i>	5.437	0.097	Githumbi et al, 2021
<i>Abies</i>	9.92	2.86	Abraham et al, 2014
<i>Pinus</i>	1.35	0.45	Abraham et al, 2014
<i>Juniperus</i>	2.07	0.04	Mazier et al, 2012
<i>Alnus</i>	2.44	0.73	Kunes et al, 2019
<i>Betula</i>	5.106	0.303	Githumbi et al, 2021
<i>Corylus</i>	1.71	0.1	Githumbi et al, 2021
<i>Fraxinus</i>	0.667	0.027	Abraham et al, 2014
<i>Quercus</i>	1.76	0.2	Abraham et al, 2014
<i>Acer</i>	0.8	0.23	Mazier et al, 2012
<i>Carpinus betulus</i>	1.36	0.36	Kunes et al, 2019
<i>Carpinus orientalis</i>	0.24	0.07	Githumbi et al, 2021
<i>Castanea sativa</i>	3.258	0.059	Githumbi et al, 2021
<i>Fagus</i>	5.863	0.176	Githumbi et al, 2021
<i>Tilia</i>	0.8	0.03	Mazier et al, 2012
<i>Ulmus</i>	1.27	0.05	Mazier et al, 2012
<i>Salix</i>	1.182	0.077	Githumbi et al, 2021
<i>Artemisia</i>	3.937	0.146	Githumbi et al, 2021
Chenopodiaceae	4.28	0.27	Kunes et al, 2015
Cyperaceae	0.962	0.05	Githumbi et al, 2021
Poaceae	1	0	
<i>Plantago lanceolata</i>	2.33	0.201	Githumbi et al, 2021
<i>Rumex acetosa</i> -t	3.02	0.278	Githumbi et al, 2021
Cerealia-t	0.75	0.04	Nielsen, 2004

Current vegetation

The results obtained from the estimation of the vegetation composition at regional level using the new set of parameters on pollen data from three superficial soil samples reflect quite faithfully the land use of the Central Po Plain and the results show a good relationship between REVEALS-estimated forest cover and vegetation abundance based on the CORINE land cover data (Fig. 55). However, it is necessary to consider that uncertainties associated with pollen productivity estimates and the size of pollen counts affect the estimated reconstruction. Entomophilous taxa show limited pollen dispersal and tend to be problematic in regional vegetation reconstruction (Mazier et al, 2012) and they are excluded from the elaboration. For this reason, the estimation of the open landscape could be reasonably underestimated because many herbaceous plants (both weeds and annual crops) are not included into the elaboration. At the same time, many arboreal crops for fruit production representing a large part of the economy of the region are missed because are not considered by the algorithm (e.g., *Malus*, *Pyrus*, *Prunus*, and *Vitis*).

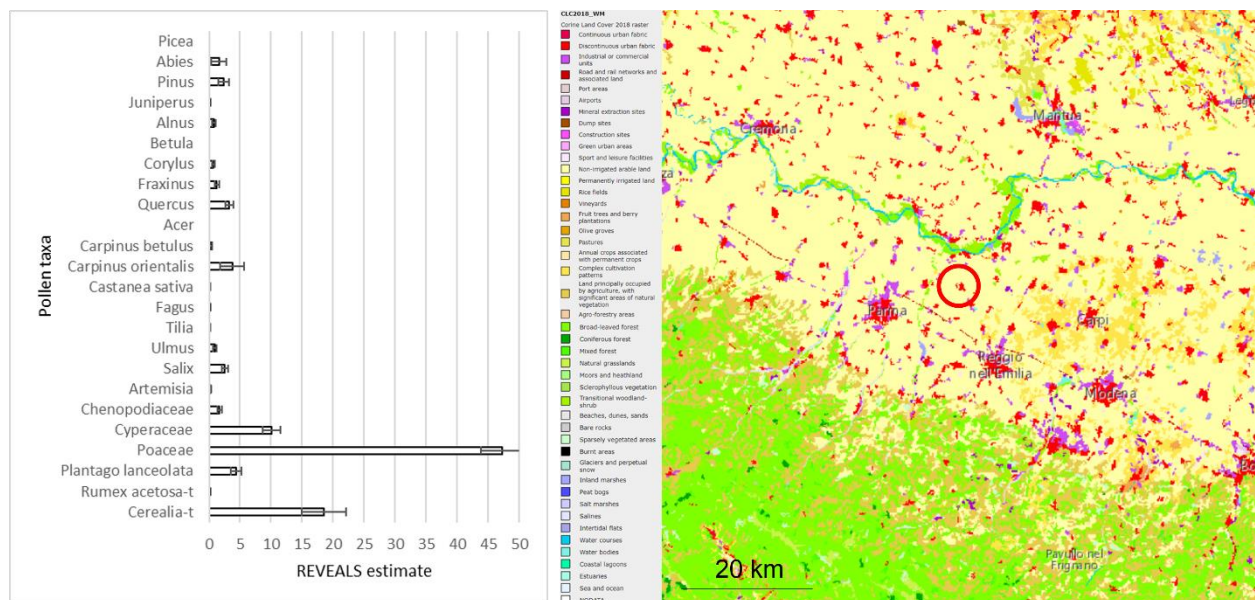


Figure 55. Summary of regional vegetation composition estimate compares to the image of the study area captured by Corine Land Cover (CLC) 2018, Version 2020_20u1

Large-scale vegetation changes in the Central Po Plain since the Late Pleniglacial/Lateglacial

The three different models developed by applying REVEALS on each core reflect very similar trend providing a long-term picture of large-scale vegetation changes (Fig. 56).

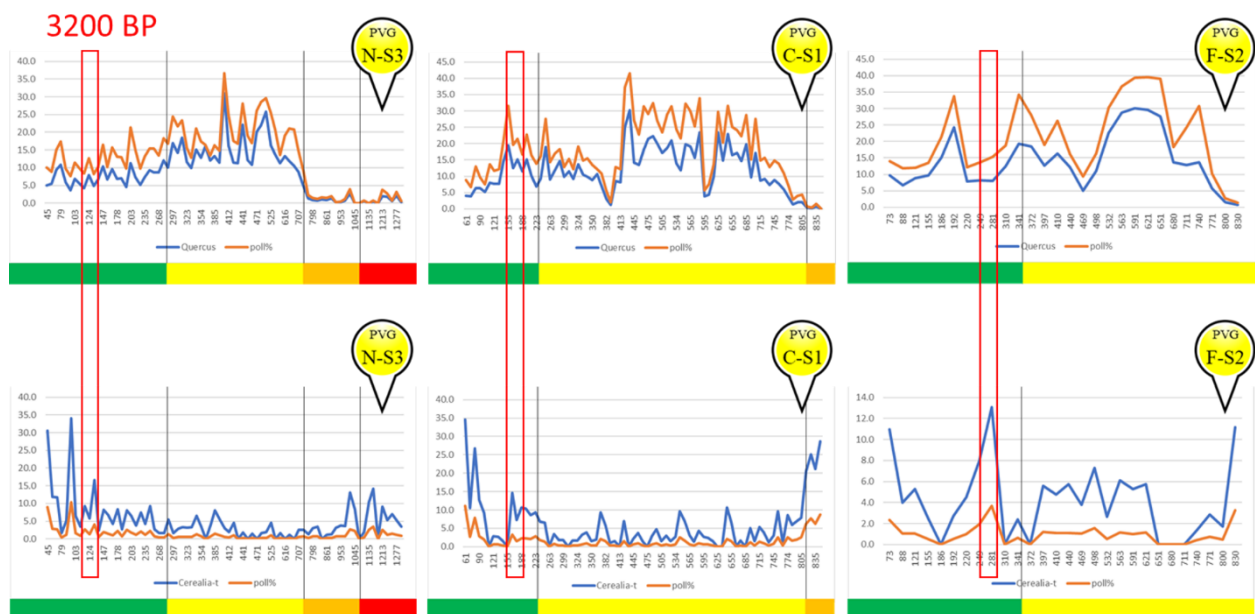


Figure 56. Regional vegetation estimates obtained through REVEALS (in blue) compared to the pollen percentages (in orange) for selected pollen taxa: *Quercus* and cereals. Levels that intercept the Bronze Age settlement are marked with red rectangles, while the color code identifies the pollen zones obtained by the cluster analysis (CONISS-Constrained Incremental Sum of Squares).

The quantitative estimation of pollen taxa composition improves the interpretation of pollen data and provides further detail for the stratigraphic correlation of the three cores. In fact, a sequence of similar values for each pollen taxon is clearly identifiable in all the sequences, and it usually agree with the pollen zones that were previously based on pollen percentages. This is evident especially for the most represented pollen taxa with similar trend in each core (see *Quercus* in Fig. 56) indicating a quite homogeneous vegetation composition in the study area without large differences related to the sampling point (at least for the pollen taxa considered).

The application of REVEALS to each pollen zone reflects four broad chronological phases characterized by different pollen assemblages (Fig. 57). The quantitative reconstruction confirms the interpretation of the pollen percentages of the first and second pollen zone, which describe the presence of an open environment dominated by pioneer herbs (Poaceae wild grass group: ca. 40% in the first and the second pollen zones) and cereals probably represented by wild and not domesticated grass species (5.4% and 10.1%, respectively). *Pinus* dominated the forest cover (16.5% and 15.8%) together with other conifers (e.g., *Abies*: 13.7% and 6.9%), while the presence of broadleaved trees was scarce. A general increase in humidity is documented in the third zone by the concomitant expansion of hygrophilous trees (*Alnus*: 5.4%, *Salix*: 3%) and herbs typical of wet environments (Cyperaceae: 26.9%).

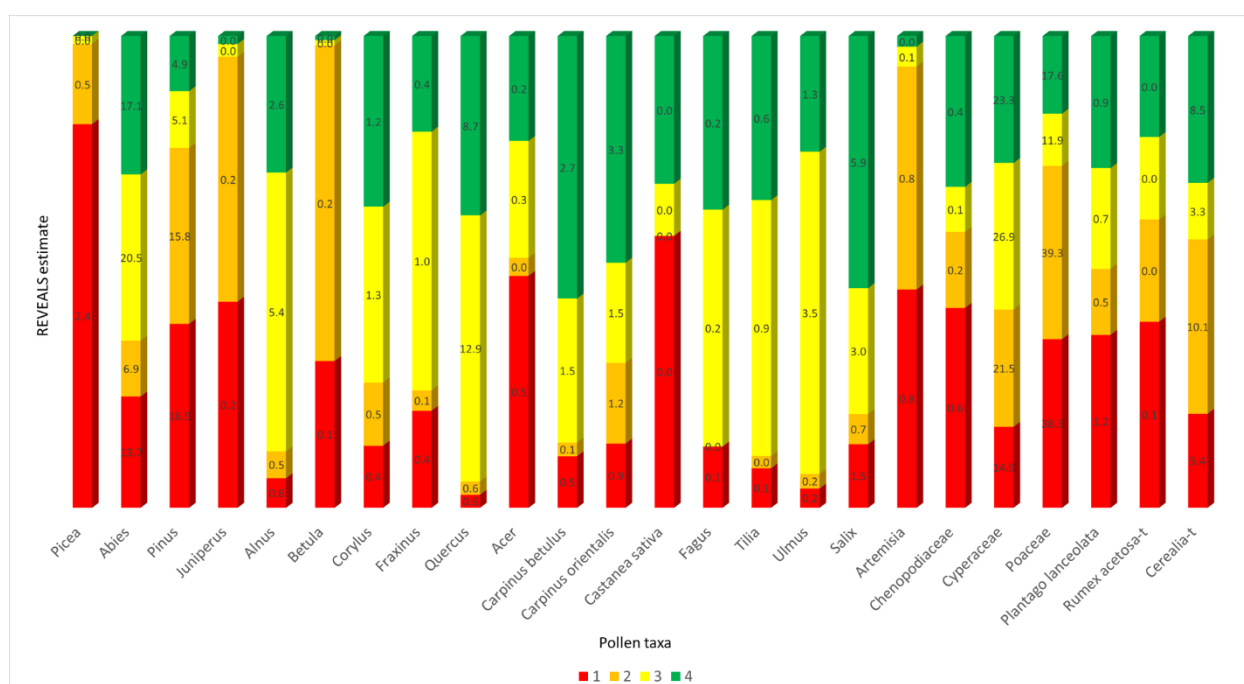


Figure 57. Regional vegetation estimate based on four main pollen zones. The color code identifies the pollen zones obtained by the cluster analysis (CONISS), from 1 to 4, sorted from the more ancient to recent chronology. REVEALS estimates are obtained by the combination of pollen data from the three cores: Pollen Zone 1 = N-S3; Pollen Zone 2 = N-S3 + C-S1; Pollen Zone 3 and 4 = N-S3 + C-S1 + F-S2.

Forest cover largely increases in the third zone up to the 60% of the regional vegetation composition (Fig. 58). A progressive decline of *Pinus* is documented, and it is replaced by the spread of *Abies* (20.5%), the mixed oak wood dominated by broadleaved *Quercus* (12.9%), and *Ulmus* (3.5%). An increasing trend of cereals characterizes the fourth zone (8.5%). The landscape became more open, and it is possible to observe a change in the abundance of the species of the mixed oak wood probably favored by human activities widely spread throughout the territory. Among which the

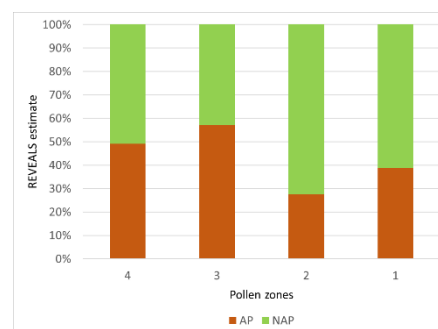


Figure 58. AP and NAP regional estimates for each pollen zone.

values of *Carpinus betulus* (2.7%) and *Ostrya carpinifolia/Carpinus orientalis* (3.3%) almost double compared to the previous pollen zone (1.5% both). *Salix* (5.9%) replaces *Alnus* (2.6%).

Middle-Recent Bronze Age

At 3200 yr BP (N-S3 = samples 11-8; C-S1 = samples 12-11; F-S2 = sample 8), the trend in the plant cover of the region within a 50-km radius from the three cores (Fig. 59) describes an open landscape in which most of the territory was devoted to cereals field interspersed with settlements, dry and humid meadows. The forest cover was scarce and was mainly represented by the mixed oak, dominated by *Quercus* together with patches of hygrophilous woods probably limited to the boundaries of watercourses. *Abies* was also well attested in the plain, while the representation of *Fagus* and *Castanea* presumably denotes their presence only at a higher altitude in hills and mountains.

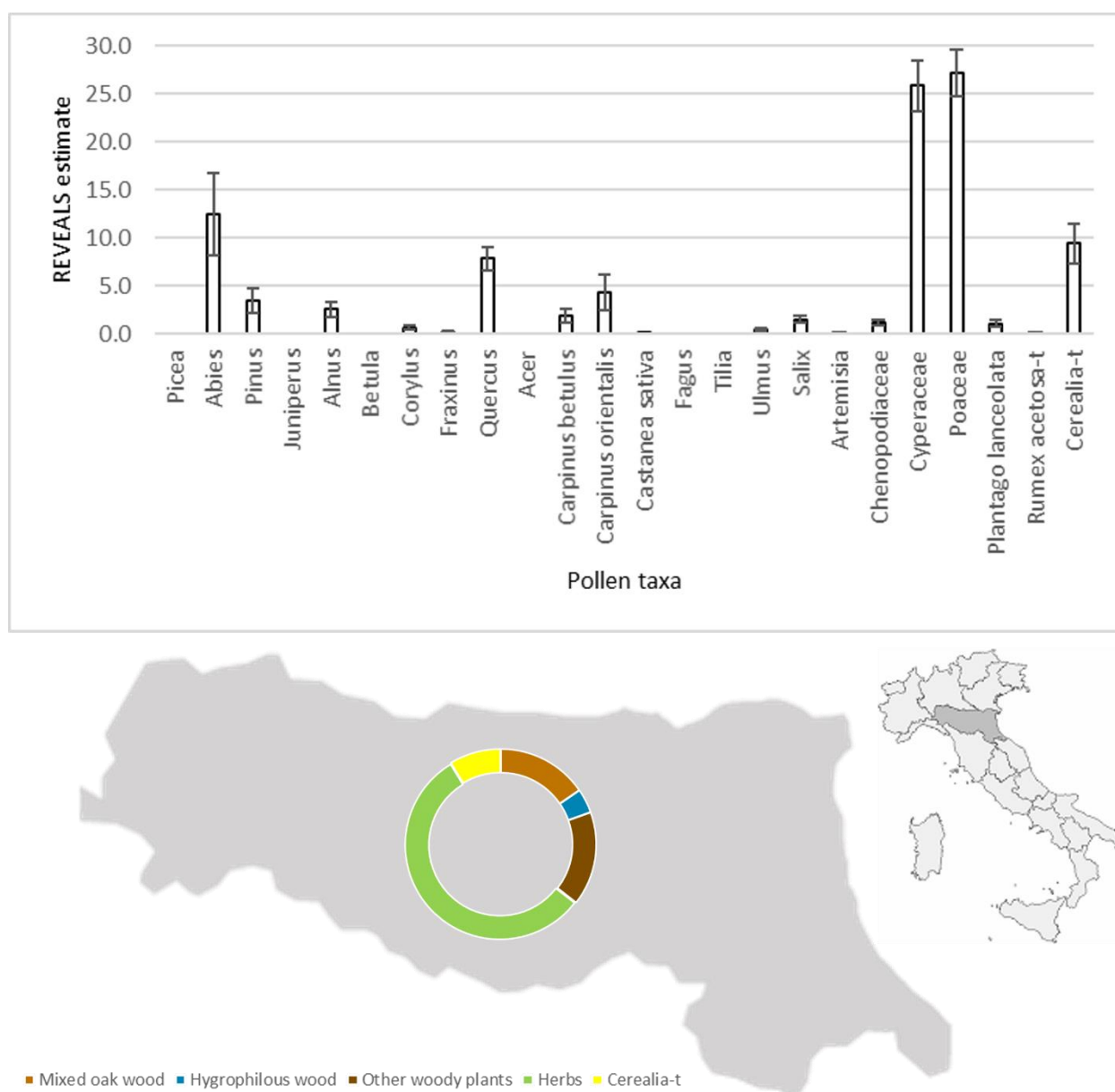


Figure 59. List and graphic representation of the regional vegetation estimates at ~3200 yr BP. Histograms relating to the pollen taxa are complete with their relative standard errors. The pie chart includes the main pollen sums useful for environmental reconstructions.

LOVE

Pollen data from analyses previously carried out within the Terramara S. Rosa di Poviglio (5 pollen samples: P5-P1, 1402–1262 cal yr BC; Cremaschi et al, 2016) and the Terramara di Montale (5 pollen samples: 35-39, 1410–1315 cal yr BC; Mercuri et al, 2006a, 2006b) were chosen to obtain the estimate of the vegetation composition at a more local scale during the BR1 (Fig. 60).

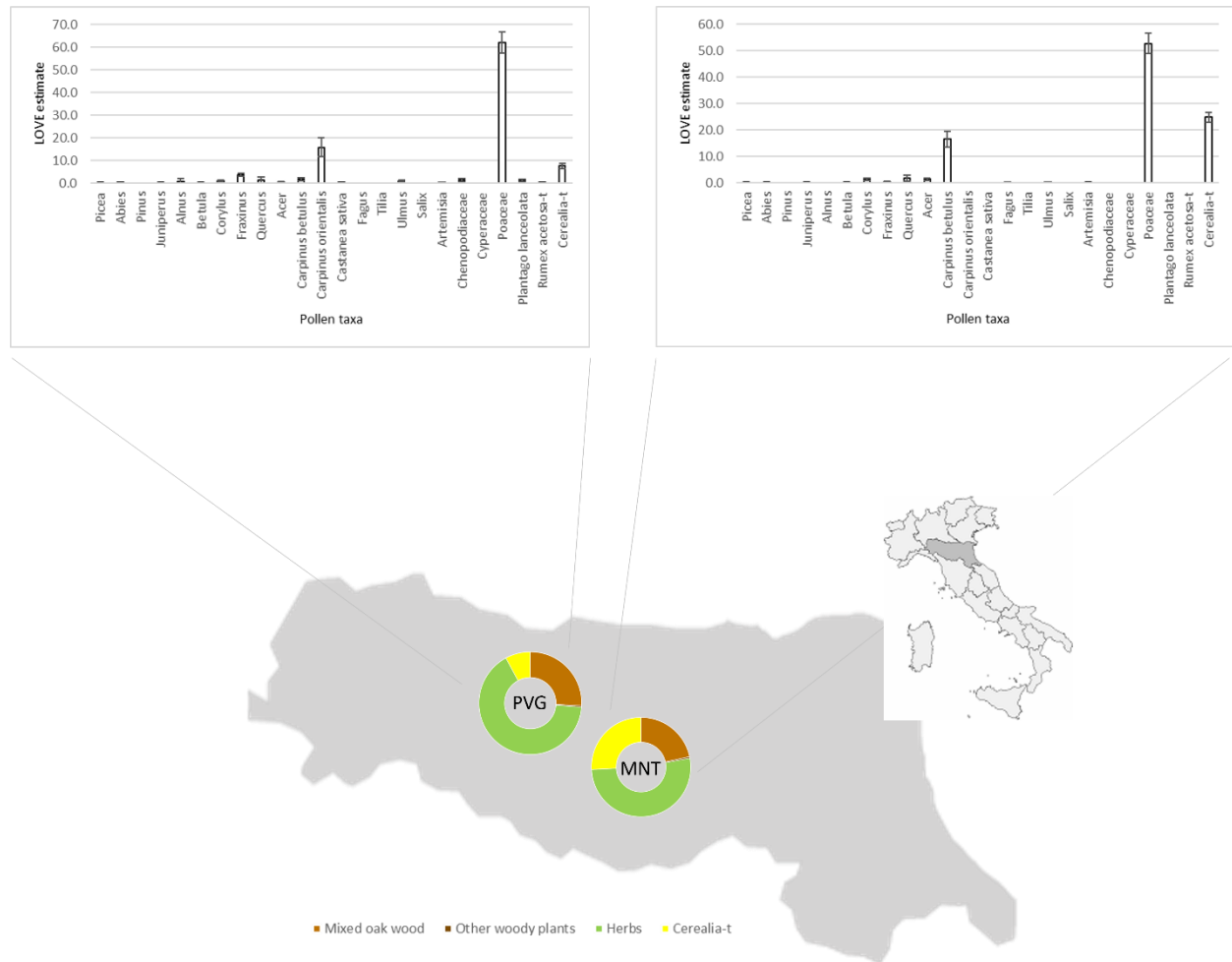


Figure 60. Local vegetation estimate for the Terramara S. Rosa di Poviglio (PVG) and for the Terramara di Montale (MNT) during the Recent Bronze Age.

The LRA algorithm assumes that airborne pollen is the major source of pollen input to deposits. However, there are many factors affecting pollen deposition inside an archaeological site, among which human activity as the agent of pollen transport that could affect the image of pollen transported by the wind above the canopy.

The application of the LOVE model allowed to quantify and then subtracts background pollen (i.e., pollen coming from beyond the relevant source area) in order to investigate local vegetation with new information that can integrate and support previous data that emerged from pollen analysis. The model estimated the local vegetation composition within a 2705 m relevant source area of pollen (RSAP) for each site, which means increasing by about 1000 m the hypothesis previously discussed by Ravazzi, Cremaschi, and Forlani (2004) and Mercuri et al (2006b).

Land cover in both sites was characterized by a predominantly open landscape, and mixed oak wood represented the dominant vegetation assemblage. However, *Quercus* was spread in the territory (REVEALS: 7.8%) but always poorly represented in the area surrounding the settlements (LOVE: 1.6%-

PVG, and 1.9%-MNT), while other components of the oak wood that could be easily maintained in shrubby habit may be grow at the edges of the settlements. It is not surprising the image of such an open landscape linked to the collection of timber mainly from local mixed oak woods by the population of the terramara. The scarce presence of *Quercus* near the settlements could be reflected the intense exploitation of this tree both to build the pile houses and many tools for daily use (Forlani, 1988; Mercuri et al, 2006a). The high presence of *Carpinus betulus* in Montale (16.6%) and of *Ostrya carpinifolia/Carpinus orientalis* in Poviglio (15.9%) is a distinguishing feature between the two settlements, even if the spread of both species may be linked to occupation of ecological niches previously dominated by oaks. It is possible that these species were kept within the settlements for fuel and fodder as plants that tolerate cutting well, together with a high resistance to fire (Debandi, 2018; Mercuri et al, 2006a). These features are closely connected with the transformation of the forms of forest governance and suggest different management of the territory adopted by the populations. Another difference is related to a higher presence of *Fraxinus excelsior* and *Ulmus* in the territory surrounding the Terramara S. Rosa di Poviglio (3.8% and 1%, respectively). The presence of a large river (a Po palaeochannel) bordering this site probably determined the greater diffusion of riparian mixed forests of *Quercus robur*, *Ulmus* sp., and *Fraxinus excelsior*, which could be in chain contact with riparian woods, even if the presence of hygrophilous trees is estimated only in traces within the relevant source area (*Alnus*: 0.7%, and *Salix*: 0%).

A different vocation of the two settlements is evident also related to the management of the fields. The high presence of cereals pollen is one of the most striking features of the archaeobotanical record from the Terramara di Montale (Mercuri et al, 2006a, 2006b), which is reflected in large areas dedicated to cereals crops in the estimate of the local vegetation composition (up to 24.8%). However, it is necessary to consider that in archaeological contexts high values of cereals pollen may indicate that flowering spikes or mature spikes with pollen trapped within the glumes, or pollen trapped on cereal collectors were brought to the site by people (Bottema, 1992). This should have been the case of the Terramara di Montale with an economy largely based on cereal fields that reasonably characterized the cultural landscape surrounding this settlement (Mercuri et al, 2006b).

A clear management of open areas does not emerge for the Terramara S. Rosa di Poviglio, due to the possibility of including few herbaceous pollen taxa in the model. However, the areas dedicated to the cultivation of cereals seems to have been less extensive (about 7.7%) while a larger space may have been dedicated to domestic animal breeding, as suggested by the presence of herbs typical of dry meadows like grasses (62.1%), *Chenopodiaceae* (1.5%), *Plantago* (1.5%), and *Rumex* (0.1%), which together can be considered indicators of pastoralism.

Differences in land use may be related to the vocation of the territory. In fact, the two investigated areas differ for the structure and composition of soils, better drained and suitable for cereal cultivation in the case of Montale, more humid and with greater water availability for Poviglio. However, the Terramara S. Rosa di Poviglio was inserted in a fluvial context but soils of similar quality to those of Montale were placed 2-3 km south of the settlement.

5.4.6 EVIDENCE FROM THE THREE CORES

The palynological analysis of the three sequences is effective for recognizing some different plant cover distributions within the general landscape reconstruction. The flora composition has the same general features reflecting the regional vegetation, but the results show details resulting from the variation of the sedimentation rate, sampling resolution, local natural events, and local human activities that may have influenced the pollen image of the three cores differently.

For these reasons, the three cores will be considered separately in this chapter.

The N-S3 core will be described in detail as it provides the framework on a longer time scale, while only the new and different features emerging from the C-S1 core and F-S2 will be discussed together with the most significant aspects for the correlation of the cores.

5.4.6.1 N-S3 CORE

Pollen Zone 1 (77-68, 1289-1060 cm) and Pollen Zone 2 (67-57, 1059-753 cm) (Fig. 61)

Late Pleniglacial/Lateglacial (19,000–11,700 cal yr BP)

The bottom of the core is attributable to the Late Pleniglacial according to the radiocarbon dates available (ca. 19,000 cal yr BP). Knowledge on the palaeoenvironmental and palaeobotanical transformation in the central part of the Po Plain during this period is scarce, due to the absence of lake successions and the difficulty to obtain radiometric datings in an alluvial context. Currently, N-S3 core is the only record available for this chronology in the study area.

The following paragraphs will discuss the spread of coniferous forests limited by the presence of unstable conditions in lowland, potential refuge stations for thermophilous species, the scarce diffusion of deciduous forests due to the dominance of ephemeral pioneer meadows, the conspicuous decrease in forest cover, and a further spread of a steppe environment during a cool and dry phase.

The presence of unstable environment subject to alluvial sedimentation conditions

The stratigraphy at the bottom of this sequence up to 1155 cm depth (until the beginning of the pollen subzone 1b) is mainly characterized by silty sand, which could likely be attributed to the Po River and not to Apennine streams due to the characteristic light gray color and the high incidence of micas. From the sedimentological point of view, they testify to the proximity of a riverbed since they are attributable to natural embankments or to alluvial fans (Zerboni & Cremaschi, 2018; see Fig. 16).

A substantial coherence between palynological and stratigraphical data emerges at the bottom of the core. High values of reworked pollen grains observed together with the significant presence of fragments of saccate pollen agree with the periodic flooding of the nearby river (for detail see the chapter 5.4.2 PALYNOLOGICAL INDEX OF ALLUVIONAL TRANSPORT), also testified in the pollen diagram by the frequent presence of *Glomus* indicating soil erosion (van Geel, 2001). *Pinus* was dominant in these levels, but the pollen image related to these woodland formations probably does not reflect the local environmental condition due to the occurrence of a large number of fragmented pollen grains attributable to the long-distance transport of them by the river course. The over-representation of saccate pollen grains is present along the whole core, but it is particularly evident in the oldest part documenting an unstable environment subjected to alluvial sedimentation conditions not compatible with the presence of local forests. According to the stratigraphy, from the most ancient levels up to 785 cm depth (at the top of the pollen subzone 2b), the study area was characterized by ephemeral pioneer meadows on silts and sands, while the *Pinus sylvestris*–*Betula* spp. woodlands with shrubs (e.g., *Juniperus*) and chamaephytes (e.g., *Helianthemum*) could be limited to the Apennine foothills and more stable areas in the Plain during the Late Pleniglacial/Lateglacial.

The presence of *Picea* and *Abies* is controversial during the Late Pleniglacial transition and at the beginning of the Lateglacial interstadial. Several attempts to know the distribution of these plants are based on palaeobotanical records and genetic analyses (Birks & Willis, 2008; Latałowa & van der Knaap, 2006; Ravazzi, 2002; Ravazzi et al, 2006; Scotti et al, 2000; Tollefsrud et al, 2008; van der Knaap et al, 2005; Vendramin et al, 2000; Vescovi et al, 2010). According to Ravazzi (2002) and several other studies (Chiarugi, 1936a, 1936b, 1958; and more recently by Bertoldi et al, 2007 and Vescovi et al, 2010), small populations of *Picea abies* probably survived the Last Glacial Maximum (LGM) in the lowlands and in the low foothills during the Alpine deglaciation at 18,000–14,500 cal yr BP. Different evaluations that compare recent pollen surface samples and the modern distribution of the species, especially in boreal forests (e.g., Hicks, 1986, 1994; Huntley & Birks, 1983; Markgraf, 1980), argue that *Picea* pollen percentages of 4(3–5)% indicate local presence, while long-distance pollen transport does not exceed this threshold value. However, these forests have no modern analogues in the northern Apennines, even if studies that support these data are also available for the north of the Alps (van der Knaap et al, 2005) and central Italy (Magri, 1999; Magri & Sadori, 1999). In this framework, the high percentages of spruce (which reaches ca. 12% in the oldest sample but then never exceeds 7%) could indicate the presence of trees close to the site or more

probably on colder slopes on the edge of the Apennines. The arrival of its pollen to lower belts was facilitated by the scarce forest cover in the Plain. Nevertheless, radiocarbon chronologies must be improved to refine this datum and contextualize it into the vegetational history of the region.

A similar evaluation can also be done for *Abies* (values ranging from about 1% to 6% in the pollen subzone 1a), but the abundant fragments of *Abies* pollen in the pollen zones 1 and 2 suggest that most of them came from a long-distance transport.

Thermophilous species: warming phase or glacial refugia?

Interestingly, the almost simultaneous occurrence of *Juglans*, *Olea*, and *Castanea* in the pollen zone 1 attested the presence of warmer slopes and soil conditions that have favored the growth of thermophilous species like olive, walnut, and chestnut.

Juglans pollen in the pollen subzone 1a (from 0.3% to 1.7%) suggests the presence of refuge stations in the hills or even closer to the site in a limited area with favorable microclimatic conditions because of the low pollen dispersal patterns. Archaeobotanical records attested the natural presence of this species in northern Italy since the Early Neolithic (Rottoli & Castiglioni, 2009; Vescovi, Kaltenrieder, & Tinner, 2010), and the occurrence of walnut pollen in pre-Holocene levels testifies the survival to the last glacial period in southern Europe as a native tree (Accorsi, Bandini Mazzanti, & Forlani, 1984; Paganelli & Miola, 1991).

Olea pollen is documented in traces in the pollen subzone 1b. This presence is due to wild olive specimens probably favored by the occurrence of a relatively warmer phase or the possibility of thermophilous refugia which are suggested also by other pollen evidence in the Levant, in central and western Mediterranean Basin, and along the western coast of north Africa (Langgut et al, 2019, and references therein).

The presence of *Castanea* pollen at the bottom of the pollen subzone 1b (0.3% - sample 71) could be considered further evidence that chestnut had survived during the LGM in refuge areas in northeastern Italy (Colli Euganei, Monti Berici, hilly region of Emilia-Romagna; Conedera et al, 2004). The presence of *Castanea* pollen could suggest a reliable indication of the local occurrence of mixed woodland with some chestnut trees (Huntley & Birks, 1983). However, according to Huntley and Birks (1983) such low percentage can also be due to a long-distance transport of this pollen which can easily reach from about 30 km (Peeters & Zoller, 1988) up to more than 100 km in relation to local topography combined with special meteorological conditions (Conedera et al, 2004, and references therein; Mercuri, 2015).

Pollen analyses of several peatbogs spanning between the Neolithic and the Bronze Age (Beug, 1964; Dalla Fior, 1932, 1940) argue the disappearance of this species from northern Italy during the Last Glacial period and the later introduction by humans. However, high values of *Castanea* pollen were recorded since the Lateglacial and in the Early Holocene in San Pellegrino peatbog near Pavullo nel Frignano with records amount to < 2% (Bertolani Marchetti et al, 1994; Mercuri et al, 2012), and other pollen records in northern Italy (Accorsi, Bandini Mazzanti, & Forlani, 1984; Accorsi et al, 1999, 2004; Krebs et al, 2004; Paganelli, 1998; Paganelli & Miola, 1991) support the hypothesis of refuge areas with suitable microclimatic and edaphic conditions in Italy. Therefore, is nowadays a broad consensus in the scientific community about the native status of the sweet chestnut (*Castanea sativa* Mill.) thank to the integration of genetic data showing high genetic variability (Mattioni et al, 2010) and palaeoenvironmental evidence, even if tracing the history of *Castanea sativa* during the Last Glacial period continues to be a challenge (Krebs et al, 2019).

Transient values of thermophilous or mesophilous trees and shrubs are represented in the pollen subzones 1a, 1b, and 2a (e.g., *Fagus*, *Quercus* and other oak wood components, *Rosa*, *Alnus*, and *Vitis*), suggesting climatic conditions that were not too rigid for the vegetative phase and flowering of these plants.

The transition between the 2a and 2b pollen subzones is marked by the increase in *Betula* which reaches the highest values of the whole sequence (up to 1.4% - sample 63). Birch was widespread within the woodland formations on the slopes of mountain ranges, as evidenced by pollen increase and the macrofossil record of *Betula* at Palughetto in the eastern Venetian Pre-Alps that suggest the expansion of this tree at ca. 15,000 cal yr BP in the subalpine forests (Vescovi et al, 2007), and the wide diffusion of the pollen at a regional level was probably favored by the mostly open landscape that characterized the plain.

These gradual changes also match the drastic drop of the open steppe woodland in the pollen subzone 2b. Climatic warming is documented in central Europe, dated at the onset of the Bølling–Allerød interstadial period (14,700–14,500 cal yr BP), with the expansion of *Betula* in open shrublands dominated by *Salix*

(Litt et al, 2001, 2003; Lotter, 1999). Also in Poviglio, *Salix* shows an increasing trend at the bottom of the pollen subzone (up to 4.6% - sample 61). A similar condition is observed later in the Pavullo hilly area, between ca. 14,500 and 12,500 cal yr BP, with the expansion of *Salix*, *Quercus*, *Ulmus*, and *Tilia* (PV-2a; Vescovi, Kaltenrieder, & Tinner, 2010). The increase in temperatures can also be witnessed by the appearance of *Rivularia* type (0.3% - sample 61; see chapter 5.4.3 *RIVULARIA* HETEROCYSTS IN THE STRATIGRAPHIC RECORD). The long-lasting decline of *Pinus* was accompanied by the limited expansion of *Quercus* at 13,100–12,800 cal yr BP before the onset of the Younger Dryas in the southern side of the Alps (Vescovi et al, 2007), with a similar trend at the bottom of the subzone 2b in N-S3.

The spread of ephemeral pioneer meadows in the lowlands

However, the development of the arboreal-shrub component was limited and did not result the replacement of herbaceous formations which were well represented locally. Marsh and alluvial plain deposits during almost the whole Late Pleniglacial/Lateglacial have also been identified in other sites in the lower-central Po Plain (Ravazzi et al, 2006). The presence of an open landscape emerges from the first two pollen zones, while the main vegetation changes documented by the pollen subzones are mainly attributable to rapid variations in the rate of humidity consequent to sudden water intake. The alternation between wetter phases suggested by the presence of Cyperaceae, *Sparganium emersum* type, *Mentha* type, *Stachys*, and *Ranunculus* type (pollen subzones 1a and 2b), and drier conditions (1b and 2a) with the increase in Amaranthaceae, *Artemisia*, Cichorieae, and other Asteraceae occurred in the plain during the entire period. An environment characterized by open spaces and large meadows probably favored the presence of grazing of wild animals, and this is also suggested by low values of coprophilous fungal spores of *Sordaria*. Common meadow grass covered most of the lawns due to the hygro-helophytes nature of Poaceae family allowing to exploit a wide variety of environments as pioneer taxa able to colonize woodland clearances between woods and swamps common in flooded areas. The same conditions also allowed the spread of cereals, mainly represented by the *Hordeum* group, produced by wild and not domesticated grass species.

Rapid changes in lowland vegetation during a cold and arid climate phase

Difficulties related to chronological uncertainties and/or temporal resolution concerning the bottom part of the N-S3 core make a challenge to unambiguously naming the cold and arid climatic phase intercepted by this pollen record in the second half of the pollen subzone 2b. A slight decline in broadleaved *Quercus* and *Carpinus* seems to occur in the plain, leaving the space to a further expansion of a steppic environment dominated by *Artemisia*, other Asteraceae, Amaranthaceae, and heliophilous trees (e.g., *Betula*) (samples 59-58). Several pollen records of the northern Apennines register a similar vegetation response to the **Younger Dryas cooling event conventionally placed between ~12,900 and 11,700 cal yr BP** (Allen, Watts, & Huntley, 2000; Bertoldi, 1980; Bertoldi et al, 2007; Branch, 2002; Cruise et al, 2009; de Beaulieu et al, 2017; Lowe, 1992; Lowe & Watson, 1993; Lowe, Branch, & Watson, 1994; Lowe et al, 1994; Guido et al, 2020; Ponel & Lowe, 1992; Vescovi, Kaltenrieder, & Tinner, 2010; Vescovi et al, 2007, 2010; Watson, 1996). The recovery of more favorable climatic and environmental conditions was likely rapid in the lowlands with the formation of unstable pools and streams with temporary oligotrophic condition, evidenced by increasing values of Crysophyceae statospore and *Rivularia* type (Smol, 1988; van Geel, Hallewas, & Pals, 1983) that reach the peak in the same sample (19.7% and 8.6%, respectively).

Among the herbaceous plant, the presence of *Cannabis* pollen is particularly indicative at the top of the pollen subzone (0.3% - sample 57). Researches about the challenged topic of the evidence of the arrival of *Cannabis* in the Mediterranean are still in progress (Palli et al, 2021) and different early occurrence of *Cannabis* in pollen spectra cover a chronological phase spanning from the Younger Dryas to the Early Holocene in central Italy and Mediterranean countries (Frank, 1969; Huntley et al, 1996; Magri & Sadori, 1999; Mercuri, Accorsi, & Mazzanti, 2002; Mercuri et al, 2001). In this framework, even if caution is recommended in the interpretation of the recovery of a single pollen of *Cannabis*, this record agrees with the hypothesis suggested by Mercuri, Accorsi, and Mazzanti (2002) of the presence during the Lateglacial of wild plants in open areas with *Artemisia* and Amaranthaceae and scattered woods dominated by *Pinus*.

Pollen Zone 3 (56-29, 752-300 cm) (Fig. 62)

Early / Middle Holocene (11,700–8200 cal yr BP / 8200–4200 cal yr BP)

To understand the vegetation changes occurred during this wide chronological period, in the following paragraphs will be discussed the phases of afforestation of the plain up to the Atlantic phase, the gradual expansion of synanthropic plants due to the presence of Neolithic populations, and the beginning of the spread of a cultural landscape characterized by a changing trend in forest composition at the beginning of the Subboreal.

The forest colonization in the lowland

The origin of the fine-grained sediments of the upper part of the core is more complex, even if they originated in an overflow environment subjected to periodical floods of one or more watercourses. More detail about these sediments will be established by specific petrographic analyses. The coherence between stratigraphic information and pollen data is confirmed by changes from silty to clay sediments and *vice versa* at boundaries of the pollen zone (see Fig. 16).

The most noticeable changes in pollen spectra reflect the expansion of the woody component (from 28.4%-pollen zone 2 to 59.4%-pollen zone 3) with a significant increase in broadleaved *Quercus* (from 1.1% to 16.3%) and *Alnus* (from 1.4% to 19.9%), and a drastic decrease in *Pinus* (from 20% to 5%). Common to almost the northern Italy and the Mediterranean area, the increase in mixed oak wood and the decrease in *Pinus sylvestris* marked the **Lateglacial-Holocene transition** (Birks & Ammann, 2000) in response to the rapid and extensive climate change with increase in temperatures and moisture availability (Finsinger, 2004; Finsinger & Tinner, 2006). The sharp increase in forest cover is evident in the subzone 3a (40.6%) and is amplified even more in the subzone 3b (68.2%). *Pinus* still maintained a dominant role in the lowland but with a tendency to decline (9% - pollen subzone 3a), and in its place began to rapidly expand mixed oak woodlands (17.9%) together with *Abies* (3.9%).

The expansion of the hygrophilous wood, even if documented, was weaker than that of the oak wood and it spread mostly later (from 9% - pollen subzone 3a to 24.7% - pollen subzone 3b). *Corylus* was second to *Quercus* during the first forest expansion, which also included the diffusion of *Carpinus betulus*. This change in physiognomy characterized the landscape of the region during the **Preboreal** that is probably intercepted in the first part of the pollen subzone 3a (sample 56).

According to overview of Holocene pollen flora/vegetation of the Emilia-Romagna Region (Accorsi et al, 1999), a great change occurred in the vegetation assemblage during the **Boreal**, with the continuous increase in broadleaved trees and *Abies* that was increasingly abundant from the Plain to the mountains. These features are documented in few levels of the subzone 3a (sample 55), together with the peak of *Tilia* with the highest values in the Holocene and increasing percentages of *Ulmus* and *Fraxinus excelsior* that replaced *Pinus* in the Plain. *Abies* and *Fagus* expansion started contemporaneous with major climatic changes occurring during the **8.2 kyr event** (Finsinger & Tinner, 2006; Tinner & Lotter, 2001), probably testified in the N-S3 core with its appearance in the pollen subzone 3a (7.6 and 0.3%, respectively - sample 54). An increasing expansion of wet environments limited the expansion of mixed oak wood after **6485–6320 cal yr BP** when a generalized wetland condition probably occurred in the study area with the spread of Cyperaceae (up to 22.2% - sample 53) and *Sparganium emersum* type (up to 24.4% - sample 52). The area was characterized by poorly drained soils, and synanthropic plants were still scarce as evidence of short-period occupations by Early Neolithic populations (Biagi, Cremaschi, & Nisbet, 1993; Nisbet, 2013).

The beginning of the subzone 3b is marked by the rapid and widespread increase in *Alnus* (22.7%). The hygrophilous wood began to expand rapidly favored by both climatic and hydrogeological conditions. The proximity of a large river determined suitable conditions for the spread of riparian mixed forests dominated by *Alnus glutinosa*, *A. incana*, *Quercus robur* (19.6%), *Ulmus* sp. (8.1%), and *Fraxinus excelsior* (0.9%). The regional context, described by Accorsi et al (1999), was more monotonous with six leading pollen taxa (*Abies*, *Pinus*, *Quercus*, *Tilia*, *Corylus*, and *Alnus*) and other trees that have been part of the vegetational

climax association of the Po Plain diffused during the **Atlantic phase** (*Carpinus betulus*, *Ostrya carpinifolia*, and *Acer campestre* type). The same picture is documented also for many European forests that were characterized by the abundance of *Ulmus* and *Tilia* between 9 and 6 kyr (Giesecke et al, 2017). According to Magri et al (2006), the rapid expansion of *Fagus* occurred between 6800–5700 cal yr BP along the inner Alpine chain and in northern Apennines (Vescovi et al, 2010). This pollen record testifies the large diffusion of drought-sensitive *Fagus sylvatica* (Finsinger & Tinner, 2006; Piovesan & Schirone, 2000) with some stations also in the plain recording a trend towards increasing in moisture availability during the Hypsithermal/Neoglaciation transition (5600–5000 cal yr BP; Magny & Haas, 2004). *Carpinus betulus* was beginning to become a major component of mixed oak wood in the plain, consistently with the most notable vegetational event that had occurred along the southern Alpine foothills during the late mid-Holocene approximately from 5700 cal yr BP (Ravazzi & Pini, 2013; Zanon et al, 2019). According to the general pattern diffused in continental Europe, the decline of *Ulmus* was followed by *Tilia* in the Central Po Plain suggesting a potential human impact on their distribution and abundance (Turner, 1962).

The human preference for more natural environments up to the establishment of a cultural landscape

Hygrophilous herbs spread in the study area with an inverse trend compared to trees that sharply decreased (from 35%-pollen subzone 3b to 9.8%-pollen subzone 3c), leaving space for herbaceous plant communities also dominated by API group with the increase in Cichorieae (1.6% - pollen subzone 3c), *Plantago* (2%), and cereals (*Hordeum* group up to 0.6% - sample 49). Synanthropic weeds began to spread with species belonging to *Artemisia*, *Centaurea nigra* type, and *Papaver rhoeas* type, nitrophilous and ruderal herbs (e.g., *Amaranthaceae* and *Rumex*), and other plants diffused in pastures and meadows (e.g., *Trifolium* type, *Potentilla* type, *Ranunculus* type, *Apiaceae*, and *Brassicaceae*). *Pteridium* was also widely distributed in this contest probably influenced by human presence (Behre, 1981). The forest cover was still little affected by human activities (Starnini, Biagi, & Mazzucco, 2018), even if pollen image described by the subzone 3b is compatible with short-period occupations in the Po Plain during the Middle and Late Neolithic.

Starting from **5315–4963 cal yr BP**, *Fagus* began to spread while *Abies* populations decreased (0.7% and 2%, respectively – pollen subzone 3c) in accordance with evidence obtained by other pollen records of northern Apennines (Lowe, 1992; Vescovi et al, 2010) and vegetational dynamics occurred in the Insubrian southern Alps at around 5000 cal yr BP. The reason of this change in forest composition is still unclear but may be related not only to the influence of climatic change, but also to human disturbance of the dense *Abies* forest which favored the conditions for the development of light-demanding seedlings of *Fagus*. At the same time, a new expansion of *Picea* occurred at higher altitudes in the Alps favored by human activities, local orography, and climate (Ravazzi, 2002).

The mixed oak wood slowly began to thin out and change in abundance of its components according to the changing trend in the composition of the forest cover at the beginning of the **Subboreal**. *Ulmus* was the first to lose its dominant role (from 8.1%-pollen subzone 3b to 2.8%-pollen subzone 3c) together with *Quercus* (from 19.6% to 15.1%), while *Carpinus* spread in the plain (from 0.7% to 1.7%). The dense forest canopy seems to be replaced by the opening of the landscape and the formation of environments with greater amount of water probably linked to a series of floods in close succession. *Humulus* and *Vitis* began to take up space within the less dense forest or at its edges within the riparian community dominated by *Alnus* (22.4%) and *Salix* (6.7%). Riparian forests spread again patchily alternating with the mixed oak wood at the time of the transition from the Neolithic to the Chalcolithic or Copper Age, when conditions were restored depending on soil drainage. This transformation in vegetation assemblage could be compared to the decreasing of temperate forest dominated by *Quercus* after 4500 cal yr BP documented by the high-resolution multiproxy study of the Adriatic marine core MD 90-917A (Combourieu-Nebout et al, 2013), where the role of Po River discharges in pollen signal reflects *Quercus* reduction and *Carpinus*, *Corylus*, and *Alnus* increase. Furthermore, a cultural landscape began to spread in the study area with a key role of plants valuable for edible fruits (e.g., *Juglans* and *Prunus*).

Pollen Zone 4 (28-1, 299-45 cm) (Fig. 63)

Late Holocene (from 4200 cal yr BP onwards)

The entire pollen zone reflects a disturbed environment well represented in floodplains, induced by either human presence or natural environmental variability. In order to distinguish as much as possible the effects of human impact from climatic factor in pollen evidence, different aspects will be considered in the following paragraphs. First, the main similarities that made possible the correlation between the N-S3 core and the nearby pollen record of Via Tolara will be discussed. The change in forest cover, exploitation of fruit trees, field management, and the presence of different crops will be deepened for the Bronze Age. The main aspects discussed for the following phases agree with the main historical sources and geomorphological evidence of the territory, such as the presence of a developed rural system in the Roman Period, the swamping phase during the Middle Ages, and the subsequent land reclamation.

The presence of settlements of the Copper Age and the correlation with the site of “Via Tolara”

The presence of human populations during the Copper Age (4900–3800 cal yr BP; De Marinis & Pedrotti, 1997) is already attested in the study area by the settlement near the Secchia River in Rubiera and ceramics remains come from the settlement in Noce di Fogliano in Albinea (De Rosa, 2015). In 2017, new traces of human occupation dating back to the Copper Age emerged in the Municipality of Castelnuovo di Sotto (RE), about 5 km from the Terramara S. Rosa di Poviglio. Pollen samples were taken in correspondence with the east bank of a palaeoriverbed located in “Via Tolara” which gave the site its name.

The pollen samples correspond to different US which are chronologically classified as follows (unpublished data):

- US 4: **4411–4245 cal yr BP** (Copper Age);
- US 3 and US 2: Middle and Recent Bronze Age.

According to the stratigraphy and comparison between pollen records, it was possible to correlate this sequence with the N-S3 core (Fig. 64). The US 4 (Via Tolara, unpublished data) and the pollen subzone 4a (N-S3) show a similar trend of a gradual decline of mixed oak wood and low percentages of hygrophilous trees. Vegetation changes seem to be more pronounced than previously occurred, probably reflecting a general condition with evidence of a climatically dry period (Bini et al, 2019). The forest cover continued to slowly and steadily thin out, especially due to gradual but constant decrease in *Quercus* (11.8%) and *Ulmus* (3.3%), to which was also added a drastic decrease in *Fraxinus excelsior* (0.4%), *Alnus* (10.3%), and *Salix* (3.6%). However, in a context of a general decline in forest cover, a local increase in *Carpinus* (2.6%), *Corylus* (3.6%), and *Ostrya carpinifolia* (0.4%) seems to have occurred. The increasing trend of *Carpinus* may be considered as a further support to the chronology correlation of the pollen subzone 4a with the Copper Age, when new woodland exploitation strategies were adopted (e.g., coppicing; Zanon et al, 2019) and major changes in the ruminant fauna occurred with a gradually lower presence of wild browsers and the rising importance of domestic grazers (“*Carpinus* invasion”; Kwiatkowska et al, 1997). Several meso-xerophilous herbs began to colonize open spaces left behind by forest thinning. Most of them were typical of pasturelands (e.g., Asteroideae and Cichorieae), while many others were ubiquitous (e.g., Apiaceae and Caryophyllaceae), or pioneering herbs exploiting disturbed environments (e.g., Amaranthaceae). Different abundances of Anthropogenic Pollen Indicators distinguish the sequence of Via Tolara from Poviglio, as synanthropic plants and cereals were more widespread near the Copper Age site of Via Tolara, even if pollen taxa that could be assimilate to human influence are documented also for the territory of Poviglio (API = 12.1%), together with weeds typical of disturbed places (e.g., *Polygonum aviculare* type, *Solanum nigrum* type, and Liliaceae). Furthermore, the local presence of fungi, algae, and cyanobacteria was favored by soil erosion (e.g., *Glomus*), decrease in water level (e.g., *Pseudoschizaea*), and eutrophic conditions (e.g., *Rivularia* type).

It is possible to assimilate the increase in forest cover at the top of the pollen subzone 4a of the N-S3 core (AP = 56.7% - sample 15) with the US 3 of Via Tolara. The increase in forest cover has been determined throughout the territory by the expansion of hygrophilous wood, which may have been aided by the onset

of a general cooling period (the Lobben glacier advance; Magny, 2004; Magny et al, 2010; Pelfini et al, 2014) and wet conditions fairly coincident with the development of the Terramare culture (3600–3100 cal yr BP; Bernabò Brea & Cardarelli, 1997).

The development of a human-shaped open environment

The pollen subzone 4b seems to intercept the entire life of the Terramara S. Rosa di Poviglio and it probably corresponds with the US 2 of Via Tolara which shows a similar vegetation assemblage as further evidence of the extensive human overprint leave on the territory.

Environmental features radically change at the beginning of this pollen subzone, which reflect the progressive increase in arid conditions, human-shaped open environments, and significant woodland clearance event. The landscape became more open related to the continue trend of deforestation showing a simultaneous decrease in different trees, which results in the pollen record with the lowest value of the forest cover during the whole Holocene (AP = 28%). Broadleaved *Quercus* continuously decreased (6.6%), together with *Carpinus* (1.7%), *Corylus* (1.3%), and *Ulmus*, while *Tilia* and *Fraxinus excelsior* type quickly disappeared (0.7% and 0.1%, respectively) probably because of fire sensitivity of these species. Among the components of the mixed oak wood, only *Ostrya* spread near the site up to the highest values of the entire sequence (up to 1.4% - sample 8). The presence of *Fagus* in the study area had probably also become limited (0.3% - sample 13), according to the general picture described by van der Knaap et al (2005) across the Alps at 3500 cal yr BP when this species began to expand at a slower rate than previously probably due to human activities and competition with other trees (Magri, 2007; Valsecchi et al, 2008). The decline of *Abies* occurred at the same time (1.5%) with a very similar decreasing trend to the core RF93-30 (Mercuri et al, 2012), where the decrease in silver fir occurred as a result of felling before that of oaks during the Early Bronze Age. The decline of *Pinus* (3.5%) also participated in the development of a more open landscape strongly influenced by human management of natural resources.

The presence of trees and shrubs supplying fruits seems to expand in the territory during the first phase of life of the Terramare settlement. Among “cultural trees” (OJC group; Mercuri et al, 2013b), *Juglans* and *Castanea* were not so widespread, while *Prunus* represented the most consistent shrub component together with *Corylus*. In relation to the low-pollen production of Rosaceae, that usually are underrepresented in pollen spectra, the presence of *Prunus* and other woody plants of the same family may be evidence of their occurrence in the source area (Mercuri, 2015a). *Cornus mas* is also well documented in this sequence like in pollen record of other Bronze Age sites as evidence of the consumption of fruits or their use in the preparation of alcoholic beverages (Mercuri et al, 2006a, 2015a). *Cornus* probably grew close to the settlement favored by the dissemination of seeds by collection of fruits in the wild and the increase in specimens growing in the area of influence frequented daily by the population. Conversely, the presence of *Vitis* was probably associated with riparian communities (Cremaschi et al, 2016).

Cereal pollen is well documented in this core suggesting the local presence of this cultivation (*Hordeum* group up to 2.2% - sample 11; *Avena/Triticum* group up to 0.6% - sample 9; *Triticum aestivum/T. spelta* 0.3% - samples 11 and 9). Together with cereal fields, forage crops were present close to the site as testified by high percentages of *Trifolium* type (up to 2% - sample 10) and other Fabaceae (up to 1.1% - sample 12). Legumes and cereal pollen grains are simultaneously present in all the Bronze Age samples reflecting a complex and diversified land use, involving intercropping of legumes and cereals growing simultaneously and in proximity on the same field or the practice of rotation between depleting and enriching crops.

Pollen of *Cannabis*, that it was observed only sporadically in the N-S3 sequence, peaks in the pollen subzone 4b (1.1% - sample 12) with values that can suggest the use of hemp and possibly its cultivation near the site close to the sampling point of the N-S3. The percentage is higher than that recorded in the moat surrounding the Villaggio Piccolo (0.3%; Cremaschi et al, 2016) and suggests its cultivation at a distance from the site, while considerable values documented in the northern ditch (up to 25%) testify the use and accumulation of this plant in dedicated areas of the settlement (Ravazzi, Cremaschi, & Forlani, 2004). Probably there was some retting of textile plants according to the pollen evidence from southern Italy where similar percentages testify the cultivation in the surroundings of lakes to obtain fibers (Mercuri, Accorsi, & Mazzanti, 2002).

As already discussed by Cremaschi et al (2016), the spread of Cichorieae (23.4%) could be related both to an ecological and economical value. In pollen-based environmental reconstructions, Cichorieae can be

considered one of the most important pastureland or grazing indicators (Florenzano et al, 2015), but the scarce presence of coprophilous fungi does not allow to confirm the presence of pastures. The regular alternation between Cichorieae and cereals suggests that the selection of these plants is probably to be traced back to a first colonization of fallow fields after the cultivation of cereals in dry environments resulting from continued human impact and arid climate conditions (Cremaschi et al, 2016). According to this, the permanence of Cichorieae in the pollen spectra marks the slow recovery of the environment even after the abandonment of the settlement by the population. A permanent ecosystem shift was probably resulted after the exceed of the threshold of resilience due to the overexploitation of natural resources at a time of negative climate factors.

The other components of the API group (here mainly *Centaurea nigra* type-0.8%, *Trifolium* type-0.8%, and *Plantago*-1.7%) together with spores of terrestrial fern (e.g., *Pteridium*) were widespread in the territory in the first phase of the settlement. The area surrounding the terramara was also characterized by the presence of wetlands, which favored the development of riparian vegetation composed by a good biodiversity of hygro-hydrophilous herbs, algae, and cyanobacteria typical of freshwater environments with variable supply of nutrients. However, hygrophilous trees steadily declined at 3200 yr BP (pollen samples 11-8) according to a climatic and hydrographic oscillations (Cremaschi et al, 2016), while hygrophilous herbs probably spread due to human management of the hydraulic structures within and surrounding the settlement.

The rural system of the Roman Period, the filling of wetlands, and the beginning of reclamation

The thickness of the post-Bronze Age deposits is very thin (see Fig. 16). This feature represents new evidence compared to previous research for the study area about Roman and Middle Ages (Brandolini & Cremaschi, 2018), which instead have a more marked thickness (from two to four meters) inside the ditches surrounding the terramara (Cremaschi et al, 2016).

The more recent levels within the pollen subzone 4b are probably related to post-Bronze Age phases and they intercept the transition to the **Subatlantic**, according also to historical, archaeological, and geomorphological context of the study area. The territory was densely occupied during the **Roman Period**, when the plain was organized into a rural system known as “*centuriation*” (Bottazzi, Bronzoni, & Mutti, 1995). The high percentages of cereals (6.4% - sample 6) agree with this new human occupation. Actually, a villa rustica of Roman Age with a residential part and its own agricultural production area was located in the same area occupied by the Bronze Age settlement (Brandolini et al, 2018; Mutti, 2007).

A palustrine environment spread in the territory following the “*Roman empire crisis*” and waterlogged processes affected the study area in **Middle Ages** (Brandolini & Cremaschi, 2018) with a large diffusion of hygrophilous herbs (54.2% - sample 5). For the first time, *Salix* became dominant compared to *Alnus* (10% and 5%, respectively) probably due to anthropic selection for its ornamental value and the greater tolerance to anaerobic conditions for prolonged period (Gorla et al, 2015). Most of the marshy and waterlogged environments were reclaimed during the **Renaissance (15th–16th centuries AD)**, especially with the large-scale land reclamation works called Bonifica Bentivoglio (1576 AD) that allowed the development of a drainage system in the Po Plain favoring a slight recovery of the oak wood. Wetlands were replaced with drained and cultivatable lands, as testified by the progressive increase in cereals (up to 6.4% - sample 1) and other synanthropic plants.

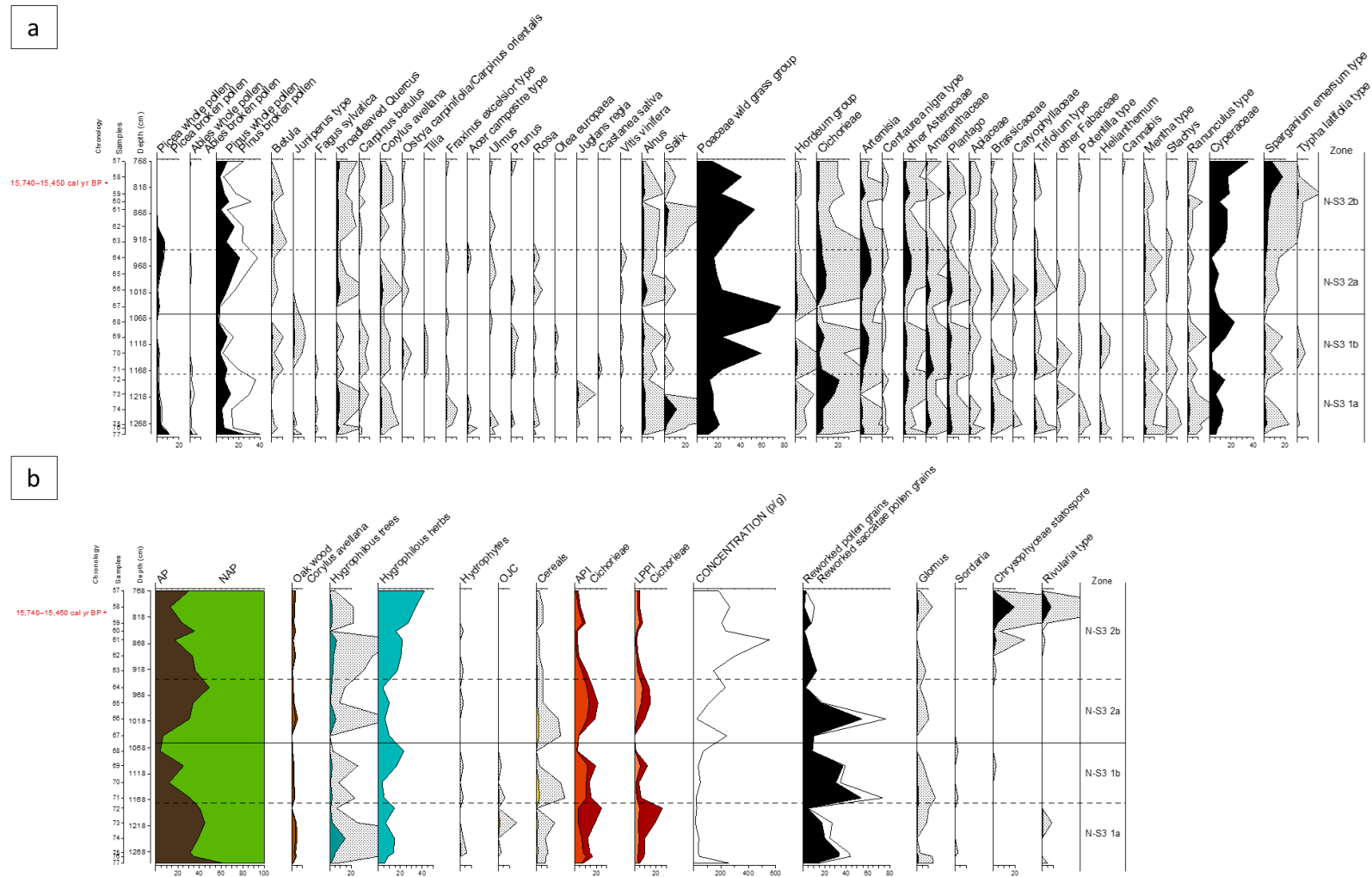


Figure 61. Pollen percentages from Pollen Zone 1 (77-68, 1289-1060 cm) and Pollen Zone 2 (67-57, 1059-753 cm) of the N-S3 core: a) selected trees, shrubs, and herbs; b) main pollen sums and selected Non-Pollen Palynomorphs. Empty curves represent 10% exaggeration.

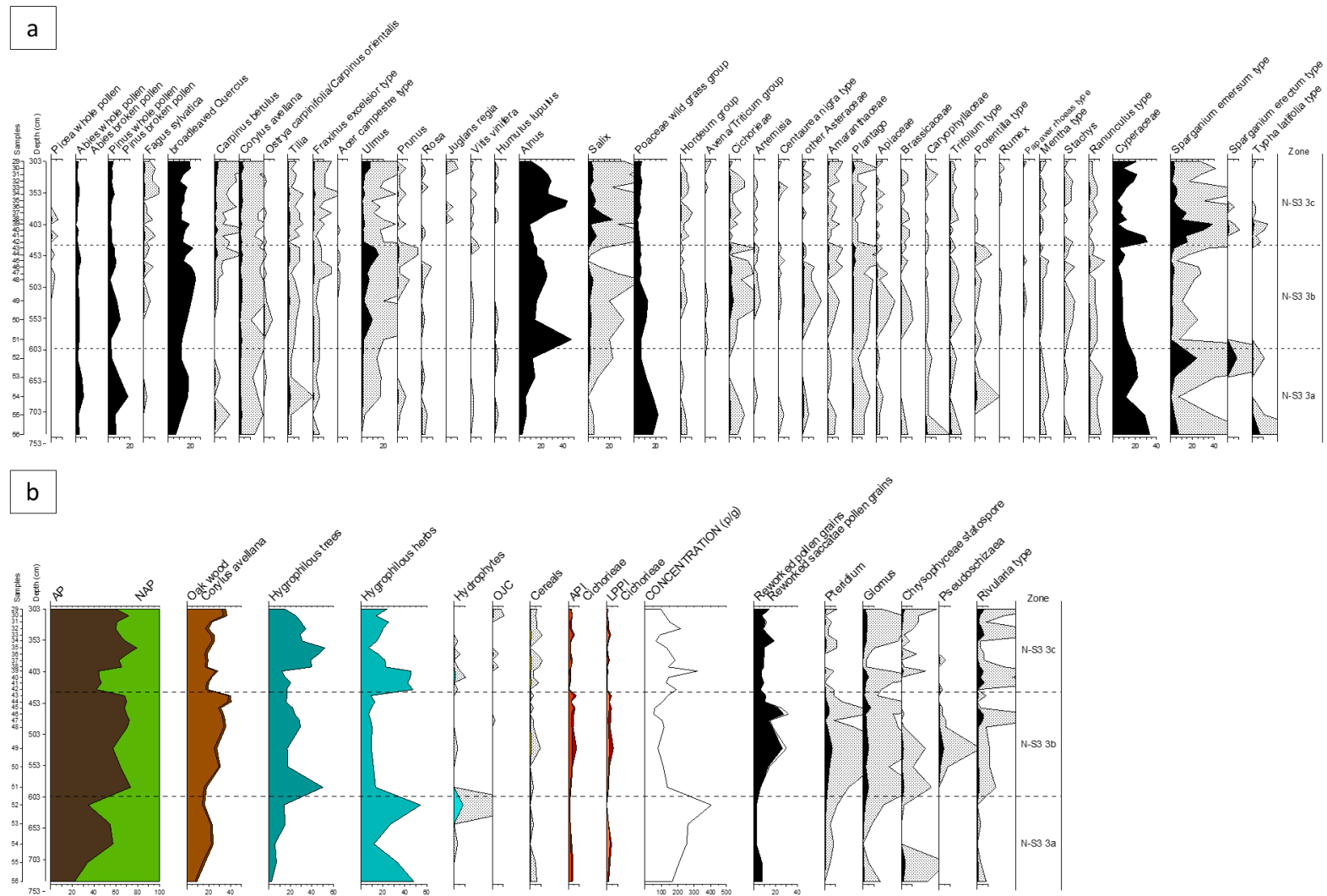


Figure 62. Pollen percentages from Pollen Zone 3 (56-29, 752-300 cm) of the N-S3 core: a) selected trees, shrubs, and herbs; b) main pollen sums and selected Non-Pollen Palynomorphs. Empty curves represent 10% exaggeration.

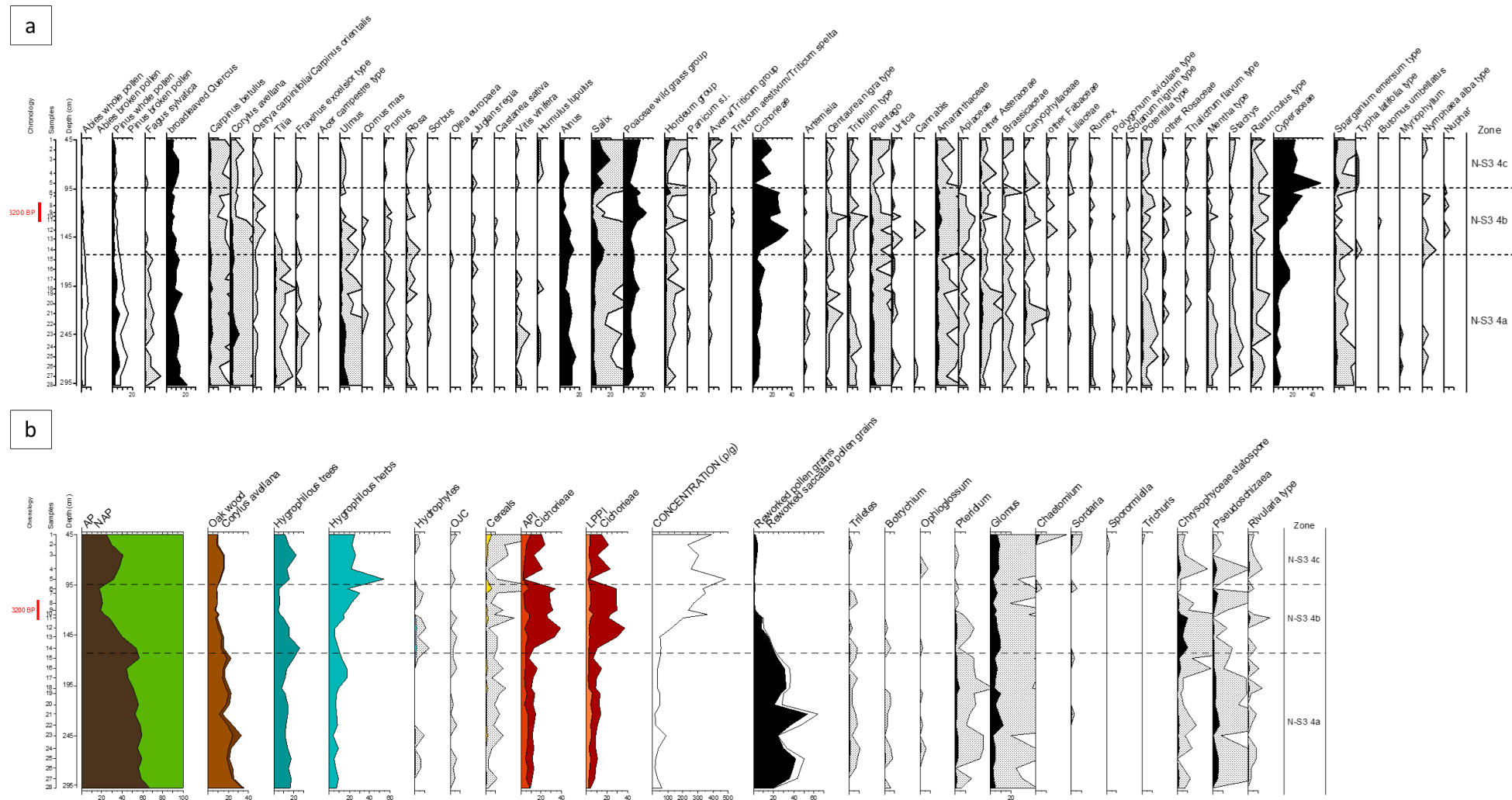


Figure 63. Pollen percentages from Pollen Zone 4 (28-1, 299-45 cm) of the N-S3 core: a) selected trees, shrubs, and herbs; b) main pollen sums and selected Non-Pollen Palynomorphs. Empty curves represent 10% exaggeration.

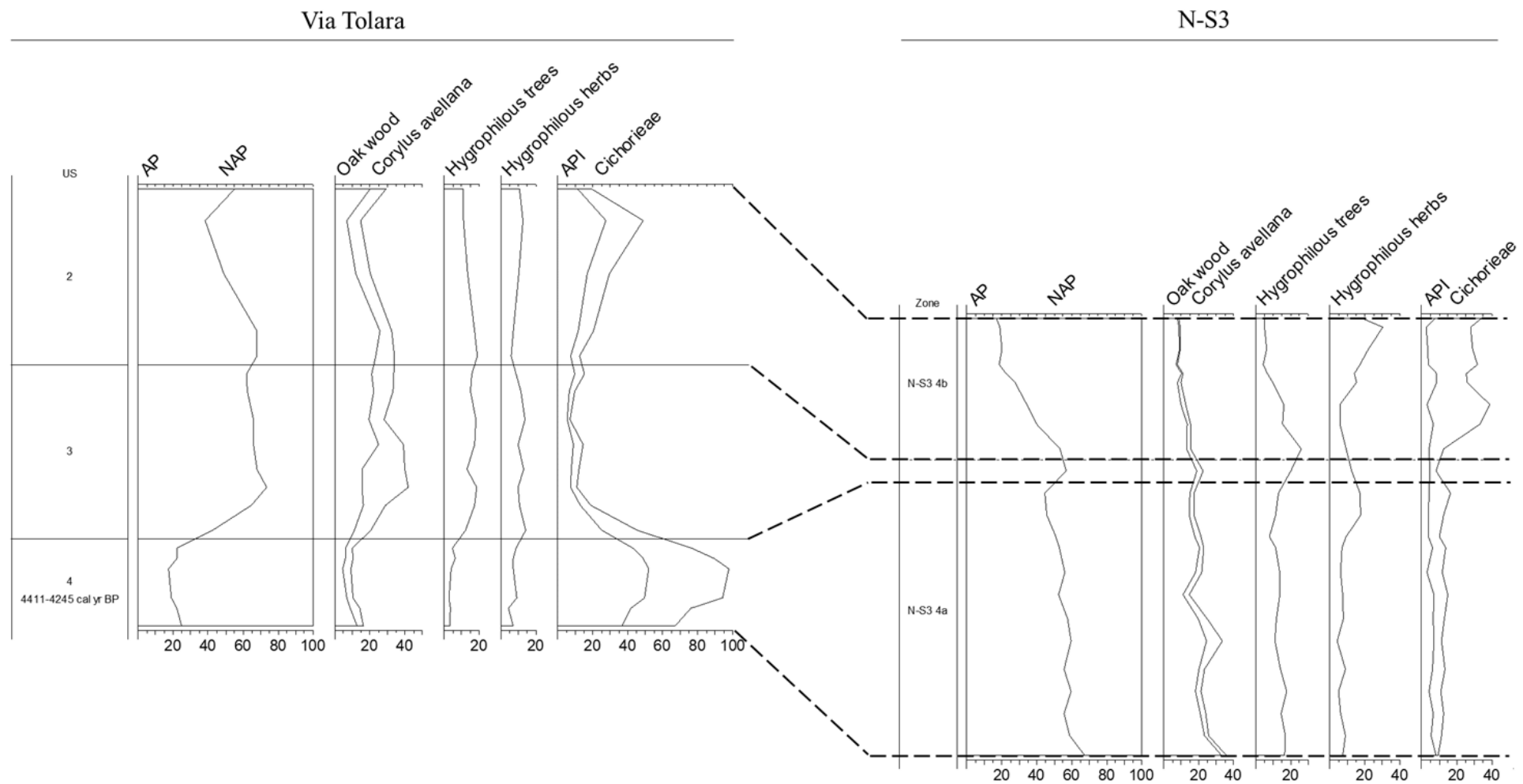


Figure 64. Selected pollen percentage curves from the archaeological site of Via Tolara (RE) and the N-S3 core (pollen subzones 4a and 4b) useful for the correlation between the two pollen records. The radiocarbon date related to the Copper Age refer to the pollen sequences of Via Tolara (unpublished data).

5.4.6.2 C-S1 CORE

Pollen Zone 2 (90-74, 972-810 cm) (Fig. 65)

Lateglacial (bottom–11,700 cal yr BP)

The following paragraph will describe the vegetation that characterized the river margins and temporarily flooded areas, composed mainly of herbs and shrubs.

The river margin vegetation and the presence of freshwater environments

The pollen assemblage observed in this core is very similar to that of the pollen zone 2 of N-S3, even if the forest cover was more limited near this sampling point. Scattered plots of hygrophilous trees left space to the diffusion of hygrophilous herbs (about 30% in the entire pollen zone) close to the watercourse which influenced humidity conditions of the soil by the continuous supply of water, thus resulting in unstable conditions unsuitable for the formation of forest communities.

According to the greater presence of freshwater environments, the occurrence of increasing values of *Panicum* s.l. along the entire pollen zone (up to 3.3% - sample 77) is probably not indicative of the presence of *Panicum* itself but rather wild grasses producing large pollen (e.g., *Echinochloa*, *Glyceria*, and *Setaria*) typical of wet and ruderal environments, such as banks, riverbeds, and swamps, and warm temperatures (Pignatti, 1986). Rising temperatures were also accompanied by increased nutrients in soil and freshwater, which favored the development of colonies of cyanobacteria and other algae.

A limited change in trend forest composition occurred as a consequence of better climatic conditions, that can be observed at the transition between the first and second pollen subzone. The mixed coniferous forest with *Pinus*, *Betula*, *Juniperus*, and *Rhamnus* were partly replaced by patches of mixed deciduous forests that became more diffused and diversified. Furthermore, the disappearance of *Picea* pollen probably marks the Lateglacial spruce expansion at higher altitudes with the abrupt warming, leaving space to thermophilous taxa. Except for *Acer*, all the components of the mixed oak wood were present albeit as scattered trees or in small groups. Among these, broadleaved *Quercus* and *Ulmus*, together with shrub formations of *Corylus*, *Prunus*, *Rosa canina*, *Cornus mas*, and *Humulus* probably characterized the margins of the wetlands. Even the presence of *Vitis* pollen, albeit always with low percentages, testifies to the diffusion of a riparian environment with poor forest cover, especially documented by shrubs or lianas.

However, the spread of these plants was abruptly interrupted by the expansion of meadows dominated by Poaceae wild grass group (up to 42.8%) and wild cereals (e.g., *Hordeum* group – up to 4.6%), while *Panicum* s.l. became less common probably related to the establishment of less favorable environmental conditions. At the same time the forest cover was drastically reduced (9.7%), similarly to what is described above for the N-S3 (13.5% - sample 58), with the occurrence of a cold and arid climatic phase. The river margin was colonized by *Sparganium emersum* type and *Typha latifolia*, while the more xerophilous component of the API group and other plants typical of the steppic environment, including *Artemisia*, other Asteraceae, and Amaranthaceae, probably were arranged in more stable patches characterized by arid conditions at the edge of wet environments.

One pollen grain of *Cannabis* was also observed in this core within the subzone 2b (0.3% - sample 79), providing further evidence of the presence of this species in pre-Holocene levels in northern Italy as wild plants spread in bush and ruderal contexts.

Pollen Zone 3 (73-18, 809-244 cm) (Fig. 66)

Early / Middle Holocene (11,700–8200 cal yr BP / 8200–4200 cal yr BP)

The following paragraphs will discuss the trend of afforestation influenced by the spread of open areas and wetlands near the river from the Boreal to the Subboreal, the key role of plants valuable for edible fruits, the disturbance effects derived from grazing and trampling, and the spread of nitrophilous and ruderal grasses according to the short-term human occupations in the Po Plain during the Neolithic.

How did river activity affect plant succession?

The **Lateglacial-Holocene** transition is well defined also in the C-S1 core by a steady and gradual increase in forest cover (from 25.5%-pollen zone 2 to 51.8%-pollen zone 3) characterized by the same pattern of the previous core. However, the expansion of the wood component was influenced by the proximity to the watercourse which determined the presence of large marshy areas near the banks. Hygrophilous herbs (dominated by Cyperaceae, which exceed 50%, and *Typha latifolia* type) covered most of the area together with aquatics (e.g., *Myriophyllum*), and herbs that indicate general humid conditions (*Panicum* s.l. - the previous paragraph). The presence of wet meadows with a tendency to flooding did not allow the expansion of the woody component. The deciduous woody component began to gradually spread, and the continuous presence of *Pinus* (up to 12.3%), which was still present probably in small groups in the Plain, connotes the bottom part of the zone 3 into the **Preboreal** (sample 73). Hygrophilous wood began to spread with both *Alnus* and *Salix* during the **Boreal** (sample 72). Broadleaved trees suddenly spread from the Boreal onward, starting with the increase in *Quercus* and all the other component of the mixed oak wood (*Carpinus*, *Corylus*, *Ostrya*, *Tilia*, *Fraxinus excelsior* type, *Acer*, and *Ulmus*). At the transition to the **Atlantic**, all the components of the mixed oak wood began to be present in the territory (starting from sample 70) but always with percentages that suggest the expansion at a certain distance from the core. Hygrophilous wood continued to expand, even if lightly delayed with respect to the vegetal formation just described. It can tolerate only short periods of drowning and probably its expansion was favored by the lowering/moving away of water close to the river, where Poaceae and a variety of different herbs that can colonize temporarily emerged areas (e.g., Amaranthaceae, *Plantago*, Brassicaceae, Caryophyllaceae, *Trifolium* type, *Potentilla* type, and *Mentha* type) began to replace the herbaceous hygrophilous component. *Fagus* expansion (0.3% - samples 71, 70, 68) occurred during the **8.2 kyr event** (Tinner & Lotter, 2001). An increasingly forested environment began to characterize the area, although still fragmented and sometimes opened by grassland and wet meadows dominated by *Ranunculus* type and temporary pools of water with marginal vegetation. A greater expansion of the wetlands occurred after **6485–6320 cal yr BP** (644 cm), with increasing values of *Sparganium emersum* type (up to 51.2% - sample 55) and Cyperaceae (up to 62.1% - sample 53).

From climax vegetation to partial landscape openness supporting the livelihood of Neolithic populations

The increase in forest cover is amplified even more in the subzone 3b (up to 65.8%). The oak-hornbeam woodlands (*Querco-Carpinetum boreoitalicum* Pign. 1953) represented the climax vegetation in the area with the dominance of pedunculata oak (*Quercus robur* L. – 24.1%) and hornbeam (*Carpinus betulus* L. – here attested with double percentages compared to the N-S3 core: 1.4%), together with smooth-leaved elm (*Ulmus minor* Mill. – here second to *Quercus*: 7.6%), common ash (*Fraxinus excelsior* L. – 0.9%), small-leaved lime (*Tilia cordata* Mill. – 0.6%), hop-hornbeam (*Ostrya carpinifolia* Scop. – 0.3%), and field maple (*Acer campestre* L. – 0.1%). The hygrophilous wood seems to play a more marginal role with constant values compared to the previous pollen subzone of both *Alnus* (from 8.5%-pollen subzone 3a to 12.5%-pollen zone 3b) and *Salix* (from 3.9%-pollen subzone 3a to 3.2%-pollen subzone 3b). *Pinus* (6.2%), *Abies* (3.8%), and *Fagus* (0.5%) also contributed to the increase in forest cover, together with the sporadic presence of *Picea*. The thinnest part of the oak wood was occupied with shrubs, including *Juniperus* and plants supplying fruits (e.g., *Prunus* and *Rosa*). Among them, the diffusion of *Vitis* (0.5%) and the abundance of *Corylus* were probably related to human influence during the Neolithic. Furthermore, the presence of *Hedera* (0.3% - sample 47) suggests that this plant was available to be used as winter fodder for cattle (Pini, 2004). Pollen clumps dark in color of Apiaceae (sample 46) and *Trifolium* type (samples 44 and 41) testified disturbance effects derived from grazing and trampling. Pollen spectra of the herbaceous components fully reflect what has already been described for the N-S3 core, according to short-period human occupations diffused in the Po Plain during the Neolithic with a low impact on the local forest cover. Nitrophilous and ruderal herbs were common among the herbaceous component, together with some specimens of *Cannabis* as weeds in the area.

The transition to the pollen subzone 3c is marked by the radiocarbon date **5315–4963 cal yr BP** (412–407 cm). Forest canopy at the beginning of the **Subboreal** was almost completely replaced by the development of large wetlands, probably amplified in the pollen record due to the proximity to the watercourse

(hygrophilous herbs = 29.1% on average). Wetter conditions favored the large diffusion of the hygrophilous wood, which seems to exceed the extent of the mixed oak wood (23.7% and 18.3%, respectively) because of the spread of *Alnus* with the highest values of the whole sequence (19.1%). In general, the forest cover was marked by many fluctuations in abundance and a less stable floristic composition. *Carpinus* did not find suitable conditions to expand locally. *Abies* began to decrease in abundance together with *Quercus* (11%) and *Ulmus* (2%), described as being the same in the N-S3 core.

Pollen Zone 4 (17-1, 243-61 cm) (Fig. 67)

Late Holocene (from 4200 cal yr BP onwards)

The following paragraphs will outline the main evidence related to the development of the cultural landscape in the Po Plain. This topic will be addressed through the description of the environment starting from the Copper Age, with particular focus on the management of the territory at a greater distance from the site during the Bronze Age. In particular, the development of different human strategies dictated by the increase in arid conditions will be highlighted. For the following phases, different cultural choices will be discussed, among them the introduction in the study area of ornamental plants and non-native crops.

The beginning of a cultural landscape

No many peculiar features are detectable in the pollen subzone 4a compared to the pollen image previously described regarding to the N-S3 core during the **Copper Age**. The territory was characterized by the expansion of a patchwork forested, semi-open and open areas. Cultivated plants (e.g., cereals – 1.5%), plants valuable for edible fruits (e.g., *Juglans* up to 0.9%), and weeds (e.g., *Convolvulus*, *Adonis*, and *Rumex*) began to spread in the study area probably related to herbivore herds and human populations, that also favored the increasing distribution of anthropogenic habitats dominated by Cichorieae (9.2%) and *Plantago* (4.7%) in combination with *Urtica* (0.6%).

A less diffusion of crops and the prevalence of grazing activities at greater distances from the site

In a generally diffused human-shaped open environment in the region during the **Bronze Age**, differences related to the land use and management of the area of influence of the archaeological site are detectable comparing the pollen subzones 4b of C-S1 and N-S3 cores.

The woody component reflects the regional trend already described for the previous core, with the only exception of *Ostrya* which in C-S1 is documented only in traces related to the high values attested in the N-S3. It is possible that some specimens grew in the area closest to the settlement, probably cared by the population for fuel and fodder as plants that tolerate cutting well.

Lower percentages of Anthropogenic Pollen Indicators have been documented at greater distances from the site suggesting different levels of direct and persistent human pressure (N-S3 average value, samples 14-8: 28.2%; C-S1 average value, samples 14-11: 26%). The space dedicated to crops was far for the place and adjacent to the settlement, as testified by the lower percentages of cereals compared to the N-S3 (*Hordeum* group up to 1.7% - sample 11; *Avena/Triticum* 0.3% - sample 14 and 11). However, the set of cereal types increased. Traces of *Panicum* s.l. (0.3% - sample 14 and 12) are index that crops probably became more diversified. The combined evidence of miliacin (17.2 ng/g – sample 12), a molecular biomarker specific of *Panicum* and other few Poaceae, may be considered a further support of millet cultivation during the dry phase occurred starting from the Recent Bronze Age (Florenzano et al, 2021b; Florenzano et al, in prep).

The sporadic presence of *Trifolium* type and other Fabaceae (never above 0.3%) and a lower percentage of *Cannabis* (never above 0.3%) compared to N-S3, agree with the general picture of a less diffusion of crops at greater distances from the site. Indeed, more constant values of grazing indicators suggest that pastures mainly occurred further from the settlement in overtrampled lawn dominated by a nitrophilous herbs community. The increase in arid conditions at greater distances from the site, probably favored by

continuous grazing, is also reflected in the general scarce presence of Non-Pollen Palynomorph related to wet environments (e.g., Cryosphyceae statospore and *Rivularia* type), which include only an increasing trend of *Pseudoschizaea* as indicator of decreasing water levels.

The trend of changing from wetter to more arid conditions is well evidenced in this core not only by the human strategy to increase the variety of cereals with the selection of those that need less water intake, but also by the drastic collapse of hygrophilous herbs (sample 11) that left space to dry grassland during increasing climate aridity (Cremaschi et al, 2016).

Cultural choices reflected in the decoration of gardens in the Roman Period

The transition to the **Subatlantic** is not well defined in this core and the succession of different historical phases seems to be less clear. However, the presence of *Platanus* pollen marks these spectra (0.3% - sample 10), suggesting the introduction in the study area of one of the shade plants common in gardens of **Roman villas** (Rosati et al, 2015). Furthermore, a slight recovery of the forest cover is observed, with a new expansion of the oak wood (from 13.9%-sample 21, up to 20.1% and 19.3%-samples 20 and 19).

From land abandonment to the introduction of non-native species

Plants of wet environments increased rapidly with diffusion of swamp in the **Middle Ages** that favored the spread of hygrophilous trees (*Salix*: 14.7%, and *Alnus*: 4.1%), hygrophilous herbs (e.g., Cyperaceae: 29.7%, *Sparganium emersum* type: 3.5%), and the sporadic presence of many species of hydrophytes (e.g., *Nymphaea alba* type, *Nuphar*, and *Lemna*). A fast retreat of wet environments occurred after the land reclamation during the **Renaissance (15th–16th centuries AD)**. The agrarian landscape began to characterize the Po Plain dominated by cereal crops in the lowland and cultivated plants valuable for edible fruits, timber, or other uses spread on the slopes of the hills and in the mountains. The recovery of *Zea* pollen in the upper part of the core (0.3% - sample 3, up to 0.8% - sample 1) is considered a good chronological bioindicator thanks to historical sources which documented the introduction in Emilia-Romagna Region **between the end of the 16th century and the first half of the 17th century**, until its greatest diffusion during the first half of the 18th century (Cazzola, 1991).

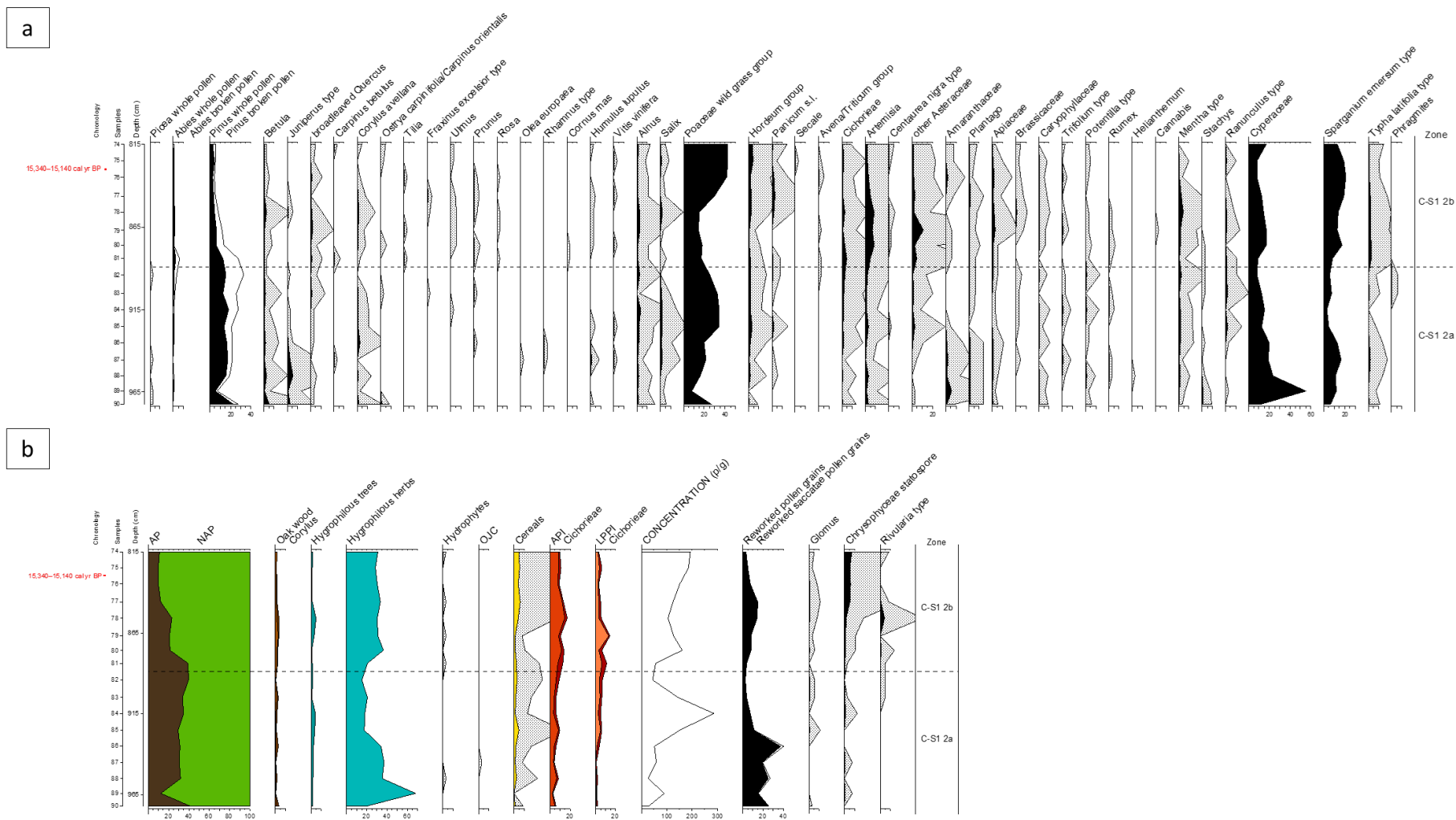


Figure 65. Pollen percentages from Pollen Zone 2 (90-74, 972-810 cm) of the C-S1 core: a) selected trees, shrubs, and herbs; b) main pollen sums and selected Non-Pollen Palynomorphs. Empty curves represent 10% exaggeration.

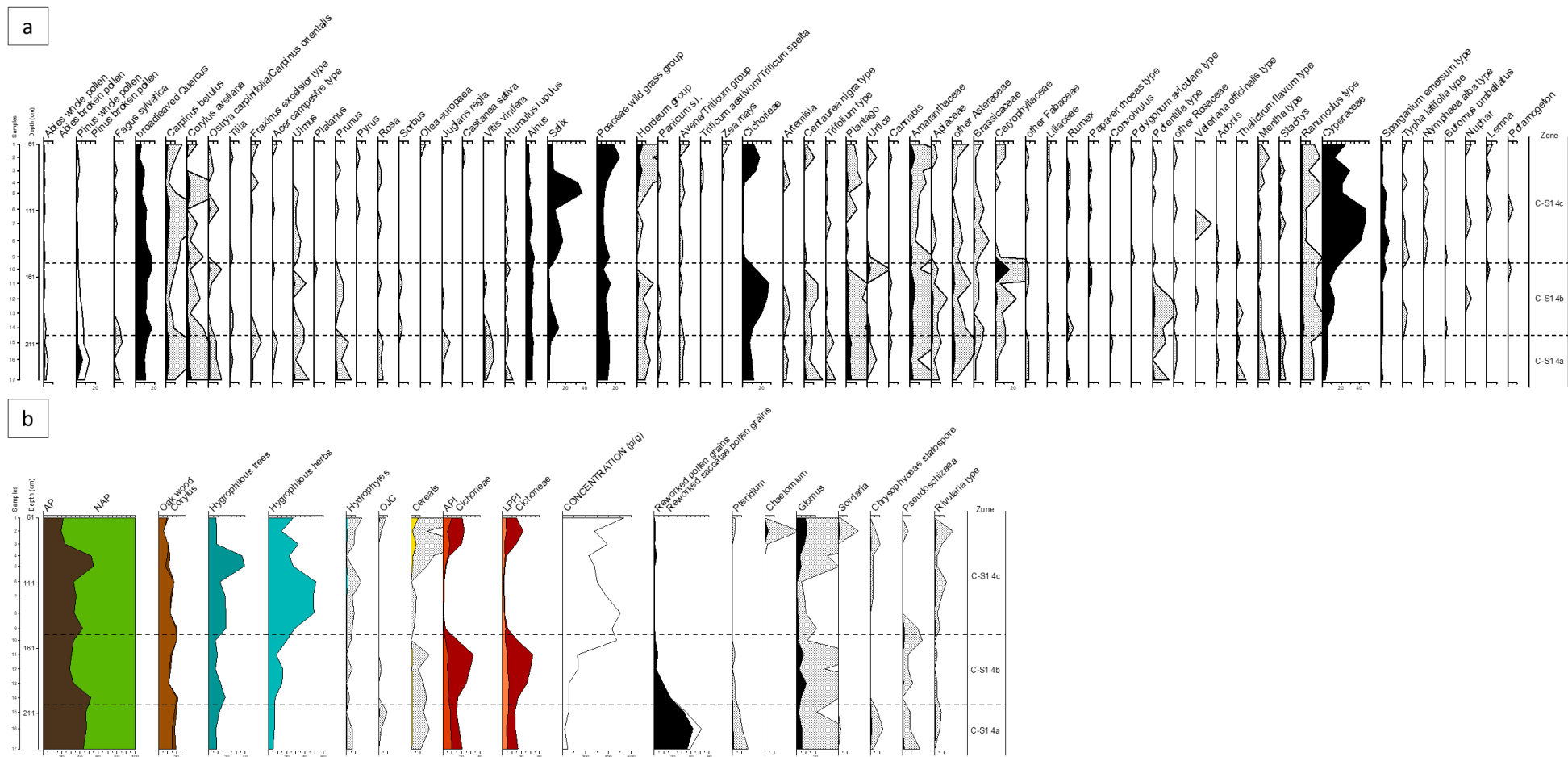


Figure 67. Pollen percentages from Pollen Zone 4 (17-1, 243-61 cm) of the C-S1 core: a) selected trees, shrubs, and herbs; b) main pollen sums and selected Non-Pollen Palynomorphs. Empty curves represent 10% exaggeration.

5.4.6.3 F-S2 CORE

Pollen Zone 3 (28-12, 830-356.5 cm) (Fig. 68)

Early / Middle Holocene (11,700–8200 cal yr BP / 8200–4200 cal yr BP)

In this zone, as throughout the sequence, the pollen samples were taken at a greater distance from each other. The type of deposition and inconsistent materials did not allow pollen sampling with stratigraphic control for all levels of the core, reflecting less stratigraphic detail. However, in the following paragraphs will be discussed the slow afforestation trend that characterized the river margins from the Boreal to the Subboreal.

The bottom part of this pollen zone is characterized by a pollen assemblage which can be referred to an arid and cold phase which determined low values of forest cover (AP = 16.9% - sample 28) and the diffusion of xerophilous plants (*Artemisia*: 5.3%, other Asteraceae: 4%, and Amaranthaceae: 1.8%). It is possible that this sample partly intercepts the **Younger Dryas**, if not slightly more advanced phases. However, as it is only one sample that present this vegetation assemblage, it has been inserted in the zone 3, which in the other cores immediately intercepts the beginning of the Holocene.

The constant presence of wetlands near the river

In agreement with the context described for the central core, the expansion of the forest cover in the early phase of the Holocene has been even more influenced by fluvial environment which determines often unstable conditions near the point sampling of the F-S2. This area was probably subject to water stagnation which favored the formation of marginal vegetation (Cyperaceae up to about 55%). However, the pollen image is similar to the other two cores with high values of *Pinus* which continued to be widespread in the plain during the **Preboreal** (14.8% - sample 27) but was gradually replaced by the expansion of the deciduous wood component during the **Boreal** (9.9% - sample 26), with values similar to the C-S1 core which are about half of those found in the N-S3. The expansion of the hygrophilous wood was particularly slow close to the watercourse, and it was represented only by the sporadic presence of *Alnus* with single elements in a predominantly herbaceous vegetation.

The transition to the **Atlantic** is not well marked in this pollen record which probably intercepts only advanced phases, when *Quercus* spread in the plain (up to 26.5%) together with all the other component of the mixed oak wood, except for *Acer*. *Abies* (10.5%) had also a growing trend. The forest cover continued to be fragmented, probably represented by patches alternating with clearings and wet meadows. In particular, the generalized wetland condition after **6485–6320 cal yr BP** allowed the expansion of the hygrophilous herbs (sample 24 - *Sparganium emersum* type: 7.8%, and Cyperaceae: 32.3%).

The increase in forest cover is amplified even more in the pollen subzone 3b (from 33%-pollen subzone 3a to 64.9%-pollen subzone 3b), showing the same trend of the other cores. The oak-hornbeam woodlands began to spread together with the presence of conifers, patches of riparian mixed forests, and bushes on the edge of wooded areas filling even the areas closest to the watercourse.

The contemporary expansion of *Fagus* and *Carpinus* occurred at **5315–4963 cal yr BP**, at the transition to the pollen subzone 3c. At the beginning of the **Subboreal**, a new rapid expansion of wetlands influenced the abundance and composition of the forest cover with the occurrence of different levels of water and humidity that has determined the increase in close succession of *Salix* (14.7% - sample 17), hygrophilous herbs (e.g., Cyperaceae: 66.3% - sample 16), and *Alnus* (30.5% - sample 15).

Pollen Zone 4 (11-1, 356.4-73 cm) (Fig. 69)

Late Holocene (from 4200 cal yr BP onwards)

The main feature that emerges from this pollen zone is a greater continuity of more natural environments, partly documented also during the Bronze Age. The management of the territory and the different distribution of human activities in relation to the surrounding environment will be discussed looking at the availability of plants valuable for edible fruit and the possible close presence of both cereal fields and pastures. The presence of an agricultural system in the Roman Period based mainly on the cultivation of cereals will be reconfirmed, while new evidence will be brought to light regarding the extensive presence of wetlands and the increase in hygrophilous trees following the land reclamation.

The continued presence of a more natural environment and a lower degree of anthropogenic pressure at the boundaries of the study area

Also in this case, the pollen subzone 4a could be easily compared to the pollen image previously described for the **Copper Age**, with the spread more and more evident of semi-open and open areas related to the initial development of a cultural landscape in the plain, marked by the most frequent occurrence of synanthropic plants. However, cereal cultivations were not yet present in this area (0.2%).

During the **Bronze Age** (pollen subzone 4b) the components of the mixed oak wood decreased both quantitatively and qualitatively. *Ostrya* was absent in accordance with the presence of some plants only close to the site, while *Acer* seems to be more represented (0.5% - sample 9). Among the trees and shrubs supplying fruits, *Juglans* and *Rosa* probably grew at the edge of the wetland.

Even lower percentages of Anthropogenic Pollen Indicators have been documented in this core, confirming the initial hypothesis that lower degree of direct and persistent human pressure could characterize the most distant core from the settlement (N-S3 average value, samples 14-8: 28.2%; C-S1 average value, samples 14-11: 26%; F-S2 average value, samples 9-8: 18.2%).

However, cereal cultivation could also be present at greater distances from the site (*Hordeum* group: 1.4% in both samples; *Avena/Triticum* group: 1.4% - sample 9), but the poor stratigraphic resolution and the scarce presence of other possible cultivated plants do not allow to make inferences on the presence of rotation or other cultivation methods adopted by farmers. The grazing indicators (LPPI - Mazier et al, 2009; Asteroideae, *Ranunculus* type, and *Potentilla* type: 3.7% in both samples) were locally spread and their constant presence may suggest also local pasture activities.

The **Subatlantic** is completely documented in this core starting from the pollen subzone 4c. The agricultural practices attested in the study area during the **Roman Period** were mainly dedicated to the cultivation of cereals which, however, were probably concentrated only close to the villa rustica (0.9% - sample 7, and 0.5% - sample 6). The rapid increase in wet environments in the middle of the subzone reflects the general condition attested during the **Middle Ages**, even if in this case the spread of wet environments was also accompanied by a local expansion of the oak wood especially related to the spread of *Corylus* (8.8% - sample 5). However, a subsequent phase of swamping seems to characterize this area with a further increase in hygrophilous herbs (up to 43.1% - sample 2), *Salix* and *Alnus* (21.2 and 8.7%, respectively - sample 1), not visible elsewhere. This might suggest that the most recent samples of this core intercept more recent phases than the other two cores. However, the introduction of *Zea* is not documented here, but a single pollen grain of *Morus nigra* testifies the presence of non-native plants in the territory at the top of the sequence (sample 1).

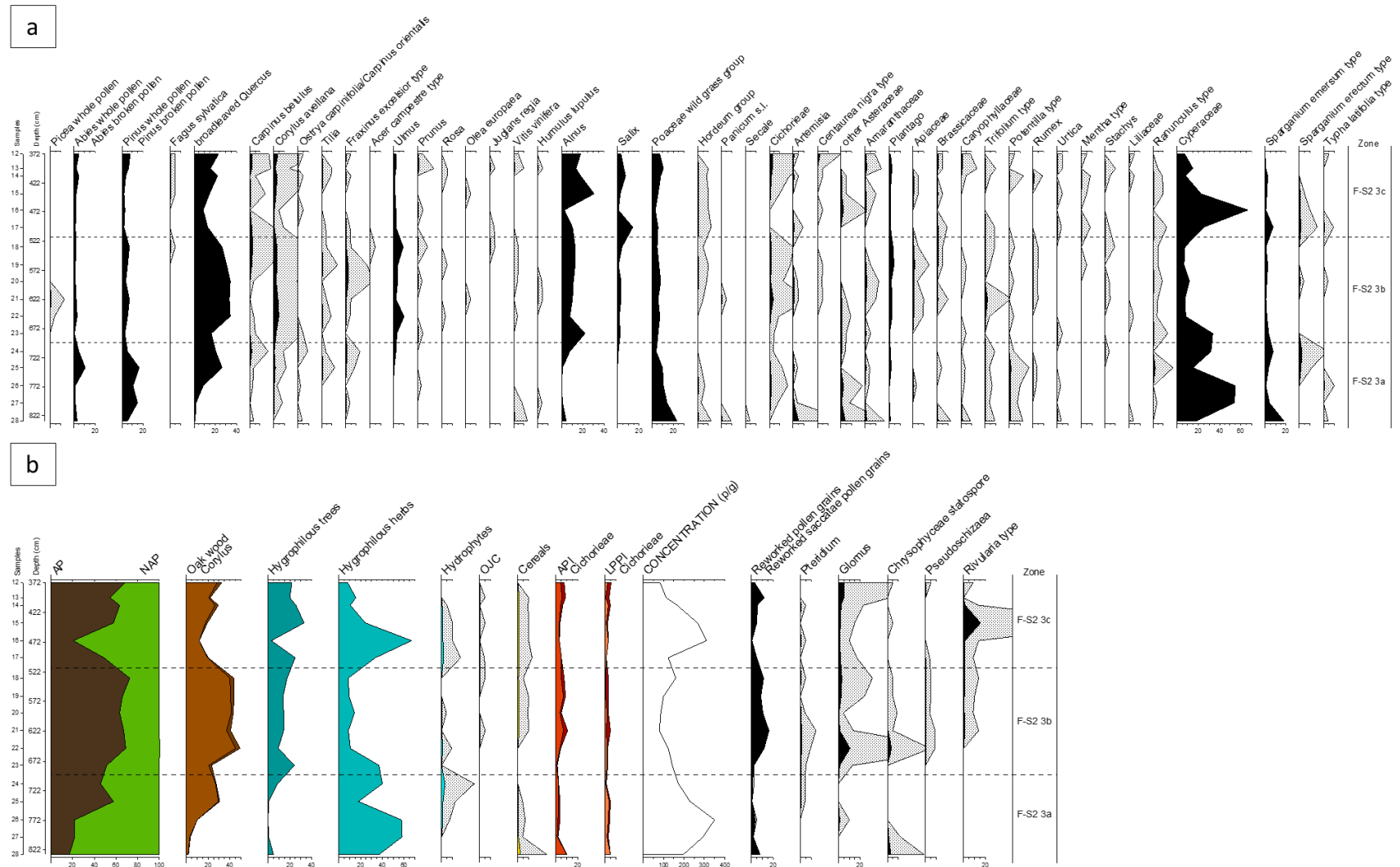


Figure 68. Pollen percentages from Pollen Zone 3 (28-12, 830-356.5 cm) of the F-S2 core: a) selected trees, shrubs, and herbs; b) main pollen sums and selected Non-Pollen Palynomorphs. Empty curves represent 10% exaggeration.

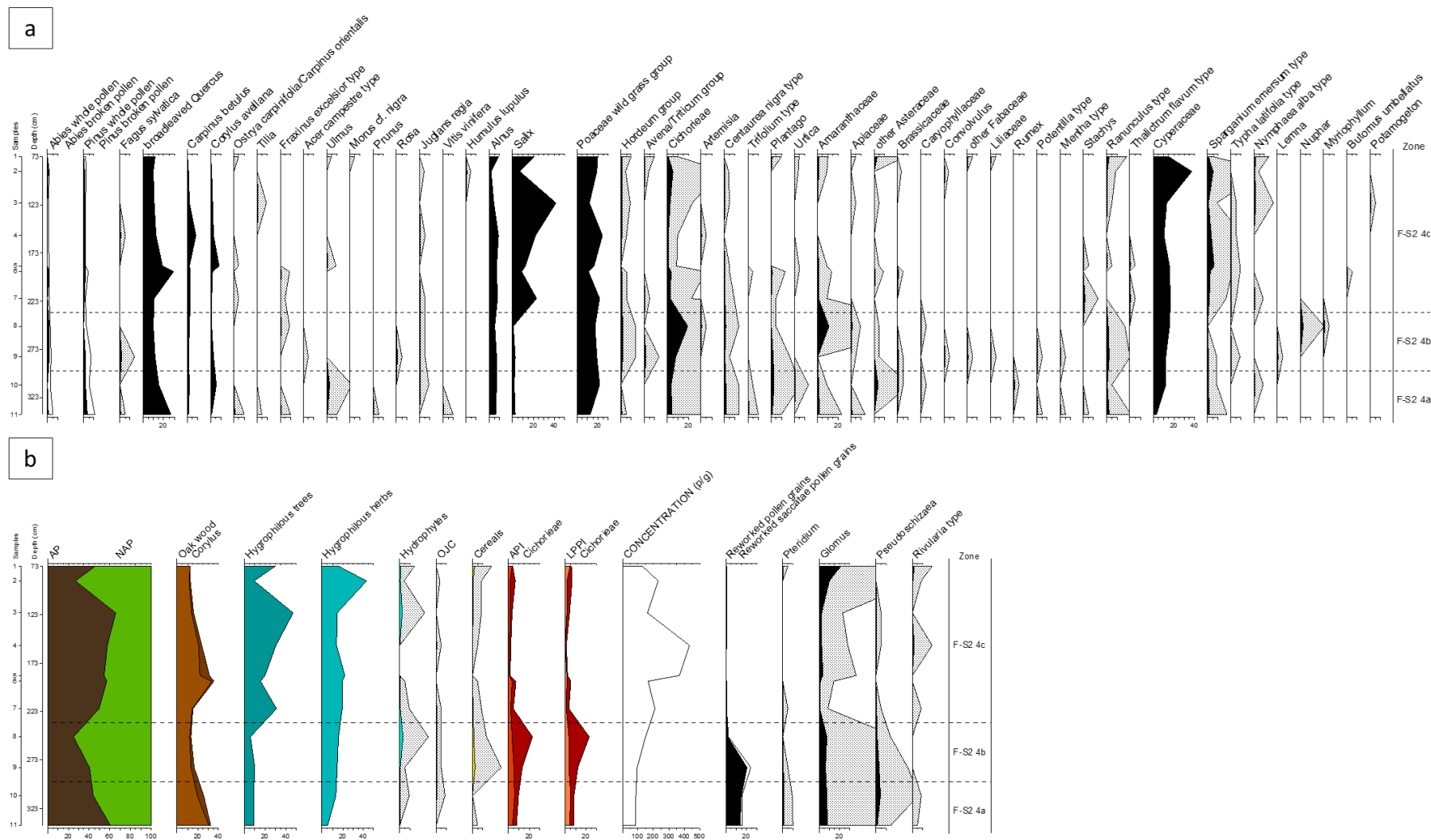


Figure 69. Pollen percentages from Pollen Zone 4 (11-1, 356.4-73 cm) of the F-S2 core: a) selected trees, shrubs, and herbs; b) main pollen sums and selected Non-Pollen Palynomorphs. Empty curves represent 10% exaggeration.

5.4.7 VEGETATION HISTORY AND LAND USE TRANSFORMATIONS IN THE LAST 19,000 YEARS

The evidence obtained from the palynological analysis of the three cores describes the main vegetation transformation in the Po Plain starting from the Late Pleniglacial/Lateglacial, and the succession of three main vegetation assemblages is recognizable in each sequence:

- an open landscape dominated by pioneer and light-demanding plants typical of xeric environments;
- a quite forested environment characterized by mixed wood formed by conifers and thermophilous trees, oak wood, and hygrophilous wood;
- a cultural landscape identified by the spread of open areas, the decrease and changes in forest composition, evidence of cultivated plants, and introduction of allochthonous species.

The data are useful to draw a regional picture for the Central Po Plain, even if the presence of the nearby watercourse has always played a key role for the environmental dynamics of the study area. The influence of the fluvial context is visible both directly through the succession of alluvial events and presence of freshwater plant communities, and indirectly by favoring the presence of human groups and civilizations for the considerable advantages that the proximity to such an important resource brings.

In this chapter the attempt will be made to develop these different aspects, dividing the last 19,000 years into four large time intervals: *Late Pleniglacial/Lateglacial*, *Early Holocene*, *Middle Holocene*, and *Late Holocene*.

Late Pleniglacial/Lateglacial (19,000–11,700 cal yr BP)

In northern Italy, the vegetation history during the Late Pleniglacial and the Lateglacial is already well known and discussed through many palaeoenvironmental records from hilly and mountain sites, mainly lacustrine environments with continuous sedimentation (e.g., Vescovi, Kaltenrieder, & Tinner, 2010; Vescovi et al, 2007, 2010; Joannin et al, 2013, and references therein). Some studies have been carried out in the eastern part of the alluvial plain but often are affected by high discontinuous sedimentation rates (Bruno et al, 2020; Marchesini, Marvelli, & Lobietti, 2017; Marcolla et al, 2021; Ravazzi et al, 2006). However, knowledge on palaeoenvironmental and palaeobotanical transformation in the Central Po Plain is still scarce, due to the few lacustrine successions and the difficulty of obtaining radiometric dating in alluvial environments (Ravazzi et al, 2007).

Figure 70 shows the possible correlation between the bottom part of the three cores and the synthesis of the palynostratigraphic information discussed by Vescovi et al (2007). In this synthesis, four biozone-climatozones were clearly identified during the interval 19,000–11,700 cal yr BP in the southern alpine side. Not surprisingly, the correlation between Central Po Plain and Alpine records with a similar general pattern of pollen curves reflects the possibility of considering the plain as a receiving basin for pollen whose transport from the mountain slopes was facilitated by the scarce forest cover in the plain. All correlations that will be discussed are based exclusively on pollen records and the existing knowledge about the changes in vegetation during this period. The available chronological references for the N-S3 and the C-S1 will not be considered (see chapter 5.2 DISCUSSION ABOUT THE CHRONOLOGY).

Pollen records from the plain identify a large open area mostly dominated by shrubby-herbaceous communities, and the arboreal component referable to a more local pollen contribution reflecting the sporadic presence of thermophilous patches. However, conifers, especially *Pinus* which has been cyclically documented in large quantities, dominate the spectrum of woody plants in the lowlands and reflect above all a long transport distance (by wind or by watercourse) from limited areas in the Po Plain and in the surrounding hilly areas, where more stable and suitable conditions may favor the formation of woodland communities with spaced trees and xerophilous bushes (Lowe et al, 1996; Mercuri et al, 2012).

The Late Pleniglacial does not yet have sufficient chronological control to correlate the reference pollen records in N-Italy (Ravazzi et al, 2007). However, the pollen assemblage at the bottom of the N-S3 core seems to correlate well with the lower part of the Origlio Lake record (> 18,000 cal yr BP; Tinner et al,

1999) and Ledro Lake (18,000? cal yr BP; Joannin et al, 2013). Both pollen records show an herb-dominated steppe tundra with the occurrence of a mixed open forest with *Pinus sylvestris*, *Betula*, and *Juniperus*. The ubiquitous presence in all records of rare pollen grains of broadleaved *Quercus*, *Corylus*, *Salix*, and other thermophilous trees exemplifies the regional presence of temperate species at the end of the LGM and in the following period.

The xerophilous herbaceous component with *Artemisia* and *Amaranthaceae* was present in the plain with fluctuating and always much lower values than at higher altitude, probably always related to alluvial processes resulting in less arid soil conditions and temporary formation of wetlands and wet meadows. Arid grasslands were probably present, but only at greater distances from streams and rivers.

The expansion of thermophilous trees remained limited during the Lateglacial probably due to the absence of suitable soils. The trend of arboreal pollen in the plain substantially reflects the decline of *Pinus* described for higher altitudinal belts. An abrupt change of forest composition and density during the Bølling–Allerød interstadial period (14,700–14,500 cal yr BP) is well attested in many lakes and mire sediment archives from the southern Alps (Vescovi et al, 2007) and from the northern Apennines (Lowe, 1992; Lowe & Watson, 1993) testifying the ascent of the tree line in a few centuries. The expansion of thermophilous taxa, at the same time of a long-lasting decline of *Pinus sylvestris*, occurred at 13,000–12,800 cal yr BP in response to the climatic warming. However, these changes in the vegetation structure are not very evident in the pollen curves of the study area, although the cold-arid conditions characterized by higher values of steppe vegetation gradually changed to a wetter and slightly warmer environment.

More marked is the vegetation changes caused by the Younger Dryas cooling event conventionally placed between ~12,900 and 11,700 cal yr BP, which seems to be well visible also in the pollen records from the lowland testifying the rapid occurrence of colder/drier conditions. The forest cover decreased conspicuously both in the plain and in other pollen records, according to the expansion of herbaceous taxa and heliophilous trees (e.g., *Betula*).

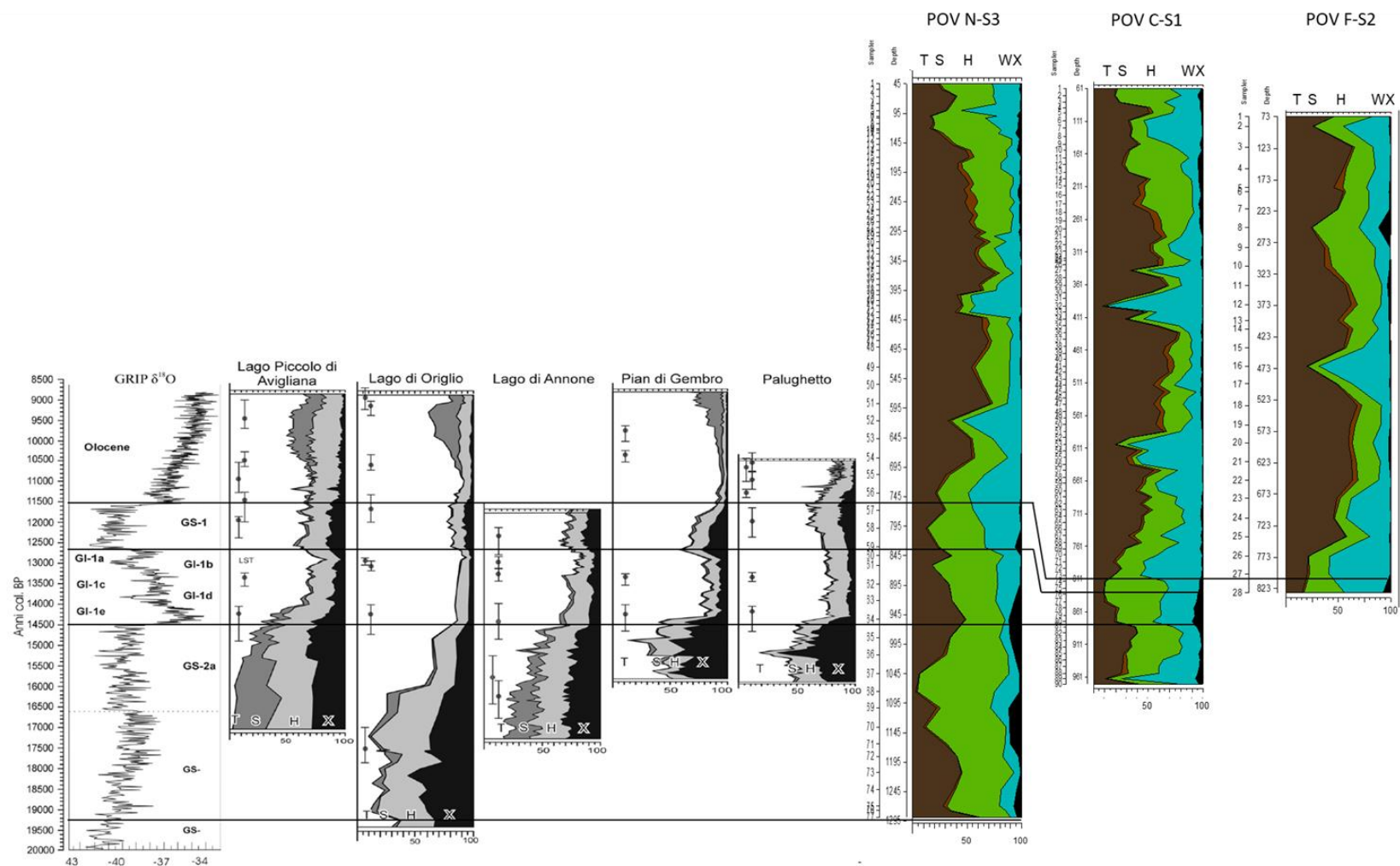


Figure 70. Correlation based on synthetic pollen diagrams of the three cores object of this thesis (on the right: N-S3, C-S1 and F-S2) and five Late Pleniglacial/Lateglacial lacustrine and palustrine sites in the Italian Alps with the indication of ^{14}C ages used for the age-depth model and the GRIP SS09 timescale for isotopic stratigraphic (Ravazzi et al, 2007). Key: T=sum of tree pollen; S=sum of shrubs pollen; H=sum of herbaceous pollen (hygrophilous herbs, hydrophytes and xerophytes excluded); W=sum of aquatic and wetland species (it should be noted that this sum is indicated only in Poviglio-PVG as it is considered a terrestrial context does not imply the exclusion of these pollen types from the pollen sum); X=sum of xerophytes (*Artemisia*, *Hippophaë*-absent in PVG, *Amaranthaceae*, and *Helianthemum*). The correlation was performed only for the deeper levels related to the Late Pleniglacial/Lateglacial.

Early Holocene (11,700–8200 cal yr BP)

The prominent role played by climate change between the end of the Pleistocene and the Early Holocene is well documented in pollen spectra that reflect changes in vegetation cover as a consequence of the establishment of new environmental conditions. Temperatures increased abruptly by about 3–4 °C starting from 11,600 cal yr BP, and then more gradually by a further 2–3.5 °C until 9800–9600 cal yr BP (Tinner & Kaltenrieder, 2005), setting off rapid biotic responses and a concatenation of ecosystems development which are ubiquitously recorded in many high-resolution records from Europe (Birks & Ammann, 2000).

In pollen records the decreasing curve of *Pinus* intersects with the growing one of broadleaved *Quercus*. However, it seems that pine remained probably present with scattered nuclei in the plain and in the surrounding hilly areas, although never with a very extensive occupation in the study area. In general, the forest cover increased, especially in relation to the initial spread of thermophilous deciduous trees (e.g., *Carpinus*, *Tilia*, and *Fraxinus excelsior* type) accompanied by the presence of shrubs which became more frequent (e.g., *Corylus*, *Rosa*, and *Prunus*). Pollen of *Picea* is no longer documented, because of small populations of this species probably moved and remained limited in the upper forest belts of the northern Apennines (Ravazzi, 2002) in response to climatic warming and competition from other more thermophilous trees, such as *Abies* that starts to expand in the region (Vescovi et al, 2010). In the early Holocene, the hygrophilous wood was undoubtedly less extensive than the oak wood. The asynchronous growing trend of these plant biocenoses may be reflect an initial phase of warming before of the increase in precipitations, which should have favored only in a second moment the increase in the moisture availability. Furthermore, the expansion of hygrophilous wood is a clear index that the biocenosis had reached its climax and that the flow of water was less and more regular. Deciduous mesophilous-mesohygrophilous woods already occupied large areas in the plain (Accorsi et al, 1999), but probably not near the study area, which was still characterized by open environments with hygrophilous herbs, Poaceae wild grass group, Caryophyllaceae, Cichorieae, and other Asteraceae.

Middle Holocene (8200–4200 cal yr BP)

The Middle Holocene is considered a period of intense environmental and cultural changes in the Mediterranean area. The earliest event corresponds to the so known “8.2 event” identified in the palaeoclimatic and palaeoenvironmental records of the Northern Hemisphere with a sharp signal of cooling (up to ca. 6 °C in Greenland, and between >3 and 1 °C in the Alps; Peyron et al, 2013) related to the change atmospheric circulation induced by freshwater pulses that produced a weakening of the thermohaline circulation in the North Atlantic (Alley et al, 1997; Peyron et al, 2013). Hydrological signal for the 8.2 kyr event with a short-term lake-level rise are documented in the Accesa Lake together with a decline in the fire regime (Vannière et al, 2008), that suggest the occurrence of wet conditions at northern latitudes (Magny et al, 2003). The signal of this event is weak in the pollen image of the Po Plain, in which a marked reduction in forest cover is not observed like in other pollen records of southern Italy (Magri & Sadori, 1999; Sadori & Narcisi, 2001) where, however, arid conditions should have characterized this event. It is possible to correlate the early expansion of *Abies* and the occurrence of *Fagus* in the pollen spectra with the expansion documented in northern Apennines that is considered the result of a fully natural process because of pollen taxa associated with human activities are often too low (Vescovi et al, 2010). *Fagus sylvatica* L. from the point of view of its ecological characteristics is considered a mesohygrophilous and mesothermic species, and atmospheric humidity seems to be a determining factor for the growth and development of the species, especially during early vegetative stages (Hofmann, 1991; Magnani, 2007). Almost simultaneously with beech, in accordance with increasing humidity conditions, hygrophilous wood began to expand in the plain. However, the expansion of beech seems to have slowed down fast probably in relation to the formation of dense forests of *Abies*, which limited the supply of light necessary for *Fagus* seedlings for development. The trend shown by the forest cover may be regarded as evidence of climate oscillations. According to Davis et al (2003), an almost linear warming from around 8000 cal yr BP onwards have occurred in southern Europe and in the Mediterranean, until the summer thermal maximum around 6000 cal yr BP, together with the establishment of permanent moisture conditions favored by the occurrence of wet summers in a homogeneous seasonal precipitation regime during the Middle Holocene (Combourieu-Nebout et al, 2013).

The anthropogenic environment was still scarce in the study area at time of the establishment of Early Neolithic farming communities in the region which largely depended on the distribution of soils suitable for agriculture (Biagi, Cremaschi, & Nisbet, 1993). Pollen records in the plain documents a decline in forest cover which, however, is not attributable for sure to anthropogenic causes. In fact, synanthropic plants in the area were still scarce, and part of the forest has been replaced by the expanding of hygrophilous herbs in accordance with increasing humidity conditions. However, starting from the Early Neolithic began a slow but steady spread of cereals pollen grains, weeds, and synanthropic plants in the study area, according to archaeological and archaeobotanical features from northern Italy during late-7th millennium BC (Rottoli & Castiglioni, 2009). The maximum expansion of the forest canopy has been reached during the middle Holocene Climatic Optimum (8000–4200 cal yr BP) with the diffusion of the final vegetational stage in the Emilia-Romagna Region. The vegetational climax association was represented by the oak-hornbeam woodlands (*Quercus-Carpinetum boreoitalicum* Pign. 1953). This association largely occupied the lowland, where *Quercus robur* L. was dominant together with *Carpinus betulus* L. However, the distribution of the single components of the mixed oak wood was certainly determined by local environmental conditions. In particular, hornbeam seems to have been unevenly present in the study area probably growing in small groups alternating with the mixed riparian vegetation, where *Ulmus* ssp. found suitable conditions at the borders of the hygrophilous woods. The large occurrence of riparian hygrophilous wood and swamp forest tree dominated by *Alnus glutinosa* and *A. incana* marked the widespread presence of wet environments from the central part of the plain to the coast (Rossi et al, 2021), usually alternating with mixed oak woods depending on hydrogeological conditions and soil drainage.

At local level, wet environments seem to replace large part of the mixed oak wood probably starting from the late-6th millennium BC because of flood events. The progressive opening of the forest left space to a predominantly open landscape dominated by wet meadows, which represented the beginning of a vegetational succession that brought to the establishment of a dense hygrophilous wood at the transition from the Neolithic to the Copper Age, reaching probably the greatest extent of the entire Holocene.

Late Holocene (from 4200 cal yr BP onwards)

Many pollen records describe significant changes in vegetation patterns between Early and Late Holocene in southern Europe, suggesting a general transition from wetter to drier climatic conditions (Sadori, Jahns, & Peyron, 2011). The “4.2 ka BP event” is a climatic event ranging from ca. 4.2 to 3.9 ka yr BP (Railsback et al, 2018), whose effects are still poorly understood and led to contemporary opposite dynamics in different regions (Bini et al, 2019; Di Rita et al, 2022). Pollen-based summer precipitation reconstructions for lakes Accesa, Ledro, and Trifoglietti documented the occurrence of such a dry event during this climatic oscillation (Peyron et al, 2013).

However, the climatic signal began to mix strongly with the anthropogenic overprints starting from the middle of the 5th millennium BC, and a cultural landscape began to appear throughout the region. The first occurrence of changes in vegetation cover in the Po Plain seems to have preceded the continuous increase in pollen assemblages of human-induced vegetation. Open areas became much more common across the plain, interspersed with bushes that include trees and shrubs valuable for edible fruits (e.g., *Juglans*, *Prunus*, *Rosa*, and *Vitis*). Especially *Vitis*, whose pollen has a very limited dispersion from the mother plant (Tumer & Brown, 2004), seems to be widespread in the territory, probably as wild specimens associated with riparian vegetation near the watercourse. The forest cover that characterized the Middle Holocene was replaced by a slow and constant expansion of open areas, which in this phase lost the connotation of wet meadows and wetlands. Grasslands and arid meadows together with patches of cereal cultivations, which especially intensify around 4500 yr BP with Copper Age settlements, began to spread in the central part of the lowland.

The strong human impact with woodland clearance and the spread of anthropogenic indicators is unquestionable and already well known at a large scale starting from the beginning of the Bronze Age (Cremaschi et al, 2016; Dalla Longa et al, 2019; Mercuri et al, 2012; Valsecchi et al, 2006). Settlement continuity and demographic increase at the time of the establishment of the Terramare culture leaved a well-marked overprint in pollen records (Mercuri et al, 2012), with the common feature of an increasing trend of deforestation and changes in biodiversity of the forest cover. This has marked the turning point of the evolution of the modern rural-cultural landscape in the Po plain.

The increasing exploitation of freshwater environment affected the river networks with the strongly

regulation of the flows leading to a homogenization of the hydrologic conditions in the floodplain and the consequent spatial reallocation of riparian vegetation. The need of the populations to constantly exploit wood resources, led to the opening of large areas around the settlements that completely dotted the plain.

The interpretation of pollen data provided by the three cores, together with the additional detail obtained through the quantitative reconstruction of the vegetation on a regional and local scale (see chapter 5.4.5 QUANTITATIVE RECONSTRUCTION OF VEGETATION), allows for a better framing of the landscape. The study area was mainly characterized by fields and pastures at least up to the distance of half a kilometer from the settlement (at least at north of the site). As described in the previous paragraphs, probably cultivated fields extended at a shorter distance from the site to allow greater proximity from the production to the processing area of raw materials which presumably took place close and inside of the settlement (Florenzano et al, 2021a). The pastures were probably distributed at a greater distance than the crops, although probably a cyclical rotation of these could favor the fertility of the soil following the cultivation of cereal that depleted the amount of nutrients (Mercuri et al, 2006a, 2006b). The mixed oak wood remained limited to restricted areas and with a specific composition different from that which characterized this formation at its mature stage. In particular, *Tilia* disappeared from the end of the Middle Bronze Age. Trees and shrubs useful for fruit production or used as fodder for livestock may occupy space between the fields or the edges of the settlement. Among trees, *Ostrya carpinifolia* played a key role for the Terramara S. Rosa di Poviglio, and some specimens were supposedly maintained by the population in the area surrounding the village. However, the pollen image from different sites highlights dissimilarities regarding the abundance of some species near the settlements, as in the case of the Terramara of Montale where *Carpinus betulus* were probably selected and maintained for local needs of the population. The quantitative reconstruction of the vegetation based on pollen data highlights that the wetlands probably characterized the territory between one settlement and the other, where more consistent patches of mixed oak wood could also find place. Hygrophilous wood characterized the banks of watercourses, although they were probably not large in extent near villages where people kept the margins clean to facilitate a continuous water supply.

Because of the low thickness of the post-Bronze Age deposits, it is not possible to get a detailed reconstruction of the study area through close correlation with other palaeoenvironmental records. However, control points of different chronological periods suggest the key steps in the transformation of the landscape up to more recent times. In general, a scarce recovery of the forest cover characterized the lowland, which soon underwent a new extensive reorganization of the countryside with the progressive Roman colonization. In the pollen spectra the signal of the consistency increase in chestnut wood of anthropogenic origin is also absent, which instead is documented in the hilly and mountain where largely replaced oak wood, populations of *Fagus*, and *Alnus* (Accorsi et al, 1999). Among the cultural trees (Mercuri et al, 2013b), only *Juglans* had an almost constant trend, while *Vitis* no longer had the high values documented during the Copper Age and the Bronze Age. Following the extensive reclamation action carried out during the Renaissance, both the expansion of *Salix*, which began to largely replace *Alnus*, and the progressive diffusion of the agricultural landscape testifies the beginning of the development of the modern landscape described by the surface soil pollen samples.

5.5 CONNECTED RESEARCH FOR DEEPENING PARTICULAR ASPECTS REGARDING THE TERRAMARE CULTURE

Three articles are reported that in recent years have been added to the already important existing knowledge about the Terramare culture, which is constantly updated and integrated with the precious contribution of many disciplines (see APPENDIXES).

The research presented provides valuable contributions on different aspects related to this civilization and develops new bases for future studies.

Sharing the Agrarian Knowledge with Archaeology: First Evidence of the Dimorphism of Vitis Pollen from the Middle Bronze Age of N Italy (Terramara Santa Rosa di Poviglio)

Mercuri, A.M., Torri, P., Florenzano, A., Clò, E., Mariotti Lippi, M., Sgarbi, E., & Bignami, C. (2021)

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On-site stratigraphy is the only type of record that allows to deepen the trends of human impact on the environment at a very local scale. Besides this, high resolution pollen identification also allowed to discover some interesting records, as in the case of *Vitis* pollen. *Vitis vinifera* is well known to be a key species in the reconstruction of palaeoenvironmental and cultural trajectories with its substantial role among the most important crops at the base of the economy development of the Mediterranean agriculture. Given its centrality in Mediterranean contexts, many archaeobotanical research has largely specialized in the study of micro- and macroremains in archaeological sites related to the presence, the selection for fruits, and the spread of the plant for cultivation. Morphological features of seeds are conventionally used to mark the transition between wild and domesticated specimens, but also pollen is increasingly studied in historical contexts to attest the use of this plant by the populations for different purposes ranging from the food production to aesthetic reasons (Montecchi & Mercuri, 2018). Pollen analysis applied in archaeological contexts did not consider the dimorphism of *Vitis* pollen yet, which instead is considered as an important factor in the determination of vineyard productivity. The pollen dimorphism of *Vitis* is a case of functional dioecy which includes trizonocolporate and inaperturate pollen. Trizonocolporate pollen grains are usually identified, but the inaperturate shape of grapevine pollen is ignored. According to the botanical and agrarian knowledge, this paper is based on the study of different plants with hermaphroditic flowers belonging to the subspecies *vinifera*, dioecious plants of the subspecies *sylvestris*, and cases of *V. vinifera* subsp. *vinifera* with morphologically hermaphroditic but functionally female flowers. Inaperturate pollen can be considered a rare trait in domesticated grapevine that produces only trizonocolporate pollen, while the wild grapevine produces also inaperturate pollen (Barbieri et al, 2012; Meneghetti, Gardiman, & Calò, 2006).

The Terramara S. Rosa di Poviglio was the scene of the first record of inaperturate *Vitis* pollen observed in samples taken from archaeological layers where high percentage of trizonocolporate pollen (18%; Cremaschi et al, 2016) suggested the presence of wild plants near the site. The observation and identification of inaperturate pollen grains are particularly important in this context as macroremains of *Vitis* have not been found so far in this site, determining a further value of this evidence. Wild plants of *Vitis* should have been exploited for food or other uses for a long time and this contributed, perhaps several times and in different ways, to the human cultural evolution. The Bronze Age is considering a critical period to investigate for disentangle the knowledge about the beginning of the cultivation of *Vitis* (Cardarelli et al, 2015; Menozzi et al, 2002; Zohary, 1995), which in Italy traced back to the Iron Age with the presence of the first Greek colonies in southern Italy. However, remains of pips from the Bronze Age suggest that the beginning of its cultivation can be anticipated of several centuries in mainland Italy and Sardinia (Ucchesu et al, 2015), with evidence also in Messenia (south Greece) since the Early Bronze Age (Valamoti et al, 2020). This plant played an important role also for the Terramare populations in the preparation of alcoholic drinks which replaced the use of the cornelian-cherry for the same purpose (Mercuri et al, 2006a). The use of grapevine was probably favored by a combination of sophisticated knowledge of the land and natural resources and local environmental conditions that favored the presence of wild specimens lived in hygrophilous woods near watercourses. The identification of many inaperturate pollen of *Vitis* in archaeological layers supports this interpretation adding the information that pollen was produced also by female flowers and that grapevine was cultivated, even not domesticated, in the site. Starting from this first evidence, the integration between agrarian knowledge with Archaeology provides an important base for deepening and continuing the investigation about the domestication history of grapevine.

All the pollen grains of *Vitis* observed in the cores are trizonocolporate and do not provide new evidence for the inaperturate morphology. However, all together the pollen records of Poviglio can help to understand the role and the distribution of this plant in the landscape. The pollen data obtained from the analysis of the three cores is in agreement with the interpretation provided by Cremaschi et al (2016), suggesting that some grapevine grew as part of the riparian communities. In fact, *Vitis* pollen in the cores is often documented in the Holocene levels, especially in samples characterized by a constant increase or stable values of hygrophilous wood in the study area. As in the case of the on-site moat, riparian vegetation is similarly

arranged in the PCA space with *Vitis* near *Alnus* (see Figs. 34-36 in the chapter 5.3.1 PRINCIPAL COMPONENT ANALYSIS).

However, *Vitis* disappears toward the zone 4b in N-S3 and C-S1 (absent in F-S2 4b). The decrease in *Vitis* in the cores precedes that observed in the moat between the Villaggio Grande and the Villaggio Piccolo, suggesting two causes which acted differently on the presence of this plant. The strong decrease in *Vitis* in the cores probably reflects the need of the population to open large areas near the settlement, at the sampling point of the cores, to be dedicated to crops and grazing. For this reason, the riparian vegetation with the presence of shrubs and lianas that had occupied a large part of the territory in previous phases, during the Bronze Age found space only at the edge of the moat surrounding the settlement (where high percentages of *Vitis*, up to 18%, testify the local presence of many specimens; Cremaschi et al, 2016). On the other hand, the subsequent decline of *Vitis* even close to the site was probably not related to voluntary action, but rather to the onset of drier climate conditions no longer suitable for this species, that have resulted in detriment of food (PVG 4; Cremaschi et al, 2016).

Paesaggio vegetale sulla base delle analisi del riempimento dei pozzi al margine del Villaggio Grande della Terramara Santa Rosa di Poviglio

Florenzano, A., Clò, E., Zappa, J., Montecchi, M.C., Furia, E., Torri, P., & Mercuri, A.M. (2021)

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Palynological research of deposits from the Terramara S. Rosa di Poviglio has been carried out over the years through the analysis of pollen sequences coming from the moats of the Villaggio Piccolo (Ravazzi, Cremaschi, & Forlani, 1992, 2004) and the one between the Villaggio Grande and the Villaggio Piccolo (Cremaschi et al, 2016; Furia, 2016-2017). The chapter deals with new information obtained by the palynological study of the filling of wells located at the edge of the moat of the Villaggio Grande (Zappa, 2018-2019), integrated with the latest investigations carried out on depositional sequences from the moat between the Villaggio Piccolo and the Villaggio Grande (Furia, 2016-2017), with the aim of contributing to the knowledge of flora and vegetation transformations between BM3 and BR1/BR2.

Water resources played a key role in the subsistence of the Terramare culture, and their management has led to profound changes in the hydrogeological plan of the territory with a dense network of ditches planned to collect and redistribute the water to irrigate fields. The peculiar feature of the Terramara S. Rosa di Poviglio is the presence of a well-structured hydraulic system composed by water wells and interconnecting ditches that was discovered in the southern part of the Villaggio Grande in coincidence with the palisade and in the peripheral moat (Cremaschi, Pizzi, & Valsecchi, 2006). Geoarchaeological investigation of the water wells reveals a drop in the water table during the late Recent Bronze age, related to the occurrence of one or more short dry episodes of regional relevance (Baroni et al, 2006; Valsecchi et al, 2006),

Pollen data obtained by the analysis of two of these special structures report clear signs of the establishment of a widespread anthropogenic environment, while the ecological information obtained by the identification of Non-Pollen Palynomorphs provides a further help in understanding the different stages of the deposition process. The first indication was obtained from the frequent observation of different pollen preservation in both wells that suggest various methods of intake in the deposit, from air transport, sediments raised, and redeposited within the structures or filling the wells themselves voluntarily by the population. Pollen spectra reflect an environment strongly transformed by anthropogenic activities, with a reduced tree cover and wetlands, and an intensive use of the land with crops and pastures testifying to the level of complexity of the agrosystem. The most significant environmental changes occurred during the last phase of occupation of the settlement, when a reduction of wet environments and the introduction of less demanding types of cereals about water supply was documented because of drying up of the soils. However, despite they were so close and quite similar in the chronology, they give interesting information on some spatial differences into the site, especially interpretable as indications of the distribution of cereal crops and the areas used for processing raw materials. In the well 6170, which was located inside the moat itself, few cereals percentages testify the presence of cereal fields in the area, conversely the high amount of cereals documented for the well 2106, which was located near the palisade of the settlement, suggests that plant processing had

occurred quite close to this well, or even the use of that to receive waste of the processing of cereals. A limited recovery of forest cover is also observed in phases characterized by a less stable human presence after the abandonment of the site, mainly due to grazing activities that seem to represent the main type of land use. A further reduction of the tree cover is also observed in the Middle Ages, probably related to alluvial phases attested by the increase in hydro-hygrophytes.

The new information obtained from the palynological analysis from the infilling of the wells, compared with those from the sequences of the moat VP/VG-II and VP/VG-III, allows to reconstruct with further detail the environmental transformations and land use at the end of the parable of the Terramare culture and after the abandonment of the Terramara S. Rosa di Poviglio. The data presented in this chapter provide an opportunity to correlate pollen data from the cores with extraordinary high-resolution sequences in which anthropogenic-induced environmental changes occurred during the Middle and Recent Bronze Age in the Po Plain. The general reconstruction of the landscape between BM3 and BR1/BR2 described in this chapter perfectly coincides with the image obtained from the analysis of the cores (pollen subzone 4b and 4c) which reflects the same main environmental transformations albeit with less stratigraphic detail:

- forest cover dropped quite sharply in the Recent Bronze Age;
- hygrophilous woods declined in the last phases of the settlements, when few evidence of wet environments suggests a certain diffused aridity;
- agricultural practices (especially cereal cultivations) were widespread in the area without interruptions during the period of occupation of the site;
- cultivated fields were probably located at a shorter distance from the site and the processing area of cereals may took place close and inside of the settlement;
- grassland and pastures were widespread especially since the Recent Bronze Age, and they continued to be the main type of land use for a long time (Cichorieae: 16% - VP/VG-II and VP/VG-III). The increase in open areas could be an indication of a reduction in soil fertility, as a result of the intense resource exploitation that has persisted on the same territory for hundreds of years;
- in the phase following the abandonment of the settlement, a slight recovery of the forest occurred with a new expansion of the oak wood;
- during the Middle Ages the reduction of the forest cover was probably connected to alluvial phases, attested by the increase in hydro-hygrophytes.

The SUCCESSO-TERRA Project: a Lesson of Sustainability from the Terramare Culture, Middle Bronze Age of the Po Plain (Northern Italy)

Cremaschi, M., Mercuri, A.M., Benatti, A., Bosi, G., Brandolini, F., Clò, E., Florenzano, A., Furia, E., Mariani, G.S., Mazzanti, M., Montecchi, M.C., Rattighieri, E., Rinaldi, R., Torri, P., & Zerboni, A. (2018)

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This work does not address aspects that emerged from the exclusive palynological analysis, but is dedicated to summary of the main objectives, the research strategy, and the future perspective of the SUCCESSO-TERRA Project (*Human societies, climate-environment changes and resource exploitation/sustainability in the Po Plain in the mid-Holocene: the Terramare culture*; 2017–2020; PRIN-20158KBLNB), an interdisciplinary research program aimed at reconstructing environmental changes and land use transformations that occurred during the development of the Terramare culture in the south-central Po Plain. “How can we mitigate the effects of climate change? How can our society develop towards models of sustainable development in the coming years?”. With these questions the text opens, immediately clarifying the final objective of the project to create a robust support of knowledge based on the study of the past from which plan reliable and responsible actions for the future.

The SUCCESSO-TERRA Project included three Bronze Age sites, among which the Terramara S. Rosa di Poviglio plays a key role because of the investigation strategy covers on-site/off-site integrated records that are useful to distinguish human pressure and impact at both a very local and regional scale. The palynological research presented in this thesis is part of the SUCCESSO-TERRA Project.

6 CONCLUSIONS AND PERSPECTIVES

The palynological analysis carried out in the Central Po Plain points out a remarkable complexity due to a fairly good floristic biodiversity and the ongoing cultural influence. The N-S3 core covers a chronological interval from the Late Pleniglacial to the Modern Age, while the palynological image of the present landscape was obtained from the analysis of three surface soil samples. The upper parts of the C-S1 and F-S2 cores, that have been analysed, start from the Lateglacial (intercepted by a single sample in the F-S2) and correlate continuously with the N-S3 sequence up to the most recent samples.

Despite the problems related to the fluvial context deposition (especially linked to the contribution of secondary deposition pollen and sometimes the occurrence of low pollen concentration), the three cores allow an impressive and reliable description of the vegetation transformations determined by natural and anthropogenic forces. The results obtained integrate the palaeoenvironmental and palaeoclimatic data already known for northern Italy, detailing the evolution of the environmental context at regional and local scale.

Different topics about both aspects strictly related to human choices and environmental features have been developed in this research. Among the key elements useful to highlight ecological processes, both the development of a palynological index of alluvial transport that considers the occurrence of pollen and Non-Pollen Palynomorphs of secondary deposition, and the systematic quali-quantitative analysis of *Rivularia* heterocysts have provided a valid support to the interpretation of pollen data with a local image of environmental changes.

Pollen spectra describe a framework in which the vegetation has evolved in relation to changes in climate and the spread of human activities. Humans seem to have exploited the environment and its resources according to its vocation and to their biological-cultural needs.

The following paragraphs will briefly summarize the main conclusions of this thesis about the reconstruction of vegetation and cultural evolution on a long-term perspective, and about the distribution of the vegetation features and types of land use during the Bronze Age.

6.1 THE LONG-TERM LANDSCAPE EVOLUTION

Three major chronological intervals were identified and discussed according to the main and most evident flora and vegetation changes.

Late Pleniglacial/Lateglacial (19,000–11,700 cal yr BP)

During the whole period the investigated area was characterized by open environments with shrubby-herbaceous communities with low floristic diversity. The area was affected by a continuous succession of flooding events that made the soil unsuitable for the formation of forest communities. The fluvial context was the main factor influencing the development of vegetation in the study area. The xerophilous component with *Artemisia*, *Amaranthaceae*, *Helianthemum*, and *Juniperus* type was present in the lowlands in patches only distributed at the edge of wetlands, and their extension was often influenced by the rapid expansion of wet environments. Wild plants of *Cannabis* probably were included in the same bush and in ruderal contexts. The large occurrence of open environment and the continuous renewal of meadows have probably favored the presence of grazing of wild animals also linked to the availability of water with the formation of unstable pools and streams connected to alluvial sedimentation conditions.

The spread of marsh and ephemeral pioneer meadows characterized the river margins and the entire surrounding area. The presence of freshwater environments favored the growth of hygrophilous herbs, including reeds, sedges, and cattails. Most of the lowland was probably dominated by the occurrence of wet meadows with perennial or annual species, adapted to wet and very wet soils, and to different water levels. *Echinochloa*, *Glyceria*, and *Setaria* probably took place together with *Mentha* type, *Stachys*, and *Ranunculus* type within the riparian habitats, which were the richest in biodiversity. The presence of colonies of cyanobacteria and other algae was favored in warmer periods. Scattered plots of hygrophilous trees found space in this environment periodically subjected to flooding events, with *Alnus* dominating in warmer phases and the expansion of *Salix* in the cooler ones.

Although the development of the arboreal-shrub component was limited in the study area, climatic conditions allowed the formation of small patches of forest in the more stable areas, although most of these presumably characterized the hillsides while only isolated trees dotted the plain. Mixed forests of *Betula* and *Pinus sylvestris* with the sporadic presence of *Picea* probably characterized the mountain slopes and marginal areas of the plain. The arboreal component referable to a more local pollen contribution reflecting the presence of small thermophilous patches with *Quercus*, and other components of the oak wood together with shrub and lianas formations of *Corylus*, *Prunus*, *Rosa canina*, *Cornus mas*, *Vitis*, and *Humulus*. Furthermore, some refuge stations with favorable microclimatic conditions in the hills or even closer to the site could have favored the occurrence of mixed woodland with some walnut and chestnut trees, possibly together with some wild olive specimens growing at distance.

However, changes in the local vegetation were not only related to fluvial events but expressed a close relationship with the rapid climatic changes that occurred throughout the Lateglacial. Rapid expansion of the xerophilous and heliophilous elements were related to some rapid changes towards drier and colder phases that limited the increase in forest cover. However, climatic conditions were not too rigid for the vegetative phase and flowering of thermophilous and mesophilous trees and shrubs.

Early / Middle Holocene (11,700–8200 cal yr BP / 8200–4200 cal yr BP)

The beginning of the Holocene was characterized by a change in the vegetation structure and composition in relation to the establishment of better climatic conditions concerning first the rise of temperature. However, the woody component continued to characterize limited areas of the plain, where extensive grasslands remained the dominant formation during the Preboreal. The forest that began to expand was mainly represented by mixed oak wood with scattered and not very extensive communities. At the same time, *Pinus* probably also grew within these forested patches in the plain and in the surrounding hillsides, although never with a very extensive occupation in the study area. The rapid increase in biodiversity has involved not only the diversification of the flora but also the increasing presence of fungi and cyanobacteria colonies. As in the previous period, the presence of trees and shrubs was influenced by the proximity to the watercourse which determined large marshy areas with the occurrence of hydrophytes (e.g., *Myriophyllum*). Hygrophilous trees began to expand later than the mixed oak wood in accordance with the regional composition (Accorsi et al, 1999) but were probably dominant among the forest cover in the study area, which was still characterized mainly by riparian vegetation.

Broadleaved trees suddenly spread from the Boreal onward, starting with the rapid increase in broadleaved *Quercus*. The oak wood maximum spread was reached during the Atlantic testifying a trend towards increasing also in moisture availability. The constant presence of atmospheric moisture also favored the expansion of *Abies* and *Fagus* especially in hilly and higher altitudinal belts, but with presence also in some lowland stations. The oak-hornbeam woodlands (*Querco-Carpinetum boreoitalicum* Pign. 1953) represented the palaeoclimax vegetation of the Po Plain (Bertolani Marchetti, 1969-1979). However, the hornbeam seems not to have had a dominant role in the study area probably due to its high soil requirements, which in the Central Po Plain often continued to be poorly drained. For this reason, the typical vegetation formations of the plain, the oak-hornbeam, in the study area was mainly represented by its hygrophilous variants with the dominance of *Ulmus* and *Fraxinus excelsior* type. *Tilia* was abundant in the Boreal-Atlantic (Accorsi et al, 1999) and was present with dense populations in the study area as well, reflecting its tolerance of shade and the capacity to grow in dense forests in association with other species. The

expansion of some components of the mixed oak wood, including *Ostrya*, seems to have been influenced by the presence of human populations since Neolithic times together with the selection by grazing and fire.

However, the landscape was still predominantly natural during these Holocene phases mainly characterized by the expansion of forest cover. The factor that most limited the continuity of this expansion in the study area was the presence of the watercourse, which usually opened gaps in the forest cover. The renewal of forest communities favored the expansion of wetlands and grassland composed mainly by Poaceae and other herbs that can colonize temporarily emerged areas (e.g., Amaranthaceae, *Plantago*, Brassicaceae, Caryophyllaceae, *Trifolium* type, *Potentilla* type, and *Mentha* type).

Late Holocene (from 4200 cal yr BP onwards)

During the Subboreal the environment began to be influenced by the anthropic dynamics that were becoming more and more widespread in the Po Plain. In a general context largely shaped by human activities, the climatic component also contributed largely to the evolution of vegetation with a transition from wetter to drier climatic conditions (Sadori, Jahns, & Peyron, 2011). Semi-open and open areas became common in the study area, as well as in a large part of the region (Accorsi et al, 1999; Mercuri et al, 2012). Shrubs found suitable light conditions in cleared patches of forest. A widespread forest management has modified the natural dynamics of forest cover in the plain, where the selection and maintenance of trees and shrubs valuable for edible fruits (e.g., *Juglans*, *Prunus*, *Rosa*, *Cornus*, and *Vitis*) also played a key role in the development of a cultural landscape. Grasslands, arid meadows, and pastures together with patches of cereal cultivations replaced most of local wetlands, that were subject to a redistribution in the territory related to the planned management of the river network for the use of water resources for irrigation. Together with the spatial reallocation of riparian vegetation and its gradual decline with the establishment of more arid climatic conditions, the composition of the mixed oak wood began to change especially starting from the Bronze Age. *Tilia* populations were not favored from the continued openness of the forest cover, while *Carpinus betulus* and *Ostrya carpinifolia* probably were cared by the population for fuel and fodder as plants that tolerate cutting well.

In general, a scarce recovery of the forest cover characterized the study area after the intensive and permanent exploitation of the territory by the terramara population. Not only the presence of mixed oak woodland remained limited in the lowlands, but also *Abies* and *Fagus* populations moved to higher altitudinal belts. The presence of patches of hygrophilous wood represented the main component of the forest cover, showing that the territory continued to be poorly drained. However, human action has clearly influenced vegetation composition, which in more recent times has become characterized by the progressive expansion of *Salix*. The presence of non-native plants, although it had begun in the Roman Period (e.g., with the introduction of *Platanus* as one of the shade plants common in gardens of Roman villas), began to widespread in the study area especially starting from the Modern Age. This change in flora composition concerned both woody (e.g., *Morus nigra*) and herbaceous components (e.g., *Zea mays*).

Today the landscape is totally devoted to industrial and agricultural productions, which are interspersed with densely populated urban areas. Vegetable and forage crops represent most of the agrarian activities together with cereal cultivations. Even today, the water table reaches the arable layer in the winter months and fertilization practices are largely applied to restore the essential nutrients for plant growth to the soil. Ornamental plants are commonly planted in private gardens, avenues, and urban parks (e.g., *Quercus ilex* type, *Juniperus* type, and *Cedrus*) and have almost completely replaced the natural vegetation of the territory that remains mainly limited to wetlands, clipped hedges, and thickets at the edge of crops.

6.2 HUMANS AS SHAPING AGENT OF THE LANDSCAPE

For a long time, humans have interacted in a synergistic way with its surrounding environment, adapting his needs to what natural resources could offer them. However, a gradual transition can be observed from human populations who have adapted to the changing environment to societies modelling the environment on their own culture (Mercuri, 2009). The ability and the need to modify and shape the environment has increased rapidly and now results in many different landscapes. Cultural evolution has always guided human behavior by striving for the best pattern of subsistence and adaptation. The different strategies adopted by populations over time result from a trade-off between the availability of natural resources, cognitive skills, technical ability and cultural identity, natural cycles of ecosystem regeneration, and environmental changes occurring on local and regional scales. The perspective given by the palaeoecological approach helps to improve the knowledge on how and how much human behaviour acted on environmental transformations over a long time.

In this case, palynological analysis on a long-term perspective has allowed to highlight subsistence and cultural changes that have triggered new strategies of exploitation of the resources and land use.

When did humans begin to act as an environmental agent? Has the relationship between human populations and the environment immediately upset the nature system? Is culture compatible with the nature system?

Palynological data clearly showed how the vegetation was still completely natural during the Early Holocene, while it began to be modified by human activities starting from the Neolithic. The local dynamics of the vegetation during the Early Holocene are referable to the occurrence of natural and climatic factors and not to the action of human populations that were probably still very limited in the territory. It is difficult to understand if the study area was already the scene of human occupation in this period, since synanthropic plants were scarcely diffused and the forest cover, especially composed of mixed oak wood, began to spread in the areas previously occupied by wetlands.

The human influence on the environment was still scarce in the study area at the time of the establishment of Early Neolithic farming communities. The low presence of human populations probably depended on the distribution of soils suitable for agriculture (Biagi, Cremaschi, & Nisbet, 1993). The area was characterized by poorly drained soils and large areas occupied by wetlands. A large part of the forest cover has been replaced by the expanding of hygrophilous herbs in accordance with increasing humidity conditions. Synanthropic plants in the area were still scarce as evidence of short-period occupations by Early Neolithic populations in natural open areas along the watercourses (Nisbet, 2013).

The sudden increase in the human pressure on the study area can be traced from greater continuity of cereal pollen, the spread of weeds, and synanthropic plants starting from the Middle and Late Neolithic.

The landscape largely changed in this period, although forest cover seems to be little affected by human activities that also involve the expansion of crops and pastures. The main change in vegetation was related to the rapid decline of hygrophilous herbs that left space to new herbaceous plant communities also dominated by API group with the increase in Cichorieae, *Plantago*, and cereals. Among crops, cereals of the *Hordeum* group and *Avena/Triticum* group played a key role in this period, which intercept the Holocene Climate Optimum with temperate/warm and wet conditions suitable for the agriculture. Furthermore, the presence of Fabaceae in the territory increased, also linked to the role of fodder crops among which *Trifolium* type had a dominant role. Common weeds of cereal crops (e.g., *Centaurea nigra* type and *Papaver rhoeas* type) began to spread in the area. Other synanthropic plants also became widespread including trampling indicators and ruderal/nitrophilous species (e.g., *Amaranthaceae*, *Rumex*, and *Cannabis*), together with herbs typical of pastures and meadows (e.g., *Trifolium* type, *Potentilla* type, *Ranunculus* type, *Apiaceae*, and *Brassicaceae*). The thinnest part of the oak wood was occupied by shrubs and plants that provided fruits (e.g., *Prunus* and *Rosa*). The presence of these plants became more and more widespread in the area and suggest a possible care of these plants by people. Among these, also the spread of *Vitis* and the abundance of *Corylus* were probably related to humans collecting fruits and disseminating seeds during the Neolithic.

A series of floods in close succession led to an imbalance in the forest communities that were largely replaced by a new expansion of wetlands at the time of the transition from the Neolithic to the Copper Age. However, human presence at local scale seems to become more continuous and with significantly greater impact on vegetation dynamics. The progressive increase in open areas was probably related to an extensive use of the slash and burn practices (Cremaschi & Nicosia, 2012; Cremaschi, Nicosia, & Salvioni, 2011), although this evidence is not supported by microcharcoals analysis that have not yet been done for these sequences. The comparison between the pollen spectra of the three cores and those of Via Tolara, a Copper Age site located at 5 kilometers from Poviglio, shows that lowland forests still covered large areas of the plain and that open areas were mostly located near settlements. The forest margins were characterized by the presence of species that provided a valuable contribution to the human diet, such as *Prunus*, *Rosa*, and *Sorbus*. *Juglans* spread through the territory together with *Vitis*, both probably exploited and cared by the populations. Cereal cultivations became more widespread than in the previous period, well represented especially by the *Hordeum* group. Furthermore, several meso-xerophilous herbs began to colonize the study area. Among them, plants typical of pasturelands (e.g., *Asteroidae*, *Cichorieae*, and *Trifolium* type), pioneering herbs (e.g., *Amaranthaceae*), and weeds of disturbed places (e.g., *Polygonum aviculare* type and *Solanum nigrum* type) quickly replaced the woody components. A mixed subsistence strategy was probably adopted by the Copper Age populations, which based their economy on a pastoral component alongside cereal cultivation and the collection of wild fruits.

The drastic reduction of the forest cover marked the beginning of the Middle Bronze Age, when the amount of timber required for the construction of large settlements was the main cause of the extensive deforestation of the Po Plain. However, trees and shrubs supplying fruits expand in the territory during the first phase of life of the Terramara S. Rosa di Poviglio. The wood exploitation together with the intensive agriculture, pastoralism, and the planned use of water resources shaped the landscape of the study area. Compared to previous periods, it is evident that this civilization was able to implement a skilled environmental management plan by making a comprehensive use of available resources (Cremaschi, 2009b; Cremaschi et al, 2016).

However, a changing trend from wetter to more arid conditions must have conditioned the habits of the population that, e.g., increases the variety of cereals with the selection of those that need less water intake. Xerophilous herbs replaced most of the hygrophilous ones and began to spread within dry grassland during increasing climate aridity. According to this, hygrophilous trees steadily declined at 3200 yr BP.

The radical modification of the landscape of the Po Plain was the most evident consequence of the cultural changes taking place from the Middle to the Recent Bronze Age. It represented the development of a society modelling the environment on their own culture. The human presence that persisted in the same territory and the spread of human activities throughout the plain produced almost irreversible effects on the environment even after the abandonment of the settlements by the population. The slow recovery of the nature system highlights the long-term incompatibility of the extensive exploitation of resources adopted during the Bronze Age which, at a time of negative climate factors, led to the crossing of the environmental resilience threshold.

The vocation of the area for agricultural activities was soon evident even in later times for Roman colonies, which soon reorganized the entire territory with a new and extensive rural system of the countryside. In particular, most of the subsistence activities of the Roman villa settled in the study area seems to involve cereal crops.

6.3 A DEEPER LOOK INTO THE LAND USE OF THE TERRAMARA S. ROSA DI POVIGLIO

The economy and the subsistence of the Terramare settlements was based on the intensive agriculture and livestock breeding, that have occupied the space opened as a result of an extensive deforestation and management of the river network. The exploitation of resources had to be very dynamic and conditioned both by natural factors (e.g., climatic and environmental variations) and by social causes (e.g., increased or decreased request of cereals and other raw material). In addition, the dynamics of individual sites often do not allow to obtain a single model of economic exploitation (Bernabò Brea, 2009; Cremaschi, 1997).

The research period carried out at the University of Bergen (Norway) provided a valid contribution for the quantitative reconstruction of vegetation on regional and local scale, through the possibility to compare different information from many sites. Many aspects are still under discussion and surely further attempts must be considered for the formal applicability of the algorithm in a (Mediterranean) study area that is not the one for which it was developed. However, the results obtained provide a further element on the land management adopted by different settlement, such as the space dedicated to cereal crops and the exploitation and management of the wood.

The chosen combination of pollen productivity estimates (PPEs), which is the main parameter needed to apply the Landscape Reconstruction Algorithm (LRA), appears to be effective for the study area. The application of the REVEALS model (Regional Estimates of VEgetation Abundance from Large Sites; Sugita, 2007a) using pollen data from the three cores describes an open landscape during the Middle and Recent Bronze Age. Most of the plain was characterized by cereal fields, grasslands, wetlands, and wet meadows interspersed with settlements. The scarce presence of the arboreal component is well described by the local reconstruction obtained from the application of the LOVE model (LOcal VEgetation Estimates; Sugita, 2007b) using pollen data from the Terramara di Montale and that of S. Rosa di Poviglio. *Quercus* was still quite widespread in the territory, but not in the area surrounding the settlements where probably the populations maintained mostly the shrub component to intersperse the large open spaces. The model estimated a relevant source area of pollen (RSAP) of about 2700 m for each site, which can presumably represent the area of influence (the territory visited every day by the inhabitants; Mercuri et al, 2019).

Carpinus betulus and *Ostrya carpinifolia* were presumably maintained near the settlements. The presence of these two species distinguishes the sites considered. This may be related to a cultural choice of the populations, but more likely their presence was related to the ecological features of these trees. Among them, the ability to grow in clay soils of *Ostrya carpinifolia* favored its spread in the Poviglio fluvial context. Indeed, the short tolerance of water stagnation for *Carpinus betulus* presumably limited its growth in Poviglio and favored its spread in Montale. The presence of the watercourse near the Terramara S. Rosa di Poviglio also favored the presence of a riparian mixed forests with *Ulmus* and *Fraxinus excelsior*, even if also this component was probably managed and thinned out by the population to allow the continuous access to the river network.

The development of human environments is well attested in both sites, where wet meadows have been replaced through the permanent transformation of soils with increasing arid conditions. A different management of the fields distinguished the two settlements probably for reasons related to soil quality and structure. A better drained soil in Montale favored cereal production on which much of the economy was based (Mercuri et al, 2006a, 2006b). Most of the open areas were characterized by dry meadows and pastures in Poviglio and less space seems to have been devoted to cereal fields.

Specific distribution of human activities in the surrounding of the Terramara S. Rosa di Poviglio

As expected, the study of the three sequences collected at different distances from the site provided quite different results in term of anthropogenic influence and land use distribution.

Pollen analysis suggests that it is possible to confirm the initial hypothesis of this research related to less direct and persistent human pressure at a greater distance from the archaeological site. The degree of human impact at different distances was evaluated by comparing the percentages of the API group, which show a greater presence of the synanthropic component closer to the site. However, fields and pastures reached distances of at least half a kilometer north to the settlement. Most of the cultivated fields took space close to the site, reasonably so that the production area was close to the processing area, which presumably was inside of the settlement (Florenzano et al, 2021a). In addition to being more abundant, crops placed near the site were also more diversified including cereals, Fabaceae, and fiber plants. Cereals were mainly barley (represented by the *Hordeum* group), but also cultivation of wheats (*Avena/Triticum* group and *Triticum aestivum/T. spelta*) were present in the surrounding area. The distribution of barley fields was almost ubiquitous but with lesser extent at greater distances from the site, where more space was occupied with wheats cultivation. Besides pollen, the millet cultivation was supported also by the combined evidence of miliacin molecular biomarker. *Panicum miliaceum* spread during the Bronze Age in the Po Plain (Filipović

et al, 2020) and it was probably introduced by the population of the Terramara S. Rosa di Poviglio during drier phases or sown at the end of the season in the same fields where other cereal crops have already been harvested.

Forage crops were present close to the site together with cereal fields. The simultaneous presence of Fabaceae and cereal pollen grains suggests a complex and diversified land use including both intercropping practices and crop rotation. In addition to these, *Cannabis* cultivation could have been present near the site close to the sampling point of the N-S3.

Cichorieae colonized the fallow fields cyclically as pioneer plants in dry meadows resulting from continued human impact. The scarce presence of coprophilous fungi does not allow to consider Cichorieae as indicators of pasture for sure. However, arid grassland dominated by nitrophilous herbs community and herbs common in pastures (e.g., Asteroideae, *Ranunculus* type, and *Potentilla* type) were widespread at a greater distance from the site, suggesting this space as most suitable for herding than cultivation. However, a cyclical rotation between fields and pastures is not excluded.

Prunus represented the most consistent shrub component together with *Corylus*, which could be cared as single elements even in the middle of the fields. *Cornus* also largely represented the shrub component selected by the population close to the settlements, while *Vitis* spread close to the moat associated with the riparian communities. *Juglans* and *Rosa* probably grew at the edge of the wetland. As mentioned before, *Ostrya* represented a particularity of the site, and pollen data suggest that this species was present mainly a short distance from the settlement.

6.4 CONCLUSIVE REMARKS AND FUTURE PERSPETIVES

The new palynological information provided by this PhD research points out the high level of complexity that had characterized the relationships between human populations, climate factors, and environmental changes, thus shaping the Central Po Plain landscape. The results obtained and the deepening of many topics for the purposes of the research represent a good opportunity to the implementation of knowledge, not only from the palynological point of view but also for multidisciplinary palaeoenvironmental studies. Starting from this research, which better clarify vegetation and cultural dynamics over the long term, other specific analyses can be developed considering the valuable archive of palaeoenvironmental information that these sequences represent. The support of a more robust chronology and geochemical proxies will surely provide additional elements of analysis and good control of the many topics already investigated. In order to obtain a more complete view of the environmental changes that have occurred in the study area, new information can be provide by microcharcoals analysis useful for the interpretation of local and regional vegetation transformation. Last but not least, a diversified analysis of molecular biomarkers specific for distinct vegetation types may provide further valid support to the pollen data and new perspective to be developed.

The data emerging from this palynological investigation is further evidence that the prolonged and intense exploitation of the territory transformed the natural environment into a cultural landscape. The important role of local differences adds key insights to the general reconstruction. It has also emerged as indication of cultural choices based on local environmental features and need for adaptation. The origins of the current landscape certainly have deep roots, probably linked to the continuous anthropic pressure that characterized the Middle and Recent Bronze Age. However, the environment has also undergone significant transformations in later times reflecting cultural evolution, choices, and adaptations to different climatic and environmental conditions. What is evident is that the current landscape is the result of long-term transformations among which the effects of culture became almost irreversible as a consequence of human permanence.

The image below (Fig. 71) represents the environment surrounding the Archaeological park and open-air museum of the Terramara of Montale during the summer months. The spread of *Cichorium intybus* L., common in uncultivated grassland and roadsides, immediately reconnects this landscape to what might have been widespread at the end of the production season in the area near the Terramara S. Rosa di Poviglio. *Could the current landscape be characterized by traces of what began in the Bronze Age?*



Figure 71. Landscape surrounding the Archaeological park and open-air museum of the Terramara of Montale. Images of 3rd July 2021, E. Clò.

Not only the current landscape seems to be characterized by actions that began during the Bronze Age, but also the human behavior more and more profit-oriented looks very similar to the strategies of subsistence adopted by the Terramare people. Every landscape is different based on the needs of the populations.

What do we observe in the current landscape (Fig. 72)? Fallow fields and long artificial canals that cross large open areas and connect to the river network. At greater distance an industrial hub borders a thin strip of riparian vegetation that reminds us of what the landscape might have been like before.

So how to proceed? Which landscape to enhance? Which environments to preserve? When solutions are needed, we can look to the past. We must convincingly begin to use the past to change the future, evaluating the choices made previously and re-proposing them in a different way.



Figure 72. Landscape surrounding the Terramara S. Rosa di Poviglio. Images of 26th October 2021, E. Clò.

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APPENDIXES

Figures of pollen and Non-Pollen Palynomorphs, and full text of connected research.

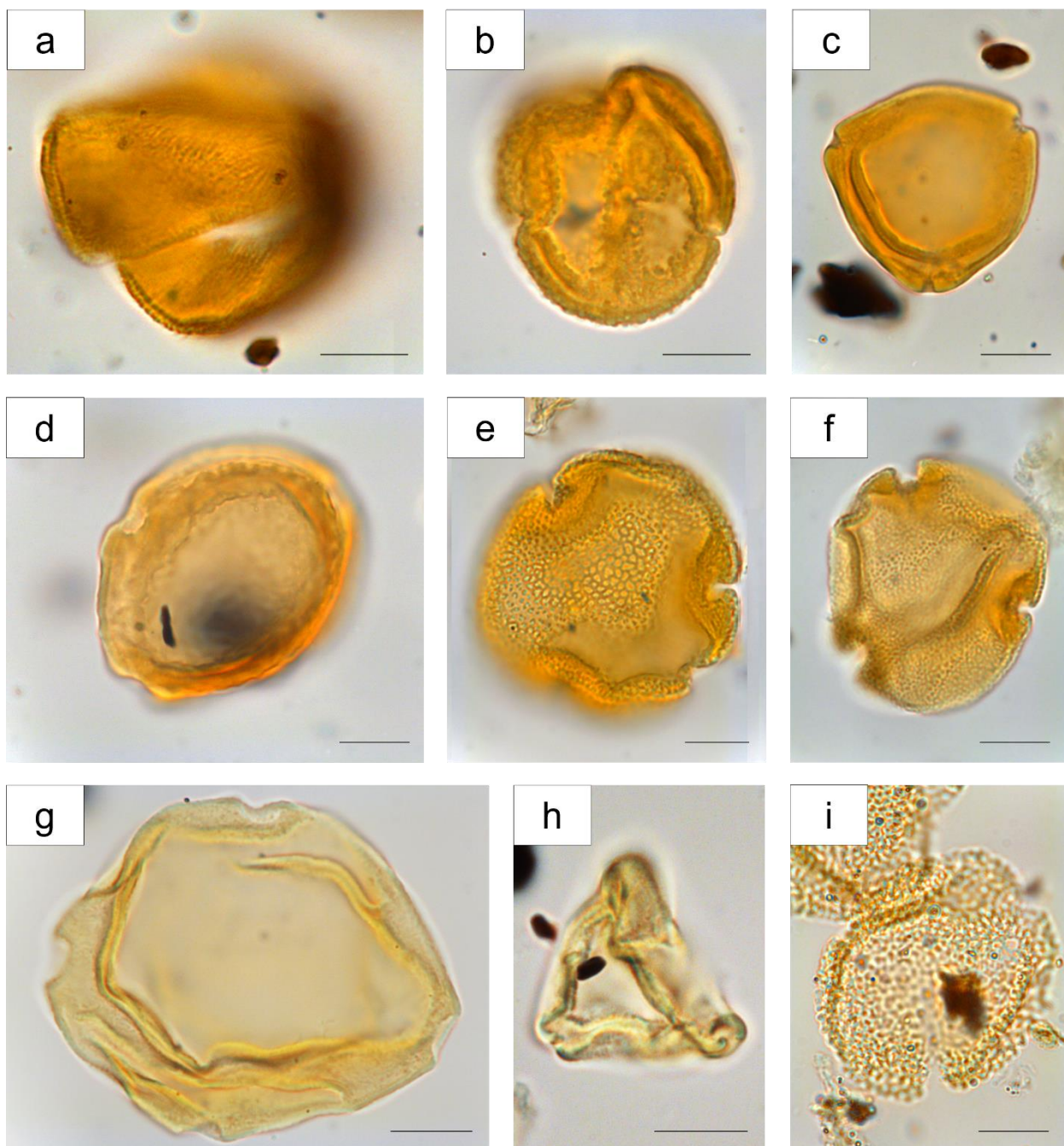


Figure I. Pollen: oak wood. a) *Acer campestre* type (35 µm); b) broadleaved *Quercus* (32 µm); c) *Corylus avellana* (30 µm); d) *Ulmus* (38 µm); e) *Tilia cordata* (43 µm); f) *Tilia platyphyllos* (36 µm); g) *Carpinus betulus* (51 µm); h) *Ostrya carpinifolia*/*Carpinus orientalis* (22 µm); i) *Fraxinus excelsior* type (40 µm). The scale is 10 µm.

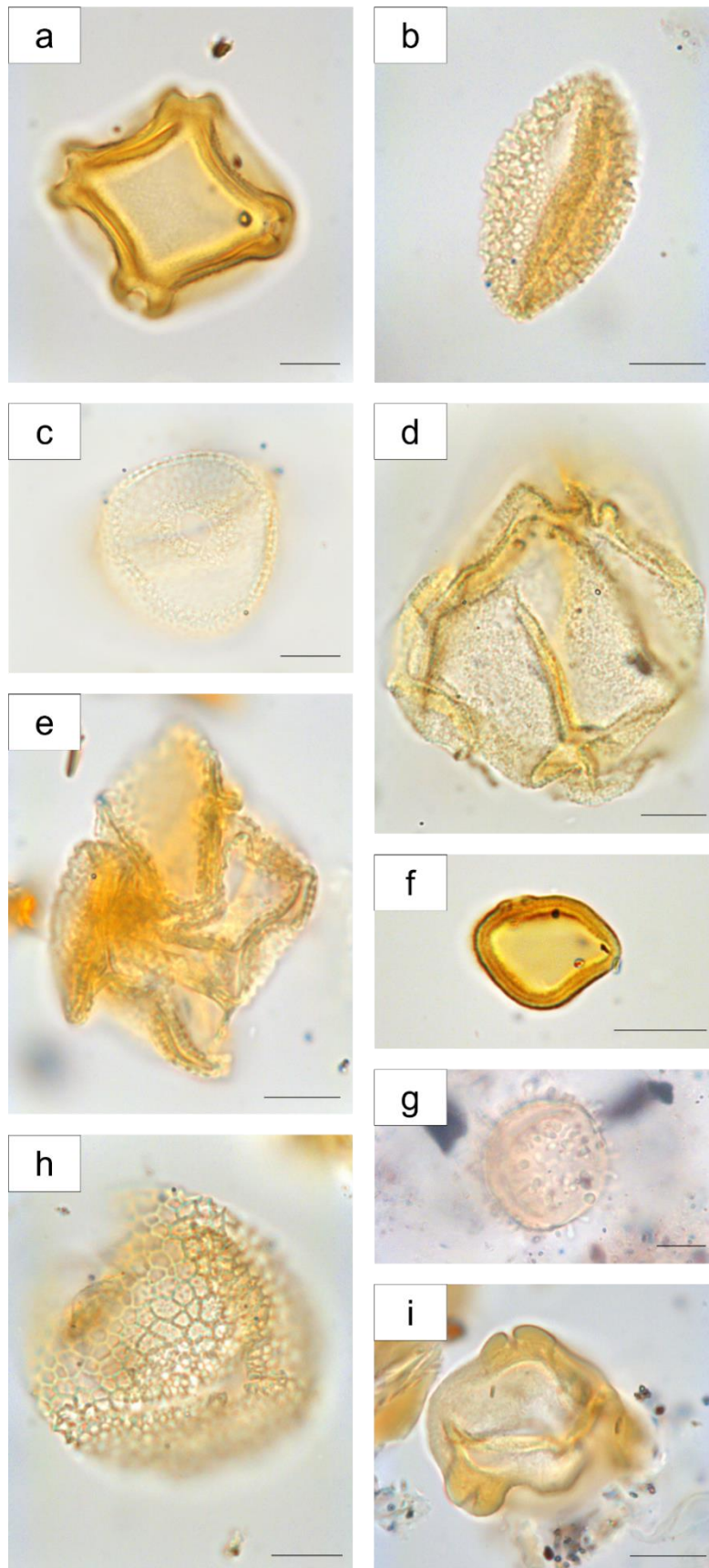


Figure II. Pollen: wet environments. a) *Alnus* (34 μm); b) *Salix* (34 μm); c) *Sparganium emersum* type (30 μm); d) Cyperaceae (49 μm); e) *Typha latifolia* type (43 μm); f) *Phragmites* (16 μm); g) *Nymphaea alba* type (25 μm); h) *Butomus umbellatus* (40 μm); i) *Myriophyllum* (30 μm). The scale is 10 μm .

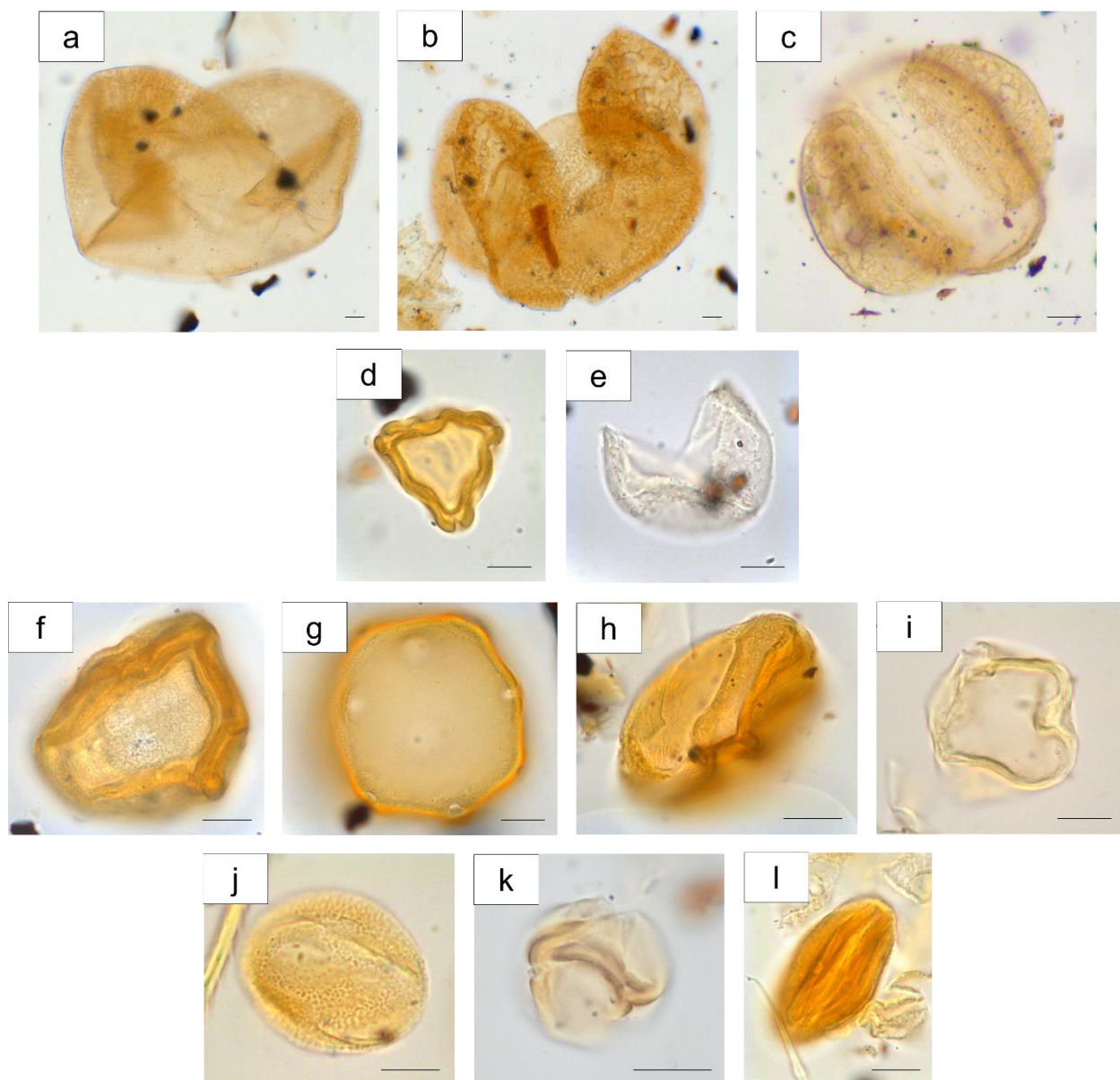


Figure III. Pollen: saccate pollen grains and other woody plants. a) *Picea* (156 μm); b) *Abies* (170 μm); c) *Pinus* (75 μm); d) *Betula* (26 μm); e) *Juniperus* type (34 μm); f) *Fagus sylvatica* (45 μm); g) *Juglans* (45 μm); h) *Prunus* (41 μm); i) *Pyrus* (28 μm); j) *Sambucus nigra* type (26 μm); k) *Cornus mas* (22 μm); l) *Vitis* (33 μm). The scale is 10 μm .

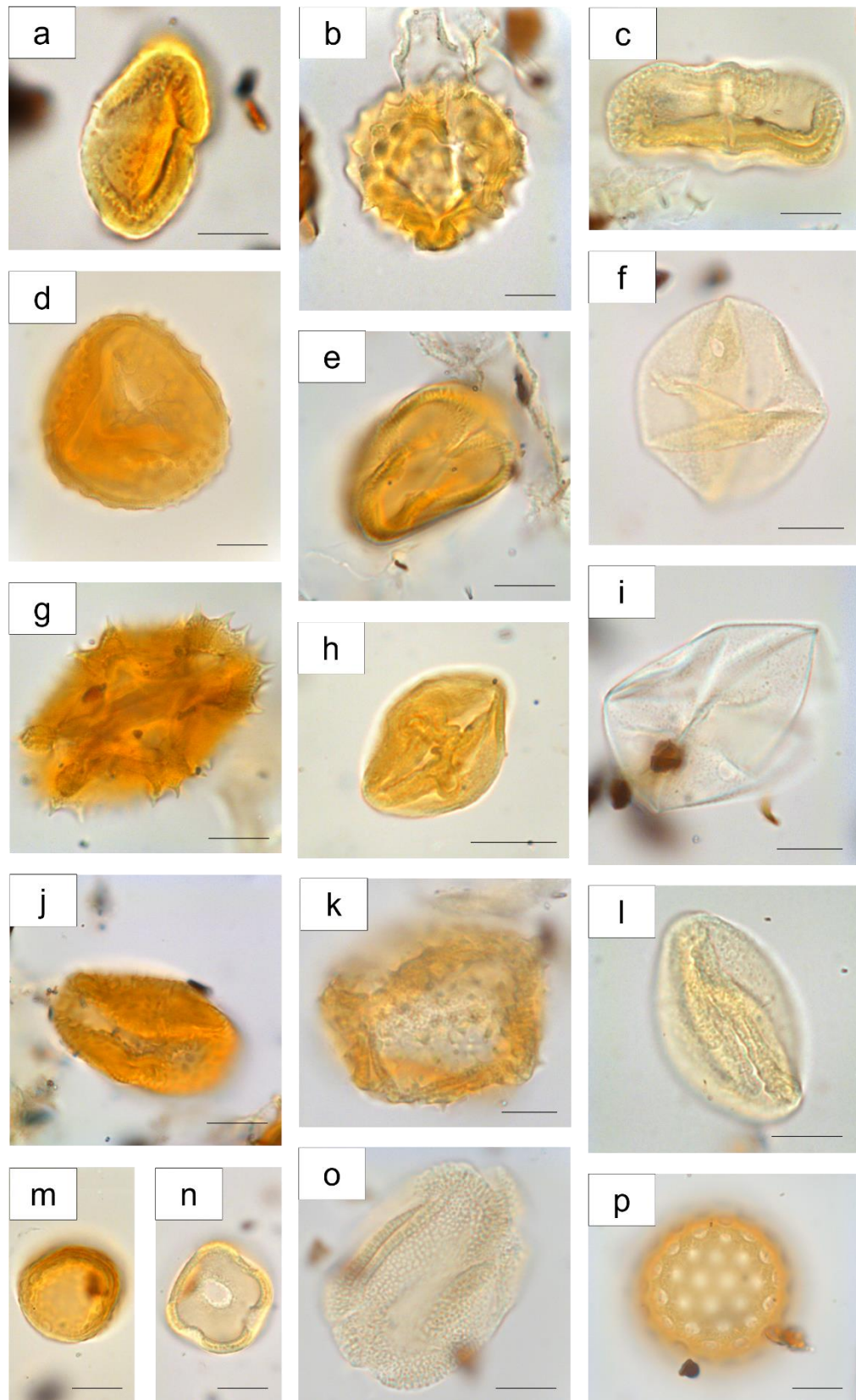


Figure IV. Pollen: herbs. a) *Artemisia* (28 μm); b) *Aster* type (32 μm); c) *Apiaceae* (38 μm); d) *Centaurea nigra* type (35 μm); e) *Aphanes* type (31 μm); f) *Poaceae* wild grass group (31 μm); g) *Cichorieae* (43 μm); h) *Potentilla* type (22 μm); i) *Cannabis* (34 μm); j) *Trifolium pratense* type (32 μm); k) *Valeriana officinalis* type (43 μm); l) *Ranunculus* type (33 μm); m) *Plantago* (22 μm); n) *Thalictrum flavum* type (21 μm); o) *Mentha* type (40 μm); p) *Amaranthaceae* (29 μm). The scale is 10 μm .

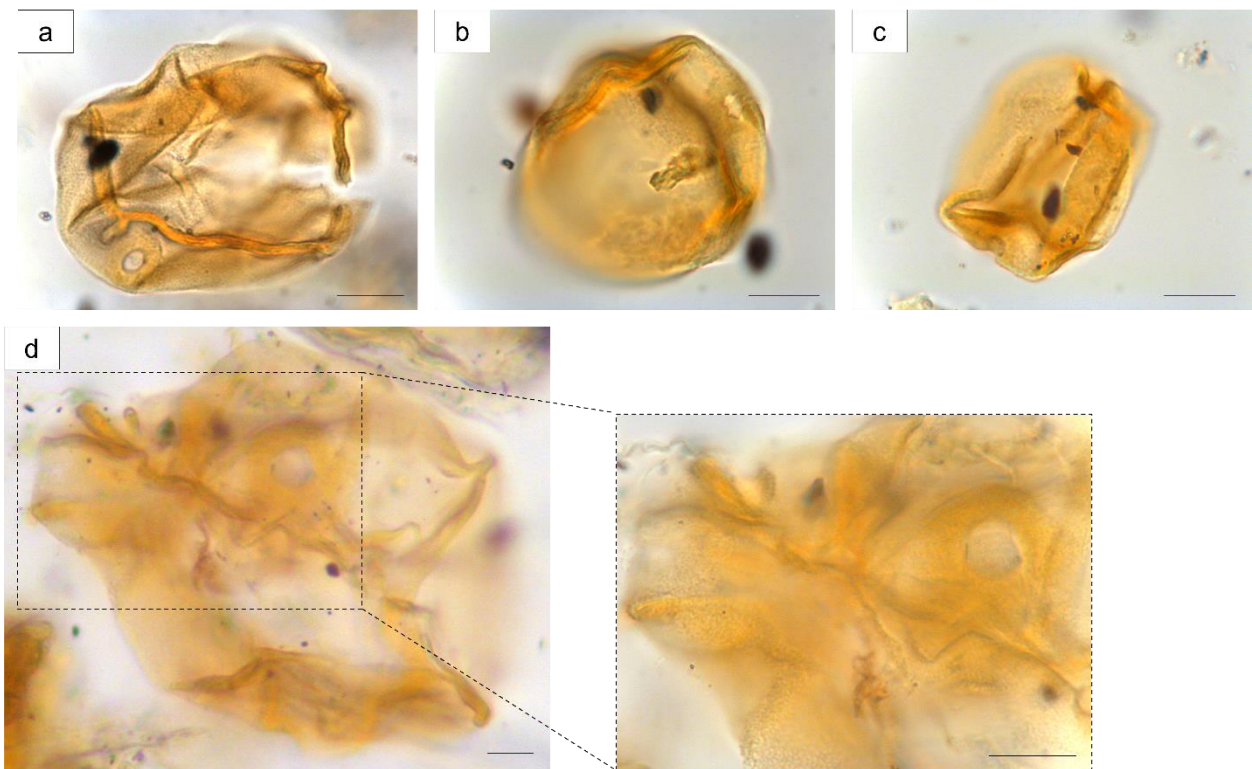


Figure V. Pollen: cereals. a) *Avena/Triticum* group (51 μm); b) *Hordeum* group (40 μm); c) *Panicum* s.l. (37 μm); d) *Zea mays* (101 μm diameter, and 18 μm porus plus *annulus*). The scale is 10 μm .

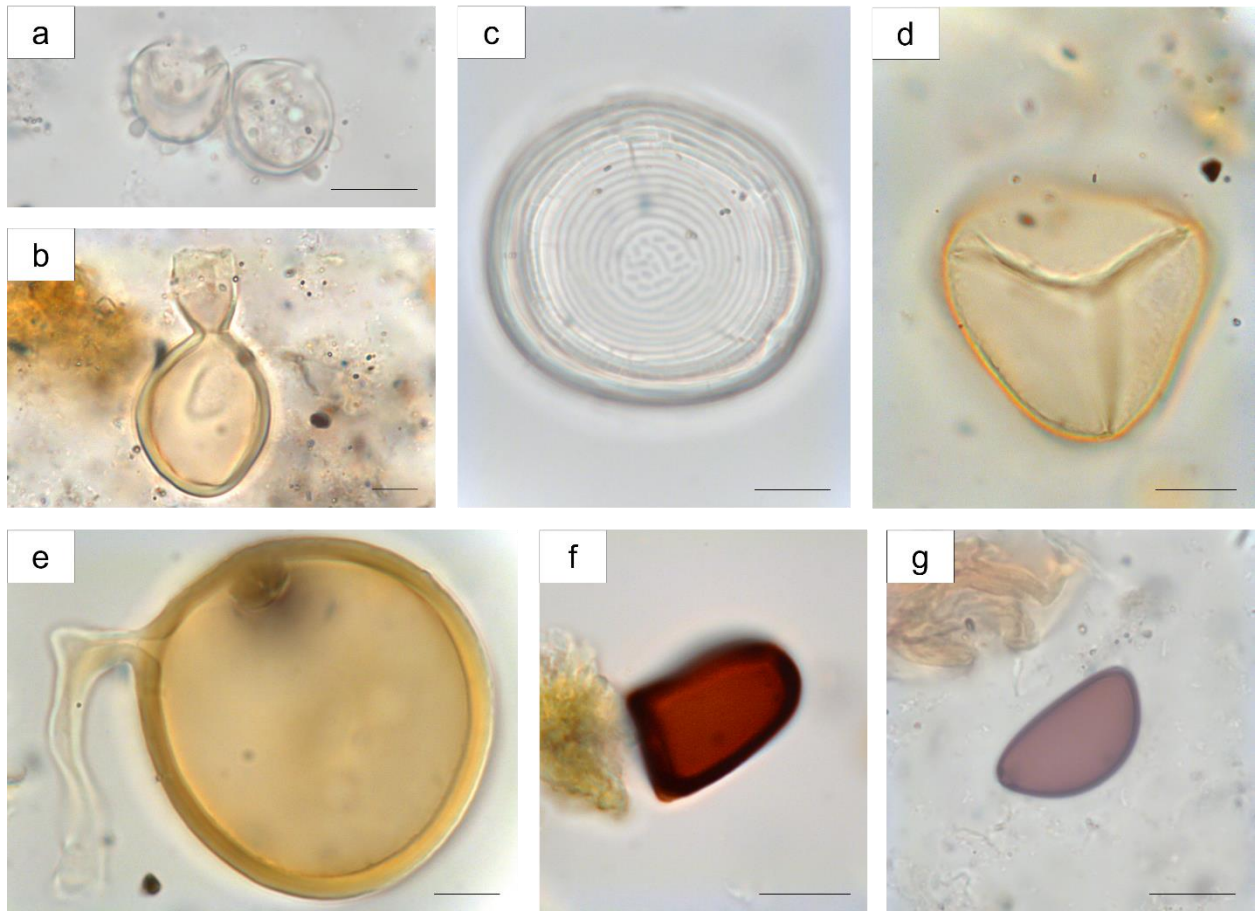


Figure VI. Non-Pollen Palynomorphs. a) Chrysophyceae statospore (14 μm); b) *Rivularia* type (33 μm); c) *Pseudoschizaea* (41 μm); d) *Pteridium* (33 μm); e) *Glomus* (54 μm); f) *Sporormiella* (20 μm); g) *Sordaria* (20 μm). The scale is 10 μm .

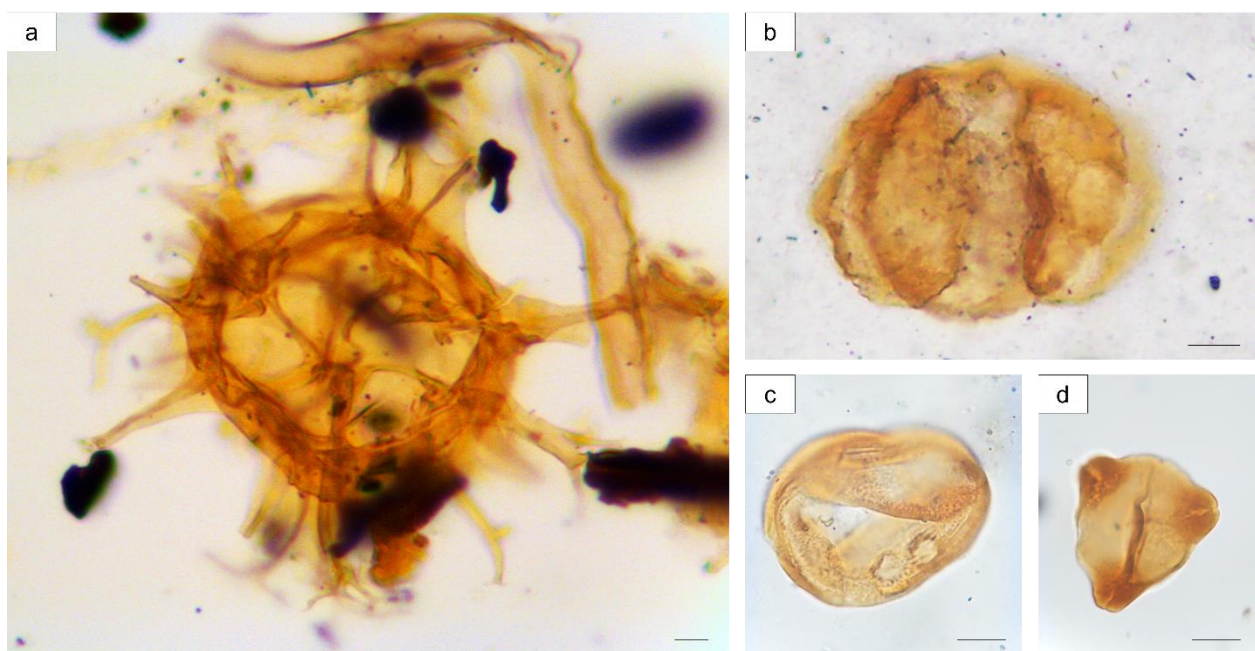


Figure VII. Reworked. a) Dinoflagellate cysts (109 μm); b) Saccate pollen grain (62 μm); c) *Corollina* (40 μm); d) *Normapolles* (31 μm). The scale is 10 μm .

Sharing the Agrarian Knowledge with Archaeology: First Evidence of the Dimorphism of *Vitis* Pollen from the Middle Bronze Age of N Italy (Terramara Santa Rosa di Poviglio)

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Article

Sharing the Agrarian Knowledge with Archaeology: First Evidence of the Dimorphism of *Vitis* Pollen from the Middle Bronze Age of N Italy (Terramara Santa Rosa di Poviglio)

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Abstract: The recovery of inaperturate pollen from functionally female flowers in archaeological layers opens the question of a possible pollen-based discrimination between wild and domesticated *Vitis vinifera* in prehistoric times. Pollen analysis applied to archaeology has not routinely considered the existence of pollen dimorphism in *Vitis*, a well-known trait in the field of agrarian studies. Therefore, the inaperturate shape of grapevine pollen is ignored by studies on the archaeobotanical history of viticulture. In this paper we investigate pollen morphology of the domesticated and wild subspecies of *V. vinifera*, and report the first evidence of inaperturate *Vitis* pollen from an archaeological site. We studied exemplar cases of plants with hermaphroditic flowers, belonging to the subspecies *vinifera* with fully developed male and female organs, cases of dioecious plants with male or female flowers, belonging to the wild subspecies *sylvestris* and cases of *V. vinifera* subsp. *vinifera* with morphologically hermaphroditic but functionally female flowers. The pollen produced by hermaphroditic and male flowers is usually trizonocolporate; the pollen produced by female flowers is inaperturate. This paper reports on the inaperturate pollen of *Vitis* found in an archeological site of the Po Plain, Northern Italy. The site dated to the Bronze Age, which is known to have been a critical age for the use of this plant with a transition from wild to domesticated *Vitis* in central Mediterranean. Can the inaperturate *Vitis* pollen be a marker of wild *Vitis vinifera* in prehistoric times? Palynology suggests a possible new investigation strategy on the ancient history of the wild and cultivated grapevine. The pollen dimorphism also implies a different production and dispersal of pollen of the wild and the domesticated subspecies. Grapevine plants are palynologically different from the other Mediterranean “cultural trees”. In fact, *Olea*, *Juglans* and *Castanea*, which are included in the OJC index, have the same pollen morphology and the same pollen dispersal, in wild and domesticated plants. In contrast, the signal of *Vitis* pollen in past records may be different depending on the hermaphroditic or dioecious subspecies.

Keywords: grapevine; pollen morphology; inaperturate pollen; cultivars; archaeological site; OJC; dioecy; domestication; reproductive biology; viticulture; Emilia Romagna

1. Introduction

Vitis vinifera L. is a creeper species characterized by pollen dimorphism. This is well-known to scholars studying cultivars and vineyard productivity, but it is not generally known to palynologists working on the reconstruction of interlaced changes of environment and culture over millennia. This paper introduces the topic as a bridge between the agrarian

expertise on modern crops and archaeobotany exploring proto-viticulture. The research points out that pollen dimorphism must be taken into consideration during palynological analyses and may be of help in discriminating between wild and domesticated plants, in the right contexts of the past.

1.1. Pollen Dimorphism

Pollen dimorphism, which means that two pollen morphotypes are present in one species, is a well-known feature of several Spermatophytes that may have a different origin. The causes of dimorphism can be found in an abnormal meiotic division of the pollen mother cell during the microsporogenesis, which results in pollen grains of different size and cytoplasmic content (in tobacco—*Nicotiana tabacum* L. [1]; in soybean cultivars—*Glycine max* (L.) Merrill [2]). Pollen dimorphism may be associated to different stamen whorls of the flower (in crape myrtle—*Lagerstroemia* L. [3]), stigma dimorphism (Plumbaginaceae [4]) and heterostyly (Plumbaginaceae, *Turnera ulmifolia* L. [4,5]). Additionally, androdioecy and dioecy, or more exactly functional dioecy, can be responsible for pollen dimorphism (e.g., *Saurauia* Willd. [6–8]; *Thalictrum macrostylum* Small and A.Heller [9]). In functional dioecy, male plants produce normal pollen grains while functionally female flowers produce pollen grains which cannot fertilize, but generally act as an attractant for pollinators in nectarless flowers [6–9]. Complex causes are involved in the case of white campion—*Silene alba* (Miller) Krause [10].

Pollen dimorphism of *Vitis* is a case of functional dioecy and a known feature in several species (*V. riparia* Michx. [11]; *V. aestivalis* Michx. [12]; *V. coignetiae* Pulliat [13]) becoming an issue for the reproductive biology of the cultivated grapevine (*V. vinifera* L. subsp. *vinifera*).

1.2. The Botanical and Agrarian Knowledge

The dimorphism of grapevine pollen is connected to the morphology of flowers. Flower morphology of *V. vinifera* has been widely described and reviewed by Oberle [14], Pratt [15], Caporali et al. [16], Vasconcelos et al. [17], and Meneghetti et al. [18].

V. vinifera subsp. *sylvestris* (C.C.Gmel.) Hegi, wild grapevine, is dioecious. It derives from a hermaphroditic ancestor [19] and, interestingly, hermaphroditic flowers were observed together with male flowers from wild grapevines studied in Georgia (table 3 in De Lorenzis et al. [20]). Wild grapevine has hermaphroditic flowers that arrest one set of sexual organs very late during their development [21]. Fully developed male flowers producing trizonocolporate pollen show abortive pistils, whereas female flowers, albeit appear morphologically similar to the male ones, have a well-developed pistil but produce acolporate pollen in the stamens [16]. Inaperturate pollen is an important food source for pollinators often attracted by scent glands of flowers. The wild subspecies has an entomophilous and anemophilous pollination, and is the ancestor of the domesticated subspecies [20].

V. vinifera subsp. *vinifera*, the domesticated subspecies, has hermaphroditic flowers, which entailed changes in the reproductive process [22–24]. Actually, grapevine reverted to hermaphroditism during domestication [25,26], and is largely self-pollinating [20].

Indeed, some grapevine cultivars have morphologically hermaphroditic but functionally unisexual flowers. The consequence is that three types of flowers can be ascribed to the domesticated *V. vinifera* subsp. *vinifera*: one is the true hermaphroditic flower, with fully developed female and male organs producing trizonocolporate pollen, and two others are the morphologically hermaphroditic but functionally unisexual flowers, which are actually male flowers or female flowers [14,15,17,18]. Particularly, female flowers have a normally developed pistil surrounded by stamens, but filaments are more or less short, or curved and backwards reflexed [14,17,27]. This floral morphology is linked to the production of inaperturate pollen that is thought to be sterile [28,29]. Pollen sterility has been correlated to the lack of apertures (furrows and pores), which prevents pollen germination, and to post-meiotic disturbances [28,30] also determining poor viability of pollen [17].

Kevan et al. [11] suggest that pollen sterility of some cultivated varieties may be linked to the dioecy that characterized the wild progenitors of the domesticated subspecies. The inaperturate condition could be among the reasons why a dramatic drop of fruit yields can occur. Therefore, the consideration of this issue is of strategic importance in agrarian studies [31,32].

1.3. A Key Plant for Archaeology

Vitis vinifera subsp. *sylvestris*, the ancestor of the domesticated species [20,23], is a common creeper in riparian deciduous woodland and willow communities of Euro-Siberian and Mediterranean regions [33,34]. The domesticated *V. vinifera* subsp. *vinifera* has cultural implications and plays a substantial role in human economy being, in fact, among the most important crops and an emblem of Mediterranean agriculture, together with the olive tree.

As archaeologists give great attention to the history of grapevine and its role in past economy, impressive amounts of plant remains, including charcoals, fruits, and pips, are studied from archaeological layers [35–40]. Human selection for fruits caused changes in the morphology of seeds [41–44]. Therefore, the knowledge of the domestication history of grapevine largely relies on archaeological seeds, their discovery, morphology, biometry, chemistry, and molecular biology (mainly aDNA) [45–52]. Wild and domesticated traits of seeds are similar but different enough to allow discrimination of the subspecies with a certain degree of confidence [53,54].

In addition to these findings, also pollen is increasingly studied to follow the introduction and spread of the plant for cultivation, the uses to produce wine or vinegar, or for decoration in very different contexts (see, for example, the pergola discovered in a Roman villa in Sicily [55]). Pollen analysis has demonstrated that the trizonocolporate *Vitis* pollen is underrepresented or rare in modern contexts [56], as well as in many archaeological samples. Actually, it may be an indicator of the local presence of viticulture [57].

Nevertheless, pollen analysis applied to archaeology did not yet consider the dimorphism of the grapevine pollen and has ignored its inaperturate shape. This trait, instead, is well known in viticulture, because of implications on vineyard yield.

In this paper we introduce the first records of inaperturate *Vitis* pollen observed in samples taken from archaeological layers. The case study is a Middle and Late Bronze Age site—the Terramara Santa Rosa di Poviglio, which has been studied from a geoarchaeological and palaeoenvironmental point of view to reconstruct the sylvo-agro-pastoral system of this culture. There is no local evidence of grapevine records as plant macroremains while trizonocolporate *Vitis* pollen was observed in many samples [58–61]. The hypothesis is that the inaperturate *Vitis* pollen, though rare, can be a supportive evidence of the presence of wild female grapevine plants blooming close to the study area (see below, Section 4.3).

2. Materials and Methods

2.1. Reference Pollen Samples

Reference pollen samples were prepared for morphological observation collecting flowers from four cultivars (=cv.) of *Vitis vinifera* subsp. *vinifera* and from accessions of *V. vinifera* subsp. *sylvestris*, three grown in a germplasm collection, and male and female plants observed close in the wild (Table 1).

2.1.1. *V. vinifera* Subsp. *vinifera*

The inflorescences were taken from vineyards cultivated in the Emilia Romagna region (Northern Italy). Lambrusco Grasparossa and Malbo Gentile are regional red grape varieties mainly cultivated in the provinces of Modena and Reggio Emilia. Covra is a very rare red grape variety probably native of the same area. Bianca di Poviglio, from Poviglio (Reggio Emilia), is a local synonym of Trebbiano Toscano, well known white grape cultivar also widely cultivated in France, with the name of Ugni Blanc. All the sampled cultivars have an ancient origin and are described in the Italian *Vitis* Database ([62], and see below).

Table 1. List of reference pollen samples, location and date of sampling.

Sample	Species	Subsp.	Cultivar/ Label	Flower Morphology	Flower Functionality	Location	Date
1	<i>Vitis vinifera</i>	<i>vinifera</i>	Covra	Hermaphroditic	Male/female	Corlo di Formigine (MO)	May 2014
2	<i>Vitis vinifera</i>	<i>vinifera</i>	Lambrusco Grasparossa	Hermaphroditic	Male/female	Corlo di Formigine (MO)	May 2014
3	<i>Vitis vinifera</i>	<i>vinifera</i>	Bianca di Poviglio	Hermaphroditic	Male/female	Reggio Emilia (RE)	May 2016
4	<i>Vitis vinifera</i>	<i>vinifera</i>	Malbo Gentile	Hermaphroditic	Female	Albinea (RE)	May / June 2009
5	<i>Vitis vinifera</i>	<i>sylvestris</i>	Accessione Canalone Sotto	Abortive pistil—fully developed stamens	Male	Torrazza Coste (PV)	May 2016
6	<i>Vitis vinifera</i>	<i>sylvestris</i>	Accessione Ponte 5	Abortive pistil—fully developed stamens	Male	Torrazza Coste (PV)	May 2016
7	<i>Vitis vinifera</i>	<i>sylvestris</i>	Accessione Pioppetto 3	Hermaphroditic	Female	Torrazza Coste (PV)	May 2016
8	<i>Vitis vinifera</i>	<i>sylvestris</i>	Wild dioecious plants	Abortive pistil—fully developed stamens	Male	Sammontana (FI)	June 2019, 2020
9	<i>Vitis vinifera</i>	<i>sylvestris</i>	Wild dioecious plants	Hermaphroditic	Female	Sammontana (FI)	June 2019

2.1.2. *V. vinifera* Subsp. *sylvestris*

The flowers of three accessions (labelled “Accessione” in Table 1) were taken from the germplasm collection vineyard established in 2006 at the Regional Research Station of Riccagioia in Lombardy (Northern Italy). These accessions had been identified and collected in Tuscany and are listed in the European Vitis Database [63]. Their flowers were drawn, and photos were taken with Leica MC120 HD under a stereomicroscope Leica Wild M10 (Figure 1). The other specimens come from “wild dioecious plants” growing at Sammontana, Florence (43°43′27.87″ N; 11°00′39.70″ E; 42 m a.s.l.), a registered station of Wild Grapevine of the Phytogeography Laboratory of the University of Florence, in Tuscany.

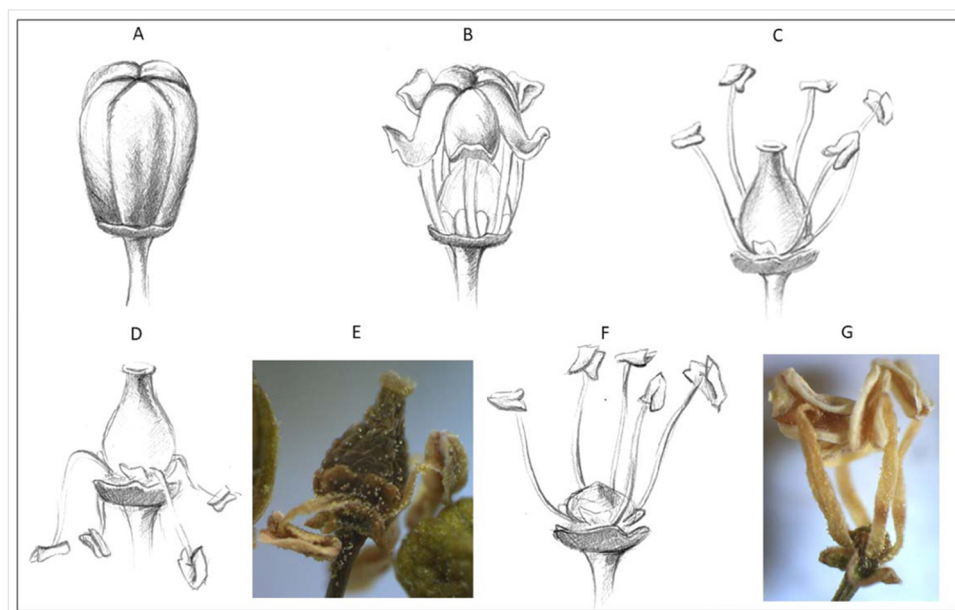


Figure 1. Hermaphroditic flower of *Vitis vinifera* subsp. *sylvestris*. (A) The petals are sticking together as a cap at the tip (calyptra); (B) the calyptra is shed explosively; (C) flower with the pistil and five stamens; (D) functionally female flower; (E) Pioppetto 3 accession (functionally female); (F) functionally male flower; (G) Canalone Sotto accession (functionally male) ((A–D,F): drawings by Alice Montanari; (E,G): photos made under stereomicroscope).

2.1.3. Acetolysis and Morphometry

The anthers of all samples were subjected to dehydration followed by acetolysis [64], and pollen slides were mounted in glycerol/water 50/50 *v/v*. The morphological parameters of trizonocolporate pollen were (a) equatorial view: polar axis (P), equatorial diameter (E), P/E ratio, maximum distance between colpi in mesocolpium (MES), polar and equatorial axes of porus (P-porus, E-porus); and (b) polar view: equatorial diameters (E1 and E2) and exine thickness (Ex). The inaperturate pollen has not a clear polarity, as any aperture location could be related directly to pollen polarity. In this case, the considered morphological parameters were the largest diameter (DM), smallest diameter (dm), DM/dm ratio, and exine thickness (Ex).

Pollen grains were measured according to Wrońska-Pilarek et al. [65]. The principal component analysis (PCA; XLStat 2014) was performed after data standardization by using the average values of the pollen grain size parameters as variables [66]: one PCA was performed with all the samples using P, E, and P/E ratio of the trizonocolporate pollen as variables; another analysis was performed with the variables obtained from inaperturate pollen (DM, dm, and DM/dm ratio), including the archaeological sample.

2.2. Pollen Viability and Germination

Considering the role of morphology in the viability of pollen, tests on viability and germination were performed on pollen of *Vitis vinifera* cv. Malbo Gentile almost totally

inaperturate. Pollen grains were collected from capped flowers (from which calyptra was removed by fine forceps) and flowers at capfall. Viability was verified applying the Fluorochromatic Reaction Test, according to Heslop-Harrison & Heslop-Harrison [67] and Shivanna and Rangaswamy [68], using fluorescein diacetate (FDA) solution. Pollen was observed under a light microscope (LM) (Orthomat, Leitz) equipped with a Leica fluorescence illuminator (filters: BP 420-490, RKP 510, LP 515). The test was carried out observing three microscope slides, each with at least 1000 pollen grains.

To check in vitro germination, 1 mg pollen grains was incubated at 30 °C in the dark for 30, 60, and 90 min, in 1 mL of a liquid culture medium containing 10% sucrose, 0.02% MgSO₄, and CaCl₂, 0.01% KNO₃ and H₂BO₃. The samples were prepared on microscopic slides at the end of each incubation time and observed under LM in order to record germ tubes emission.

2.3. Scanning Electron Microscopy

SEM observations of inaperturate pollen were independently made on fresh and acetolyzed pollen grains. The acetolyzed pollen of the Wild dioecious plant (sample no. 8) was washed in acetic acid and ascendant series of acetic acid and ethanol, dried at Critical Point Dryer using CO₂ as the transition liquid. The samples were mounted on aluminium stubs, gold-coated (10 nm thick), and observed with ZEISS EVO MA15 (MEMA—University of Florence).

Flowers of *Vitis vinifera* cv. Malbo Gentile (sample no. 4), were conventionally fixed in glutaraldehyde (3% in 0.1 M phosphate buffer pH 7.0 at 4 °C), rinsed in the same buffer, dehydrated in ascendant acetone series, and dried at Critical Point Dryer using CO₂ as the transition liquid. Samples were mounted on aluminium stubs, gold-coated (10 nm thick), and observed with a Philips XL 30 Scanning Electron Microscope at CIGS (Interdepartmental Large Instruments Center—University of Modena and Reggio Emilia).

2.4. The Archaeological Record for Pollen Analyses

Cremaschi et al. [60] report the pollen extraction from sediments, and the counts and results on paleo-environmental reconstruction and land-use. A total of 31 archaeological samples were treated for pollen extraction. They were labelled Poviglio P31 to P1, from the oldest to the most recent. Laboratory treatments included sieving with a nylon 7 µm mesh and heavy liquid separation [69]. Pollen identification was made at 400× and 1000× magnification on permanent slides. For this study, the same permanent slides where trizonocolporate pollen was observed, were read again to search for inaperturate pollen grains. The sample Poviglio P19 contained inaperturate pollen that were subjected to morphometrical observations. Morphometric parameters of the *Vitis* pollen were measured: in the trizonocolporate pollen, polar axis (P), equatorial diameter (E), P/E ratio and exine thickness (Ex); in the inaperturate pollen, larger diameter (DM), smaller diameter (dm), and exine thickness (Ex).

3. Results

3.1. Pollen Morphology of Reference Pollen Samples

A total of 262 trizonocolporate and 120 inaperturate pollen grains were measured. The observed ranges are summarized and reported as mean value of each parameter measured over a minimum of 30 pollen grains per sample (Tables 2 and 3).

Trizonocolporate pollen was observed in all the samples belonging to hermaphroditic or functionally male flowers. The maximum values were measured in the *Vitis vinifera* subsp. *sylvestris* accessions.

Polar axis (P) ranges from $\sim 20.7 \mu\text{m}$ (cv. Lambrusco Grasparossa) to $\sim 24.9 \mu\text{m}$ (Ponte 5 accession); Equatorial axis (E) ranges from $\sim 20.5 \mu\text{m}$ (cv. Lambrusco Grasparossa, cv. Covra, Wild dioecious) to $\sim 23.6 \mu\text{m}$ (cv. Bianca di Poviglio). The mean values of the P/E ratio are mostly $\sim 1/1.1$, and the pollen grains are suboblate to prolate in shape (terminology according to Erdtman [70]; Figure 2). The maximum distance between colpi in mesocolpium (MES) ranges from $\sim 9.8 \mu\text{m}$ (cv. Covra, cv. Bianca di Poviglio) to $\sim 12.5 \mu\text{m}$ (Canalone Sotto accession) and ~ 13.2 (Wild dioecious); the porus diameter ranges from $\sim 1.4 \mu\text{m}$ (Ponte 5 accession) to $\sim 2.6 \mu\text{m}$ (Wild dioecious). Exine thickness (Ex) is thin in the present and in the archaeological specimens ($0.8\text{--}0.9 \mu\text{m}$) with the only exception of the Wild dioecious that is $\sim 1.6 \mu\text{m}$ thick. Exine sculpturing looks slightly micro-reticulate under light microscopy and micro-rugulate at SEM (Figure 3).

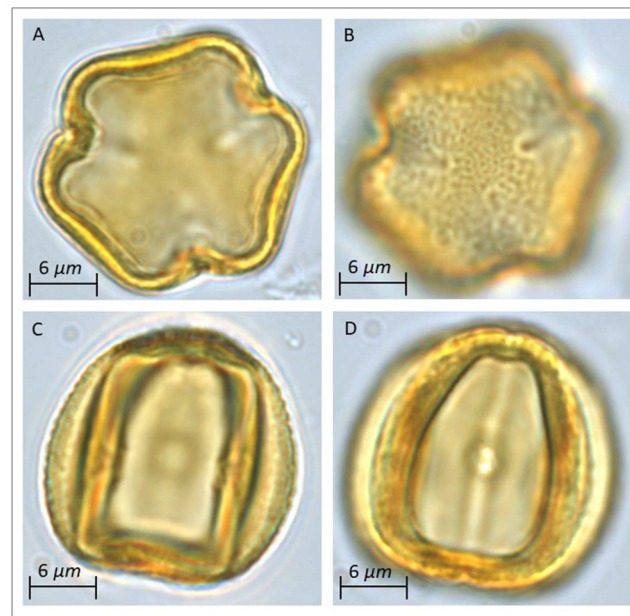


Figure 2. Light microphotographs of trizonocolporate pollen of *Vitis vinifera* cv. Bianca di Poviglio. (A) polar view, with the exine thickness in focus; (B) polar view, with the upper surface in focus showing the exine reticulate; (C) equatorial view with two colpi in focus; (D) equatorial view with the lower surface in focus showing the third colporus.

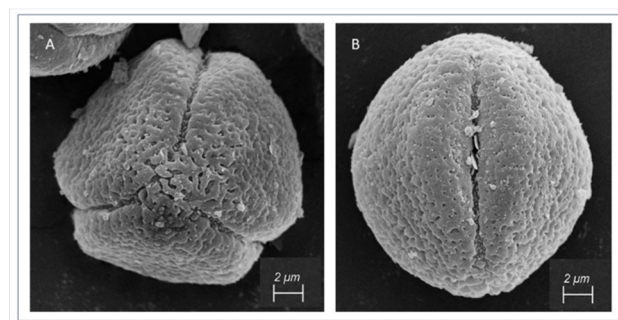


Figure 3. Scanning electron microphotographs of trizonocolporate pollen of Wild dioecious functionally male flower (A) in polar view; (B) in equatorial view.

Inaperturate pollen was observed in the samples belonging to functionally female flowers of the two specimens of the female accessions of *V. vinifera* subsp. *sylvestris* and in the cv. Malbo Gentile. The maximum values were measured in the cv. Malbo Gentile (Table 2; Figure 4A,B). DM ranges from $\sim 21.9 \mu\text{m}$ (Wild dioecious) to $\sim 27.1 \mu\text{m}$ (cv. Malbo Gentile), and dm ranges from $\sim 20.3 \mu\text{m}$ (Wild dioecious) to $\sim 25.0 \mu\text{m}$ (cv. Malbo Gentile; Pioppetto 3 accession). The mean values of the DM/dm ratio are mostly $\sim 1/1.2$, and the

pollen grains are from oblate-spheroidal to prolate in shape. Exine thickness (Ex) is thin (1.1–1.3 μm) but slightly thicker than in the trizonocolporate pollen.

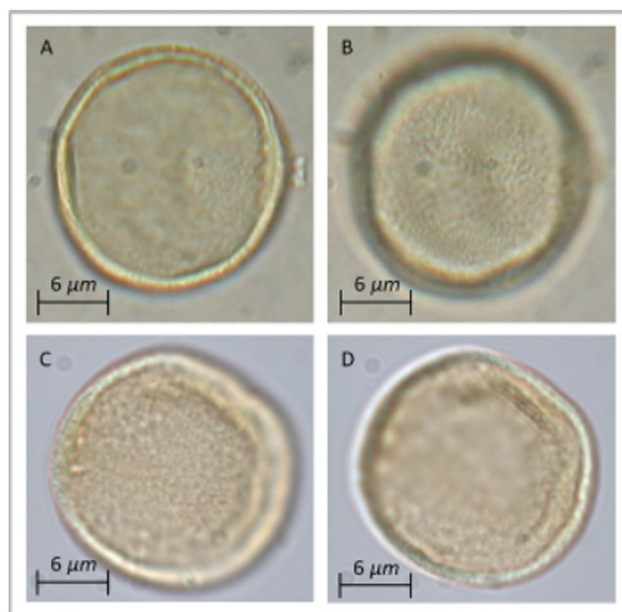


Figure 4. Light microphotographs of inaperturate pollen grains. (A) *Vitis vinifera* cv. Malbo Gentile; (B) image of the same pollen grain taken at different focus distance; (C) *Vitis* in the archaeological sample Poviglio P19; (D) image of the same ‘archaeological’ pollen taken at different focus distance.

Under light microscopy exine sculpturing looks slightly micro-reticulate in Pioppetto 3 accession, micro-rugulate in cv. Malbo Gentile and in Wild dioecious. Under SEM exine sculpturing looks micro-rugulate (Figure 5).

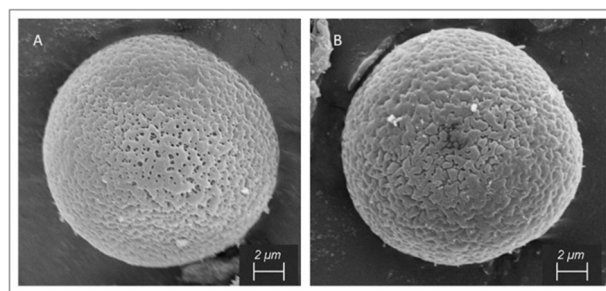


Figure 5. Scanning electron micrographs of Wild dioecious plant. (A) Inaperturate pollen grain of functionally female flower; (B) image of the same pollen grain taken at different focus distance.

3.2. Pollen Viability

Only 4.5% of pollen of cv. Malbo Gentile was observed with apertures. The result of pollen viability test on inaperturate pollen was positive, with 92.4% (± 6.1) of pollen tube grains viable (Figure 6). In vitro germination and pollen growth were not observed, even after 90 min of incubation. This result of the in vitro germination test, associated with the high percentage of pollen resulting positive under the Fluorochromatic Reaction Test, allows excluding the possibility that cv. Malbo Gentile produces some cryptoaperturate pollen (sensu Punt et al. [71]). Indeed, this suggests that pollen sterility is due to the inability to let out pollen tube [29], in agreement with scientific literature [32,72]. The same tests are currently applied to trizonocolporate pollen, i.e., in *Vitis vinifera* cv. Lambrusco Salamino, obtaining positive results also in pollen germination [73].

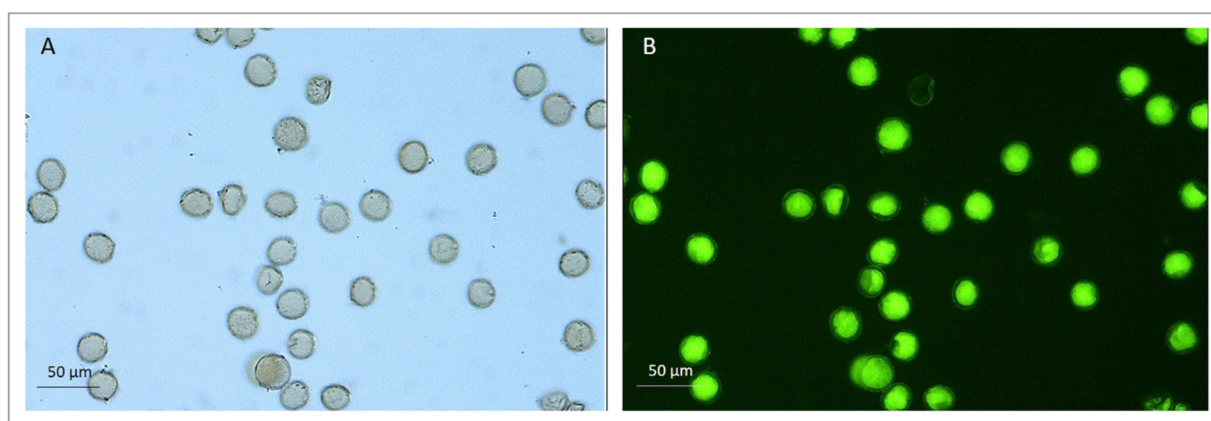


Figure 6. Results of viability test on pollen of *Vitis vinifera* cv. Malbo Gentile. (A) light microphotograph showing inaperturate pollen grains; (B) the same sample observed under UV light. All viable pollen grains show intense bright green fluorescence.

3.3. Pollen from Archaeological Samples

Inaperturate pollen was observed also in the samples taken from the archaeological site. Previous results from pollen analyses have shown that *Vitis* pollen, detected in 87% of the samples, reached 3% on average [60]. The maximum value of 18%, consisting of trizonocolporate pollen, was counted in sample P19, dated to the Middle Bronze Age. Interestingly, the re-examination of the slides allowed counting also 15 inaperturate pollen grains in the same sample.

Regarding morphology, the trizonocolporate pollen looked more prolate than the reference records (Table 3; Figure 7), showing a large $P = \sim 23.6 \mu\text{m}$ but a decidedly low $E = \sim 15.8 \mu\text{m}$. This results in a relatively high $P/E = 1.49$, i.e., prolate shape (Tables 2 and 3). The inaperturate pollen has diameters of $\sim 25.7 \times 22.5 \mu\text{m}$, quite similar to the largest measurements observed in the reference pollen of cultivated plants (Figure 4C,D). Under light microscopy exine sculpturing looks slightly micro-reticulate like in Pioppetto 3 accession.

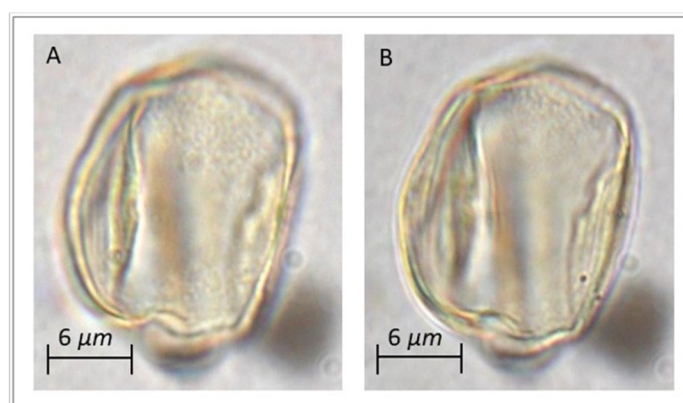


Figure 7. Light microphotographs of *Vitis* trizonocolporate pollen grain in equatorial view in archaeological sample Poviglio P19. (A) *Vitis* pollen grain with the upper surface in focus; (B) the same pollen grain at a different focus, showing the colpor features.

4. Discussion

The record from the Terramara Santa Rosa di Poviglio represents the first finding of inaperturate pollen of wild grapevine female plants observed in an archaeological site. Pollen data suggest the compresence of male or hermaphroditic *Vitis* plants (producing trizonocolporate pollen) and female plants (producing inaperturate pollen) growing in the site.

The evidence opens the question about a possible pollen-based discrimination between wild and domesticated *Vitis vinifera* in prehistoric times. Can the inaperturate pollen be associated with the growth of wild species in a study area? Can this record be considered an interesting marker of wild *Vitis* in archaeobotanical analyses? Based on the pollen morphology of modern specimens of *Vitis vinifera*, the archaeological evidence may be compatible with the presence of both wild dioecious vines or some domesticated grapevines living close to the deposit studied.

Therefore, the positive answers to the above-mentioned questions cannot be based only on the pollen evidence. It depends also on the availability of other archaeobotanical data (fruits and pips remnants, morphology of the seeds), which are often available from archaeological sites and can integrate this information. However, as we know, macroremains of *Vitis* have not been found so far while pollen is quite common in the Bronze Age samples from the Terramara Santa Rosa di Poviglio [60]. The pollen evidence can be of particular importance in case of lack of macroremains. Furthermore, the detection of an increase of inaperturate pollen grains overtime (centuries and millennia) could be a sign of a trend towards a conscious use of female wild vines near the settlements [74], which could be regarded as a typical step of proto-viticulture.

4.1. Pollen Dimorphism of Current *Vitis vinifera*

Observation of pollen morphology confirms that trizonocolporate and inaperturate pollen grains can occur in both the *Vitis* subspecies in this study.

In the PCA of trizonocolporate pollen parameters (P, E, P/E; Figure 8A) the two principal components are responsible for 61.74% and 38.18% of the total variation. The distribution shows that samples with the highest values of P and E are grouped in the second sector of the PCA. Pollen samples are distributed along the second principal component reflecting the size of polar axis (P) and showing a clear clustering of both the *V. vinifera* subsp. *sylvestris* accessions (Canalone Sotto and Ponte 5) and the pollen from ancient varieties of *V. vinifera* subsp. *vinifera* (cv. Bianca di Poviglio). Only Wild dioecious is quite distinct from other samples of the same subsp. *sylvestris*. The archaeological sample (P19) is clearly distinguished from the reference pollen samples through a grain size-based gradient.

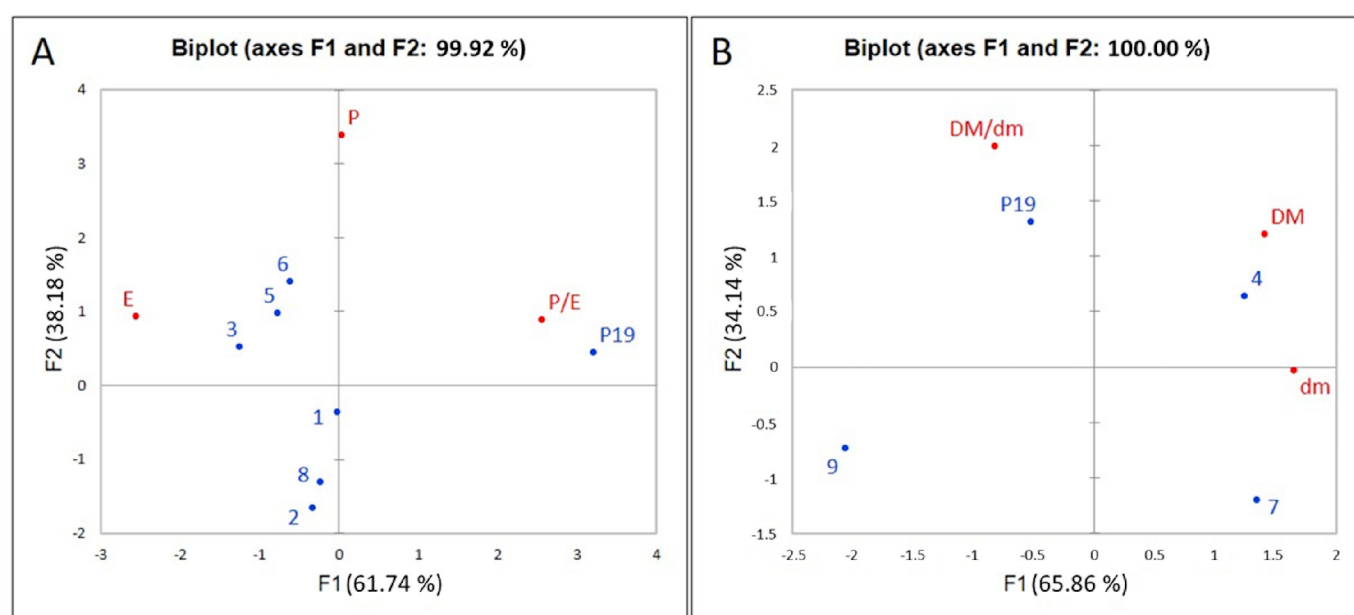


Figure 8. Principal component analysis. (A) Trizonocolporate pollen grain size parameters (P, polar axis; E, equatorial diameter; P/E ratio); (B) Inaperturate pollen grain size parameters (DM, largest diameter; dm, smallest diameter; DM/dm ratio). Names of samples are labelled following codes in Table 1.

The two main axes of the PCA processing inaperturate pollen grain size parameters (DM, dm and DM/dm; Figure 8B) explain 65.86% and 34.14% of the total variation, respectively. The distribution of the samples is independent and does not show clustering based on the variables considered.

4.1.1. Trizonocolporate Pollen

Usually, hermaphroditic and male flowers produce pollen grains that are morphologically similar in the two subspecies since they are all trizonocolporate and characterized by micro-reticulate structure of the exine. This morphology is in accordance with Punt et al. [75] and Gallardo et al. [76]. Pollen has a quite rounded shape ($P/E \approx 1$). Particularly, the pollen from ancient varieties of *V. vinifera* subsp. *vinifera* (cv. Bianca di Pioviglio) looks quite similar in size/shape to the pollen of the subspecies *sylvestris*. The significant similarity could be related to the domestication process, and the transition from unisexual to hermaphroditic flowers.

In the archaeological record the shape ($P/E = 1.49$) is decidedly more prolate than in modern pollen grains. This difference is most probably due to post-depositional processes and related to the fact that once incorporated in sediments pollen undergoes different degrees of compaction effects. The sub-fossil, archaeological, pollen has a distorted, folded or partially flattened, shape.

4.1.2. Inaperturate Pollen

During pollen analyses, this morphology can be associated with that of similar pollen or palynomorphs from which, however, diagnostic discrimination is possible. Inaperturate pollen is common in Gymnosperms and characterizes many Angiosperm groups. Presence of orbiculi (e.g., *Cupressus*) and exine thickness are important traits for identification. Size overlapping may be observed with the spores of Bryophyta, which range from 7 to 8 μm up to 40 to 50 μm , but the exine thickness with more or less irregular processes—determining a more diaphanous/yellow colour of the spore—is quite different from that of pollen in the same samples. Further, the pollen of *Populus* has a pretty similar morphology. In the different species, this is inaperturate and ranges from 16 to 37 μm in diameter, whose size partly overlaps with that of the inaperturate pollen of *Vitis* (in the range of 22–27 μm). However, *Populus* pollen has extremely thin exine (0.7–1.0 μm [77]), with granules or microgemmae irregularly sparse, while the *Vitis* inaperturate pollen has slightly thicker exine (1.0–1.3 μm) with more regular pattern of the surface wall. In *Populus*, the reduction of the exine thickness through which the pollen tube can easily exit may be related to its wind-pollination. This pollination strategy does not require the presence of large cavities in the wall for the storage of the pollenkit and it is favored by a reduction of the exine amount, which makes pollen more aerodynamic [8].

In our study, direct pollen examination confirms that the female flowers of subspecies *sylvestris* Pioppetto 3 and the Wild plants, as a result of the dioecious status, produce inaperturate pollen. However, this special character is observed also in cv. Malbo Gentile of the subspecies *vinifera*, where viability and germination tests support the hypothesis that the absence of colpora may be responsible of sterility in this cultivar. A gene, named INAPERTURATE POLLEN1 (INP1), specifically involved in the formation of pollen apertures, has been recently isolated and characterized in *Arabidopsis thaliana*; loss of INP1 entails the lack of furrows and INP1 protein shows an exact localization in developing pollen [78]. Inaperturate pollen was interpreted as a loss-of-function mutation of aperture formation, and an 8 bp deletion causes such male sterility in homozygous (FF) *Vitis* females [16,26]. This may have been an ancestral feature that was lost during the developing of hermaphroditism in the domesticated subspecies. New molecular data has recently demonstrated that dioecy has been lost during domestication through a rare recombination event between male and female haplotypes [26]. In some cultivars, and under particular conditions, the same character may return to be manifest as in the case of cv. Malbo Gentile. The nature of the new appearance as a plesiomorph character is still debated. It may be

due to anomalies in the microsporogenesis process [8], or an abnormal division of the tapetum cells. Büyükkartal et al. [79] observed that the insufficient supply of nutrients to mother cells by the tapetum cells causes a low fertility of pollen in cv. Cavus. Any anomalous feature, then, may be fixed, possibly propagated by some anthropic practices like seedling [80].

4.2. The Current “Ancient Cultivars”

The cultivars analyzed in this research can be considered all ancient cultivars, according to agrarian and historical studies. Covra has been mentioned for the first time in 1752 by Niccolò Caula, as reported a century later by Maini [81]. Currently, this variety, which has a typical distribution in the Emilia region, has become rare due to the replacement with more productive varieties with larger clusters. This replacement is known to have occurred between the end of the 19th century and the beginning of the 20th century, and to the abandonment of viticulture in mountain areas where Covra was cultivated.

Lambrusco Grasparossa, which is currently the second grape variety in terms of cultivated area in the province of Modena, has been present at least from the end of the 18th century [82].

Bianca di Poviglio is the local name of a variety that genetic analyses have revealed to be Trebbiano Toscano, one of the oldest Italian grapes widely cultivated in Italy, whose origin, however ancient, is uncertain from both geographical and historical point of view: based on molecular studies, it is assumed to refer to the Medieval or even to the Roman periods [83]. So far, no historical documents have been found on the appearance of the variety in Poviglio, beyond the oral evidence on the long link with that territory.

Malbo Gentile, with its synonym Amabile di Genova, has been cited for the first time in 1805 by Filippo Re in a manuscript, and then in 1840 by Bertozzi as reported in [84].

The study of the floral biology and pollen traits of ancient cultivars can provide useful information for verifying the relationship between wild and cultivated grapevines. As previously reported, the presence of functionally female flowers, here represented by cv. Malbo Gentile, constitutes an ancestral characteristic that seems to derive from the wild vines. The comparison of pollen found in archaeological sites with that of cultivated varieties presenting ancestral characteristics suggests possible connections between the use of (wild) grapes and its domestication.

The first genetic evidence of the link between wild grapevine and varieties grown in the 19th century is now available and concerns the Emilia area. Analyses of molecular markers SSR and SNP on over 300 genotypes of cultivated varieties, rootstocks and wild vines give a first experimental evidence of the close relationship between wild vines and Lambrusco di Sorbara, another ancient cultivar with inaperturate pollen and male sterility, as well as with “Lambrusco a Foglia Frastagliata”, a variety with true hermaphroditic flowers [85]. Today, the wild grapevine populations are an important resource for breeding programmes in order to avoid genetic erosion and in the perspective of a possible adaptation of the grapevines to the future environmental changes [86].

4.3. Viticulture during the Bronze Age in the Po Plain

Archaeobotany and organic residues in ceramic vessels allowed investigating early cultivation and use of *Vitis vinifera* in Georgia [42,87], the Near East [88] and the eastern Mediterranean [89]. The most ancient proofs of wine production may be dated to the Neolithic (6000–5800 BC) without the possibility of distinguishing if the wine was produced from wild or domesticated *Vitis vinifera* both exploited in the South Caucasus [42]. Even more ancient proofs (7000 BC) of production of a fermented beverage come from a local, high-sugar wild vine in China but it was a mixed wine–juices drink [90].

Starting from a quite familiar concept dealing with wild cereals—for which plant processing and cultivation is assumed to have begun long time before domestication (for example, see Mercuri et al. [91])—we assumed that the wild plants of *Vitis* should have been exploited for food or other uses for a long time. Even wild vine was known to be

useful to prepare some fermented drinks, and therefore people had enough cultural knowledge assuring an easy transposition of practices from “old” to “new” plants producing more pleasant fruits. However, wild vines are thought to produce far less fruits than the domesticated vines [42], as male plants looked sterile to people. This should have involved a rapid adoption of the domesticated species, which demonstrated to be more suitable for food production [92], for example because all plants give fruits and there is more fruits production over the same surface.

In Italy, the cultivation of *Vitis vinifera* is traced back to the beginning of the Iron Age in relation to the presence of the first Greek colonies in southern Italy. However, remains of pips from the Bronze Age suggest that the beginning of its cultivation can be anticipated of several centuries in mainland Italy and Sardinia [47,93]; also pollen analysis suggests an early *Vitis* cultivation around 2000 BC in the Massaciuccoli Basin, Tuscany-central Italy [94].

An early consumption of products from this species, i.e., wine or vinegar or must, was suggested by Pecci et al. [52] based on organic residues analysis conducted on pottery from Canale Anfora-Aquileia, near Udine, and from Pilastrì di Bondeno, near Ferrara. These two sites of north-eastern Italy dated to the Bronze Age. Pilastrì di Bondeno is part of the Terramare culture. Moreover, seed/fruit remains found in the Terramara di Montale near Modena suggested that also other plants were used in the preparation of alcoholic drinks. *Cornus mas*-cornelian cherry has been among the most common and used plants to prepare alcoholic drinks since the beginning of the Terramare culture. Then, the exploitation of grapevine increased at the transition between the Middle Bronze Age (ca. 3600–3450 years ago) and the Late Bronze Age (ca. 3450–3170 years ago [95,96]) testifying to a preference for grapevine over the cornelian-cherry. Cornelian cherries continued to be used and were probably processed in the Etruscan farmhouse of Pian d’Alma, southern Tuscany, during the 6th century BC [97].

Therefore, the archaeobotanical context of the Terramare suggests that *Vitis vinifera* was known and used in the Po Plain about 3600–3100 years ago [96]. This alluvial plain was full of wet habitats suitable for the wild vine subspecies. It probably lived in hygrophilous woods near rivers, while the oak woods marked the limits between the villages. The use of grapevine was probably favored by a combination of local environmental conditions and cultural knowledge. In fact, trizonocolporate *Vitis* pollen is common in the sites of the Po Plain as a direct evidence of plants living close to the sites or in the surrounding areas.

As mentioned above, in the Terramara S. Rosa di Poviglio, the high percentage of *Vitis* pollen (18% in sample P19) clustered with riparian and willow communities thus suggesting the wild vine grew near ditches and channels of the site [60]. The interdisciplinary research demonstrated that people had a sophisticated knowledge of the land, also being able to shape the water and wood landscapes for improving their stability and resources exploitation [58,61]. We concluded that also the records from *Vitis* pollen may be actually a further evidence of some management of the plant at the Middle and Recent Bronze Age phases, and that grapevine was cultivated, even not domesticated, in the site [60]. The inaperturate pollen supports this interpretation adding the information that these plants also produced pollen from female flowers.

4.4. Inaperturate Pollen as Evidence of Wild Plants in Past Records

The reference pollen collected from the living plants studied in this research corroborates the assumption that the inaperturate pollen is a feature proper of *Vitis vinifera*. However, our observations confirm that the lack of colpora brings serious problems of fertility. This is irrelevant in the wild dioecious subspecies; the presence of remnants of hermaphroditism does not reduce the functionality of female flowers with anomalous stamens (Figure 1), and the inaperturate pollen only acts as a reward for pollinators.

Sterility may be a major handicap for vineyard yield and, therefore, inaperturate pollen is a rare and not favored character in many cultivars of the domesticated subspecies. Actually, the ancient cultivar Malbo Gentile produces only this type of pollen, seriously carrying fall of productivity if it is cultivated alone or far from hermaphroditic grapevines

serving as pollinizer [29]. This anomaly occurs also in other cultivars such as Lambrusco di Sorbara, Picolit, Trebbianina (Trebbiano di Spagna), all registered in the “national catalogue” of grape varieties, and other local minor grapevines [27,31].

Today, the presence of inaperturate pollen is a not common trait in modern cultivars. Moving back to the Bronze Age in Italy, the general context and the whole pollen data obtained from the Terramara di Poviglio (see the inclusion of *Vitis* pollen in the hygrophilous wood group based on the figure 11 in [60]) strongly suggest that the inaperturate pollen was produced by wild dioecious plants of *Vitis vinifera* subsp. *sylvestris*.

In general, the inaperturate *Vitis* pollen in archaeological samples is an index of the presence of female flowers. In prehistoric times and in appropriate contexts, the compresence of the two types of *Vitis* pollen may be a good and reliable index of the presence of wild, or intermediate forms, of grapevines. This is of crucial importance dealing with a period of transition between the use of wild and domesticated grapevine.

5. Conclusions

Pollen dimorphism demonstrates that pollen production and dispersal differ in the wild and domesticated subspecies of *Vitis*, and therefore the signal of *Vitis* pollen in past records changed depending on which subspecies was present. This makes grapevine botanically different from the other Mediterranean cultural trees. In fact, *Olea*, *Juglans* and *Castanea*, which are included in the OJC index [98], did not change their reproductive strategies during domestication as grapevine, and consequently comparable pollen production and dispersal are expected in wild and domesticated plants. The proposal of an OJCV index (where V means *Vitis*) [99,100], which ignores this difference, seems not justified from a palynological point of view.

Moving to the basic question of this paper, can the inaperturate pollen be a marker of female wild *Vitis vinifera* in prehistoric times? Inaperturate pollen has never been detected so far in archaeological sediments. In the site studied here, Terramara Santa Rosa di Poviglio, we did not find such inaperturate pollen in layers dated to the more recent phases, subsequent to the Bronze Age, that surely refer to the cultivation of domesticated *Vitis* in the Po Plain. Therefore, we can conclude that our Bronze Age record bears witness of a very local growing of *Vitis vinifera*, and that the occurrence of dimorphism is coeval with the Bronze Age.

Based on our data, considering the inaperturate pollen a rare (plesiomorphic) trait in the domesticated grapevine, we suggest that the record should be interpreted according to the chronology and the archaeological context. Particularly, the record of both trizonocolporate and inaperturate pollen in the same samples may be a good indicator of wild grape—*Vitis vinifera* subsp. *sylvestris*—in prehistoric times.

Locally, the interdisciplinary research carried out in the Terramara Santa Rosa di Poviglio suggested that the (wild) plants grew in hygrophilous woods, next to the ditch and to the river, were cared for or cultivated during the Middle and Late Bronze Age periods [60]. In a general perspective, a complex agro-sylvo system and high skills in agriculture practices characterized the Terramare's people who were aware of the diversity of natural resources [61]. Grapevine processing and preparation of beverages—as wine or other products releasing tartaric acid in special vessels—were well known [52]. Nevertheless, we can agree with McGovern and colleagues [42] who suggest that the history of viticulture “illustrates human ingenuity in developing horticultural and winemaking techniques, such as domestication, propagation, selection of desirable traits, wine presses, suitable containers and closures, and so on”. The plants growing next to the villages were wild grapevines, protected and managed by people who also knew how to exploit them, for food and wood. As hypothesized by Zohary [74] about selection criteria, Bronze Age people have selected plants producing fruits for centuries, and this has favored both female and the wild hermaphroditic grapevine growing in the same places. The latter wild plants were observed in Georgia, a region that is regarded as one of the earliest areas of *Vitis* domestication [20]. The case study of Poviglio further demonstrates that the technological

competence should have been acquired before domestication, allowing the shift of the same practices (cultivation, processing) from the wild to the domesticated species, subspecies in the case of *Vitis vinifera*.

We conclude that the inaperturate pollen of *Vitis* found in the archaeological layers of the Terramara Santa Rosa di Poviglio testifies to the presence of wild grapevine close to the archaeological site. This is of special importance because Bronze Age is known to have been a period of transition between the grape collection in the wild and the introduction of the domesticated grape subspecies in the Italian peninsula [47,60,90] as well as in the East Mediterranean [53,101]. This study adds new important elements to the knowledge of the relationships between people and grapevine, also underlining the importance of botany in understanding environmental contexts and archaeology, crop history, and human cultural evolution.

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Paesaggio vegetale sulla base delle analisi del riempimento dei pozzi al margine del Villaggio Grande della Terramara Santa Rosa di Poviglio

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5.1 PAESAGGIO VEGETALE SULLA BASE DELLE ANALISI DEL RIEMPIMENTO DEI POZZI AL MARGINE DEL VILLAGGIO GRANDE DELLA TERRAMARA SANTA ROSA DI POVIGLIO

ASSUNTA FLORENZANO, ELEONORA CLÒ, JESSICA ZAPPA, MARIA CHIARA MONTECCHI, ELISA FURIA, PAOLA TORRI, ANNA MARIA MERCURI

5.1.1 INTRODUZIONE

La ricerca palinologica di depositi e contesti inerenti la Terramara Santa Rosa di Poviglio è stata portata avanti negli anni grazie ad analisi di serie verticali provenienti dai fossati del Villaggio Piccolo (Ravazzi, Cremaschi, Forlani 1992, 2004) e quello tra il Villaggio Grande e il Villaggio Piccolo (Cremaschi *et alii* 2016a; Furia 2016-2017). Queste analisi hanno consentito di ricostruire eventi riguardanti le trasformazioni ambientali di questo territorio, principalmente a carico della copertura boschiva e dello sviluppo dell'agrosistema, modifiche avvenute nel sito in modo evidente durante l'età del Bronzo (dal Bronzo Medio al Bronzo Recente) e poi nelle fasi successive (dall'età del Ferro/romana all'età post romana-rinascimentale). Nonostante alcune trasformazioni siano state determinate da cause climatiche, legate a un processo generale di inaridimento e conseguente spopolamento regionale (Cremaschi, Pizzi, Valsecchi 2006; Cardarelli 1997a e 1997b, 2010; Cremaschi 2009; Cremaschi 2010), i risultati delle analisi palinologiche condotte fino ad oggi mostrano che i cambiamenti a livello locale devono essere avvenuti anche grazie a una significativa determinante antropica.

Le attività umane, ad esempio, hanno portato allo sviluppo di strutture idrauliche nei villaggi (Cremaschi e Pizzi 2006, 2011). In questo capitolo presentiamo le analisi palinologiche di due pozzi situati al margine del Fossato del Villaggio Grande. Il pozzo US 2106 è collocato nei pressi della Recinzione dell'abitato, mentre il pozzo US 6170 si trova all'interno del Fossato stesso. La cronologia va dal BM3 (eventualmente BM2) fino al Bronzo Recente avanzato. I campioni dai pozzi sono stati confrontati con quelli di due serie polliniche pre-

cedentemente campionate nei riempimenti tardi del fossato tra Villaggio Piccolo e Villaggio Grande (i Vertisuoli: VP/VG-II e VP/VG-III) (Cremaschi *et alii* 2016a), corrispondenti dal punto di vista stratigrafico e litologico a quelli che nel Fossato del Villaggio Grande si sovrappongono al pozzo US 6170.

L'indagine palinologica del riempimento dei pozzi fornisce informazioni puntuali sulle modalità di formazione dei depositi ad integrazione del dato stratigrafico, testimoniando le varie fasi successive all'utilizzo dei pozzi fino al loro completo riempimento in seguito a crolli o alla rifunzionalizzazione come rifiutaie. Inoltre, i dati pollinici danno indicazioni su flora e vegetazione nei pressi dei pozzi, nei momenti del loro utilizzo e nelle fasi di riempimento. Il confronto/integrazione dei dati ottenuti dalle analisi dei pozzi con quelli dalle sequenze dei fossati (in particolare con le serie polliniche prelevate nei Vertisuoli) consente una ricostruzione del paesaggio e dell'uso del suolo, dettagliando i cambiamenti della vegetazione nelle fasi di vita e abbandono dell'abitato. Tali informazioni sono fondamentali per investigare tempo e cause della crisi idrica e della concomitante azione antropica. Il livello delle falde acquifere nella Terramara dipendeva fortemente dal fiume Po e dalle sue piene, ma un evento arido, circa 3100 anni fa, fu probabilmente la base della crisi idrica subita da questa civiltà (Cremaschi e Pizzi 2006). L'evento climatico, però, deve essersi innestato su un ambiente già compromesso dall'attività umana, con sfruttamento relativamente intensivo delle risorse e accelerazione della crisi della civiltà terramaricola (Mercuri *et alii* 2006b; Cremaschi, Pizzi, Valsecchi 2006; Bernabò Brea, Cardarelli, Cremaschi 1997; Cremaschi *et alii* 2018b).

5.1.2 MATERIALI E METODI

I campioni pollinici

Il riempimento dei pozzi è stato campionato nel 2018, da monoliti di sedimento prelevati durante le campagne di scavo 1996 e 2011, sigillati da un avvolgimento di carta e orientati. I campioni pollinici sono stati presi ad intervalli regolari di circa 5-10 cm in successione stratigrafica (Fig. 1). Sono stati raccolti complessivamente 25 campioni pollinici (Tab. 1).

Dal riempimento del pozzo US 6170 provengono 10 campioni risalenti presumibilmente al BR2:

- 2 campioni (PV-P1-2) dalla parte superiore costituita da sedimenti di tessitura argillosa;
- 3 campioni (PV-P3-5) da unità intermedie contenenti blocchi di terreno franati dalle sponde del pozzo;
- 5 campioni (PV-P6-10) dai sedimenti argillosi ricchi di sostanza organica del fondo.

Tabella 1. Elenco dei campioni pollinici dei pozzi US 6170 e US 2106 della Terramara Santa Rosa di Poviglio, con relative unità stratigrafiche, profondità e cronologia.

<i>Pozzo</i>	<i>Campione</i>	<i>US</i>	<i>Profondità (cm)</i>	<i>Cronologia</i>
6170	PV-P1	6171	2	BR2
	PV-P2		12	
	PV-P3	6174	20	
	PV-P4		25	
	PV-P5		30	
	PV-P6	6188	32	
	PV-P7		36	
	PV-P8		40	
	PV-P9	6189	48	
	PV-P10		55	
2106	PV-P11	2114	5	BR1/BR2
	PV-P12		8	
	PV-P13	2142	12	
	PV-P14		18	
	PV-P15	2144	23	
	PV-P16		28	
	PV-P17	2147	31	
	PV-P18		36	
	PV-P19	2164	37	
	PV-P20		39	
	PV-P21	2244	42	BM3
	PV-P22		48	
	PV-P23	2244 bis	55	
	PV-P24		60	
	PV-P25		67	

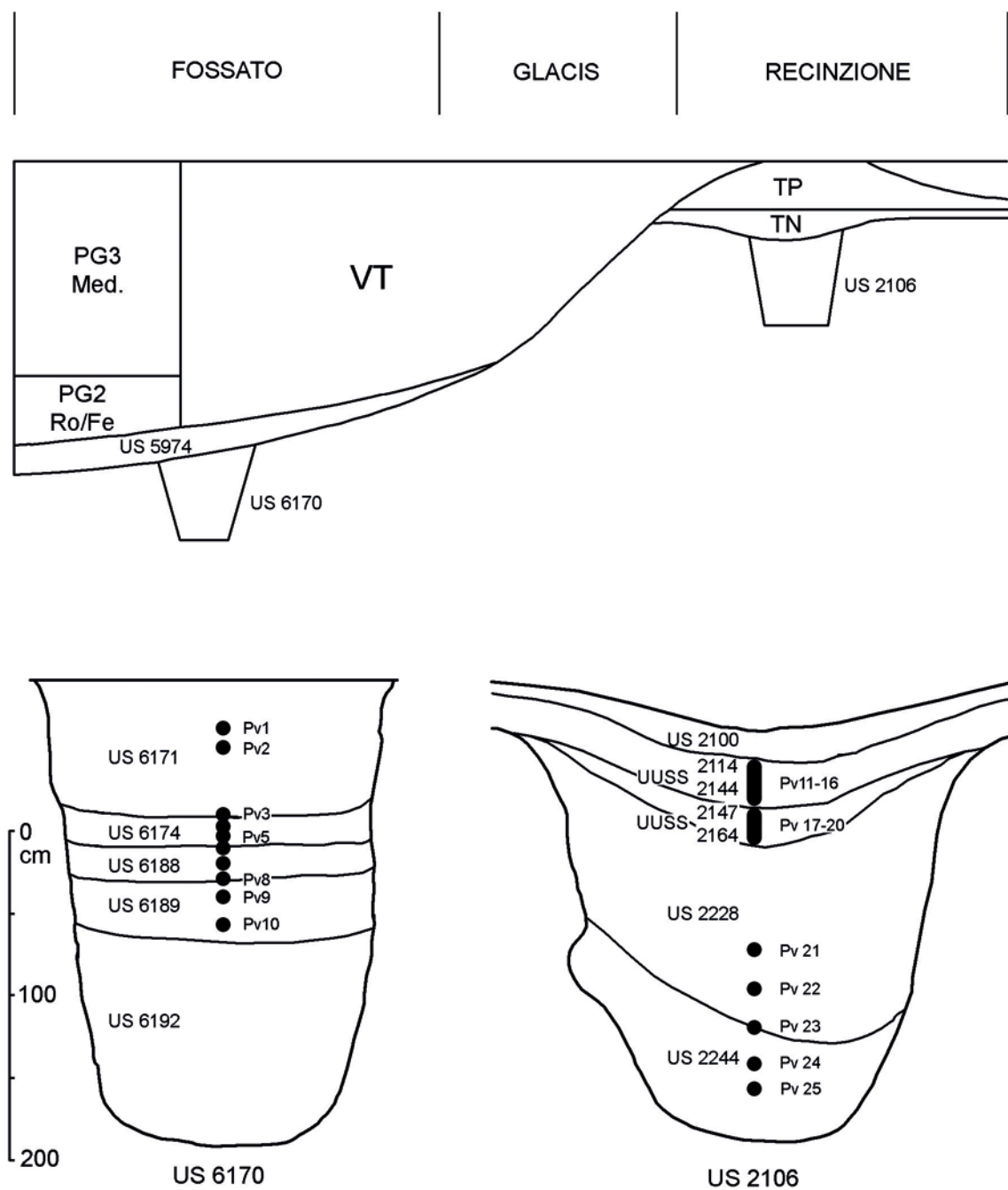


Fig. 1 - In alto: schema stratigrafico delle serie polliniche studiate nell'area della Recinzione e del Fossato; VT: Vertisuali; TP: Terrapieno; TN: Terre Nere; Med.: depositi di età medievale; Ro/Fe: depositi dell'età del Ferro e d'età romana. In basso: stratigrafie dei pozzi con posizionamento campioni.

Dal riempimento del pozzo US 2106 provengono 15 campioni con una cronologia che va dal BM3 al BR2:

- 6 campioni (PV-P11-16) dagli strati ricchi di sostanza organica delle rifiutaie al margine del villaggio, le Terre Nere, collassate nei pozzi dopo la loro defunzionalizzazione; il materiale ceramico è messo in posto durante il BR2 e, pur rimescolando materiale del BR1 e BM3, il suo contenuto pollinico può essere considerato BR2;
- 4 campioni (PV-P17-20) dai depositi corrispondenti a piani pavimentali relativi ad un edificio collassato all'interno del pozzo; qui, il materiale archeologico è specialmente BM3 / BR1;
- 5 campioni (PV-P21-25) da depositi di decantazione nella parte basale del riempimento, contestuale alla vita del pozzo.

I Vertisuoli del riempimento del Fossato, con cui sono stati confrontati i campioni dei pozzi, sono stati raccolti nel corso della campagna di scavo 2015 nella sezione ovest Settore Nord del fossato tra Villaggio Piccolo e Villaggio Grande. Anche se le sequenze VP/VG-II e VP/VG-III (Furia 2016-2017) dettagliano fasi più lunghe, in questo lavoro sono illustrati i risultati degli 11 campioni che presentano una cronologia coeva (Bronzo Recente, 9 campioni) e successiva (periodo di transizione età del Ferro/romana, 2 campioni) a quella dei campioni dei pozzi.

Estrazione e conte dei palinomorfi

Nel Laboratorio di Palinologia e Paleobotanica di Modena, i campioni sono stati sottoposti a un trattamento di estrazione pollinica che ha previsto, tra l'altro, una fase di arricchimento con liquido pesante e aggiunta di spore di *Lycopodium* per il calcolo della concentrazione pollinica (espressa in p/g = granuli pollinici per grammo). In particolare, il trattamento ha previsto le seguenti fasi (Florenzano *et alii* 2012): deflocculazione con Na-tetrapirofosfato idrato, dissoluzione dei carbonati con HCl 10%, settacciatura con filtro di nylon, flottazione con Na-metatungstato idrato (liquido pesante che porta a un arricchimento, cioè una concentrazione di polline anche in presenza di scarsa so-

stanza organica o contesti esposti a rischio di ossidazione: è dunque particolarmente adatto per lo studio di strati archeologici), disidratazione in acido acetico e acetolisi (bollitura in anidride acetica + acido solforico con un rapporto 9:1), dissoluzione dei silicati con HF 40%, passaggi in alcool e inclusione in glicerina. Il residuo, raccolto in eppendorf, è stato seccato in stufa a circa 50°C. Dopo il trattamento sono stati allestiti i vetrini fissi, conservati ora nella Palinoteca, numerati, etichettati e idonei alla lettura al microscopio ottico a luce trasmessa.

Le analisi polliniche sono state eseguite con ingrandimenti di 400x e 1000x ad immersione in olio. Le determinazioni polliniche sono state effettuate con utilizzo di chiavi dicotomiche e atlanti fotografici (Moore, Webb, Collins 1991; Reille 1992, 1995, 1998; Beug 2015) e la collezione pollinica di confronto di Modena. Sono stati contati ca. 300 granuli pollinici in media per campione. Le percentuali sono state calcolate su una somma pollinica di base che include tutti i granuli contati, inclusi quelli non determinati/non determinabili. Le percentuali di spore di felci, i palinomorfi non pollinici e il polline di deposizione secondaria sono stati calcolati su somme polliniche diverse, ciascuna costituita dalla somma pollinica di base più loro stessi.

Sono state, inoltre, calcolate alcune sommatorie utili alla ricostruzione paleoambientale:

- AP = somma delle piante legnose, alberi e arbusti, utile a dare indicazioni sulla copertura forestale
- Alberi igrofilici (*Alnus*, *Salix*);
- Igrofiti erbacei (*Scirpus*, *Cyperaceae* indiff., *Phragmites*, *Thalictrum*, *Typha*);
- Idrofiti (*Lemna*, *Myriophyllum*, *Hydrocharis*, *Nuphar*, *Nymphaea*, *Potamogeton*);
- Querceto misto (*Carpinus*, *Corylus*, *Ostrya carpinifolia*/*Carpinus orientalis*, *Quercus decidue*, *Tilia*, *Fraxinus*, *Acer*, *Ulmus*);
- Alberi di conifere (*Abies*, *Pinus*);
- OJC gruppo (*Olea*, *Juglans*, *Castanea*; Mercuri *et alii* 2013a);
- API (*Artemisia*, *Centaurea*, *Plantago*, *Urtica*, *Trifolium*, *cereali*, *Cichorieae*; Mercuri *et alii* 2013b);
- Cereali (*Hordeum* gruppo, *Avena*/*Triticum* gruppo, *T. aestivum*/*T. spelta*).

5.1.3 RISULTATI

Tutti i campioni esaminati sono risultati polliniferi. La concentrazione pollinica dei due pozzi è risultata ca. 15.500 p/g, con valori variabili da un minimo di 4450 p/g (campione PV-P18 del pozzo US 2106) a un massimo di 48.950 p/g (campione PV-P12 del pozzo US 2106), in dipendenza della proporzione tra materiale organico che include apporto pollinico e il sedimento inorganico negli strati.

I granuli pollinici sono stati osservati con uno stato di conservazione generalmente buono, ma variabile all'interno dello stesso campione, tra i campioni dello stesso pozzo e, in parte, tra i depositi dei due pozzi. Questo elemento può essere interpretato come evidenza di apporti pollinici da trasporti diversi nei campioni (Dimbleby 1985; Faegri e Iversen 1989): un trasporto di particolato già deposto a terra, probabilmente con i sedimenti esterni al pozzo e franati al suo interno (granuli accartocciati, piegati o deteriorati), soggetto a disseccamento (granuli assottigliati, chiari) e un trasporto aereo di polline caduto nel pozzo in funzione e sedimentato in acqua (polline non accartocciato e ben conservato; vedi dopo).

Le liste floristiche comprendono un discreto numero di taxa, ca. 40 in ogni campione, raggiungendo 118 e 100 taxa nei due pozzi US 2106 e US 6170, rispettivamente; i taxa erbacei costituiscono 68-69% di queste liste suggerendo una ricchezza floristica basata su specie con tale *habitus*. Tra le legnose, sono ubiquitari *Alnus*, *Corylus*, *Quercus* e *Pinus*; tra le erbacee, *Aster* tipo, *Cichorieae*, *Cyperaceae* e *Poaceae* caratterizzano gli spettri.

La copertura forestale, indice calcolato sulla base del rapporto tra percentuali totali di legnose AP e di erbacee NAP, contribuisce a ¼ degli spettri pollinici medi, ed è la stessa nei due pozzi ($AP/NAP = 23/77$ nel pozzo US 6170; $24/76$ nel pozzo US 2106), segnalando una ridotta copertura boschiva in tutta l'area interessata dal sito archeologico.

Nella quasi totalità dei campioni esaminati sono stati osservati sporomorfi non pollinici, attribuibili in particolare a spore della micorriza *Glomus*, fungo simbiote delle radici delle piante e indicatore di fenomeni erosivi, accanto a cisti algali di *Pseudoschizaea*, anche essa indicatrice di erosione, e di cianobatteri del genere *Rivularia*, comune nelle acque dolci.

Di seguito, sono descritti analiticamente i tratti principali emersi dalle analisi polliniche dei due pozzi, illustrando prima il pozzo US 6107, e poi il pozzo US 2106 che include i livelli più antichi. I dati sotto riportati si riferiscono al valore medio misurato nei campioni di ciascun pozzo descritto.

Dati pollinici dal pozzo US 6170 (da PV-P1 a PV-P10) (Fig. 2)

Nei 10 campioni esaminati sono stati contati 3155 granuli pollinici.

Concentrazione media: ca. 16.600 p/g. Le concentrazioni polliniche sono risultate < 10.000 p/g nel 40% dei campioni, mentre negli altri i valori oscillano da ca. 10.100 p/g (PV-P4) a ca. 34.000 p/g (PV-P1).

Stato di conservazione: è complessivamente buono nei livelli più bassi, con maggiore presenza di granuli pollinici deteriorati nei livelli più alti; lo stato è relativamente migliore rispetto al pozzo US 2106.

Ricchezza pollinica: i taxa totali sono 31 legnose e 69 erbacee, 42 taxa in media per campione.

Aree boschive: il 23,4% di piante legnose include una componente del 10,7% di querceto misto con 5,8% di polline di *Quercus* decidue.

Aree umide: 15,1%, con *Alnus*+*Salix* 8,1% a costituire la componente di boschi igrofilo.

Cereali: 1,2 %, con apporto prevalente di orzo rispetto ai frumenti. Le evidenze di cerealicoltura sono attestate da granuli appartenenti ai gruppi *Hordeum* (1,0%) e *Avena/Triticum* (0,2%).

Altre coltivazioni e aree pascolate: le legnose coltivate/coltivabili e con frutti eduli sono rappresentate principalmente da *Corylus* (2,7%), con presenza di *Juglans*, e tracce di *Cornus mas*, *Rubus*, *Sorbus* e *Ficus* (<0,1% ciascuno). *Vitis* e *Cannabis* sono presenti. Tra le leguminose-Fabaceae (1,0%), pur se in proporzione più bassa rispetto al pozzo precedente, sono presenti piante forse coltivate per foraggio come *Medicago*, *Melilotus*, *Trifolium*. Tra le piante strettamente correlate ad attività di pascolo, troviamo *Cichorieae* (5,3%) e *Asteraceae* (5,4%).

Palinomorfi non pollinici: sono quasi ubiquitarie le cisti algali di *Pseudoschizaea*, e altrettanto ricorrenti sono le eterocisti di *Rivularia* (assenti solo in 2 campioni); si osservano poche clamidospore di *Glomus*, in solo in 3 campioni del riempimento.

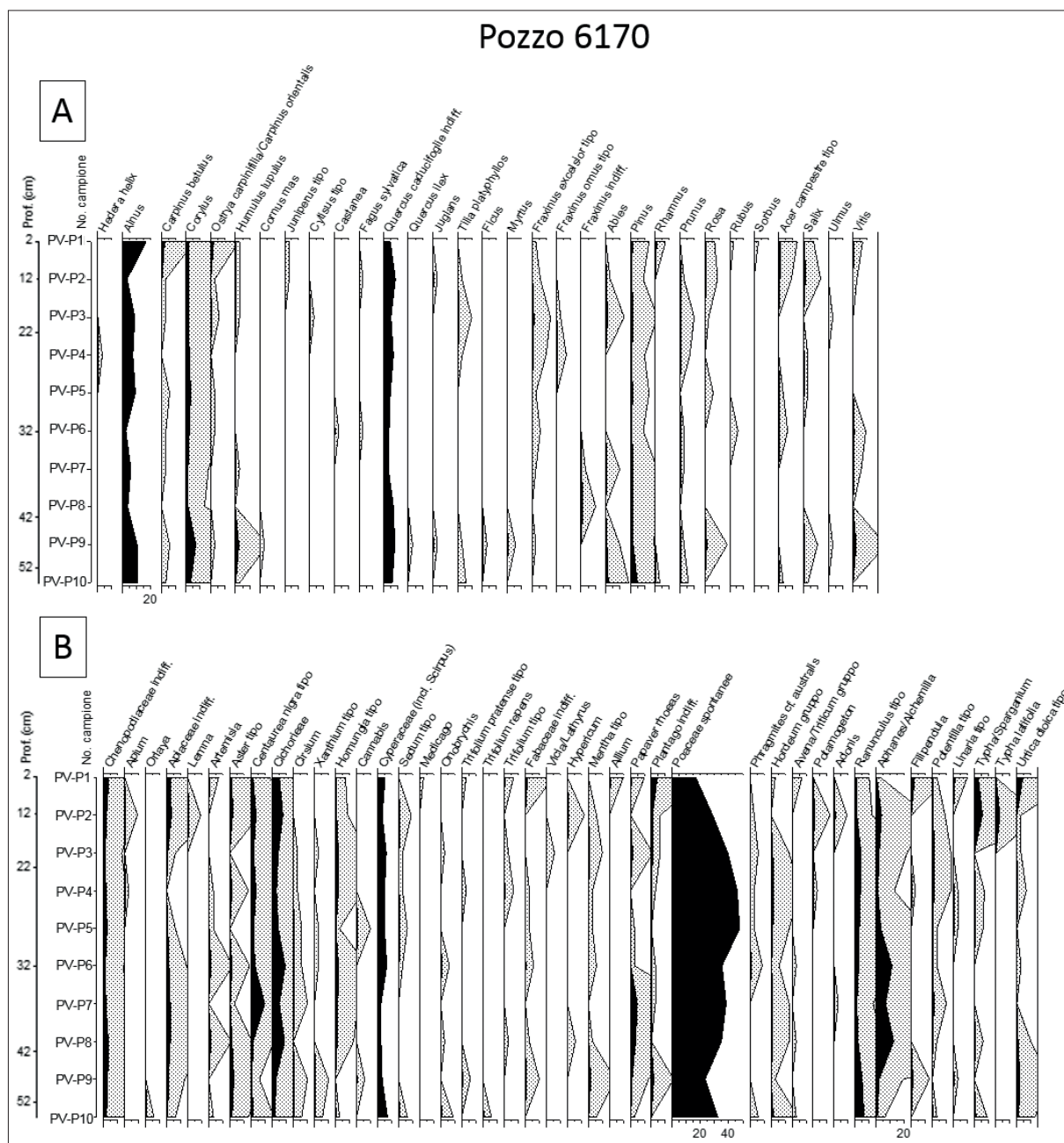


Fig. 2 - Diagramma pollinico percentuale, Pozzo US 6170: A) alberi e arbusti; B) piante erbacee. Curve amplificate con fattore 10. Sono esclusi dai diagrammi i taxa pollinici con valori percentuali < 0,6%.

In generale, gli spettri pollinici del pozzo US 6170 mostrano lo stesso tasso di forestazione, oltre il 30% in soli due campioni (PV-P1 e PV-P9). Nella composizione dei boschi predominano le specie del querceto misto (principalmente *Quercus* decidue, *Corylus* e *Carpinus betulus*), i cui valori sono compresi tra 5,8% (PV-P7) e 16,5% (PV-P9); nei campioni più superficiali (PV-P1-P4) non è mai inferiore a 10%. Le piante di ambiente umido (che includono alberi igrofilo, igrofite erbacee e idrofite) hanno valori variabili da 6,5% (PV-P8) a 25,7% (PV-P1).

Il gruppo OJC è sporadicamente rappresentato da *Castanea* (PV-P6: 0,3%) e *Juglans* (PV-P2 e PV-P9: 0,3%). Tra le erbacee prevalgono Poaceae (34,2%), Cichorieae (5,3%), Cyperaceae (4,7%) e Chenopodiaceae (2,5%). Il gruppo API (6,7%, costituito da *Artemisia*, *Centaurea*, *Plantago*, *Urtica*, *Trifolium* e cereali) è sempre ben rappresentato negli spettri con valori tra 3,5% (PV-P5) e 12,1% (PV-P1).

*Dati pollinici dal pozzo US 2106
(da PV-P11 a PV-P25) (Fig. 3)*

Nei 15 campioni esaminati, sono stati contati 4711 granuli pollinici.

Concentrazione media: ca. 14.400 p/g. Le concentrazioni polliniche sono risultate < 10.000 p/g nel 47% dei campioni, mentre negli altri i valori oscillano tra ca. 13.700 p/g (PV-P19) e ca. 49.000 p/g (PV-P12).

Stato di conservazione: granuli in buono stato accanto a numerosi granuli deteriorati, particolarmente variabile nei campioni più profondi.

Ricchezza pollinica: i taxa totali sono 37 legnose e 81 erbacee, 39 taxa in media per campione.

Aree boschive: il 24,0% di piante legnose include una componente del 11,7% di querceto misto con il 7,8% di *Quercus decidue*.

Aree umide: 15,6%, con *Alnus*+*Salix* 8,0% a costituire la componente di boschi igrofili.

Cereali: 5,9%, con apporto comparabile di orzo e frumenti. Le evidenze di cerealicoltura sono attestate da granuli appartenenti ai gruppi *Hordeum* (3,1%), *Avena/Triticum* (2,8%) e *Triticum aestivum/T. spelta* (0,1%).

Altre coltivazioni e aree pascolate: le legnose coltivate/coltivabili e con frutti eduli sono rappresentate principalmente da *Corylus* (1,5%), con presenza di *Prunus*, *Olea* (0,1%), *Cornus mas* e *Pyrus* (<0,1%), con tracce di *Rubus* cf. e *Vitis*. Tra le possibili altre specie utili, è da segnalare *Vicia* (<0,1%), una leguminosa forse coltivata per foraggio e *Cannabis* (0,4%), di uso per la fibra tessile. Tra le piante strettamente correlate ad attività di pascolo troviamo soprattutto *Cichorieae* (5,3%) con altre *Asteraceae* (2,8%), e *Fabaceae* (1,8%).

Palinomorfi non pollinici: come nel caso precedente, in tutti i campioni sono presenti cisti algali di *Pseudoschizaea*, con *Rivularia* (assente nei 3 campioni al top della sequenza) e clamidospore di *Glomus*.

Gli spettri pollinici del pozzo US 2106 mostrano un tasso di forestazione che, pur restando sempre <60%, mostra valori relativamente più alti nella parte basale (PV-P22-P25; 40-51%) rispetto alla metà superiore della sequenza (PV-P11-P18; ca. 13%). La composizione floristica vede *Quercus decidue* (7,8%) e *Alnus* (7,4%) ubiquitari, con valori più alti (8-26%, e 8-25%, rispettivamente) nei campioni più profondi (da PV-P21 a PV-P25).

Il querceto misto (oltre a *Quercus decidue*, anche *Corylus* e *Carpinus betulus*) si attesta con valori che variano da 4,3% (PV-P17) a 29,4% (PV-P23); nei campioni della parte basale del riempimento (PV-P19-P25) il querceto ha percentuali > 10%.

Le piante di ambiente umido sono presenti con valori che oscillano tra 6% (PV-P17) e 27,4% (PV-P12); la componente maggiore risulta essere quella degli alberi igrofili nei campioni più recenti (PV-P11-P19, ad esclusione di PV-P17), mentre sono più diffuse le igrofite erbacee nei campioni più antichi (PV-P20-P25 e PV-P17). Il gruppo OJC è scarsamente rappresentato, con solo tracce di *Castanea* (PV-P22: 0,6%) e *Olea* (PV-P12-P13: 0,5%).

Tra le erbacee prevalgono *Poaceae* (36,7%), *Cyperaceae* (6,6%) e *Cichorieae* (5,3%).

Il gruppo API, costituito principalmente da *Centaurea nigra* tipo, *Plantago* e cereali, è sempre presente negli spettri (9,5%) con percentuali comprese tra 5,5% (PV-P16) e 18,6% (PV-P20).

Il contenuto pollinico dei Vertisuoli (Fig. 4)

Gli 11 campioni delle serie VP/VG-II e VP/VG-III datati al BR e al periodo di transizione età del Ferro/romana sono risultati altamente polliniferi, con concentrazioni medie rispettivamente di ca. 42.400 p/g e 56.500 p/g (Furia 2016-2017). Il polline ha uno stato di conservazione discreto, e si presenta meglio conservato nei campioni alla base della sequenza VP/VG-II. Il polline di deposizione secondaria, indice di deposito di sedimenti da erosione fluviale, è presente in tutti i campioni.

La lista floristica è piuttosto ricca, con 44 taxa in media per campione. Il rapporto legnose/erbacee è anche qui a favore delle erbacee, con le legnose pari a 16,4% in media nei 9 campioni del bronzo, e 17,4% per i due campioni successivi. La percentuale di erbacee è sempre >80%, con predominanza di *Poaceae* spontanee (23,8%), *Cichorieae* (16%) e *Cyperaceae* (15,3%).

La copertura arborea è composta principalmente da querceto misto (9,9% in media nei campioni del BR, e 9,5% in quelli del periodo Ferro/romano). Il querceto misto è testimoniato dalla presenza di querce caducifoglie (3,9% e 5,6%); sono inoltre presenti nocciolo (1% e 0,5%), carpino nero/carpino orientale (2,2% per entrambe le fasi cronologiche) e carpino bianco (1,5% e 0,5%), e tracce di frassino maggiore e ti-

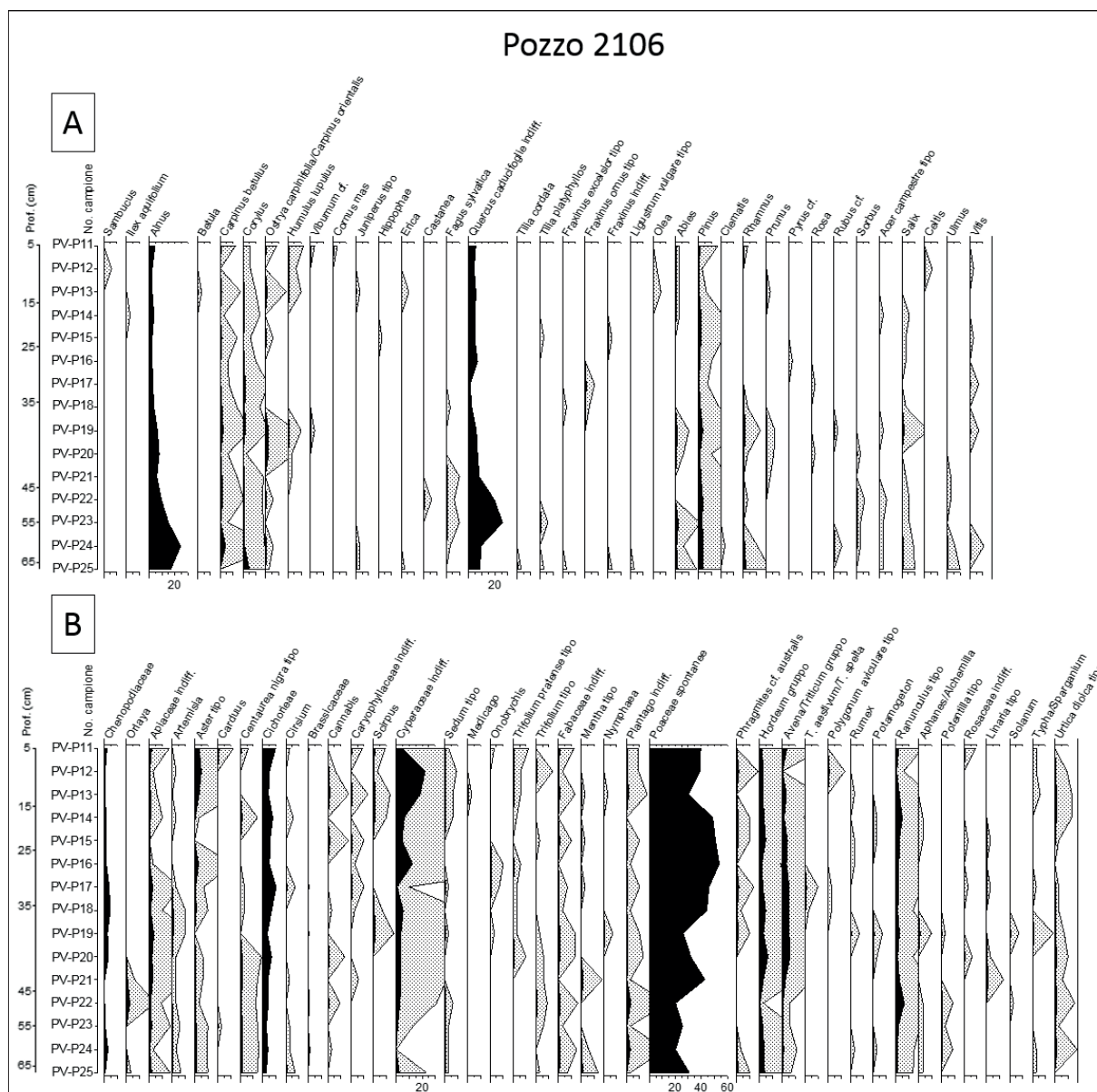


Fig. 3 - Diagramma pollinico percentuale, Pozzo US 2106: A) alberi e arbusti; B) piante erbacee. Curve amplificate con fattore 10. Sono esclusi dai diagrammi i taxa pollinici con valori < 0,6%.

glio. I boschi igrofili risultano meno evidenti ma sono sempre ben attestati (3,1% e 4,9%), e costituiti principalmente da ontano (2,1% e 3,2%), con salice (0,8% e 0,5%) e pioppo (0,2% e 0,3%). La presenza di prati e aree umide è al 20% per i campioni del BR e al 25% per quelli del periodo Ferro/romano. Questo è indicato soprattutto dalla presenza di piante igrofite e idrofite come *Cyperaceae* (14,5% e 17,6%) e in minor misura *Sparganium emersum* tipo (0,4% e 0,7%).

Tra le legnose coltivate/coltivabili per il frutto edule sono presenti il nocciolo (1,1% e 0,4%) e il pruno (0,1% e 0,4%). Di interesse è anche la vite,

rinvenuta solo nei campioni iniziali del Bronzo Recente (<1% in media, max.: 1,6%). Anche se il polline di *Vitis* coltivata è indistinguibile da quello di *Vitis* selvatica, il contesto rende plausibile che si tratti di vite spontanea ripariale a crescita favorita dall'azione antropica (Cremaschi *et alii* 2016a). Il castagno e il noce, che fanno parte del gruppo OJC, sono presenti in tracce (0,1%).

Gli indicatori antropogenici (API) sono attestati al 26,8% nel Bronzo e al 20,4% nella fase successiva.

Gli spettri pollinici dei campioni del Bronzo Recente presentano diverse di tipologie di cereali

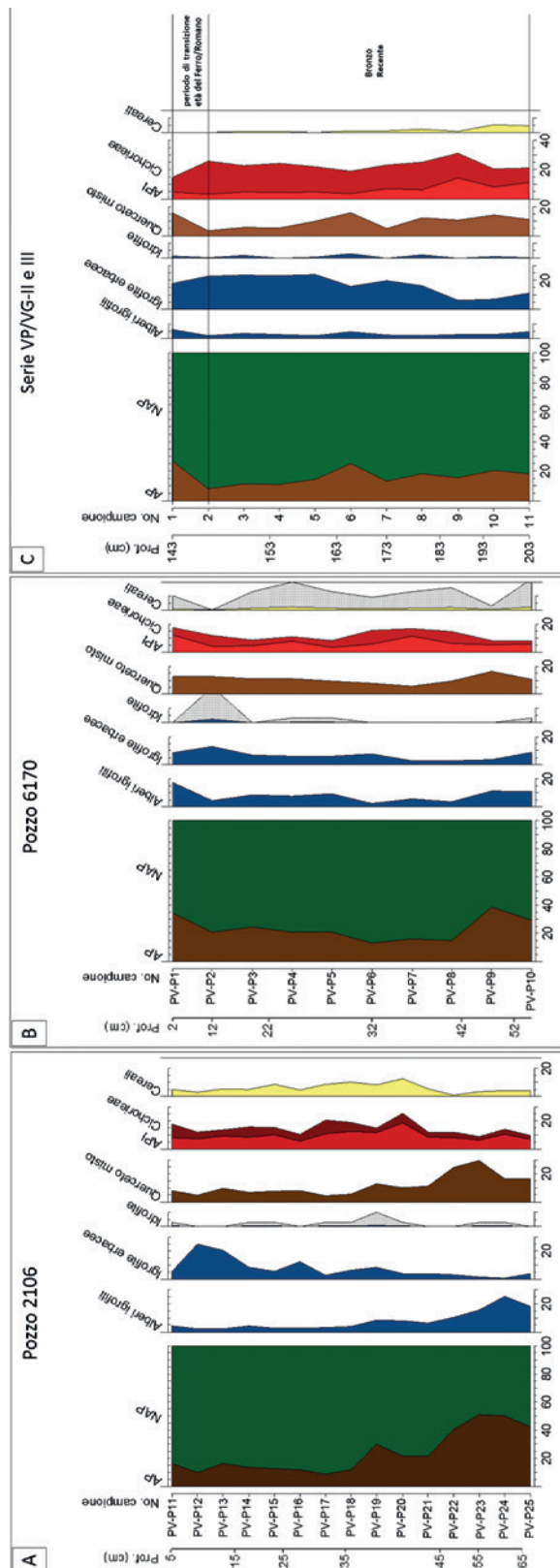


Fig. 4 - Diagrammi pollinici sintetici con le principali somme per la ricostruzione ambientale e delle attività antropiche dei campioni dai Pozzi (A) US 2106 e (B) US 6170, e (C) di campioni scelti delle serie VP/VG-II e III dal riempimento del Fossato.

(*Avena/Triticum* gruppo – 1,1%, max. >3% nei 2 campioni più antichi; *Hordeum* gruppo – 0,7%; *Panicum* – 0,2%), mentre per la fase successiva è attestato solo l'orzo (0,2%).

Tra gli indicatori antropogenici troviamo polline di sinantropiche spontanee tipiche di margine di campi coltivati o abbandonati (*Centaurea*, *Convolvulus*, *Orlaya*, *Artemisia*), di piante ruderali (*Urtica*) e indicatrici di calpestio (*Plantago*).

Tra le piante indicatrici di pascolo troviamo Cichorieae (16%) e altre Asteraceae (ca. 2%). Sono attestate anche piante utilizzate come foraggio (es. *Trifolium*, *Medicago*), presenti in discrete quantità (1% e 1,5% rispettivamente nei campioni del Bronzo Recente e del periodo Ferro/romano).

La presenza degli NPP è piuttosto scarsa in tutti i campioni; i palinomorfi più frequentemente osservati sono cisti algali di *Pseudoschizaea* e di cianobatteri del genere *Rivularia*.

5.1.4 DISCUSSIONE

Stato di conservazione e processi di formazione del deposito

Lo stato di conservazione del materiale pollinico è risultato generalmente buono ma, come già menzionato, accanto a polline ben conservato e non ripiegato sono stati osservati granuli con diversi caratteri di deterioramento (Fig. 5). Si tratta di una condizione abbastanza frequente in contesti archeologici e depositi dove granuli coevi hanno aspetto diverso: accanto a una deposizione stratigrafica abbastanza indisturbata, da trasporto aereo (come, ad esempio, al centro di bacini lacustri), nel deposito possono essere incorporati granuli pollinici mobilitati dall'azione umana, compattati dal calpestio o sollevati dallo smottamento del terreno.

Nei campioni dei pozzi qui studiati, i granuli pollinici ben conservati sono probabilmente testimoni di un arrivo di polline nel deposito attraverso il vento, con caduta in ambiente presto anossico che abbia assicurato una buona conservazione dell'esina (la sua parete di rivestimento): possiamo ritenere che questo sia avvenuto soprattutto durante fasi nelle quali il pozzo conteneva acqua, e che tale ambiente ab-

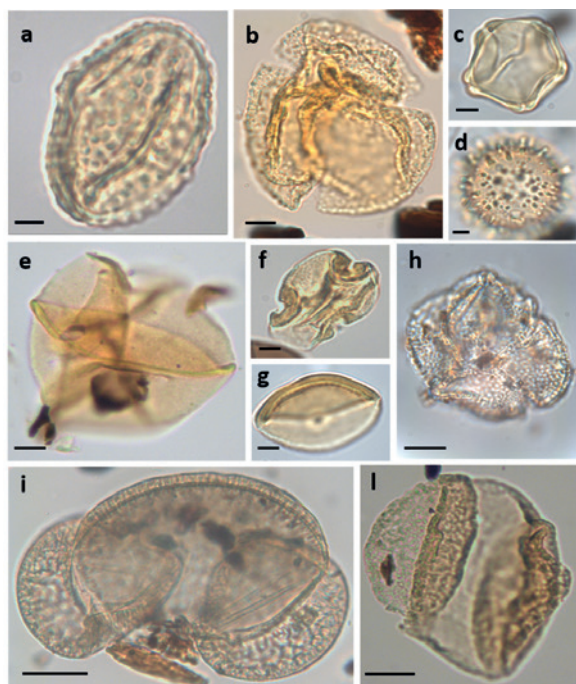


Fig. 5 - Polline dal riempimento dei Pozzi UUSS 6170 e 2106. a) *Centaurea nigra* (PV-P7), b) *Quercus* (PV-P22), c) *Alnus* (PV-P23), d) *Nymphaea alba* (PV-P19), e) *Avena-Triticum* gruppo (PV-P4), f) granulo accartocciato di *Tilia* (PV-P10), g) *Phragmites* (PV-P25), h) *Typha latifolia* (PV-P2), i) *Abies* (PV-P7), l) *Pinus* (PV-P6).

bia preservato i granuli. Le due principali tipologie di deterioramento osservate, invece, sono state accartocciamento del granulo e corrosione dell'esina, con e senza assottigliamento della stessa. Tali forme di deterioramento possono indicare l'attività di processi post-deposizionali (es., disidratazione, compattazione dei depositi, ossidazione; Dumbleby 1985).

Nel pozzo US 6170, i granuli ben conservati suggeriscono un arrivo tramite vento e inoltre indicano la presenza di un ambiente di deposizione più idoneo alla conservazione di materiale organico (il riempimento argilloso saturo d'acqua nel fossato mantiene condizioni anossiche).

Nel pozzo US 2106, la maggiore quantità di granuli deteriorati evidenzia sia un diverso apporto dei granuli (tramite calpestio che ha sollevato sedimenti, rifiuti e crolli), sia una diversa tipologia di depositi che, seppure ricchi di materiali organici, non ne ha garantito la perfetta conservazione (mentre sul fondo del pozzo c'è una decantazione di depositi argillosi, il resto del riempimento è costituito da crolli o accumuli rapidi legati all'utilizzo del pozzo

come rifiutaria dell'abitato che rendono il deposito più disturbato).

In generale, lo stato di conservazione dei livelli più antichi è risultato migliore di quelli più recenti, almeno nel pozzo US 6170, una condizione in accordo con il fatto che nelle fasi iniziali possa esserci stata acqua, mentre in quelle finali il pozzo potrebbe essere stato riempito da sedimenti e crolli di varia origine. Anche se il polline del pozzo US 2106 è risultato meno preservato di quello del pozzo US 6170, lo stato di conservazione del polline dei pozzi è risultato migliore di quello osservato nelle sequenze polliniche VP/VG del Fossato finora studiate (Cremaschi *et alii* 2016a; Furia 2016-2017).

Infine, in tutti i campioni sono stati osservati granuli pollinici di deposizione secondaria, che indicano arrivo di sedimenti da erosione fluviale. Il polline secondario risulta più abbondante nei livelli di decantazione del pozzo US 2106 (BM3; da PV-P25 a PV-P21), e continua ad essere ben rappresentato, seppure con fluttuazioni, anche negli altri campioni datati al Bronzo Recente anche avanzato di entrambe le sequenze polliniche. La costante presenza del polline di deposizione secondaria testimonia l'importanza dei processi fluviali nella formazione dei depositi sedimentari del Fossato e del Terrapieno che circondano il villaggio terramaricolo (Ravazzi, Cremaschi, Forlani 2004; Mercuri *et alii* 2012).

Le informazioni ecologiche fornite dai palinomorfi non pollinici aiutano nella comprensione delle diverse fasi nel processo di formazione dei depositi. Ubiquitari nei riempimenti dei pozzi sono le cisti algali di *Pseudoschizaea*, che indicano variazioni del livello idrico con fasi di disseccamento ed erosione; ricorrenti, sebbene poco concentrate, risultano anche le eterocisti di *Rivularia*, indicatrici di acque calde o stagnanti.

Nel pozzo US 6170 si osserva una certa uniformità nella presenza delle due tipologie di cisti algali lungo tutta la sequenza, ad indicare una sostanziale uniformità delle condizioni ecologiche nel deposito. Il lieve relativo incremento di *Rivularia* nei campioni dell'ultima fase di riempimento del pozzo testimonia un possibile temporaneo ristagno d'acqua, forse piovana, trattenuta dalla natura argillosa dei sedimenti.

Nel pozzo US 2106 *Pseudoschizaea* è più concentrata nei depositi delle fasi di decantazione alla base del pozzo, confermando quindi una fluttuazione della falda con un progressivo inaridimento del pozzo nel BM3. Negli stessi livelli si osservano anche eterocisti di *Rivularia* relativamente più abbondanti rispetto alle fasi successive, a documentare la presenza di acqua alla base del pozzo almeno in alcuni momenti. Negli strati di crollo del BR1 permangono entrambi gli elementi algali, ma sono poco rappresentati ad indicare un possibile temporaneo ristagno di acqua non necessariamente legato alla risalita della falda, quanto piuttosto ad un accumulo di acque piovane. Nell'ultima fase del riempimento della sequenza sono assenti le cisti di *Rivularia*, mentre *Pseudoschizaea* segnala una fase di inaridimento.

Le spore della micorriza *Glomus*, osservate comunemente nei suoli sottoposti ad erosione, sono sporadiche nei depositi del pozzo US 6170 mentre sono presenti lungo la sequenza del pozzo US 2106, ad indicare una maggiore vicinanza di radici presso questo pozzo.

IL PAESAGGIO VEGETALE

La ricostruzione dei boschi e delle aree umide

Gli spettri pollinici di tutti i campioni esaminati riconducono a un paesaggio con una ridotta copertura forestale con querceti e boschi igrofili, caratterizzato da aree aperte con una forte presenza di indicatori di frequentazione antropica.

Anche se il valore di AP è in media <25%, è interessante notare che nella parte basale del riempimento del pozzo US 2106 sono presenti valori più alti, ca. 40-50%, per lo più imputabili alle querce e agli ontani (Fig. 3). Ciò suggerisce una relativamente più alta presenza di legnose nelle fasi più antiche. Nel complesso, la composizione della copertura arborea vede la dominanza di elementi del querceto misto (principalmente *Quercus decidue*, *Carpinus betulus*, *Corylus* e *Ostrya car./Carp. or.*), con boschi igrofili (*Alnus*, meno frequente *Salix*) e qualche conifera (*Abies* e *Pinus*).

Nel pozzo US 2106, il calo dei boschi è visibile dai campioni datati alla fine del BM3 (PV-P20-P21: 21,6% in media, rispetto a ca. 46% in PV-P22-P25) con una fase di ripresa solo nella parte basale delle Terre Nere, costituita dai piani pavimentali (ca. 30% in PV-P19). Nelle fasi successive, il dato pollinico segnala una certa

costanza nella copertura arborea, seppure con piccole fluttuazioni. Possibile, anche che il forte calo osservato tra BM e BR sia in parte imputabile alla mancanza di risoluzione dei dati pollinici al passaggio tra i depositi di decantazione e il crollo, oppure dalla provenienza diversa dei materiali del deposito. Infatti, mentre i sedimenti datati al BM3 sono depositi di decantazione del fondo del pozzo che quindi documentano l'immagine pollinica della vegetazione circostante, quelli alla base delle Terre Nere sono piani pavimentali dal crollo di un edificio e il dato pollinico potrebbe allora rispecchiare sia la vegetazione sia l'ambiente interno alla struttura.

Nel pozzo US 6170, non sono presenti grandi oscillazioni nella copertura arborea, ad eccezione di un aumento della forestazione (da 29,4% a 38,8%) nella prima fase del riempimento; imputabile ad un incremento di *Quercus decidue*, *Corylus* e *Ostrya carp. /Carp. or.* (Fig. 2).

Tra le legnose, la costante presenza di alberi igrofili (*Alnus* soprattutto, ma anche tracce di *Salix* e *Ulmus* <0,5%) indica la presenza di habitat boschivi igrofili diffusi in prossimità di zone umide o soggette a impaludamento. Significativa è inoltre la distribuzione dei reperti di piante erbacee legate ad aree umide (principalmente *Cyperaceae* e *Typha* tra le igrofite, e *Potamogeton*, *Nymphaea* e *Lemna* tra le idrofite). Il polline delle piante acquatiche risulta in associazione con elementi di fitoplancton, che danno un'indicazione di acque calme o stagnanti (ad es. *Rivularia*; Mudie *et alii* 2010) o di fluttuazioni nel livello idrico con fasi di inaridimento (*Pseudoschizaea* sp.; Grenfell 1995). Nel complesso, tali rinvenimenti indicano la presenza di substrati umidi e la prossimità a corsi fluviali.

L'interpretazione degli indicatori di zone umide indica una situazione locale secondo la quale i pozzi dovevano essere mantenuti abbastanza puliti durante le fasi di utilizzo e, dismessi, sono stati riempiti da sedimenti di crolli (delle sponde del pozzo stesso – pozzo US 6170, o di una struttura abitativa – pozzo US 2106) o di rifiuti dell'abitato (Terre Nere, ricche di materiale organico – pozzo US 2106).

Riassumendo, l'andamento della copertura forestale registrato negli spettri dei pozzi mostra una evidente riduzione dei boschi negli strati alti del BM3. Un temporaneo incremento della vege-

tazione si osserva nel pozzo US 2106, in coincidenza con la defunzionalizzazione del pozzo ed il crollo in esso dei piani pavimentali e alla fine della sequenza del pozzo US 6170 che si colloca nel BR2 avanzato, alla vigilia dell'abbandono del sito. Nel dettaglio, la composizione della copertura arborea nelle fasi di relativamente alta forestazione degli strati basali del riempimento datato al BM3 vede un'iniziale predominanza di alberi igrofilo (*Alnus*), seguita da un repentino calo dei boschi umidi e un altrettanto rapido incremento del querceto misto. Molto verosimilmente, la presenza del querceto nel territorio non ha subito variazioni nelle ultime fasi del BM3, ma è stata mascherata dai boschi umidi posti più vicini al fossato che hanno schermato l'arrivo del polline del querceto planiziale. Differente è invece la situazione che si registra in concomitanza dell'aumento di forestazione al momento della messa in posto delle Terre Nere: il picco delle legnose vede infatti il contributo sia degli alberi igrofilo sia del querceto misto. Anche il lieve incremento nella forestazione che si registra nell'ultimo campione del pozzo US 6170 è legato ad un aumento degli alberi igrofilo, mentre il querceto misto si attesta con valori pressoché simili a quelli dei campioni precedenti.

Le serie polliniche dai Vertisuoli confermano una copertura boschiva esigua (16% in media, max. 25%) rappresentata soprattutto dal querceto misto e dal bosco igrofilo. I valori di copertura forestale della sequenza VP/VG-II sono simili a quelli osservati nella fase finale della sequenza VP/VG (20%; Cremaschi *et alii* 2016a), confermando la diminuzione della forestazione che vede i valori minimi nell'ultima fase di vita del villaggio. In generale, il paesaggio aperto intorno alla Terramara a partire dal Bronzo Medio è sotto forte influenza antropica: l'aumento demografico che si registra tra BM e BR porta, infatti, a una riduzione dei boschi per l'alta richiesta di materiale da costruzione e l'aumentata necessità di aree da adibire a campi per la produzione di cibo (Cremaschi, Pizzi, Valsecchi 2006).

Le attività antropiche: coltivazioni e pastorizia

Negli spettri pollinici sono costantemente attestate specie che indicano presenza e attività antropica (Fig. 4). La categoria API (*Anthropogenic Pollen Indicators*) è ben rappresentata lungo la sequenza dei due pozzi, con valori più alti nel

pozzo US 2106 in corrispondenza dei campioni del crollo di un edificio ai margini del villaggio e vicino al pozzo che ha in parte riempito, datati al BM3/BR1.

Anche le pratiche colturali (in particolare la cerealicoltura) sono evidenti nei riempimenti dei due pozzi testimoniando che queste coltivazioni, diffuse nel territorio, non devono avere subito interruzioni nell'area studiata e nel corso delle fasi descritte da questi depositi. Dal confronto dei due pozzi emergono però delle differenze locali, interpretabili come indicazioni della distribuzione prevalente dei campi o delle aree adibite a lavorazione dei cereali, in alcuni distretti: nel pozzo US 2106, il valore del polline di cereali è mediamente cinque volte più alto rispetto a quello nel pozzo US 6170 (5,9% vs 1,2%, rispettivamente). Gli spettri pollinici del pozzo US 2106 presentano anche le percentuali più elevate (fino a 6,4%) in corrispondenza dei livelli costituiti dai piani pavimentali dell'edificio crollato nel pozzo nella fase BR1. Ciò considerato, è possibile ipotizzare una diversa distribuzione degli spazi dedicati alla coltivazione/lavorazione dei cereali:

- esistenza di un'area dedicata alla lavorazione dei cereali presso il pozzo US 2106
- utilizzo del suddetto pozzo per ricevere scarti della lavorazione dei cereali, incluse glume e steli con polline intrappolato.

Il polline di cereali in genere è trasportato dal vento poco lontano dalla sorgente ed è sempre sottorappresentato negli spettri; il rinvenimento di buone quantità di polline in siti archeologici attesta la vicinanza di campi coltivati a cereali, e può essere anche riferibile ad un accumulo in sito legato a scarti di processamento e lavorazione di piante in loco. Ad esempio, nel sito medievale di Parma-Piazza Garibaldi, i campioni da buche nella piazza in cui si teneva il mercato presentano quantità di cereali dal 10% al 20%, indicando l'utilizzo delle buche come rifiutaie della pulizia della piazza (Bosi *et alii* 2012). Nel sito rurale romano di Case Nuove (Grosseto; V secolo d.C.) in una struttura poi identificata come butto, l'elevata quantità di polline di cereali (4,5%) ha suggerito l'attività di pulitura del grano in prossimità della struttura nella quale erano poi eliminati gli scarti di lavorazione (Bowes *et alii* 2015). È pertanto possibile che i valori di cereali riscontrati nelle fasi di crollo nel pozzo US 2106 siano indicativi della lavorazione dei cereali in loco, con traspor-

to di spighe e loro trattamento nell'abitato. Negli altri livelli del pozzo i valori di cereali sono comunque mediamente buoni e, oltre a rispecchiare la presenza del polline nel deposito formato dall'accumulo di rifiuti del villaggio, segnalano anche la presenza di campi coltivati in prossimità del sito. I valori di cereali osservati nel pozzo US 6170, seppure meno significativi, testimoniano comunque la presenza di campi nelle vicinanze. Tali dati sono concordanti con i risultati delle indagini polliniche condotte nei fossati orientali tra Villaggio Piccolo e Grande e il fossato a nord del Villaggio Piccolo (Ravazzi, Cremaschi, Forlani 2004), dove i campioni delle fasi coeve all'insediamento terramaricolo presentano buone quantità di cereali (<5%, nel fossato a nord, anche > 10% nei fossati orientali).

Nei pozzi qui in esame, la cerealicoltura è attestata lungo l'intera sequenza pollinica, con un andamento che rispecchia quello del gruppo API, a cui appartengono anche le infestanti delle colture (es., *Papaver*, *Convolvulus*, *Polygonum*, ecc.).

La prevalenza di orzo nei livelli del pozzo US 6170, corrispondenti quindi alle fasi più recenti BR1/BR2, suggerisce una preferenza per la coltivazione di cereali più rustici e con più basse esigenze idriche rispetto al frumento. Nel pozzo US 2106, invece, in media i valori delle due tipologie di cereali differiscono di poco, quindi non si apprezza una significativa variazione nella coltivazione delle colture. Tuttavia i livelli restituiscono l'immagine pollinica della lavorazione dei cereali nell'area prospiciente e dunque non danno un'informazione circostanziata del tipo di coltivazione prevalente. A supporto dell'indicazione di un incremento di messa a coltura di specie più resistenti alla carenza idrica è il rinvenimento nei livelli del Bronzo Recente della sequenza VP/VG-II di polline di *Panicum*-miglio (cereale minore tipico di ambienti aridi) che affianca l'incremento di *Hordeum* contestualmente alla scomparsa di *Avena/Triticum*; nella sequenza questi risultano essere i soli tipi di cereali presenti nell'ultima fase di vita dell'abitato e nella fase successiva.

Nei campioni dai pozzi, le altre erbacee coltivate sono rappresentate principalmente da leguminose utilizzate per foraggio (es., *Medicago* e *Trifolium*; vedi dopo) e coltivate in rotazione con i cereali, da *Cannabis* la cui coltivazione per la fibra

doveva essere favorita dalla disponibilità idrica nell'area, e soprattutto da cereali.

Tra le legnose, le evidenze di coltura/cura di alberi sono rappresentate da tracce di noce, castagno che è probabilmente un arrivo di polline dall'Appennino, e olivo, anche esso probabilmente un trasporto da lunga distanza. Al gruppo OJC-*Olea*, *Juglans*, *Castanea* si aggiungono sporadiche ma significative testimonianze di corniolo e di vite. Lo studio effettuato nel fossato tra Villaggio Grande e Villaggio Piccolo, dove alcuni livelli hanno restituito valori alti di polline di vite, ha suggerito che quest'ultima poteva essere sia una pianta ripariale e crescere spontaneamente lungo il fossato, probabilmente già coltivata anche se non ancora domesticata (Cremaschi *et alii* 2016a). Una ricca serie di piante legnose con frutti eduli sono presenti negli spettri: ad esempio il nocciolo-*Corylus* e gli scarsi reperti di *Prunus*, *Pyrus*, *Rubus* cf., *Sorbus* e *Ficus* che potrebbero appartenere a specie utili per i frutti eduli raccolti sullo spontaneo.

Le pratiche colturali o di cura degli alberi sono attestate anche dai taxa pollinici negli spettri delle fasi del Bronzo Recente dei Vertisuoli (serie VP/VG-II), che presentano valori generalmente simili a quelli dei pozzi.

Negli spettri dei due pozzi, tra le piante strettamente correlate ad attività pastorali troviamo innanzitutto Cichorieae, selezionate negativamente dalla brucatura e pertanto comuni in aree soggette a pascolo (Florenzano *et alii* 2015). Anche altre Asteraceae sono poco o per nulla appetite, quali alcuni generi di cardi (*Cirsium* e *Carduus* tipo), e ancora *Aster* e *Matricaria* tipo, sono dei buoni indicatori antropogenici di pastorizia. Negli spettri coevi dei Vertisuoli, tuttavia, si osservano valori di Cichorieae triplicati rispetto a quelli dei pozzi, mentre le Asteraceae sono simili. Questo dato conferma la diffusione di aree a pascolo nel territorio della Terramara.

Altri elementi che suggeriscono pratiche di allevamento e pascolo sono le leguminose o Fabaceae (es., *Astragalus*, *Lotus*, *Melilotus*, *Medicago*, *Trifolium*), generalmente presenti nei prati/pascoli e che possono essere coltivate per foraggio nei campi in rotazione con i cereali (come osservato per il Bronzo Medio nella Terramara di Montale; Mercuri *et alii* 2006a). La differenza di percentuali di leguminose tra i due pozzi non è

significativa (1,8% e 1,1% nel pozzo US 2106 e US 6170, rispettivamente) ma potrebbe indicare la presenza elementi di piante foraggiere caduti nel pozzo US 2106 al margine del villaggio. Leguminose foraggiere sono pure presenti nei campioni della sequenza VP/VG-II, con gli stessi valori (ca. 1%), a conferma del dato dei pozzi.

Segnali ambientali di pastorizia provengono anche dallo sviluppo di praterie dominate da Poaceae, che rappresentano la risposta della vegetazione al prolungato calpestio del bestiame (Ejarque, Miras, Riera 2011). Nei campioni dei pozzi si osservano alte percentuali di polline appartenente al gruppo delle Poaceae spontanee (35,5% in media), che si osservano in discrete quantità (25,5%) anche nei campioni coevi dei Vertisuoli. Poaceae in genere attestano il paesaggio aperto tipico delle zone aride e semi-aride (Horowitz 1992), ma nello studio dei pozzi la presenza contemporanea di tipici indicatori di pastorizia conferma l'origine antropica di questi ambienti.

5.1.5 LE TRASFORMAZIONI DEL PAESAGGIO VEGETALE E DELL'USO DEL TERRITORIO

I dati pollinici dei campioni dal riempimento dei pozzi, confrontati con quelli dalle sequenze del fossato VP/VG-II e VP/VG-III, consentono di ricostruire nel dettaglio le trasformazioni ambientali e l'uso del suolo nelle fasi precedenti la fine della vita dell'abitato, e di avere indicazioni delle trasformazioni del paesaggio dopo l'abbandono della terramara.

Sulla base del record pollinico dei pozzi e della sequenza dei Vertisuoli, l'ambiente risulta aperto, con boschi lontani e poco estesi costituiti principalmente da querceti misti e boschi igrofili, ad *Alnus* e *Salix*, in prossimità dei corsi d'acqua. La copertura boschiva sembra ridursi abbastanza bruscamente nella fase finale del Bronzo Recente (Fig. 4). Anche i boschi igrofili si riducono nelle ultime fasi dell'abitato, quando le poche evidenze di ambienti umidi fanno pensare a una certa aridità diffusa. Tale evidenza conferma l'ipotesi che una fase di incremento dell'aridità abbia contribuito alla crisi della Civiltà delle Terramare (Cremaschi e Pizzi 2006). Il declino di questa civiltà è, infatti, coincidente con un periodo di deterioramento climatico che tra la fine del Bronzo Recente e l'inizio del Bronzo Finale

colpisce il Nord Italia, registrato in diversi archivi biostratigrafici e sedimentari lacustri dell'arco alpino (Magny 1993, 2004; Lokwood 2001; Holzhauser, Magny, Zumbuhl 2005; Magny *et alii* 2012; Baroni *et alii* 2006; Valsecchi *et alii* 2006) e osservato anche su scala globale nelle variazioni del C14 residuo (Stuiver *et alii* 1998; Blaauw, van Geel, van der Plicht 2004). Un calo nella disponibilità di acqua nei suoli ha ripercussioni su flora e vegetazione determinando la riduzione della copertura forestale, ma lo stesso effetto posso avere le attività di uso del suolo legate all'agricoltura. Difficile, dunque, resta distinguere il ruolo del clima da quello dell'azione antropica nelle diverse trasformazioni ambientali avvenute nel corso del IV millennio a.C., anche se una visione sistemica suggerisce l'interazione tra i due fattori, con un significativo impatto antropico documentato negli spettri pollinici di varie terramare (Mercuri *et alii* 2006b, 2013a, 2013b, 2015; Cremaschi *et alii* 2016a).

La ricerca palinologica condotta a Poviglio indica che, nelle fasi finali del Bronzo Recente, i cambiamenti ambientali più significativi sono stati il calo del bosco (indice di sovrasfruttamento delle risorse locali) e la riduzione degli ambienti umidi (per variazioni idrografiche locali o aumento climatico dell'aridità). Nel Bronzo Recente, l'incremento demografico attestato dall'ampliamento del villaggio e il conseguente forte sfruttamento del suolo, in concomitanza con il verificarsi di un periodo di crisi idrica, hanno inciso in modo più significativo aumentando l'impatto dell'insediamento sul paesaggio vegetale.

Anche la variazione delle tipologie di cereali coltivati in questa fase, con l'attestazione di quelli con minori esigenze idriche (orzo e miglio) rispetto al frumento, può deporre a favore di una fase più arida. Nel Bronzo Recente, la cerealicoltura sembrerebbe essersi ridotta, coesistendo ormai con una espansione crescente delle aree a pascolo, maggiore rispetto alla fase precedente documentata in dettaglio nella sequenza VP/VG del fossato (Cremaschi *et alii* 2016a). È soprattutto dalla fine del Bronzo Recente che si afferma il prato-pascolo, che da questa fase in poi sarà la principale forma di uso del suolo per lungo tempo. L'aumento delle aree a prato-pascolo potrebbe essere indice di una riduzione di fertilità del suolo, impoveritosi a seguito dell'intenso sfrut-

tamento locale dell'insediamento che ha insistito sullo stesso territorio per centinaia anni.

Nella fase successiva alla fine delle Terramare, corrispondente all'abbandono dell'abitato, si osserva una lieve ripresa del bosco, con una nuova espansione del querceto, ma restano ben rappresentate le aree a pascolo. Nei campioni dai riempimenti tardi del fossato (VP/VG-III, campioni di età medievale) gli indicatori di pastorizia aumenteranno ulteriormente, mentre la forestazione subirà nuovamente una lieve diminuzione, dovuta principalmente ad un calo del querceto (Furia 2016-2017). La continuità di uso del territorio a pascolo ha contribuito alla mancata ripresa del bosco, seppure in momenti in cui la presenza dell'uomo meno stabile (come attesta il netto calo di cereali dalla fine delle Terramare in poi) avrebbe dovuto favorirne lo sviluppo. In particolare, nel periodo medievale si osservano anche momenti di riduzione della copertura arborea probabilmente collegati a fasi alluvionali, attestate da aumenti delle idro-igrofite. Solo i campioni che intercettano il più recente periodo medievale mostrano una ripresa del bosco e dei campi coltivati rispetto alla pastorizia (Furia 2016-17).

5.1.6 CONCLUSIONI

Lo studio palinologico del riempimento dei pozzi, integrato con i dati pollinici delle sequenze deposizionali del fossato, contribuisce alla conoscenza della composizione dell'assetto vegetazionale, l'uso del territorio e le sue trasformazioni in risposta a cambiamenti climatici e impatto antropico. L'immagine pollinica restituita dai campioni dei depositi nei pozzi al margine del Villaggio Grande fornisce informazioni

sulle fasi di vita dell'abitato dal BM3 al BR2, dettagliando inoltre la modalità di formazione dei depositi. Per queste ultime, le diverse tipologie di conservazione dei granuli in entrambe i pozzi analizzati indicano varie modalità di apporto nel deposito, suggerendo fasi di riempimento legate a decantazione di acqua (polline ben preservato) o in seguito a crolli o accumuli di rifiuti (polline deteriorato).

Gli spettri pollinici danno indicazioni di un ambiente fortemente antropizzato, con una ridotta copertura arborea e ambienti umidi, e un intensivo uso del suolo con coltivazioni e pascoli. Le modifiche ambientali più significative, nelle ultime fasi di vita e abbandono dell'abitato, sono una riduzione degli ambienti umidi e l'inserimento di tipologie di cereali meno esigenti, a seguito di inaridimento dei suoli.

La fase immediatamente successiva all'abbandono della Terramara, documentata nelle serie del fossato, evidenzia una lieve ripresa del bosco e la presenza di ampie aree umide, con diffusione di prato-pascolo. Una simile tipologia di vegetazione e lo stesso uso del territorio si mantengono anche nel successivo periodo medievale, sebbene con alcune fluttuazioni probabilmente legate a fasi alluvionali (Furia 2016-17).

L'insieme delle informazioni sul paleoambiente e l'utilizzo del territorio ottenute dalle analisi palinologiche va a completare il quadro delle conoscenze sull'evoluzione del paesaggio nell'area ottenute dall'approccio interdisciplinare, fondamentale per investigare le trasformazioni ambientali legate a cambiamenti climatici e impatto antropico, e per comprendere l'interazione tra ecosistemi e comunità umane (Cremaschi *et alii* 2018b).

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A look at the region

The SUCCESSO-TERRA Project: a Lesson of Sustainability from the Terramare Culture, Middle Bronze Age of the Po Plain (Northern Italy)

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ABSTRACT

This backstory article deals with the SUCCESSO-TERRA Project (2017–2020), an interdisciplinary research program aiming at reconstructing the land-use transformations that occurred during the development of the Terramare culture in the southern-central Po Plain of Northern Italy. Topics include climate-environment changes, human impact and exploitation of natural resources that are interconnected topics in human ecology and environmental sciences. These topics can only be understood in a long-term perspective integrating archaeology, geology, botany and other sciences. The text includes the theoretical basis, the research strategy and the main methodological approaches given by geoarchaeology and palynology, the two research sides constituting the partnership of the project.

1. Background

How can we mitigate the effects of climate change? How can our society develop towards models of sustainable development in the coming years? The “bridge” to sustainability is a pivotal topic of international debate and is among the priorities of the agenda of the Horizon2020 Societal Challenges, linking the past with the future. Despite the many achievements emerging from some new solutions, it is becoming increasingly aware that the study of the past is at the root of reliable and responsible actions for the future.

The SUCCESSO-TERRA Project (*Human societies, climate-environment changes and resource exploitation/sustainability in the Po Plain in the mid-Holocene: the Terramare culture*; 2017–2020) is an interdisciplinary research program aiming at reconstructing the landscape and land-use transformations that occurred during the

trajectory of the Terramare culture in the southern-central Po Plain of Northern Italy (Figure 1). The project, funded by

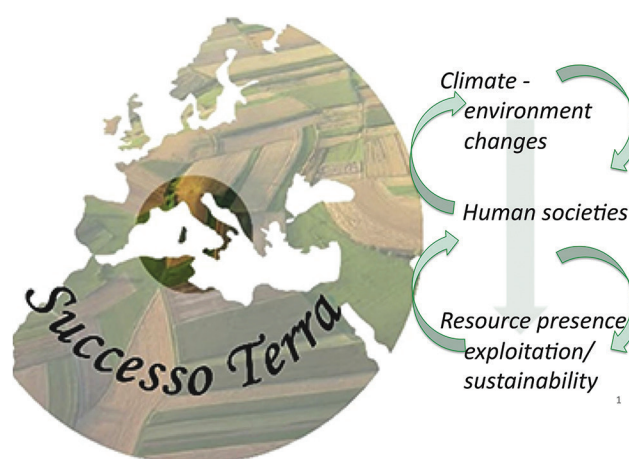


Figure 1. The logo and concept of the SUCCESSO-TERRA Project.

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MIUR (Ministry of Italy for University and Research, action 20158KBLNB, P.I.: M. Cremaschi) joins together experts on Geoarchaeology (University of Milan) and Palynology (University of Modena and Reggio Emilia) to study high-resolution archaeological sediments with an interdisciplinary ecological perspective.

SUCCESSO-TERRA points towards the relationships between climate-environment changes, human impact, and exploitation of natural resources – topics that are traditionally interconnected in human ecology (Butzer, 1982). These topics can only be understood given a long-term perspective: integrating archaeology, geology, and biology (mostly consisting of botany and zoology). The concept that archaeological sciences can be a tool to deal with modern societal challenges is at the basis of SUCCESSO-TERRA: an “old but new approach” to compare current issues to those concerning sustainability in the 3rd millennium BP.

Archaeological scientific investigations with a long-term perspective have repeatedly suggested a possible nexus between changes in climate (main trends and rapid events) and societal crises during the Holocene (Jalut *et al.*, 2009; Mercuri *et al.*, 2011); the main role played today by the on-going climate change in influencing human adaptation is also evident (Oldfield, 2005; Mercuri *et al.*, 2015a). To establish if climate change influenced the cultural trajectory of the Terramare culture – and if so, then to estimate its true contribution – is the core of the project. The Terramare settlements are exemplar archaeological/palaeoenvironmental contexts showing the complex dynamic between regional climatic/environmental changes and land use.

SUCCESSO-TERRA avoids climatic determinism and maintains a bi-directional perspective in the study of the relationships between climate, environment, and people – considering as it does the environment and civilizations as part of a complex dynamic system (*e.g.* Stoffle *et al.*, 2003; Mercuri, 2008; Cremaschi, Zerbini 2009; 2011; Mercuri, Sadori, 2012). From one side, climate changes have triggered environmental and cultural adaptations. From the other side, people have continuously, and deeply, shaped the landscape in which they settled. However, a continuing and increasing human exploitation of natural resources creates an imbalance in the system (Diamond, 2005), resulting in possible episodes of population relocation or the collapse of human societies. Within this framework, Bronze Age Mediterranean civilizations have offered us several examples of crises with catastrophic outcomes. Similar dramatic effects have been recorded along the Alpine fringe with the crisis of the pile-dwelling communities (Magny *et al.*, 2011). All these episodes led to significant changes in the structure of the involved civilization that, experiencing as they were the first steps of urban culture at that time, had an unsustainable impact on the environment.

Interdisciplinary research is mandatory if we want to understand the adaptive strategies of civilizations at different times and within a long-term perspective (Mercuri and Florenzano, 2019). The Terramare case study refers to

the changing environment during the Middle and Recent Bronze Ages (ca. 1550–1170 years BC; Bernabò Brea *et al.*, 1997; Mercuri *et al.*, 2006a), at the Middle to Late Holocene transition, and at the border between continental and Mediterranean Italy.

2. The Terramare narrative based on archaeological and scientific evidence

The term Terramare indicates the banked and moated villages of the Bronze Age, located in the alluvial plain of the Po River of Northern Italy, mostly in present-day Emilia Romagna (Pearce, 1998; Bernabò Brea, Cremaschi, 2009; Cremaschi, 2013). The Terramare culture flourished in the central part of the Po Plain during a period spanning the 16th to the 12th century BC. The Terramare economy was based upon farming, herding, and metallurgy (Bernabò Brea *et al.*, 1997); moreover, Terramare settlements relied on having a well-developed management of water and wood resources. The people settled in an open environment that hosted scattered woodland and plentiful water resources. The Terramare people promoted networks of commercial exchange between northern Europe and the Mediterranean region. This civilization lasted for approximately 500 years, before suddenly collapsing around 1150 BC (Cardarelli, 2009).

Extensive excavations and geophysical surveying disclosed the complexity of their settlements and the interconnections between residential areas, defensive structures, fields and the natural hydrography. Agriculture in fields was supplied with irrigated water, and an innovative and sophisticated management system of the natural hydrographic network was developed (Cremaschi, 2009). Large artificial canals were excavated to draw water from rivers to the moats surrounding villages; then, water was redistributed to the fields through a dense network of irrigation ditches (Cremaschi, Pizzi, 2007; 2011; Cremaschi, 2018). The irrigation strategy and competent agriculture triggered this skilled civilization to its apogee with a demographic increase from the Middle to the Recent Bronze Age. Mesophilous woods (oaks and hornbeams) gave a major supply of natural raw material for building, fuel, and food (Cardarelli, 2009; Cremaschi, 2010; Mercuri *et al.*, 2006a; 2015b). Pollen diagrams show low forest cover close to sites with a significant presence of wet environments and a set of anthropogenic habitats testified by pollen indicators of crops and synanthropics (API, as described by Behre, 1981; Mercuri *et al.*, 2013).

According to the palynological record, the agricultural economy was based on forest management including coppicing, fruit collection in the wild, and crop fields. The fields included different types of cereals (Ravazzi *et al.*, 1992; 2004; Mercuri *et al.*, 2015b; Cremaschi *et al.*, 2016) with evidence of intercropping with legumes (Mercuri *et al.*, 2006a; 2006b). Moreover, most of the open landscapes around the villages were used for pastures as suggested

mainly by Cichorieae and other pasture pollen indicators (Ravazzi *et al.*, 2004; Mercuri *et al.*, 2006b; 2015b; Cremaschi *et al.*, 2016). These land-use types have also been confirmed by the recovery of well-preserved macrobotanical remains in most of the studied contexts (Rottoli, Motella, 2004; Rottoli, Castiglioni, 2009).

The intensification of the food demand probably caused cereal production to be inadequate for such a high number of people. Environmental stresses became ever more evident and wood resources were renewing slowly. For instance, the last phases of the pollen diagram from the Terramara di Montale show a decrease of woodland together with a reduction in cereal fields suggesting that soil and wood overexploitation might have been among the actual causes of the Terramare's crisis (Mercuri *et al.*, 2006b). At the top of the sequence of Santa Rosa di Poviglio, in correspondence with the drying of the moat system, a similar dramatic decrease of woods suggests that there may have been a twofold causation in the societal crisis affecting the Terramare culture: the increased aridity (a natural factor) and the overgrazing of natural resources (an anthropogenic factor) might have played a fairly synchronous action on the landscape (Cremaschi *et al.*, 2016). The societal collapse of the Terramare culture is dated at ca. 1150 years BC; settlements in the central Po Plain were abandoned and Final Bronze Age settlements survived only in the northern sector of the Po Plain and in the Northern Apennines.

3. Research strategy

3.1 Key archaeological sites

The SUCCESSO-TERRA Project analyses data from three Bronze Age sites (Figure 2): (i) the Terramara Santa Rosa di Poviglio (Bernabò Brea, Cremaschi, 2004) (Figures 3–5) and (ii) the Vasca di Noceto site (Bernabò Brea, Cremaschi,

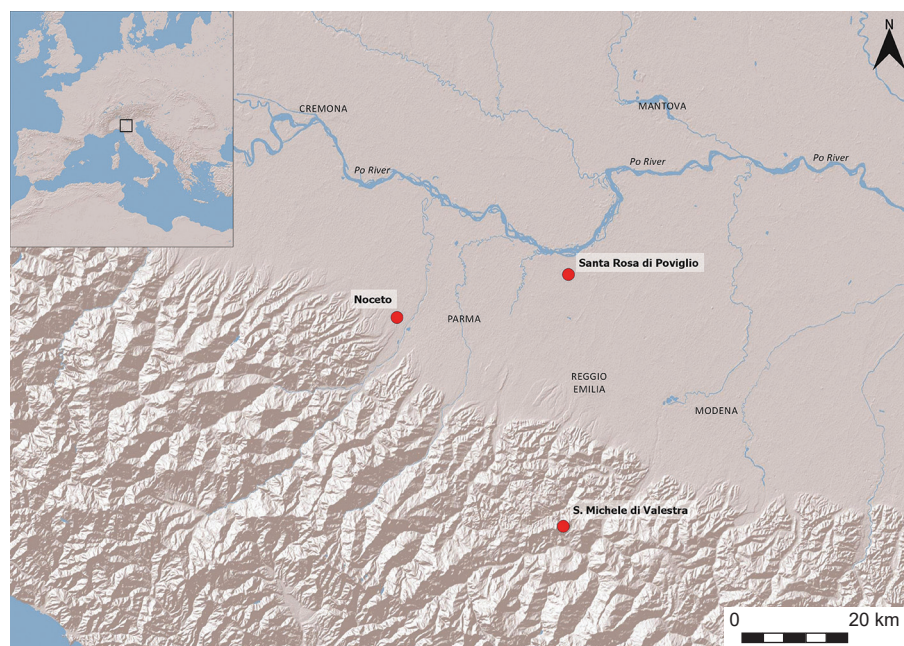
2009) (Figures 3, 6–8) are in the Po Plain; while (iii) the San Michele di Valestra (Cremaschi, 1997) site is a coeval settlement in the Apennines (Figures 3, 9–10). The first and second sites are well-known archaeological sites belonging to the Po Plain Terramare culture, whose excavations have been on-going for many years. The latter – San Michele di Valestra – is a Bronze Age site, located outside the Terramare territory, but in the adjoining Apennine range. This site survived the Terramare crisis and was settled with continuity throughout the Middle, Recent, and Final Bronze Ages, up to the Iron Age.

The methodology of the project is interdisciplinary; it is mainly based on geoarchaeological and archaeobotanical (pollen and macroremains) investigations. The main actions are on-going: to carry out archaeological excavations in the key sites, and a regional survey in areas surrounding the main archaeological settlements.

3.2 Geoarchaeology

Geoarchaeological investigations at selected sites are on-going, the main aim being to understand the human and natural contributions to the development and abandonment of the Terramare settlements in the Po Plain. Since the beginning of research into the Terramare in the nineteenth century, it has been clear that the moats surrounding these sites were connected to adjoining rivers from which water was obtained by canals (Pearce, 1998; Cremaschi, 2013). Additionally, the moats were fed by artesian wells excavated within the limits of each settlement (Cremaschi *et al.*, 2006; 2016). At the Santa Rosa di Poviglio site (Figures 3–5), for instance, all these hydrological structures date back to the late Middle Bronze Age and, along with the infrastructure and residential buildings, are part of the urban planning project. Many large water wells had been opened along the edge of the settlement after the Middle Bronze Age and they

Figure 2. Map of the central sector of the Po Plain of Northern Italy indicating the sites investigated in the SUCCESSO-TERRA Project.



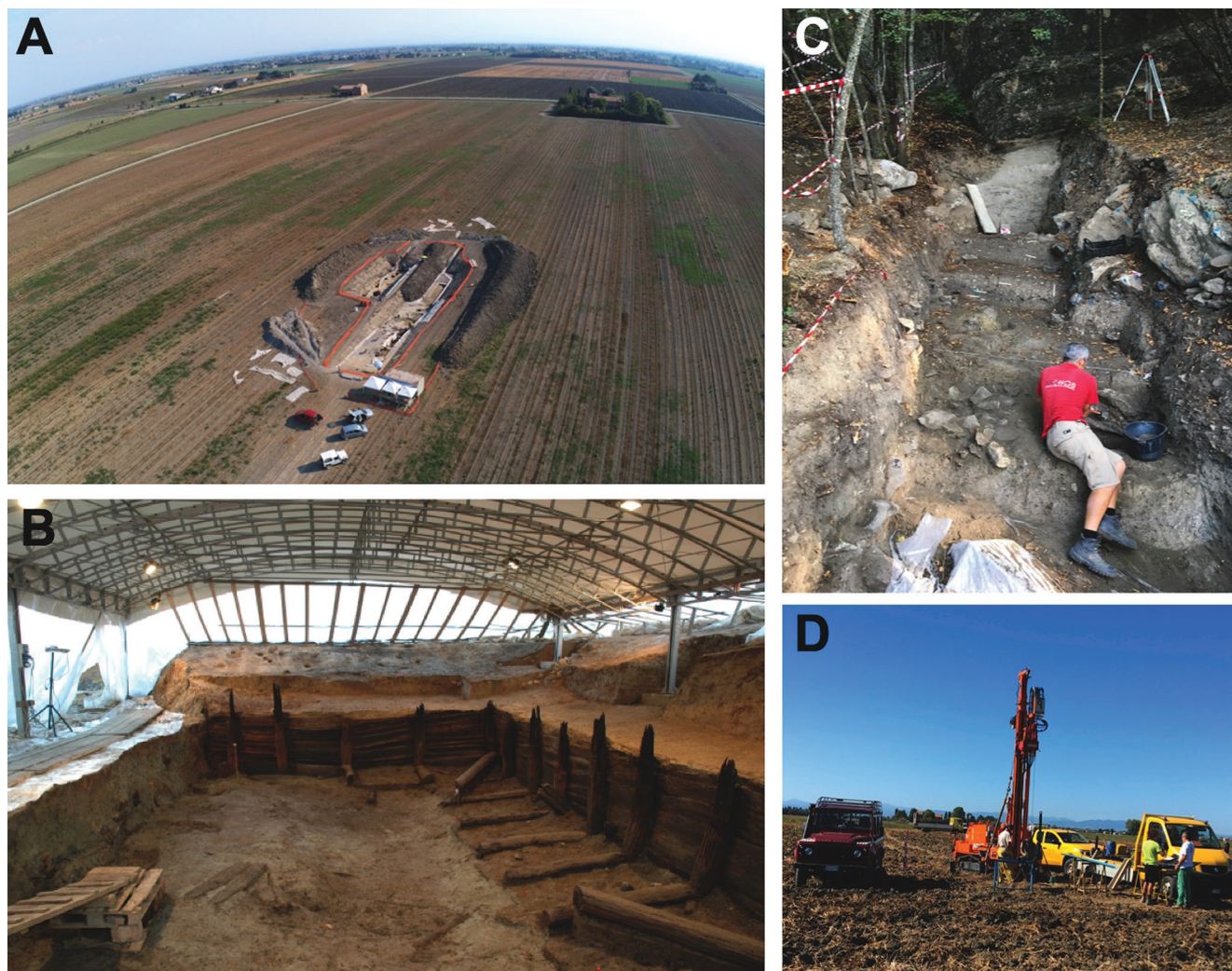


Figure 3. Pictures of the investigated sites: A) oblique aerial view of the Terramara Santa Rosa di Poviglio; B) the Vasca di Noceto site; C) the stratigraphic sequence of the San Michele di Valestra site; D) coring in the vicinity of the Terramara Santa Rosa di Poviglio.



Figure 4. Oblique aerial view of the excavation of the moat of the Terramara Santa Rosa di Poviglio; note the alignments of postholes and several water wells.

Figure 5. Excavation of the moat of the Terramara Santa Rosa di Poviglio.



Figure 6. A detail of the wooden structure of the Vasca di Noceto site (from Bernabò Brea, Cremaschi, 2009).



had been re-excavated several times. The wells exploited the sandy aquifers (at 2 to 3 m of depth), and several ditches conveyed water, not to the interior of the village, but to the moat (Cremaschi, 2013). The excavation of the Santa Rosa di Poviglio site thus illustrates that wells went out of use and silted up in the Final Bronze Age; as a consequence, the moat was also deprived of water and silted up (Cremaschi *et al.*, 2016).

Natural archives of proxy data have been selected in order to gather further data and explain the reasons and timing of the environmental crisis determining the lowering of the water table in the region and the subsequent reduction in water reservoirs (Cremaschi *et al.*, 2016). We collected several sediments cores in the vicinity of the Terramara Santa Rosa to investigate the local dynamic of the alluvial plain

(Figure 3) and sampled a speleothem from the Tana della Mussina Cave in the Apennines, representing a very well preserved local archive of changes in Mid-Late Holocene rainfall. Moreover, geoarchaeological excavations at the San Michele di Valestra site (Figures 3, 9–10) will elucidate the key factors that enabled the higher resilience of the Bronze Age groups living in the Apennine ranges which survived the environmental crisis.

3.3 Palynology

Pollen samples were collected from trenches excavated in the main archaeological structures of the selected sites: (i) the moat and ditch surrounding the Santa Rosa di Poviglio site; (ii) the infilling of the Vasca Grande di Noceto; and (iii) a trench cutting the occupation layers of



Figure 7. A ritual deposition of pottery and wood tools within the Vasca di Noceto site (from Bernabò Brea, Cremaschi, 2009).



Figure 8. A detail of the sedimentary infilling of the Vasca di Noceto; note the thinly laminated deposits formed by decantation (from Cremaschi *et al.*, 2009).

the S. Michele di Valestra site. Moreover, three offsite cores have been extracted in the area surrounding the Terramara Santa Rosa di Poviglio. The sampling strategy covers on-site/off-site integrated records that are useful to distinguish human pressure and impact at both a very local and regional scale (Mercuri, 2014).

Besides the basic treatments, the pollen extraction has included sieving and heavy liquid floatation to concentrate microscopic remains: this is mandatory to obtain good pollen content from the archaeological layers (Florenzano *et al.*, 2012). Pollen, non-pollen palynomorphs (algae, fungi, animal fragments) and microcharcoal particles help to reconstruct the flora composition, vegetation dynamics

and palaeoecology. A set of anthropogenic pollen indicators (common in the spectra from Italian archaeological sites; Mercuri *et al.*, 2013) may be especially useful to reconstruct the agricultural dynamics, besides the distribution of wild vegetation (wood and wetland plant associations). The palynological research allowed details of some of the complex processes in the agricultural economy to be filled in, such as were practiced on the basis of wood management and crop fields.

Since the first attempt of reconstructing the ancient land use, it appears evident that the area of influence of each Terramare settlement was a complex mosaic of natural and human-controlled landscapes; however, new results point to

some local differences in the availability and exploitation of wood and water resources at each archaeological site. As a general rule, the pattern was of cereal and legume fields that were alternated to pastures. Trees had a strategic role at Poviglio, Baggiovara, and Casinalbo. The large availability of water furthered the spread of hygrophilous woods near rivers, but oak woodland with oaks and hornbeam were also cared for. The Terramare people were aware of the importance of natural resources, and used the oak-woodland trees for collecting fruits, feeding animals, and making tools. We found signs that they maintained their oak woodlands by coppicing for hundreds of years, at least up until the time, when environmental stresses still allowed their cultural knowledge to survive in these lands.

4. General remarks and perspectives

For the first time, the SUCCESSO-TERRA Project offers to fully investigate the complex environmental and human nexus in the Bronze Age of the Po Plain, shining new light on the mutual interconnection between climate change, land-use, and human resilience. Our interdisciplinary approach will disclose the natural (aridification) and anthropic (overexploitation) reasons for the collapse of the Terramare culture in the Po Plain, and why in mountain areas coeval communities displayed a higher resilience to incoming climatic changes.

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Figure 9. Excavation of the San Michele di Valestra site; view of a rock shelter buried and filled by the archaeological stratigraphy.

Figure 10. Stratigraphic section of the excavation of the San Michele di Valestra site.



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