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The Roman Legacy on European Chestnut and Walnut Arboriculture

Patrik Krebs[a], Fabiano Ulmke[a], Willy Tinner[b] and Marco Conedera[a]

[a]Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Insubric Ecosystems, Cadenazzo, Switzerland; [b]Institute of Plant Sciences and Oeschger Centre for Climate Change Research, University of Bern, Bern, Switzerland

ABSTRACT
The political and administrative unification process under the Roman Empire resulted not only in a progressive linguistic, religious, and cultural homogenisation of the concerned population, but also in the need of trade and exchanges for satisfying new dietary habits and markets. In this paper, we use palaeoecological pollen and macroremain records extracted from Neotoma online database and from scientific literature to analyse the contribution of the Romans in the distribution and cultivation history of *Castanea sativa* and *Juglans regia*, two tree species, which are usually considered highly connected with Romanisation. Our results highlight a substantial difference in the impact of the Romans on the history of the two species between the territories of the Western and Eastern Empire, where the Roman influence is much less evident. In the western territories, *Juglans regia* experienced a significant pre-Roman increase and spread, which was only partially intensified under Roman domination. *Castanea sativa*, on the contrary, benefited from a significant boost following the Roman conquest, especially in the mountain areas south of the Alps and in France. After the fall of the Roman Empire this led to the traditional medieval chestnut civilisation in which the chestnut tree became a main source of livelihood.

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Introduction

At time of its greatest expansion, the Roman Empire ran from Britain in the North to Northern Africa in the south, comprising all circum-Mediterranean areas from Iberia to the Black Sea and Syria (Jones 2021). Although with different trajectories, all conquered territories of the Empire underwent far-reaching socio-economic and cultural changes, making a fall back to pre-Roman conditions almost impossible (e.g. Spickermann 2018). The political and administrative unification process under the Empire resulted in the establishment of complex military and urban settlements with a related impact on the landscape planning and a progressive linguistic, religious, and cultural homogenisation among the resulting multiethnic population (Palet and Orengo 2011; Spickermann 2018; Adamik 2021). Among major novelties, especially for the Northern provinces, there is a delineation of social hierarchies, specifically the creation of a new social group of food consumers such as the military, administrators, and other townspeople (van der Veen, Livarda, and Hill 2008). New markets and the need of a long-distance trade and exchanges raised for satisfying the specific dietary habits and requests of the new consumer classes (Orengo and Livarda 2016; Deforce et al. 2021). This on turn highly influenced the variety of animal and plant food processing and consumption and represented the most significant shift in the agriculture since the transition to farming (van der Veen, Livarda, and Hill 2008; Rizzetto, Crabtree, and Albarella 2017; Valenzuela-Lamas and Albarella 2017; Bosi et al. 2020; Trentacoste et al. 2021). Although the introduction or import of plant food is already documented for the Late Iron Age, the amount of newly introduced vegetal food in the Northern provinces from the Mediterranean and beyond significantly increased during the Roman period (van der Veen, Livarda, and Hill 2008; Bosi et al. 2020). Among them, special attention received also fruit and nut crops such as apple, pear, cherry, plum, damson, grape, almond, olive, fig, mulberries, and pine nuts among others (van der Veen, Livarda, and Hill 2008; Bosi et al. 2020). In this context, palynological records are very useful to reconstruct the ethnobotanical history of fruit-bearing trees over the centuries (e.g. Conedera et al. 2004a; Pollegioni et al. 2017; Langgut et al. 2019).

In this paper, we use palaeoecological pollen records to analyse the contribution of the Romans in the distribution and cultivation history of the two tree species sweet chestnut (*Castanea sativa* Mill., hereafter referred to as *Castanea*) and the common

CONTACT Patrik Krebs patrik.krebs@wsl.ch Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Insubric Ecosystems, a Ramél 18, Cadenazzo CH-6593, Switzerland
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walnut (*Juglans regia* L., hereafter referred to as *Juglans*) all over Europe, paying particular attention to the territories of the Western Roman Empire. In addition to pollen data, we also consider the most relevant information deriving from plant macroremains (in particular seeds and fruits).

Castanea sativa is an insect and wind-pollinated tree which produces small pollen grains. Its pollen production is low to high depending on the environmental conditions (Lang 1994; Astray et al. 2016; Larue et al. 2021). When wind transported over long distances, *Castanea* pollen may be occasionally overrepresented in sediments (Peeters and Zoller 1988; Krebs et al. 2019). On the other hand, in case of wet weather conditions during the florescence, which highly reduce the anemophilous fraction of the pollination, *Castanea* may be underrepresented in the pollen record (Conedera et al. 2006; Conedera 2007). *Juglans regia* is considered as a low pollen producer among wind-pollinated trees with heavier, medium-sized pollen grains that fall more rapidly (Stolze and Monecke 2017). Also *Juglans* may be either underrepresented or overrepresented in the pollen rain, mostly depending on the distance from the source trees (Beer et al. 2007; Dehghani et al. 2017).

During the Last Glacial Maximum, both species managed to persist in southern Europe in scattered and favourable (micro)refugia (Pollegioni et al. 2017; Krebs et al. 2019). After a prehistoric period of post-glacial spontaneous spread from existing refugia (e.g. Krebs et al. 2019), the subsequent expansion and distribution of both species became highly human-mediated (Conedera et al. 2004a; Pollegioni et al. 2011; Pollegioni et al. 2015). Since the last millennium BC the spreading trends of *Juglans* and *Castanea* are mainly attributable to cultivation and arboriculture, so that their pollen records are considered suitable anthropogenic pollen indicators useful for reconstructing the human impact on the landscape (Mercuri et al. 2013; Stoddart et al. 2019), likely more diagnostic than e.g. *Olea* (Mercuri et al. 2013) and *Vitis* (Berger et al. 2019), which can also occur quite abundantly under natural conditions in the Mediterranean area (Arroyo García and Revilla 2013; Gianguzzi and Bazan 2019; Deza-Araujo et al. 2020; Fanelli et al. 2022). In fact, prior to classical antiquity, *Juglans* and *Castanea* may occur in European pollen records, but usually as sporadic finds. Exception comprise sites close to the glacial refugia, where pollen abundances were higher (Torri 2010; Lazarova et al. 2011; Tonkov and Possnert 2014; López-Sáez et al. 2017; Pollegioni et al. 2017; Krebs et al. 2019; Gómez-Orellana et al. 2021).

It is thus generally agreed that the expansion of the Roman Empire played a decisive role in the spread of these two tree species in Europe and their cultivation, both as fruit trees and for timber production (Conedera et al. 2004a; Pollegioni et al. 2020). As a result of such a rapid, human-assisted and spatially defined introduction, originating from the territories already conquered by the Romans, both species highlight a relatively low biocultural (i.e. genetic and ethno-linguistic) diversity in Western Europe with respect to the Transcaucasian (both species) and Asian (walnut) areas of Last Glacial Maximum (LGM) refugia (see Mattioni et al. 2013, 2017; Fernandez-Lopez et al. 2021 for *Castanea sativa* and Pollegioni et al. 2020 for *Juglans regia*).

According to the ancient literature, Greeks and Romans were interested in the chestnut tree mainly for its rapid growth when managed as a coppice and the durability of the produced timber, whereas fewer in number and in some cases also less enthusiastic were the descriptions on the use and the qualities of the chestnut fruits (see Conedera et al. 2004a for details). Walnut, on contrary, was probably valuated in a more balanced way as food and as timber (especially for the construction of tables) as it results from a number of citations in the ancient literature (e.g. Pliny the Elder Naturalis Historia XV, 24; Macrobius Saturnalia III, 18, 3; Juvenal Satura XI, 90-135). Walnuts and chestnuts were thus integrated into the diet not only of the conqueror but also of the indigenous communities, acquiring variable importance depending on the geographical contexts (Castelletti 1972; Nisbet 2000; Peña-Chocarro and Zapata Peña 2005; Arobba et al. 2013; Costa Vaz et al. 2016; Teira-Brión 2021).

At present, *Castanea* and *Juglans* are economically important tree species for the European continent, cultivated for both timber and fruit production (Conedera et al. 2004a; San-Miguel-Ayanz et al. 2016). They require mild-temperate climate conditions and display poor competitive fitness against late-successional species. Species' preferences diverge, however, in term of soil conditions, which should be deep, well-drained and acid to neutral for the chestnut and rich and possibly high in pH (i.e. 6–7.5) for the walnut (Kaltenrieder et al. 2010; Conedera et al. 2016; de Rigo et al. 2016).

Materials and Methods

Study Area and Data Collection

We defined the study area as stretching from 25° to 65° Latitude North (i.e. from North Africa to Southern Scandinavia) and from −25° to 60° Longitude East (i.e. from the Atlantic Ocean to the Caspian Sea) in order to allow spatial interpolation around the maximum extension of the Roman Empire (Figure 1). We first performed a systematic and quantitative analysis based on the palynological data available in the Neotoma Paleoecology Database, searching then for further palynological and archaeological literature

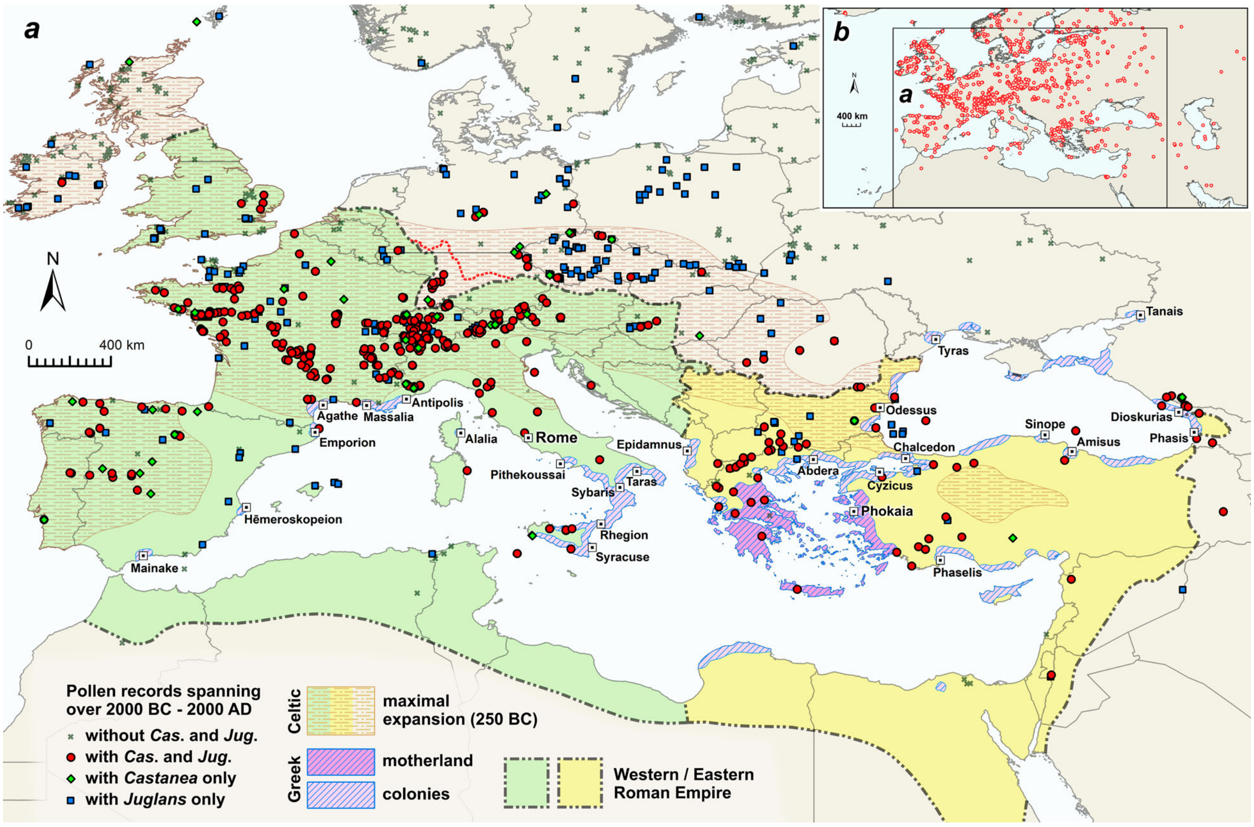

Figure 1. Detailed Map (a) depicting the extension of the Western and Eastern Roman Empire, the maximal expansion of Celtic peoples, the Greek colonisation, as well as the distribution of the Neotoma pollen records divided into four categories (471 with neither *Castanea* nor *Juglans*, 443 with both species, 265 with *Juglans* only, and 42 with *Castanea* only). In Germany the Upper Germanic-Rhaetian Limes is depicted by a red dashed line. The overview map at the top right of the image (b) shows the entire study area stretching from 25° to 65° latitude North and from −25° to 60° longitude East, with in red all the 1221 Neotoma pollen records spanning over the last four millennia.

in order to qualitatively check the results obtained from the Neotoma database.

Although a consistent number of published pollen data are not included in Neotoma, this public database represents so far the best systematic and up-to-date collection of pollen records in the form of standardised, well-structured, and open-access data at the European continental scale (Williams et al. 2018). For a quantitative approach, any other options consisting in trying to obtain the pollen data for the whole study area by requesting data directly from the palynologists or by digitising the published pollen diagrams would have resulted in an extremely time-consuming and problematic approach, especially in terms of data uniformity and selection bias.

Neotoma pollen records have been thus systematically extracted using specific R scripts (R Development Core Team 2022) to select, download, elaborate, analyse and summarise a large number of datasets hosted in this online repository. In particular, we used the functions included in the 'neotoma' add-on R package to acquire all dataset information and related pollen records (Goring et al. 2015).

For a qualitative assessment and discussion of the obtained results, we further screened the scientific literature on websites and online platforms (e.g. ScienceDirect, SAGE Journals) searching for peer-reviewed paleoecological and archaeological publications reporting on sedimentary macroremains or pollen records, not included in Neotoma, with *Castanea* and/or *Juglans*, located in or close to the territories of western Roman Empire, and dated to the periods before, during and after the Roman age.

Shapefiles representing the country boundaries including territorial waters (i.e. territorial sea) has been obtained from the Marine Region portal (www.marineregions.org, accessed 10 January 2022). Bedrock characteristics were retrieved from the International Hydrogeological Map of Europe 1:1,500,000 (www.bgr.bund.de, accessed 10 January 2022). Shapefiles representing Roman vici and settlements, road network, and province boundaries for a range of periods have been downloaded from various websites (e.g. http://projectmercury.eu, www.arcgis.com, accessed 10 January 2022). GIS-data describing the current distribution range of *Juglans* and *Castanea* are provided by different services (i.e. 'European Atlas of Forest Tree Species' project, EUFORGEN programme; see also Conedera et al. 2004b).

Data Analysis

Among all pollen datasets downloaded from the Neotoma online repository, only those having a chronology have been retained. In case of multiple chronologies, we gave priority to the ones in calendar or calibrated years, to the most recent or updated ones, and to those preferred or approved by the authors of the palynological investigation. For the pollen records having single chronologies in uncalibrated years BP (i.e. Before Present) only, we used the available list of absolute and relative dates (i.e. radiocarbon dating and pollen-stratigraphic markers) to elaborate new age-depth models and related chronologies in calendar time scale by exploiting the 'clam' add-on R package and applying linear interpolation between each dated level. In rare cases, we had to revise the chronological controls obtained through the 'get_chroncontrol' function in order to fix the problem of age-depth inversions.

For each retained palynological site, we calculated and attributed geographical characteristics such as location within present national boundaries (including the territorial seas), main bedrock features (i.e. calcareous vs siliciclastic rocks), as well as geodesic distances to present *Juglans* and *Castanea* distribution range, to Roman settlements and roads, and to the territories of Roman Empire at various epochs (i.e. 264, 146, 60, and 44 BC; 14, 69, 117, 200, 315, 395, and 500 AD).

Taking into account the rough definition, complexity and weak stability of political and administrative boundaries in ancient times, we choose to refer preferably to the present distribution of European countries allocating territorial waters based on the current definition of maritime exclusive economic zones. In the case of Germany and Great Britain (i.e. the union of England, Scotland and Wales) we differentiated the northern from the southern by using the lines of latitude at 50° and 54° North respectively (Figure 1).

Each pollen dataset has been then processed through a R script in order to extract the counted pollen grain numbers and the pollen percentages of *Castanea* and *Juglans* at subsequent time intervals of 100 years covering the last four millennia (i.e. 2000 BC–2000 AD). For both species and for each pollen record we calculated also the trend of pollen percentage (expressed as absolute difference and as ratio) at regular time intervals by comparing the periods before and after the considered points along the time axis. By means of Esri ArcGIS Pro (v. 2.9.2) and using Natural Neighbour as spatial interpolation technique, we produced maps of the European continent at 500-year intervals showing the evolution of the species presence and distribution according to pollen data.

Main change points in time series were detected by multiple comparison between pollen data in subsequent periods using unpaired Wilcoxon test (Wilcoxon 1945). Further, we used the 'strat.plot' function of the 'rioja' package in R to produce simplified pollen diagrams for selected sites plotting side by side the pollen percentages of *Castanea* and *Juglans* with other important anthropogenic pollen indicators (e.g. *Olea*, *Vitis*, Cerealia-type, *Secale*, *Plantago lanceolata*-type, *Urtica dioica*-type), as well as the ratio between arboreal and non-arboreal pollen taxa (AP/NAP).

For the qualitative assessment based on published pollen records not included in the Neotoma repository, the change over time in the presence/absence of *Castanea* and *Juglans* during the pre-Roman, Roman and post-Roman periods has been determined by visually inspecting the pollen percentage curves for each selected pollen diagram. The degree of agreement between these pollen curves and the main trends emerging from the quantitative analysis of Neotoma database has been then evaluated visually on a seven-step scale going from −3 (full disagreement) to +3 (full agreement). For each publication on carpological remains, we verified and summarised in tabular form the type and number of seeds and fruits, the depositional context, the preservation conditions, as well as the chronology and spatial coordinates of the archaeological site. In order to better synthesise the findings (see results), we adopt 100 BC as time limit for the beginning of the Roman period in Western Europe. The definition of a common limit for the onset of the Roman period is very challenging given that the Roman colonisation lasted for centuries. However, in most territories of the Mediterranean Basin outside Central and Southern Italy it occurred between ca. 200 BC and 1 AD, making 100 BC an adequate average (Martin 2012; Capogrossi Colognesi 2014; Spickermann 2021).

Results

Available Data

Neotoma hosts 2189 pollen datasets laying in the spatial range of interest, i.e. from 25° to 65° North latitude and from −25° to 60° East longitude. For four of them (i.e. ID 40607, 40608, 40611, and 40612) we encounter failures during the download process, whereas additional 767 (35%) have been discarded since devoid of a time scale. We ended up with 1418 datasets provided with at least one chronology. In most cases ($n = 1281$) we used the available chronology in calendar or calibrated years, whereas for the remaining cases ($n = 137$) we had to elaborate new chronologies in calendar time scale.

Among these 1418 palynological sites, 26 out of 1418 (2%) are located on sea or ocean floors, 14 (1%) belong to North African countries, while the remaining 1378 (97%) are on the landmass of the

Eurasian continent. Even considering Eurasia only, pollen records are clearly clustered (i.e. unevenly distributed), showing a highly significant departure from a spatial randomness (p-value < 0.0001). Nearly three-quarters of the sites are concentrated in about 10% of the total land area with lots of overlapping sites and an observed median neighbour distance of 5.5 km, against an expected median distance for random points of 48.8 km (nearest neighbour ratio = 0.113). Regarding the time scale, 1221 have a time span covering at least in part the last four millennia (i.e. from 2000 BC to 2000 AD), 155 cover the Early and Middle Holocene without reaching 2000 BC, whereas the remaining 42 cover the Late Pleistocene without reaching the beginning of the Holocene (ca. 11,500 cal yr BP).

For the qualitative assessment, a total of 96 recently published and well dated pollen records covering the Late Holocene have been retained. The records are distributed in the territories of the Western Roman Empire, specifically 8 in Austria, 6 in the British Isles, 17 in France, 12 in Germany, 19 in Iberia, 24 in Italy, and 10 in Switzerland (Appendix A). In regard to the macroremains, we found in total 110 archaeological sites dated to the pre-Roman and/or Roman periods, of which 11 sites with chestnut only, 85 sites with walnut only and 14 sites with both chestnut and walnut fruits (Appendix B). Post-Roman macroremain assemblages have been discarded from the analysis because the number of collected publication was judged insufficient to provide a comprehensive account of all the research available.

Neotoma Castanea and Juglans Records

Among the 1221 pollen datasets spanning over the last four millennia, there are 750 displaying the target species in the list of taxa, of which 443 with both species, 42 with *Castanea* only, and 265 with *Juglans* only (Figure 1).

The overall temporal evolution of the average pollen percentages as summarised in Figure 2 reveals substantial differences between the Western and Eastern Roman Empire as well as between the two species. Generally, the progressive Roman conquest did not have a significant impact on the presence and abundance of *Castanea* and *Juglans* in the territory of the future Eastern Roman Empire, whereas a significant increase in abundance occurred in the western territories, especially for *Castanea*. In pre-Roman times both species tend to be more abundant in the eastern territories, where they experienced a peak in the first half of the 2nd millennium BC (Figure 2), as detectable in several Anatolian (e.g. Ladik Gölü ID24157; Beysehir Gölü ID3927; Ova Gölü ID4326; Pinarbasi ID24166) and Balkan sites (e.g. Straldzha mire ID22738; Edessa ID784). The abundance of *Juglans* in the eastern territories shows again an upward trend during the last millennium BC, reaching a maximum at the beginning of the Christian Era (Figure 2) as highlighted by many Balkan sites (e.g. Vegoritis 8 ID4513; Elatia-Rhodopes ID24325; Nisi Fen ID45101).

In the western territories, there is significant evidence of a slight upward trend starting at ca. 1000 BC for *Juglans* and ca. 800 BC for *Castanea*, although in the latter case the mean of pollen percentages remains very low (Figures 2 and 3). Then, approximately at the time of the establishment of the Roman Empire (27 BC), a marked rise in pollen percentages occurs for *Castanea* while for *Juglans* the upward trend continues with only a slight acceleration. During the migration period after the barbarian sacks of Rome (e.g. 410 and 455 AD), a temporary drop in *Castanea* pollen percentages occurs in the western territories while a more persistent decline is observed for *Juglans* in the Eastern Roman Empire. *Juglans* pollen abundances do not recover to high values in the east, while *Castanea* pollen percentages increase after ca. 1000 AD in the west (Figure 2). Since then, both species display an upward trend during the High and Late Middle Ages, with *Castanea sativa* increasing much more than *Juglans regia* both in the West and the East (Figure 2).

Castanea and Juglans Records Recovered From Published Studies

Assuming 100 BC as time threshold between the pre-Roman and the Roman periods in the western territories, the palynological records lacking in the Neotoma database as well as the carpological finds generally support the trends emerging from the quantitative analysis of Neotoma pollen data (Figure 4). In particular, concerning the palynological records, 52% of the considered trends are clearly confirmed (i.e. 21 trends out of 40 with a sum above 10), 35% are partially confirmed (i.e. 14 trends with a sum between 0 and 10), and only 13% are invalidated (i.e. five trends with a negative sum).

Taking in consideration the carpological finds reported in scientific literature, we observe the following increases. The number of archaeological sites with remains of chestnut fruits grows from 2 to 21 after the Roman conquest, while in terms of walnut fruits the increase is from 9 to 82 (see Appendix B for the list of sites and related references). More than 95% of these sites are located in the territory of the Western Roman Empire. In terms of stratigraphic units, the increase is even more evident. The number of units with carpological remains rises from 2 to 44 for *Castanea*, and from 10 to 134 for *Juglans*. When considering the total amount of remains and conservatively estimating the missing data, the number of fruit fragments increase from 15 to 1854 for *Castanea*, and

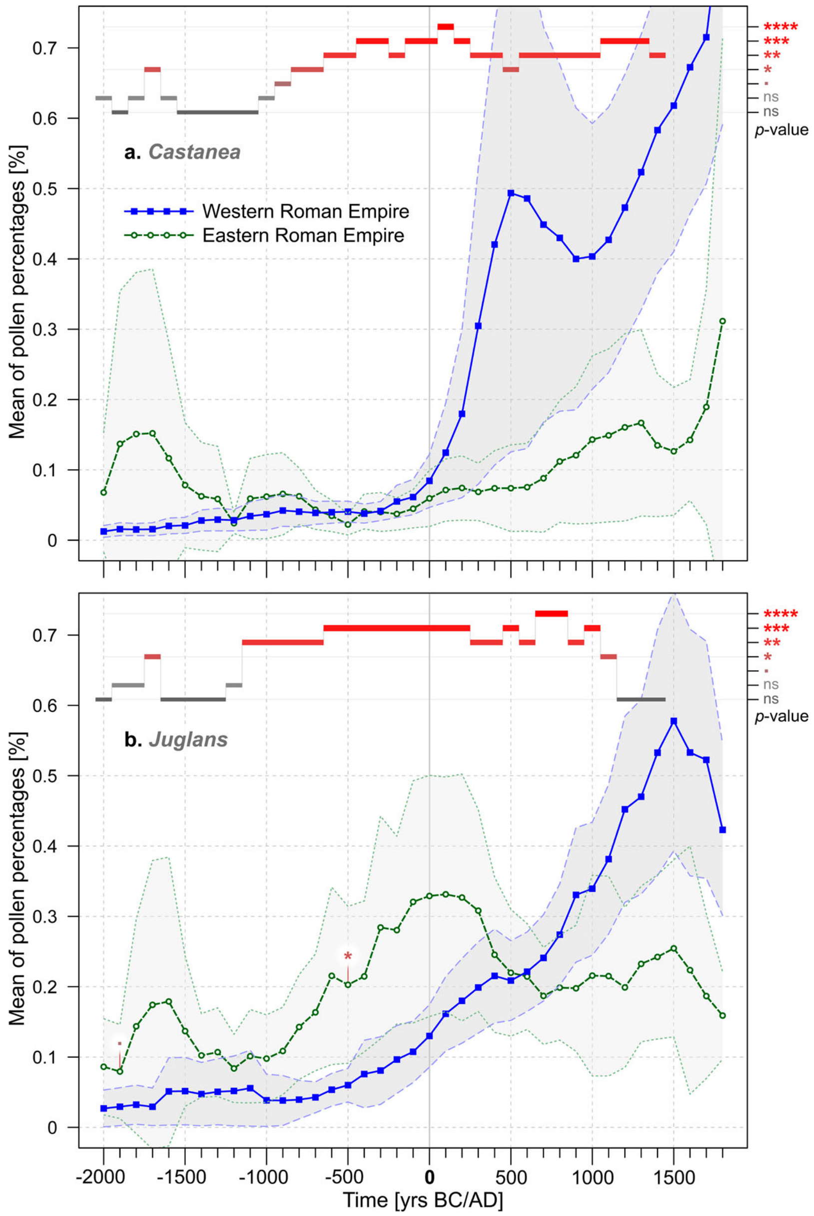

Figure 2. Charts showing the evolution of the mean of pollen percentages for *Castanea* (a) and *Juglans* (b) with the confidence interval (grey area) in the Western and Eastern Roman Empire during the last four millennia according to the analysis of the Neotoma pollen database. The level of significance of the changes observed in the pollen data over the next 400 years for the Western Roman Empire, calculated with the Wilcoxon test and split into seven classes (i.e. >0.2, ≤0.2, ≤0.1, ≤0.05, ≤0.01, ≤0.001, ≤0.0001), is indicated on the top. The curves referring to the Eastern Roman Empire do not show any significant change, except at 1900 and 500 BC for Juglans.

from 18 to 2323 for *Juglans*. The percentage of fruit macroremains dated to the Roman period which have been found in waterlogged conditions is much higher for *Castanea* (61%) than for *Juglans* (21%).

Pre-Roman Evolution in the Western Territories

When going into regional details in the western territories, a first modest but significant rise in pollen percentages of *Castanea* and *Juglans* is dated at ca. 1700 BC (Figure 2). At that time, *Castanea* displays a first slight increment in pollen frequency especially in Italy (e.g. Lago di Martignano ID4256; Ortasee ID22898) and Iberia (e.g. Peña Negra ID41746; El Payo ID41671), while *Juglans* presence becomes more consistent notably in south-eastern France (e.g. Le Jolan ID24465; Lac du Lauzon ID25273) (Figure 3). *Juglans* further displays pre-Roman positive trends starting at ca. 1100 BC in Iberia (e.g. Albufera Alcudia ID22628; Culazón ID41760), at ca. 800 BC in Italy (e.g. Colfiorito ID3994; Lac de Villa ID22732; Malschötscher Hotter ID24061), and at ca. 500 BC in France, South Britain and Switzerland (e.g. Rezé ID24854; Saint Julien de Ratz ID4373; Lake of Annecy ID25400; Etang de Luissel Bex ID32260) (Figure 3). The last pre-Roman increase in mean pollen percentages concerns the Iberian Peninsula, where a new rise of the *Castanea* curve begins at ca. 300 BC (e.g.

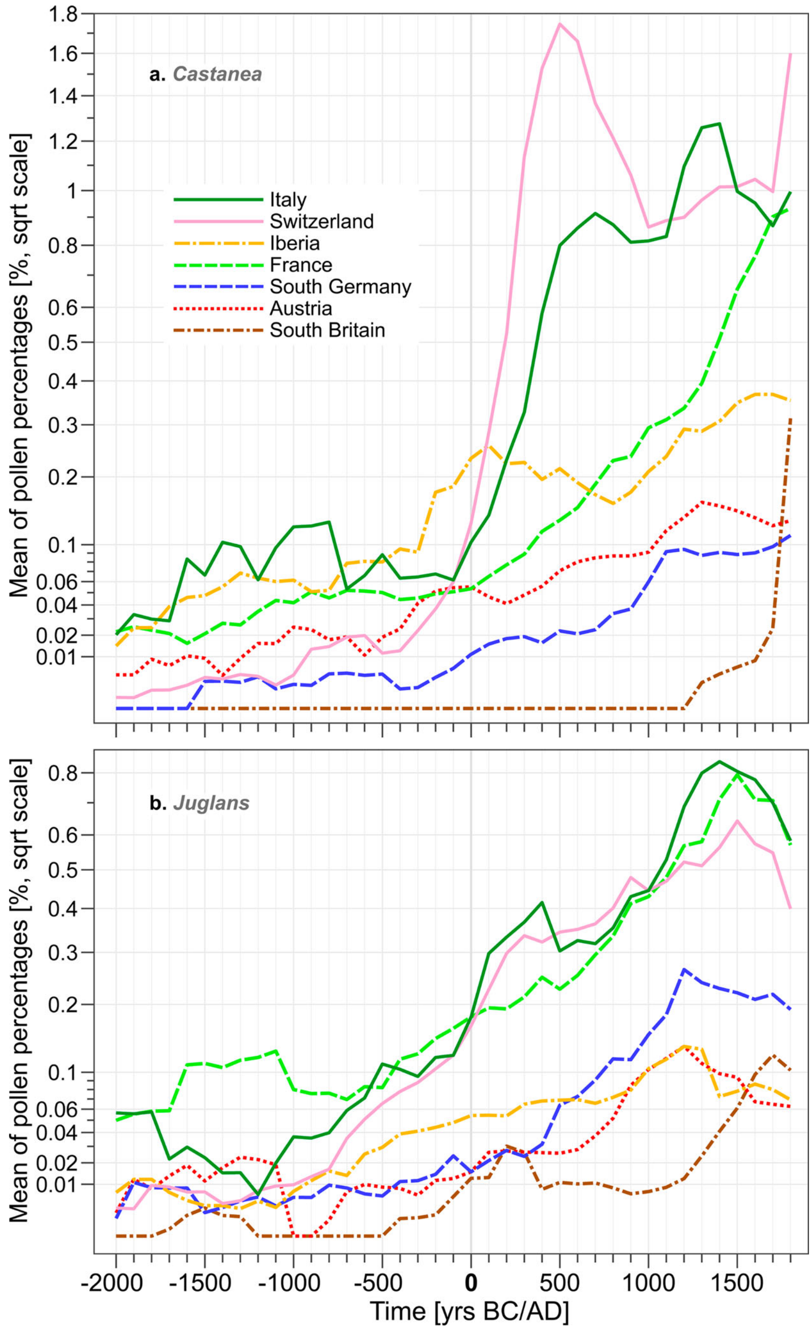

Figure 3. Charts showing the evolution of the mean of pollen percentages for *Castanea* (a) and *Juglans* (b) in seven regions of Western Europe during the last four millennia according to the analysis of the Neotoma pollen database. We use a square-root scale on the y-axis to ensure small values remain visible.

Charco da Candieira ID41909) that is just before the Roman conquest (220–19 BC).

Most of these pre-Roman trends are confirmed by the selected non-Neotoma pollen records (see trends 1–3, 20 and 23–25 in Figure 4), with exception of two subsequent upward trends of *Juglans* starting at ca. 1700 and 500 BC in France (trends 21 and 22 in Figure 4), which are not confirmed by our qualitative check.

Roman Impact in the Western Territories

During or soon after the Roman conquest of south-eastern Gaul (i.e. Cisalpine Gaul 222–13 BC, Gallia Narbonensis 125–118 BC), a marked rise in *Castanea* pollen percentages occurs in northern Italy and on the southern slope of the Alps (e.g. Lago di Massaciuccoli ID41600; Lago Piccolo di Avigliana ID 22908; Lago di Origlio ID41467; Lago di Muzzano ID41770) starting at ca. 100 BC, as well as in southern France (e.g. Saint Sixte ID4423; Le Grand Lemps ID4197) right at the beginning of the Common Era (Figure 3). A rough coincidence in time between the Roman conquest and a slight increase in the *Castanea* percentage can be outlined also in the region of Southern Germany between the Lake of Constance and the Upper Rhine Plain (Figure 3), which was the only one subjugated

Species	Period	Region	Trend	From	No.	Sum
Castanea	Pre	Iberia	1 UP	-1700	12	15
		Iberia	2 UP	-300	16	6
		Italy	3 UP	-1700	19	7
	Rom	France	4 UP	0	13	7
		Germany	5 UP	100	9	17
		Italy	6 UP	-200	18	22
		Switzerland	7 AC	-100	8	11
	LPR	France	8 UP	500	14	19
		Germany	9 ST	200	9	6
		Iberia	10 DO	100	12	-8
		Iberia	11 UP	800	14	24
		Italy	12 ST	500	17	-8
		Switzerland	13 DO	500	9	-1
	HLMA	Austria	14 UP	1000	6	11
		British Isles	15 UP	1200	4	5
		France	16 UP	1200	16	31
		Germany	17 UP	900	10	19
		Italy	18 UP	1100	16	23
		Switzerland	19 UP	1000	8	14
Juglans	Pre	British Isles	20 UP	-500	2	1
		France	21 UP	-1700	12	-8
		France	22 UP	-500	10	-4
		Iberia	23 UP	-1100	10	5
		Italy	24 UP	-800	21	16
		Switzerland	25 UP	-500	8	7
	Rom	Italy	26 AC	-100	16	21
		Switzerland	27 AC	-100	9	11
	LPR	Austria	28 ST	200	5	6
		Austria	29 UP	600	8	13
		France	30 AC	500	13	27
		Germany	31 UP	300	7	8
		Iberia	32 ST	300	5	4
		Italy	33 DO	400	15	3
		Italy	34 UP	700	17	18
		Switzerland	35 ST	300	7	3
		Switzerland	36 UP	700	7	11
	HLMA	British Isles	37 UP	1200	3	3
		Germany	38 AC	900	9	16
		Iberia	39 UP	900	7	11
		Italy	40 AC	1000	14	20

UP upward; AC acceleration; DO downward; ST stagnation

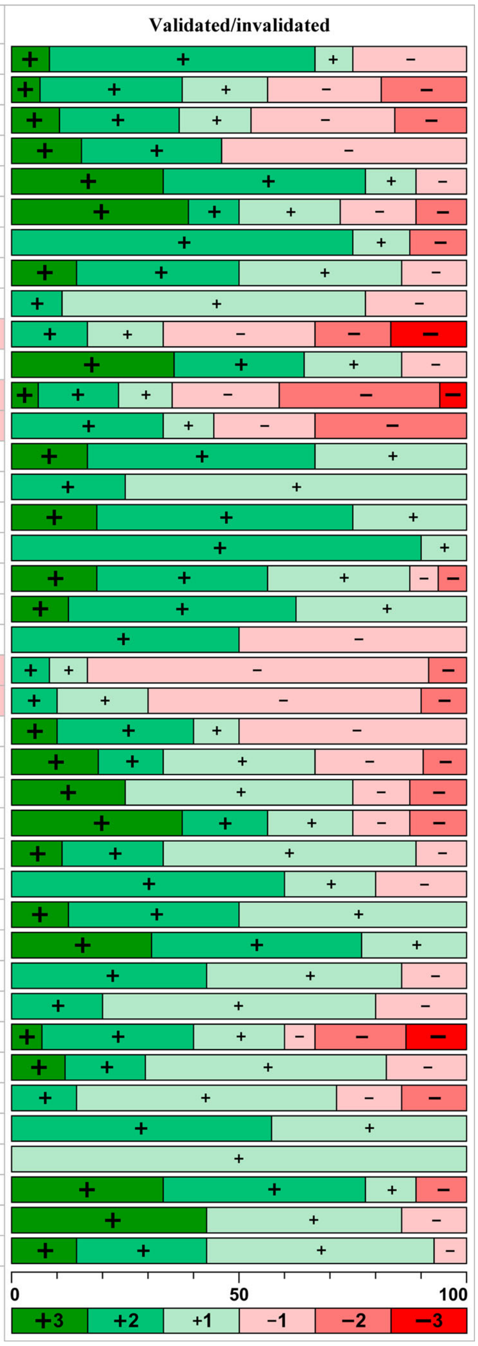

Figure 4. Degree of validation of 40 trends resulting from averaging regional Neotoma pollen data, based on the comparison with a selection of pollen records (sites) not included in the Neotoma database. The trends are sorted firstly by species, and then by period (PreR: Pre-Roman, Rom: Roman, LPR: Late and Post-Roman, HLMA: High and Late Middle Ages), region and starting time (column 'From' in years BC/AD, respectively negative and positive). The bar plot on the right represents the percentage of the non-Neotoma sites validating or invalidating each trend, by distinguishing six levels of validation (+3: clearly validated, +2: validated, +1: partly validated, −1: partly invalidated, −2: invalidated, −3: clearly invalidated). The last two numerical columns indicates, for each trend, the number of verification sites considered ('No'.) and the sum of the levels of validation for these sites ('Sum').

by Rome during the 1st century AD (e.g. Glaswaldsee ID42668; Durchenbergried ID40958). In regard to *Juglans* pollen we observe an acceleration of the upward trend at ca. 100 BC, especially in Italy and, to a lesser extent, in Switzerland.

All these trends during the Romanisation time are clearly confirmed by the non-Neotoma pollen records (see trends 4–7, 26 and 27 in Figure 4). For instance, the positive trends of *Castanea* and *Juglans*, occurring in Italy at ca. 100 BC, are particularly evident in the pollen spectra of Armentarga, Lago di Fimon and Mogge di Ertola (records 44, 50 and 62 in Appendix A). For the upward trend of *Castanea* in France, on contrary, the qualitative assessment through non-Neotoma pollen records is less conclusive, with 7 profiles out of 13 rather in disagreement (trend 4 in Figure 4), often characterised by a later start in the Middle Ages of the continuous *Castanea* curve (e.g. records 15, 19, and 23 in Appendix A).

Consequences of the Roman Decline

The transition between the classical antiquity and late antiquity resulted in a different impact on the two species. Generally, *Castanea* pollen percentages display a setback starting during the Roman Empire's crisis of the Third Century (235–284 AD) and even more the fall of the Western Roman Empire (476 AD) (Figure 2). Negative trends, although at rather high levels, are clearly displayed in Iberia (100–800 AD) and Switzerland (500–1000 AD), whereas periods of stalemate occur in South Germany (200–700 AD) and Italy (500–1100 AD). Instead, the progressive rise in *Castanea* pollen percentage continues in France during the Early Middle Ages, where many pollen records show remarkable positive trends just in the Dark Ages. This is for instance the case in the Massif Central (Lac de Chambedaze ID3977; Les Chaux de Coudert ID25238; Les Laubies ID24441) and in Brittany and Pays de la Loire along the northern Atlantic coasts (e.g. Marais de Kerdual ID24600; Lac de Brennilis ID24488) (Figure 3).

Among these *Castanea* trends during the Late and post-Roman period, only the French one (trend 8 in Figure 4) is clearly confirmed by the selected non-Neotoma pollen records (e.g. records 17, 18, and 30 in Appendix A). All others, i.e. the two downward trends in Iberia and Switzerland (trends 10 and 13 in Figure 4) and the two stagnation trends in Germany and Italy (trends 9 and 12 in Figure 4), returned ambiguous outcomes. For instance, the stalemate phase in Italy during the early Middle Ages (trend 12 in Figure 4) is evident at Lago della Costa and Lago di Mezzano (records 47 and 51 in Appendix A), but absent in others pollen records, such as at Lago Rotondo and Mogge di Ertola (records 56 and 62 in Appendix A).

Signs of decline of *Juglans* pollen percentages appear toward the end of the Roman Empire in Italy only (400–700 AD), while a stagnation can be outlined for Iberia (300–800 AD), Switzerland (300–700 AD), and Austria (200–600 AD). Elsewhere, as in France, *Juglans* pollen percentages progress at a lower rate during the first centuries of the Christian era and then accelerate at the beginning of the Early Medieval Period (500 AD). Positive trends for *Juglans* during the Dark Ages are also evident in Austria starting from 600 AD, as well in Italy and Switzerland from 700 AD. In southern Germany, the end of the Roman Empire even overlaps with the beginning of the greatest increase in *Juglans* percentages (e.g. Litzelsee ID40999; Herrenwieser See ID42692) (Figure 3).

On the whole, these *Juglans* trends during the Late and post-Roman period show a good match with the non-Neotoma pollen records, although with more convincing evidence and higher scores for the upward and acceleration trends (trends 29–31, 34, and 36 in Figure 4) than for the downward and stagnation trends (trends 28, 32, 33, and 35 in Figure 4). In particular, mixed results have been obtained for the negative *Juglans* trend in Italy after the first Visigothic invasion (trend 33 in Figure 4), with some sites showing a rise in walnut percentages right in the first centuries of the Middle Ages (records 55 and 57 in Appendix A).

Further Development in the Middle Ages

With the end of the Dark Ages and the beginning of the High Medieval Period at the turn of the millennium, there are clear indications of a general increase of pollen percentages of both *Castanea* and *Juglans* (Figure 2), although with marked differences among species and countries in terms of time, duration and amplitude (Figure 3).

For *Castanea*, the resumption or the strengthening of the upward trends takes place early in Iberia and Southern Germany (at ca. 800–900 AD) and later in Austria, Switzerland, Italy, and France (at ca. 1000–1200 AD). In the case of *Juglans*, this acceleration is quite evident in Iberia, Southern Germany, and Italy at ca. 900–1000 AD.

In South Britain the beginning of the Late Medieval Period (ca. 1200 AD) marks the start of the presence of *Castanea* pollen in the pollen spectra as well as a notable increase in the presence of *Juglans* pollen (Figure 3).

In general, the selected pollen records missing in Neotoma provide unambiguous support for all these positive trajectories (trends 11, 14–19, and 37–40 in Figure 4). For instance, *Castanea* rises in pollen percentages occur at Siegmoos in Austria, Bastani Lake in France, Dürrenbühlmoos in Germany, Lago di Pergusa PG2 in Italy, and Lac de Champex in Switzerland (records 7, 15, 33, 52, and 89 in Appendix A). For *Juglans*, this is the case at Elzhof in Germany, core RF93-30 in Italy, and Basa de la Mora in Spain (records 34, 46, and 71 in Appendix A). The qualitative assessment provides instead less convincing results in the case of the British Isles, owing to the small number of non-Neotoma pollen records with *Juglans* and *Castanea* (trends 15 and 37 in Figure 4).

Discussion

Western vs. Eastern Roman Empire Territories

The two considered species exhibits clearly distinct evolutions between the territories corresponding to the Western and the Eastern Roman Empire, respectively. As a rule, in the eastern territories pollen spectra display higher percentages for both species since the second millennium BC already, experience rises or peaks in the pre-Roman period, but fail then to peak during or after the Roman conquest as it is the case in the western territories.

A first reason for such a clear contrast may be found in the bioclimatic differences between the two areas. Favourable local conditions may have advantaged the survival of *Castanea* and *Juglans* during the Last Glacial Maximum in the regions of the ancient Near East, especially towards the Black Sea and Caspian Sea, enhancing their early spontaneous spread during the Late-Glacial and Holocene periods (Huntley and Birks 1983; Aradhya, Potter, and Simon 2006; Krebs et al. 2019). Second, the eastern territories correspond to the areas of early development of the agricultural techniques, including arboriculture (Blockley and Pinhasi 2011; Borrell, Junno, and Barceló 2015). In particular the Middle Eastern region of the Levant has provided the oldest evidence for fruit tree cultivation and domestication, with for instance the emergence of oleiculture starting from the Late Neolithic (Jenkins, Baker, and Elliott 2011; Oflaz, Dörfler, and Weinelt 2019; Langgut et al. 2019). The beginnings of grape (*Vitis vinifera*), date palm (*Phoenix dactylifera*) and fig (*Ficus carica*) fruit growing are also found in the Middle East (Kislev, Hartmann, and Bar-Yosef 2006; Weiss 2015; Fuller and Stevens 2019).

In the case of chestnut and walnut, the first evidences of propagation by humans or arboriculture as an ancillary agricultural activity are usually associated to eastern countries, such as Iran starting from 2500 BC (Djamali et al. 2010), Georgia from 2400 BC (Kvavadze 2016), Israel from 1800 BC (Langgut 2014), as well as Turkey and Greece from 1500 BC (Bottema 2000; Bottema-Mac Gillavry 2005; Çizer 2006; Stock et al. 2020; Fairbairn 2021), even if there is palynological evidence of Neolithic usage in Italy (Kelly and Huntley 1991; Kaltenrieder et al. 2010). The latter finding seems to question the scheme of an origin of cultivation generally flowing in the East to West direction.

Considering the mean of pollen percentages, we highlighted the first remarkable increases of *Castanea* in the Balkans and of *Juglans* in Turkey already between 2000 and 1600 BC (data not shown), that is concurrently with the rise of the Hittite Old Kingdom (Stephens 1979) and in agreement with an eastern origin of cultivation, but well before the beginning of the Beyşehir Occupation Phase (BOP), which is usually dated towards the middle of the 2nd millennium BC (Bottema and Woldring 1990; Kuzucuoğlu 2015). Indeed, it is generally accepted that the Romans did not invent the arboriculture of either walnut or chestnut. Specifically, the cultivation of these two fruit trees was, in fact, a part of the agronomic knowledge of the ancient Greeks, although of limited practical relevance in terms of number of trees planted (Conedera et al. 2004a; Pagnoux 2019; Margaritis 2014).

At time of the Roman conquest, the eastern territories were thus in general already well developed in both agricultural practices and diversification of crops, including fruit tree species relying on a long-lasting tradition of extensive agriculture and broad-scale arable systems with multiple stages of cropping intensification going back to at least to the Bronze Age (Fall, Falconer, and Lines 2002; Kaplan, Krumhardt, and Zimmermann 2009; Weiberg et al. 2019; Takaoğlu 2021), while only some areas of Western Europe may have had old fruit tree cultivation legacies (Kelly and Huntley 1991; Kaltenrieder et al. 2010; Ledger et al. 2015).

In addition, it is likely that already then the eastern territories were more affected than the western by dry climate conditions unfavourable to long-term success of large-scale planting of chestnut and walnut trees, which need more than 600–800 mm of annual precipitation accordingly to the temperature (Conedera et al. 2016; Reinders et al. 2003; Finné et al. 2019; Erdkamp, Manning, and Verboven 2021; Paź-Dyderska, Jagodziński, and Dyderski 2021). This may explain the lack of significant changing points at that time in the *Castanea* and *Juglans* pollen records in the Eastern Roman Empire (Figure 2) and the differing genetic and ethnolinguistic features of the chestnut and walnut trees and the related culture between the eastern and western territories (Pollegioni et al. 2017, 2020; Mattioni et al. 2017).

Pre-Roman Trends in the Western Territories

In general, pre-Roman rises in the pollen percentages of *Castanea* and *Juglans* should be interpreted with caution. On one hand, such trends are not prominent and are thus more likely related to problems of data coverage and consistency as a result of the uneven distribution of pollen records, causing a lack of data in some regions (see chapter on the suitability and limits of the approach). In addition, disentangling direct human-induced changes (e.g. arboricultural activities, cultivation and domestication), indirect human-induced events (e.g. effect of forest clearing through pasture or slash and burn), and natural disturbances (e.g. windthrow, natural wildfires) based on trends in pollen percentage only is a very challenging task.

So for instance, the increase in the presence of walnut in south-eastern France starting from 1700 BC, although it has been reported by some authors (e.g. Argant and Argant 2000; Visset et al. 2004; Ledger et al. 2015) would require a confirmation by additional sites, when accounting for the little number of representative Neotoma pollen records, the negative sum score of the selected non-Neotoma pollen records (trend 21 in Figure 4), and the almost total absence of remains of walnut nuts dated to the Bronze Age for this area (Pérez-Jordà et al. 2021; Bouby et al. 2022).

As regards the Italian pollen diagrams, some important confirmation of a slight increase in chestnut pollen frequency in the middle of the 2nd millennium BC can be found in many pollen records not included in the Neotoma database (trend 3 in Figure 4), such as at core RF93-30, Lago della Costa, Lake Ledro, Mogge di Ertola and Stagno di Maccarese (records 46, 47, 57, 62, and 67 in Appendix A). But even in this case we are unable to specify the importance of human intervention with respect to the capacity of spontaneous spread of the species.

Instead, the remarkable increases in *Juglans* pollen percentages occurring from the early and mid-1st millennium BC especially in Italy, France and Switzerland, on account of their unprecedented magnitude, are mainly attributable to human activities and presumably to new subsistence strategies involving arboriculture, which is in line with what is reported for the same period in the Balkans (e.g. Bottema 2000; Reinders et al. 2003; Valamoti et al. 2018; Weiberg et al. 2019).

As regards Italy, some authors discuss this trend relating it to an important demographic shift, but without indicating major distinction between *Juglans* and *Castanea* (Mercuri et al. 2013; Palmisano et al. 2021). In agreement with Ravazzi et al. (2013), our analysis of Neotoma pollen data suggest instead an important time gap between the major spread trends of *Juglans* and *Castanea*, with the first one starting already in pre-Roman Iron Age times (especially from 800 BC), very likely in relation with the rise of Etruscan civilisation (900–500 BC) and above all the wave of Greek colonisation (ca. 800–500 BC). The expansion of these two cultures triggered an unprecedented development of the maritime trade network along the northern coasts of the Mediterranean (Malkin 2011; Gran-Aymerich 2013; Tsetskhladze 2006). In particular the Greeks extended their dominion and influence on long stretches of shores in southern France and Italy, in the Balkans, Anatolia and all around the Black Sea (Figure 1), thus connecting the regions of southwestern Europe with the eastern lands, where the arboriculture in general and the cultivation of walnut and chestnut originate (Conedera et al. 2004a; Pollegioni et al. 2017).

According to our results, in France and Switzerland a wide process of spread of *Juglans* based on cultivation and arboriculture started (at the latest) from around 400 BC, that is during the Celtic Iron Age (La Tène period), around three centuries before the Roman conquest. This outcome is in contrast to previous research that consider this species as a marker of Romanisation both in France (Reille and Lowe 1993; Miras, Guenet, and Richard 2011) and in Switzerland (Burga 1988; Lotter 1999), and gives support to those authors who question this interpretation (Arnaud-Fassetta et al. 2000; Ledger et al. 2015).

We interpret the ambiguous outcome of the validation by pollen records missing in the Neotoma dataset (e.g. trends 22 and 25 in Figure 4) as related to the low number of validation sites in comparison to those in Neotoma, dating issues, or even more likely to particular local or regional cultural or territorial characteristics of arboriculture.

Although irregular, such a widespread pre-Roman upward trend of *Juglans* also outside the Mediterranean coastal areas, especially in France (e.g. Ancenis ID24645; Rezé ID24854; Lac des Boites ID24996), Switzerland (e.g. Lobsigensee ID4213; Montilier ID40454) and northern Italy (e.g. Lac de Villa ID22732; Malschötscher Hotter ID24061) strongly suggests an active involvement of Celtic peoples in the initial spread of walnut. In consequence of their great territorial expansions, first in northern and central France, north-western Iberia and southern Britain (ca. 700–500 BC), then in southern France, northern Italy (i.e. the Po valley) and into the middle and lower Danube basin (ca. 500–300 BC, see Figure 1), the Celts came into contact and established important trade relations especially with the Greek colonies (Freeman 1996), going as far as to threaten the Greeks and Romans in their motherlands, and settling in the central Balkans and Anatolia (Campbell 2009; Gavrilović 2013). Specifically, after the foundation of Massalia (i.e. modern Marseille) by Ionian settlers coming from Phocaea in Western Anatolia (Figure 1), the sixth and fifth centuries BC were a period of great intensification of the trade interactions between the Mediterranean world and temperate Europe (Green 1995; Rankin 1996; Wells 2004; Bridgman 2005). In some cases, the long-distance trade of exotic foods and the import of new agricultural products in relation with the emergence of new consumption practices may have led Celtic tribes to gradually adopt new agricultural crops and techniques. In this regard, there is evidence of a pre-Roman origin of viticulture in southern France resulting from the long-lasting commercial relationship based on the importing of Etruscan wine through the Greek colonies (McGovern et al. 2013; Bouby et al. 2014; Rageot et al. 2019). When comparing the processes of viticulture and walnut growing as described in the Latin text on agriculture (e.g. *De agri cultura* written by Cato the Elder, *De re rustica* by Varro, *De re rustica* by Columella), the latter is much less complex in terms of infrastructures and techniques. It is, therefore, plausible that there has been some important progress towards the adoption of walnut cultivation in the Celtic world prior to the Roman colonisation.

Surprising in this respect is the lack of a similar and coeval pre-Roman rise in the pollen percentages of *Castanea*, even though pollen evidence of chestnut cultivation since ca. 1000 BC has been reported for Latium in central Italy by Mercuri, Accorsi, and Mazzanti (2002, 2013). Following Conedera et al. (2004a), we can only speculate that in pre-Roman times and in the Greek civilisation in particular, chestnut fruits had probably little commercial value especially in long-distance trade. Maybe because of their high perishability, chestnut fruit were probably not part of the luxury, exotic, precious or valuable foods and goods that circulated along the maritime trade routes and were sold with profit especially for elite consumption during the period of greatest fortune of the Hellenic colonies. As a matter of fact, while for walnut fruits there is some evidence of presence in the cargo of Greek merchant ships, chestnut fruits make their first appearance among maritime archaeobotanical remains more than one thousand years later during the Carolingian Middle Age (Pollegioni et al. 2020).

Concerning the use of the chestnut tree for timber production, it seems highly unlikely that Celtic tribes could have been inclined in adopting and cultivating the chestnut tree when they were accustomed to exploit the excellent mechanical properties, the high durability and the great availability of oak for construction purposes (Bernard 2005; Haneca, Čufar, and Beeckman 2009; Tegel et al. 2016). Further, it must be stressed that oak remained a hardwood with enormous value and success as construction timber even during and after Roman times (Durand 2002; Haneca, Čufar, and Beeckman 2009; Toriti 2018; Bernabei et al. 2019; Tegel et al. 2022). Therefore, the adoption of *Castanea* for wood production could only take place within particular contexts and conditions (Buonincontri, Saracino, and Di Pasquale 2015; Bernabei et al. 2016).

The Roman Influence

The synthesis of Neotoma pollen spectra suggests that the contribution of the Romans to the diffusion of walnut is probably less crucial than commonly assumed or reported. But when considering the huge increase in the number of archaeological sites with carpological remains of *Juglans* just in coincidence with the onset of the Roman period, it seems undeniable that there is a link between the Roman culture and the habit of eating walnuts. Moreover, at least in Italy and Switzerland, the accelerating trend of *Juglans* at the time of the Roman expansion has been confirmed also through the analysis of pollen records lacking in Neotoma (trends 26 and 27 in Figure 4).

In the case of sweet chestnut, both the Neotoma pollen data, the selected non-Neotoma pollen spectra, and the plant macroremains agree in indicating that Romans played a key role in promoting its cultivation. In Western Europe, the most significant increase of the mean *Castanea* pollen percentage during the last four millennia occurs just at around 100 AD, when Rome is at the height of its hegemony.

As reported by Conedera et al. (2004a) the attitude of the Romans with respect to the chestnut tree clearly evolved at the beginning of the Christian era, in coincidence with the conquest of the northern territories. As reported in the coeval Latin literature, Romans were perfectly aware of the ecology of the chestnut trees and of the coppicing techniques allowing to produce valuable and versatile timber in relatively short time (Conedera et al. 2004a).

When projecting pollen data on maps, we can follow this spread of chestnut cultivation like a wave impacting at first on the southern slope of the Alps and its forelands and then, in a second stage, involving a large part of France (Figure 5). Many pollen profiles show a sudden rise in *Castanea* percentage with at the same time an increase of other anthropogenic pollen indicators, as for instance Lago di Origlio ID41467, Lago di Muzzano ID41770, Lago del Segrino ID46650, Lago di Massaciuccoli ID41600, Le Grand Lemps ID4197, Saint Julien de Ratz ID4373, Marais de Lisle ID24865, Tourbière de Chabannes ID25230, Tourbière de Roussy ID25232, and Saint Hilaire du Rosier ID25276 among the Neotoma records as well as Pierre-sur-Haute, Saint Florent, Armentarga, Lago di Bargone, Lago di Mezzano, and Guèr among the non-Neotoma records (records 29, 30, 44, 49, 51, and 88 in Appendix A). In the Roman Gaul, which besides France initially included Northern Italy and southern Switzerland (i.e. the Gallia Cisalpina), the intensification of chestnut presence appears in the pollen records as a very evident and long-lasting process.

An indirect sign of the importance of the Roman culture and organisation for the cultivation of the chestnut tree is represented by the remarkable interruption (and even reverse) in the growing trend of the mean of *Castanea* occurrence in the pollen records, which occurs in a relevant part of the western territories such as Iberia, South Germany, Switzerland, and Italy (but not in France) at the turn from Late Antiquity to the Early Middle Ages, even if non-Neotoma pollen records provide ambiguous outcomes (trends 9, 10, 12 and 13 in Figure 4). In fact, many pollen records in France but also in the mountain regions of Italy and Switzerland (e.g. records 17, 25, 26, 58, 62, 87, and 92 in Appendix A), reveal a positive trend of *Castanea* even during the first centuries of the Early Middle Ages. This may be interpreted as a clear sign that the chestnut arboriculture had become an indispensable component of the local economy, irrespective of the main cycles of development and crisis of the dominant civilisations (Quirós Castillo 1998; Squatriti 2013; Krebs, Tinner, and Conedera 2014).

The primacy of *Castanea* compared to *Juglans* in terms of Roman imprint can be further confirmed by the comparative linguistic analysis of the phonetic

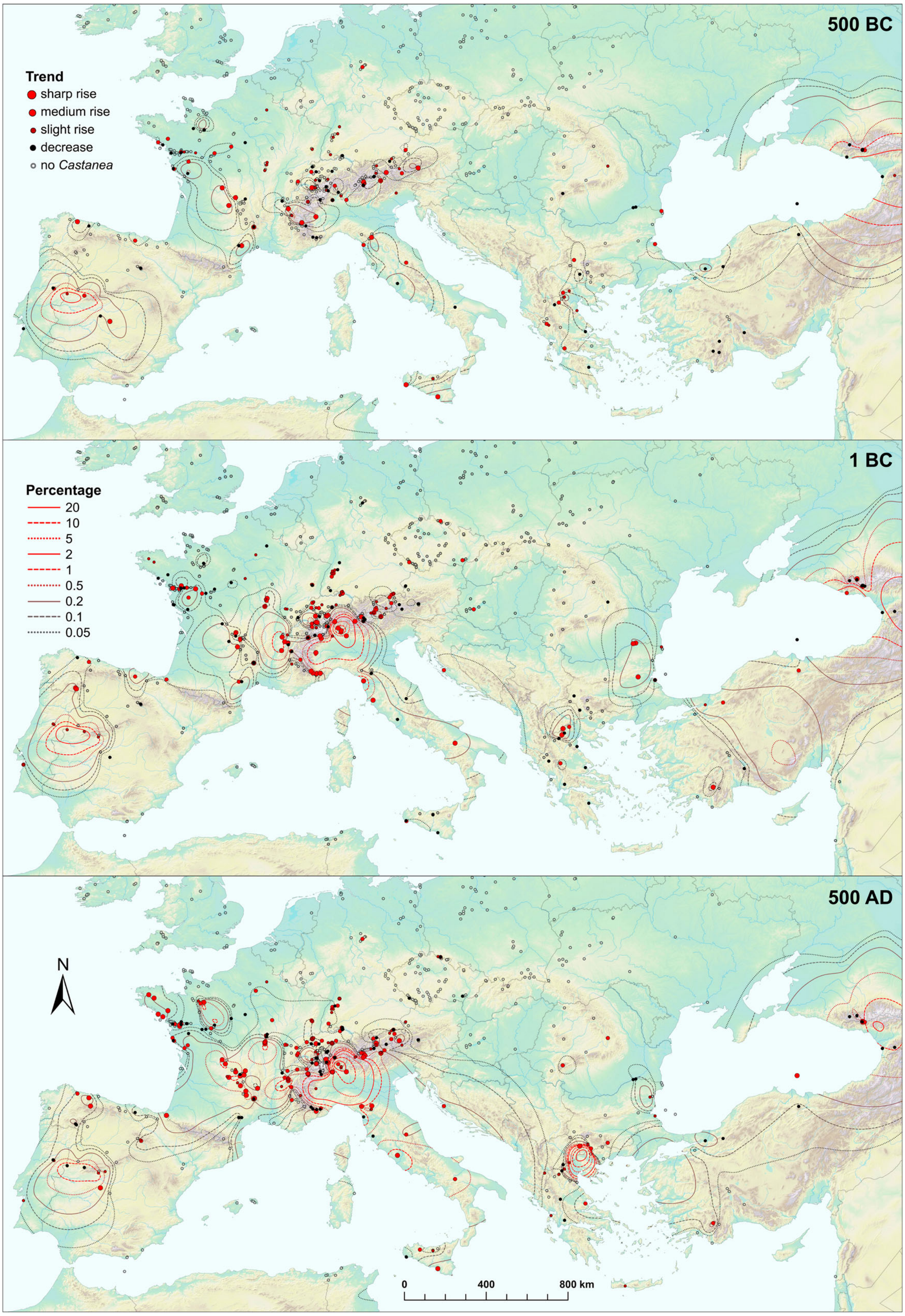

Figure 5. Trends in *Castanea* pollen percentages at ca. 500 BC, 1 BC (i.e. the astronomical year 0) and 500 AD according to the Neotoma pollen records (points). The isolines represent the interpolated percentage calculated through Natural Neighbour technique.

forms of words in the different languages of Europe. Contrary to what is observed for walnut, the nouns for 'chestnut' are in fact very similar not only in all Italo-Celtic and Romance languages, but also in Hellenic, Albanian, Germanic and Balto-Slavic languages (Pollegioni et al. 2020). This extraordinary lexical similarity can be explained by the transfer of knowledge from Greece to Rome, the great contribution of the Romans to the spread of chestnut cultivation and the consequent adoption and evolution of loanwords in other languages mainly through horizontal transmission of the Latin word *castanea* (Piccioli 1901; Pitte 1986).

Finally, it deserves attention the spread of *Castanea* in the so-called *Agri Decumates* territory between the Lake of Constance and the Upper Rhine Plain. In this particular case, the impact of the Roman conquest is evident both spatially and temporally. Contrary to what is observed in the central and northern territories of Germany, most of the pollen records located south of the Upper Germanic-Rhaetian Limes show the presence of *Castanea* during the Roman dominion (e.g. records 36, 37, 39, 40, and 42 in Appendix A), albeit with very low percentages and in the form of fleeting and discontinuous occurrences (Rösch 2013) (Figures 1 and 5). Hence, we can assume that the Romans cultivated there the species only in small and sparse tree populations at the warmest sites. The most accredited hypothesis is that chestnut was introduced together with grape vine in sheltered areas at low altitude mainly for the purpose of producing vineyard poles (Mäckel, Friedmann, and Sudhaus 2009; Rösch and Tserendorj 2011; Herchenbach and Meurers-Balke; 2017).

Concerning the walnut, the overall positive pre-Roman trend in the spread and cultivation of the species continued also during the Roman domination. However, Romans did not have such a direct and throughout impact on its diffusion as for chestnut. Indeed, only in Switzerland (e.g. Lobsigensee ID4213; Rotsee ID4382; Hinterburgseeli ID22992; Etang de Luissel Bex ID32260; Le Loclat ID40450; Lej da Champfèr ID43513) and Italy (e.g. Colfiorito ID3994; Malschötscher Hotter ID24061) we clearly observe an acceleration of the upward trend in the *Juglans* pollen percentage following the Roman conquest (see Figure 3, trends 26 and 27 in Figure 4, and Figure 6).

Post-Roman Period

After a short period of crisis in the first post-Roman period, the cultivation of chestnut for both timber and staple food production generally gained ground during the late first millennium AD. This has been especially the case in the European mountain areas devoid of alternative commercial outlets, but very suited for growing the chestnut tree from a climatic and ecological point of view (e.g. Quiros Castillo 1998 and Squatriti 2013 for Italy; Pitte 1986 and Bruneton-Governatori 1984 for France; Krebs, Tinner, and Conedera 2014 for southern Switzerland; Conedera et al. 2004a for an overview). In these areas, the chestnut tree cultivation introduced by the Roman further developed to a proper chestnut civilisation (Guinier 1951; Cherubini 1981) where the chestnut tree became the 'bread tree', the main object of collective interest as well as the main pillar of the society in both economic and cultural terms around which most territorial, legal and institutional structures were organised.

With the beginning of the Medieval Warm Period at ca. 900 AD (Lamb 2011; Easterbrook 2016), the species continued to spread even at the edges and outside the former Western Roman Empire. This trend culminated towards the end of the Middle Ages and in the early modern period, when the chestnut cultivation reached its maximum extent and development, with remarkable evidence also in England (Jarman, Chambers, and Webb 2019a), Ireland (Jarman et al. 2019c), Netherlands (Fischer et al. 2021), northern Germany (Karg 2010; Bouffier 2018), Czech Republic (Kosňovská 2013), Slovakia (Fehér 2018), Hungary (Gyulai 2010) and even in Denmark (Overballe-Petersen et al. 2012), and Poland (Piętka and Ciurzycki 2018). According to Jarman et al. (2019b), the overall scarcity of pollen records of *Castanea* in the British Isles even during the past millennium may be partly explained by the unfamiliarity of some analysts with this pollen type.

Suitability and Limits of the Approach

The approach used for this research allowed us to recognise the main aspects of the spread of *Juglans* and *Castanea* in the different European regions during the Late Holocene. The systematic and quantitative analysis presented in this paper essentially bases on the availability on the Web of the Neotoma palaeoecological database, which provides open access to more than a thousand European fossil pollen records with a time scale. The dependence on this database is at the same time the main strength and weakness of our analysis. In fact, the Neotoma database represents a unique and comprehensive resource for summarising palynological data, but unfortunately it also has obvious limitations in terms of geographical completeness and temporal accuracy of available data, as long as pollen data producers do not systematically contribute their results to such open repositories.

First, the distribution of the Neotoma pollen records is very inhomogeneous among the European and circum-Mediterranean countries. Data are particularly scanty in some important areas such as North Africa, south and west Iberia, southern France, southern Italy, western Balkans, eastern Turkey and Levant. In addition, it can reasonably be assumed that only a minor part of the published pollen data (very likely less than one-quarter) can end up in the Neotoma database (Krebs et al. 2019). Thus, relying only on the Neotoma data inevitably leads to incomplete results.

Another major issue is the difficulty of evaluating the chronologies stored in the Neotoma database (Giesecke et al. 2014; Li et al. 2022). Often for the same pollen record there are multiple and partly contrasting chronologies. The selection of chronologies can,

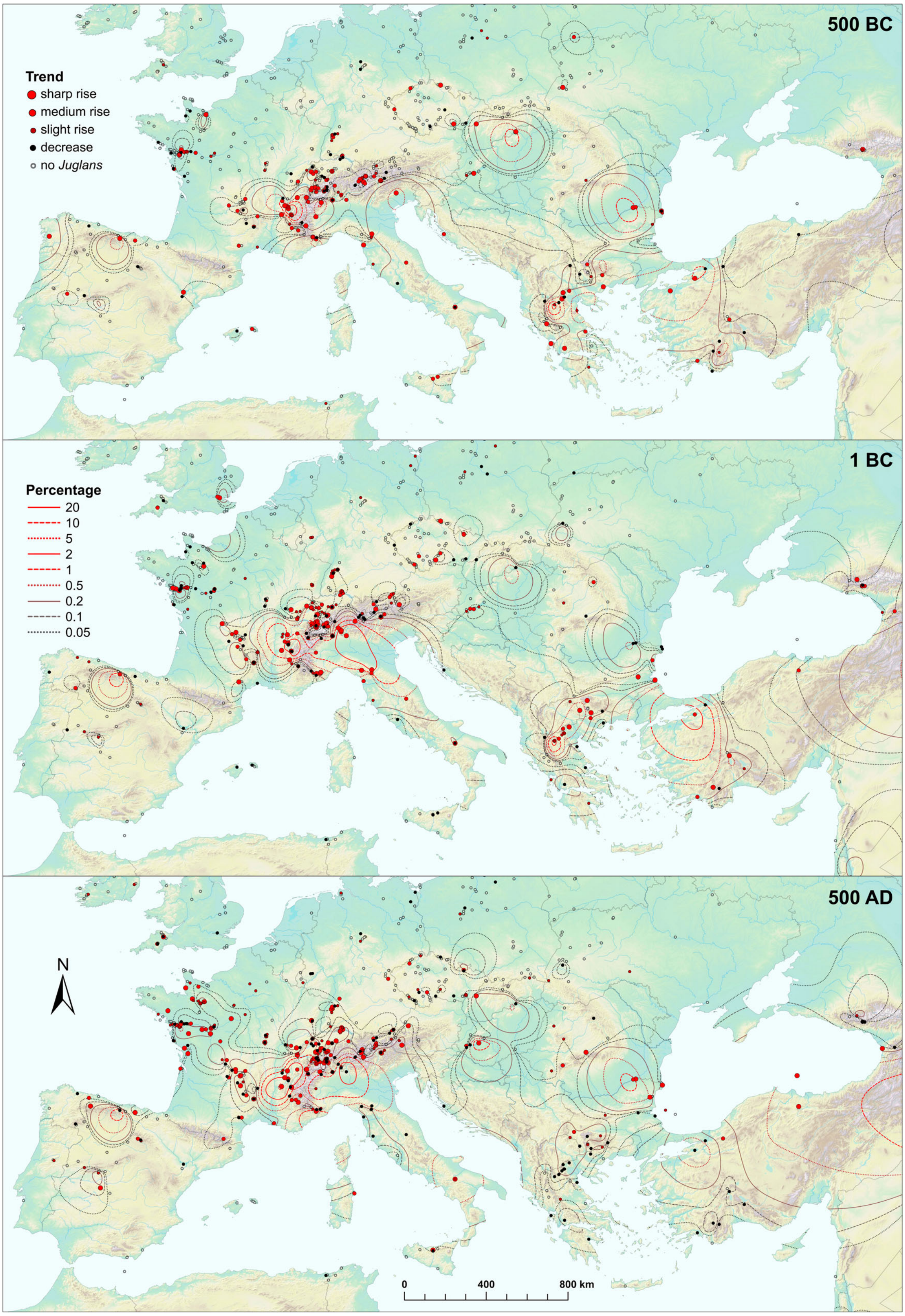

Figure 6. Trends in *Juglans* pollen percentages at ca. 500 BC, 1 BC (i.e. the astronomical year 0) and 500 AD according to the Neotoma pollen records (points). The isolines represent the interpolated percentage calculated through Natural Neighbour technique.

therefore, be very decisive. Even the best chronologies still have a considerable degree of temporal uncertainty (Blois et al. 2011; Trachsel and Telford 2017). There are often chronologies based on few age control points. To avoid extending the areas devoid of information and reducing the data available for the analysis, we preferred to retain also those pollen records relaying on few radiometric dates. We are confident that age inaccuracies should have a limited impact when focusing on the main trends obtained through the averaging of many pollen spectra, as long as the number of sites considered is high enough.

As regards our efforts in considering pollen profiles which are missing in Neotoma as well as macrobotanical remains, the results presented here inevitably are a fraction only of the published data. For archaeological studies in particular, there is a generally low level of digitisation of past research, a partial ineffectiveness of web search engines in performing targeted and multilingual searches, and the great difficulty in obtaining or accessing the relevant documents (e.g. unpublished archaeological reports produced by state offices) and publications (e.g. short notes in national scientific journals). This all eventually makes a systematic and numeric review extremely challenging and time consuming.

Furthermore, the differential preservation of plant remains is another issue that deserves attention when interpreting the carpological records (Pearsall 2016). Each plant tissue has specific preservation potential depending on a multitude of factors both endogenous (e.g. toughness and strength of the biological material, sensitivity to corrosion and degradation, nutritional value and chances to be eaten) and exogenous (e.g. depositional context, charring or burning in cooking fires, desiccated or waterlogged preservation conditions). In particular, chestnut cotyledons (halves) have relatively high sugar and moisture content (about 50% of water), high enzyme activity, and are, therefore, prone to decay (Blaiotta et al. 2014; Vettraino et al. 2019; Pino-Hernández et al. 2021). Moreover, the brown-black or brown-red involucre (pericarp) is rather thin and very porous which facilitates water absorption and contribute to the high perishability of the fruit (Beccaro et al. 2019). On the contrary, the outer protective shell of walnut (i.e. the endocarp) is extremely hard and highly resistant to biodegradation (Antreich et al. 2019; Roquia, khalfan hamed Alhashmi, and hamed Abdullah alhasmi 2021). Even the shelled walnuts are much more durable compared to chestnut cotyledons thanks to the high oil content (60–70%), which can lead to rancidification but allows the long conservation of the kernel structure (Gama et al. 2018). Looking at just these characteristics, one should be very cautious in making comparisons between the recurrence of *Juglans* and *Castanea* fruits remains in archaeological context. Yet even more caution should be employed when comparing fruit and wood remains in relation to human settlements and subsistence practices. When used as timber or as fuel, chestnut wood could become nearly imputrescible when charred and transformed into wood charcoal after accidental or intentional fire exposure. The fruits instead were usually consumed after roasting over a fire and the waste (e.g. the pericarps) usually thrown into the fire and eliminated (Bandini Mazzanti et al. 2005; Bandini Mazzanti and Bosi 2011). Considering the lower mass and higher flammability of pericarp fragments compared to wood, it is likely that there are more chances to find this species among anthracological remains than in a carpological assemblage. It is thus not surprising to see *Castanea* pericarps reported as extremely rare or even absent in extensive carpological investigations referring to regions and periods where the chestnut tree was confirmed to be an important source of livelihood (Ruas, Bouby, and Pradat 2006; Ruas 2010; Bosi et al. 2011; Dal Fiume et al. 2015).

The crucial role of differential preservation of plant remains has clearly emerged from the studies of the origin of chestnut cultivation (*Castanea crenata*) during the Jomon period in Japan from around 5500 cal. BP. Japanese archaeologists started to find lots of chestnut fruit remains only when they undertook large-scale excavations in the humid lowland and had the possibility to analyse well-preserved macroremains assemblages in waterlogged conditions (Mason 1992; Noshiro and Sasaki 2014).

Conclusions

The European-wide analysis of the palynological and archaeological evidence of the presence and abundance of *Castanea sativa* and *Juglans regia* allowed us to reconstruct the main trends of the spread and cultivation of these two important tree species at the continental scale and the imprint of the Roman Empire in particular.

Following general patterns can be highlighted:

- There is a substantial difference in the timing and magnitude of spread of both species between the territories corresponding to the Western and Eastern part of the Empire, given that in the latter, close to no Roman impact can be detected.
- In the western territories, *Juglans* experienced a significant pre-Roman increase and spread, which has been prolonged, but only partially further intensified under the Roman domination.
- *Castanea*, on contrary, exhibits a strong upward trend coinciding with the Roman dominion, especially in the mountain areas of the Gallia Cisalpina and Transalpina.
- The mountain areas of the main chestnut spread during Roman times inspired the rise of the traditional medieval chestnut civilisation based on the cultivation of the chestnut tree as one of the main staple food.

Beside such very clear general trends, highly differentiated local and regional trends exist, which are, however, hard to detect with our approach, mainly because of the coarse data resolution for most of the areas considered.

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Notes on contributors

Patrik Krebs is geographer and scientific staff member at the Swiss Federal Institute for Forest, Snow and Landscape Research WSL, in the branch station located on the southern slope of the Alps. His research interests are focused on historical geography and interdisciplinary history. By using multiple sources (e.g. manuscripts, environmental proxies) and methods (e.g. anthracology, GIS analysis), he studies the genesis and evolution of the cultural lanscapes, with insight into the history of wood charcoal industry and chestnut cultivation.

Fabiano Ulmke is business engineer, recently graduated from Zurich University of Applied Sciences. His main study fields are discrete event simulation, optimization and data management.

Willy Tinner is professor for paleoecology and vegetation dynamics at University of Bern. He studied geography, botany and archaeology at University of Bern. After his PhD in biology he was a postdoc at University of Illinois at Urbana-Champaign and SNF-professor at ETH Zurich. He addresses ecological questions on annual to millennial time scales and uses quaternary sedimentary sequences (e.g. pollen, spores, macrofossils, charcoal) and modelling approaches to study the long-term interactions among climate, the biosphere and society.

Marco Conedera is forest engineer and head of research unit Community Ecology at the Swiss federal Research Institute WSL. His main research interests are fire history, fire ecology and management, historical and ecological aspects of the chestnut cultivation, invasive neobiota, and landscape dynamics.

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