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ORIGINAL PAPER

Timber economy in the Roman Age: charcoal data from the key site of Herculaneum (Naples, Italy)

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Abstract The city of Herculaneum (Naples, southern Italy), buried by the volcanic eruption of Mount Somma-Vesuvius in 79 AD, is a key site for understanding the timber economy during the Roman period. In this paper, the results of charcoal analysis of different building element types are presented. Beams, joists, poles, planks and door and window frames were investigated allowing us a view of which timber the Romans preferred for building in this area. We also fit the taxonomic results into the reconstruction of the ancient Campanian landscape, and finally, we discuss the knowledge that the Romans had about the technological properties of the wood that they used for building and the possible selection criteria that they followed in choosing them. Coniferous timber is the preferred material for building purposes. *Abies alba* is especially used, this fact confirming its stronger presence in southern Italian woods during the past and suggesting that its decline is mainly due to human overexploitation. The large presence of *Cupressus sempervirens*, selectively used for the production of poles, confirms that this tree was cultivated in plantations for timber production in the Vesuvius area. Furthermore, it might indicate that cypress could have been present as a natural tree in the local vegetation, suggesting a forest type that nowadays almost completely disappeared from this area and from the entire Italy. The findings of *Juglans regia*, *Pinus pinea* and *Olea europaea*, typical elements of the Mediterranean cultural landscape, show that their use was not limited to fruit production and that Romans also appreciated their timber. Beside these local resources, the presence of *Picea abies* and *Picea*/*Larix* indicates the importation of timber from northerly regions, probably the northern Apennines and the Alps.

Keywords Southern Italy · Building timber · Wood technological properties · Coniferous wood · *Abies alba* · *Cupressus sempervirens*

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Introduction

In European archaeological wood and charcoal studies, it is not common to find perfectly preserved wooden building material. With the exception of waterlogged remains, such as the Neolithic and Bronze Age pile dwelling settlements (Billamboz 2014; Cicirelli and Albore Livadie 2012) or the shipwrecks (e.g. Allevato et al. 2010; Giachi et al. 2003; Sadori et al. 2015), the wood/charcoal analyst generally works with fragments that are not bigger than some centimetre. This is true for the Roman Age: despite the majestic vestiges found in the territory of the Roman Empire, testifying the building activity of the Romans, only in few cases, the wooden parts of such constructions are entirely preserved (e.g. Birley 2009; Goodburn 1991). In this scenario, it is easy to understand the great importance of Herculaneum for this field of studies.

The Roman city was buried in 79 AD under a 16–30-m-thick volcanic deposit that allowed the preservation of the town: not only private and public buildings were preserved in an excellent state, but also a huge amount of other material, such as sculpture, furniture, various household implements and work instruments, pottery, glass objects and jewellery (Wallace-Hadrill 2011). Moreover, in Herculaneum, the high temperature of the pyroclastic surges and the anaerobic environment created by the pyroclastic flows allowed recovery of many kinds of organic materials, among them wood (Rizzi 2005). The latter was preserved through carbonisation, desiccation and, on the "antica spiaggia," in waterlogged conditions (Tamburini et al. 2013). The amount and the preservation state of the wooden finds span the different construction elements used for building frames, ceilings and internal roof supports as well as many furniture pieces. Despite this abundance of material, few studies have been yet undertaken to investigate the wood and charcoal remains of Herculaneum. Those completed have focussed on the interior furniture and are characterized by an historical-artistic perspective, where wood identification is totally missing (Bischop 2006; De Carolis 2007) or limited to a small number of samples (Mols 1999, 2002). Wood analysis is missing also in a recent work by Guidobaldi et al. (2008) on the wooden ceiling structure of Herculaneum.

Fioravanti et al. provide analysis of wooden furniture and structural elements from Herculaneum, although the number of samples is still low (Caramiello et al. 1992), and the data published are brief (Fioravanti and Caramiello 1999; Fioravanti and Galotta 1998). Discussion focuses mainly on the issue of wood conservation (Galotta 1999). In Pompeii too, charcoal analysis regarded fuel wood (Coubray 2013; Veal 2014), but no timber used for building.

Numerous studies are available on Roman architecture and building technology (Adam 1988; Cifani 2008; DeLaine 1997: Giuliani 1990), some of them focusing especially on wood (Camardo and Notomista 2015; Goodburn 1991; Ulrich 2007). In these cases, the focus is also placed on the materials and techniques but less on taxonomical wood identification.

In this paper, we present the results of anthracological analyses conducted on a large number of building elements still preserved in situ in several areas of Herculaneum or collected during the archaeological campaigns at the site and stored in different warehouses. Our main aims are as follows: (1) to specify those trees that the Romans preferred for building and to discuss the knowledge that the Romans had about the technological properties of the woods that they used and the possible selection criteria that they followed in choosing them, (2) to understand whether local or imported timber was used, and (3) to provide more data for the reconstruction of the past landscape of the Vesuvius area and of ancient Campania.

Study area

The ancient city of Herculaneum is located along the Bay of Naples at the foot of the western slope of Mount Somma-Vesuvius under the modern town of Ercolano (40° 48′ 49″ N, 14° 21′ 49″ E; Fig. 1).

The origins of the city are still not completely understood: Dionysus of Halicarnassus (*Roman Antiquities* I. 44: Cary 1937) ascribes the establishment of the city to Hercules, suggesting, in this manner, its Greek origins. Strabo (*Geography* 5.4.8: Roller 2014), instead, indicates that Herculaneum is first a city of the Italic populations Opici-Osci, then of the Etruscans and finally of the Samnites (Guidobaldi 2006). In fact, the basic outline of the city and its street pattern go probably back to a local Oscan-speaking settlement of the fourth century BC or earlier, but scarce archaeological evidence remains of it (Wallace-Hadrill 2011). In 308 BC, Herculaneum enters the sphere of influence of the Romans attracted to Campania by the fertility of the soil (Lepore 1989). In the Roman Imperial period, Herculaneum became a flourishing city, as the vast villas, numerous shops and valuable artistic objects testify. However, its life was cut short: in 79 AD, the volcanic eruption of Mount Somma-Vesuvius definitively buried the city.

Tunnels to explore the ruins of the city and to extract marble and other precious material were excavated starting from the Middle Ages, as archaeological evidence testifies (Camardo 2013; Wallace-Hadrill 2011). Nevertheless, the modern rediscovery of Herculaneum occurred in 1710 by the Prince d'Elbeuf, and systematic excavations started only in 1738 at the command of Carlo III Bourbon, king of the Kingdom of Naples, and under the direction of Rocque Joaquim de Alcubierre (Wallace-Hadrill 2011). Numerous excavations followed intermittently and on a small scale. In 1927, under the direction of Amedeo Maiuri, scientific excavation was initiated and continued until 1961, when almost the entire area now visible was brought to light (Camardo 2007; Maiuri 1959; Wallace-Hadrill 2011). The excavation was particularly difficult in Herculaneum due to the nature of the volcanic deposit. The town was buried by a sequence of pyroclastic flows originating after the collapse of the vertical eruptive column. Pyroclastic flows consist in high-speed avalanches of pumice, ash, mud and gases with a temperature of 300–400 °C (Cioni et al. 2004), flowing down the flanks of the volcano and becoming, after solidification, a stony deposit (Sheridan et al. 1981; Sigurdsson et al. 1982; Sigurdsson 2007). Each of the pyroclastic flows was preceded by a pyroclastic surge, i.e. a turbulent cloud of volcanic ash and 400/500 °C hot gases travelling at a speed often exceeding 100 km/h (Capasso 2001; Mastrolorenzo et al. 2001). These instantly charred most parts of exposed building timber, furniture and wooden objects in the city, thus allowing their preservation.

The study area is characterized by a Mediterranean climate. The mean minimum temperature in the coldest month (January) is 6.8 °C, and the mean maximum temperature in the hottest month (August) is 25.7 °C. Mean annual precipitation amounts to 865 mm, with a maximum in November

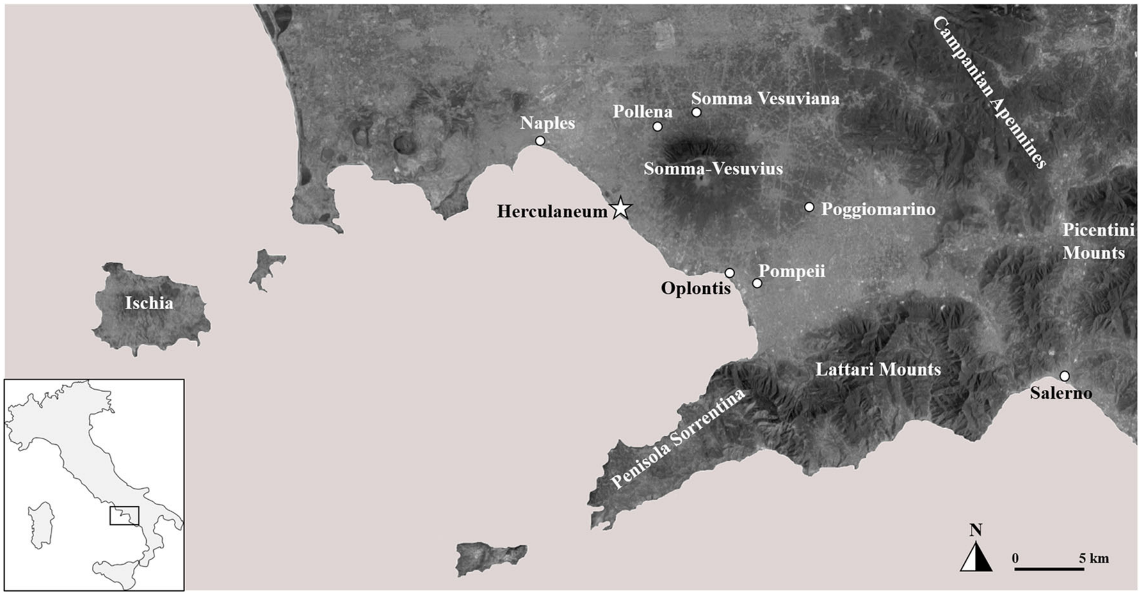

Fig. 1 The Vesuvius area (Naples, southern Italy) showing Herculaneum and the most important places cited in the text

with 126 mm and a minimum in July with 16 mm (Università degli Studi di Napoli Federico II weather station, 50 m above sea level (a.s.l.), 10 km from the study site).

The modern landscape around the study area is strongly modified by human settlement. The entire Bay of Naples is densely populated. On the south-western slope of Mount Somma-Vesuvius, a pine forest with dominance of *Pinus pinea* prevails, while on the north-eastern slope, a mixed mesophilous forest dominated by *Quercus pubescens*, *Ostrya carpinifolia* and *Fraxinus ornus* is present together with *Castanea sativa* woodlands. On the top of the Somma slope, mixed stands of *Populus tremula*, *Alnus cordata* and *Betula pendula* grow, while *Quercus ilex* is present on the steepest inland slopes of Mt. Somma and on Mount Vesuvius.

On the Lattari Mountains, south of the investigated site, *C. sativa* and *A. cordata*, together with *O. carpinifolia* and *Fagus sylvatica*, populate the highest elevations, while *Q. ilex*, *F. ornus* and *Q. pubescens*, together with *Arbutus unedo*, *Rhamnus alaternus* and *Erica arborea*, grow on the lower belt.

Material and methods

This research took place within the context of a broader network of scientific projects supported by the Herculaneum Conservation Project. A systematic analysis was carried out aimed at sampling the largest number possible of building timbers preserved at the site. Charcoal analysis was undertaken on 436 building elements preserved in almost their entirety. Since the timber elements were entirely preserved, the sampling strategy consisted in collecting a charcoal fragment for each element. When possible, building elements still preserved in situ, i.e. in their original location in the building structure or in the place of discovery, were sampled. Nevertheless, this was not always possible, since a large amount of building elements brought to light in past excavations is now stored in different storerooms and the original location is unknown. In the overall of the collected samples, 110 are still preserved in situ and 326 are unprovenanced elements. For the samples still preserved in the original building structure, the precise identification of the building element and the determination of its function in the building frame were possible (for example, rectangular ceiling beam, doorjamb, door lintel, etc.). For most part of the other samples, only a more general description was feasible (except for the case of a door, fully preserved in one of the storerooms). For a subsample of 170 elements (all unprovenanced), measurements of the diameter or the width and thickness were performed. It was not possible to measure the length, since the timber elements were broken or, sometimes, cut to simplify their rescue during past archaeological excavations. The measurements refer to carbonized wood: indeed, a probable shrinkage of 15 to 35 % has to be taken into account when estimating the original size of each element (Braadbaart and Poole 2008).

Taxonomic identifications were made with an incident light microscope at magnifications of ×100, ×200 and ×500, using the reference wood collections of the Institute for Ecosystem Research—Paleoecology Unit at Kiel University and of the Laboratory of Vegetation History and Wood Anatomy at the University of Naples Federico II and wood anatomy atlases (Greguss 1955, 1959; Schweingruber 1990).

Results

Of the 436 analysed samples, only one was not identifiable beyond being a conifer. All others were identified at a species or genus level (Table 1).

Although wood anatomy does not allow for a distinction between the different species of *Abies* present in the Mediterranean (Quézel and Médail 2003), we can reliably attribute our samples to *Abies alba* (silver fir) due to its wider distribution along Italy (Pignatti 1982). Silver fir was the preferred timber (64 % of the total; Fig. 2) and was employed for almost all of the different building elements: it is especially used not only for squared beams, planks and squared joists, but also for big-sized poles, slats, different elements of door and window framing and for a treenail (Fig. 3). *Cupressus sempervirens* (cypress) follows with 15 % (Fig. 2), and it was particularly used for poles (ceiling poles and other poles, the function of which is unknown being them unprovenanced), for which it constitutes the almost exclusively used timber. It was also employed for a few squared joists and squared beams (Fig. 3). The distinction between *Picea abies* (Norway spruce) and *Larix decidua* (European larch) could be complicated, the only distinguishing character for small fragments being the shape of pit exterior borders in ray tracheids (Bartholin 1979; Schweingruber 1990; Talon 1997). At Herculaneum, the very good preservation of the samples allowed in some cases the attribution to *P. abies*. Norway spruce and *Picea*/*Larix* (together 11 %; Fig. 2) are especially employed in squared beams, squared joists and planks, but also for door framing (Fig. 3). Among the conifers, a plank made of *Pinus* group *sylvestris* and a squared joist of *P. pinea* (stone pine) were also found (Fig. 3). Concerning the latter, if the identification of the different taxa among the "Mediterranean pines" could be problematic, *P. pinea* shows some characteristics that allow it to be distinguished from the others: smooth ray tracheids (García Esteban et al. 2000; Schweingruber 1990) and the small diameter of the pits in cross-fields (no larger than 2–5 μm) (García Esteban et al. 2000).

C. sativa (chestnut; 4 %; Fig. 2) was the most common taxon among the broadleaved trees: in particular, it was used for squared beams, planks and squared joists (Fig. 3). Deciduous *Quercus* (deciduous oak) at 3 % (Fig. 2) was employed for planks, squared joists and a slat and for two tenon fragments (Fig. 3). *F. sylvatica* (common beech), *Juglans regia* (walnut) and *Ulmus* (elm) represented at only 1 % (Fig. 2) were used for planks and a pole and for squared joists and planks, respectively (Fig. 3). A squared joist made of *Olea europaea* (olive tree) was also found (Figs. 2 and 3).

In Fig. 4 and Table 2, the location of the in situ timber elements is given, together with the taxonomical identification and the indication of the element type. Concerning the unprovenanced timber elements, beams, joists, planks, slats, poles, door rails, door stiles and door panels, treenails and

Table 1 Identification results: frequencies (number of charcoal fragments) of the identified taxa among the building elements

Taxon	Element type: Squared, rectangular, round beam	Squared joist	Squared slat	Pole	Plank	Door jamb	Door lintel	Door stile	Door rail	Door sunken panel	Window jamb	Window sill	Treenail	Tenon fragment	Indet.
Abies alba	93	71	4	9	74	3	1	3	5	2	2	1	1		11
Cupressus sempervirens	3	4		55											4
Picea abies + *Picea*/*Larix*	24	9			9			1	1	1					1
Pinus group *sylvestris*					1										
Pinus pinea		1													
Fagus sylvatica				1	2										
Castanea sativa	6	4			4										5
Juglans regia		1			2										
dec. *Quercus*		2	1		4									2	2
Ulmus		2			2										
Olea europaea		1													
Conifer						1									

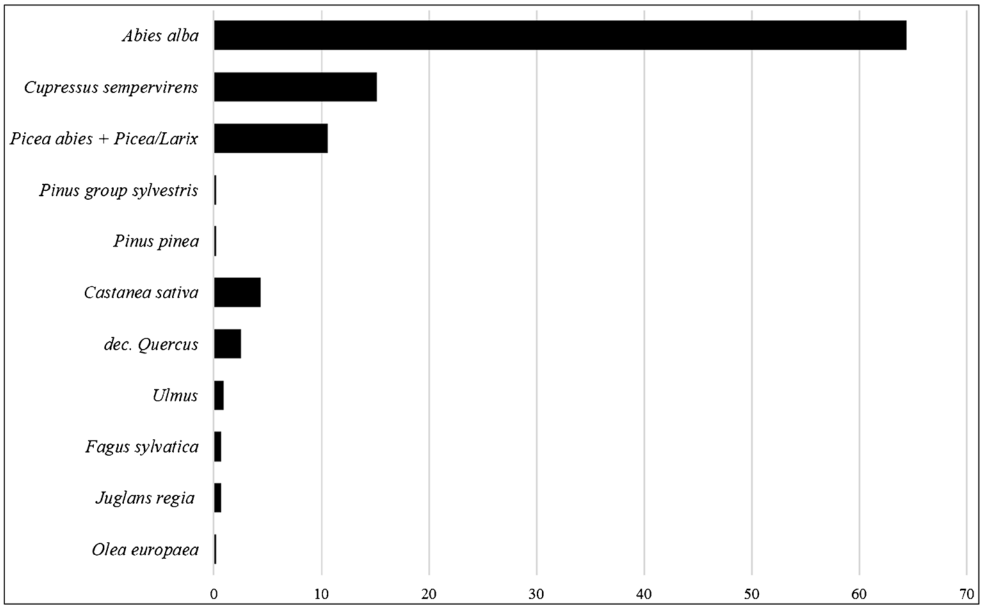

Fig. 2 Identification results. Percentage diagram of the wood taxa identified in Herculaneum. Total number of charcoal pieces 435

fragments of tenon elements preserved in different rooms at the Casa di Granianus, at the Fornici and at the storeroom close to Villa dei Papiri (Fig. 4) were analysed.

In Table 3, the results of the measurements carried out on unprovenanced timber elements are shown. Squared beams are 9 to 30 cm wide and 7 to 18 cm thick, squared joists are 4 to 20 cm wide and 3 to 14 cm thick, squared slats are 4 to 6 cm wide and 2 to 3 cm thick, and planks are 6 to 28 cm wide and 1.5 to 15 cm thick. Poles have a diameter of 6 to 18 cm.

Discussion

The study of charcoal and wood remains from archaeological contexts is a useful tool for understanding past vegetation and its changes linked to human activities (Asouti and Austin 2005; Chabal 1994). Nevertheless, in the case of building elements, bias due to a higher selective human choice of the timber for this specific purpose has to be taken into account (Chabal 1994). When studying complex societies, such as the Roman civilisation, also the issue of the importation of raw materials from a more or less long distance has to be addressed. A way to go beyond these limits might be to combine charcoal and pollen analysis from neighbouring paleoarchives, strengthening, in this manner, the interpretation on vegetation composition and dynamics on a local, extra-local and regional scale (for the application of this method, see Nelle et al. 2010). When close-by paleoarchive suitable for pollen analysis is not available, as in the case of Herculaneum, the comparison with pollen records from the wider region can

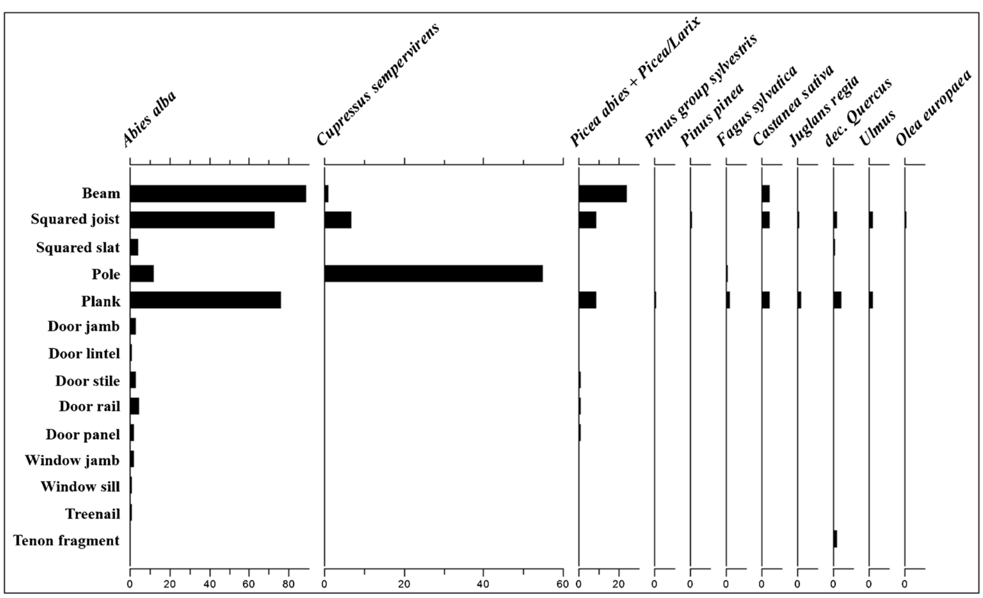

Fig. 3 Timber products analysed in Herculaneum. For each type, the percentage of the different employed taxa is given

Taxa:

● *Abies alba* ● *Picea abies + Picea/Larix* ● *Castanea sativa* ● *Ulmus* ● Conifer

● *Cupressus sempervirens* ● *Pinus* group *sylvestris* ● deciduous *Quercus* ● *Juglans regia*

Locations of the "not *in situ*" samples:

1▲ Store room Fornici 2▲ Store room Casa di Granianus 3▲ Store room Villa dei Papiri

Fig. 4 Map of the archaeological site of Herculaneum with the location of the collected samples. *Round dots* refer to single timber elements still preserved in situ: *different colours* correspond to different taxa (see legend). *Numbers* refer to Table 2. *Triangles* indicate the locations of the rooms where unprovenanced timber elements are stored. Authors' elaboration from an original map by Massimo Brizzi (Herculaneum Conservation Project)

help in reconstructing the past landscape and in disentangling the question about the use of local or imported resources.

Local timber: forest cover in the Vesuvius area and in ancient Campania

Silver fir is currently present with scattered small populations in the western Mediterranean regions (Quézel and Médail 2003). In central and southern Italy, it grows in small populations on the Apennines, mainly above 1000 m a.s.l. (for a detailed distribution map, see Di Pasquale et al. 2014a, Fig. 4 and Appendix S1). The spontaneous stands of silver fir nearest to the study area are located on Monte Motola in Cilento (Moggi 1958), on the Monti Picentini (Moraldo et al. 1981–1982), on the Matese Massif in the Molise-Campanian Apennines (Bianchini 1987) and on the Monti Faiatella and Cervati in the Cilento National Park (Abbate et al. 1997). Despite its current scattered distribution, the range of archaeobotanical and paleoecological data available for central and southern Italy strongly indicates that until the Late Holocene, silver fir was largely present all along Italy and its decline can be ascribed to human exploitation for timber (e.g. Allen et al. 2002; Di Pasquale et al. 2014a; Drescher-Schneider et al. 2007; Joannin et al. 2012; Russo Ermolli and Di Pasquale 2002). Moreover, the data specify that it also grew at lower altitudes than today and it was associated with deciduous oak and other mesophilous broadleaves (Di Pasquale et al. 2014a; Tinner et al. 2013).

Table 2 Location, taxon and timber product of the timber elements still preserved in situ at Herculaneum

Location	No. (Fig. 2)	*Taxon*	Element type
Villa dei Papiri—northern wall	1–4	*Abies alba*	Squared beam
	5	Conifer	Door jamb
Villa dei Papiri—northern room	6	*Abies alba*	Plank
North-western *Insulae*—residential quarter	7	*Abies alba*	Squared beam
	8–10	*Abies alba*	Round beam
	11	*Abies alba*	Rectangular beam
	12–14	*Abies alba*	Plank
	15	cfr. dec. *Quercus*	Squared joist
	16–17	dec. *Quercus*	Squared joist
	18	*Abies alba*	Pole
	19–20	*Abies alba*	Plank
	21–22	*Abies alba*	Squared beam
	23	*Abies alba*	Rectangular beam
	24	dec. *Quercus*	Plank
	25	*Abies alba*	Rectangular beam
	26–28	*Cupressus sempervirens*	Pole
	29	dec. *Quercus*	Plank
	30	*Abies alba*	Rectangular beam
North-western *Insulae*—nympheum	31	*Castanea sativa*	Squared beam
	32–33	*Castanea sativa*	Squared joist
North-western *Insulae*—shipyard	34	*Abies alba*	Rectangular beam
	35	*Ulmus*	Plank
	36–38	*Abies alba*	Rectangular beam
	39	*Pinus* group *sylvestris*	Plank
North-western *Insulae*—*domus*	40–41	*Abies alba*	Rectangular beam
	42–46	*Abies alba*	Plank
	47	*Abies alba*	Rectangular beam
	48–49	*Abies alba*	Squared joist
Bourbons tunnel	50	*Abies alba*	Squared joist
	51	*Ulmus*	Squared joist
	52	*Cupressus sempervirens*	Squared joist
Insula VII—north wall	53	*Abies alba*	Squared beam
	54–55	*Abies alba*	Squared ceiling beam
	56	*Picea*/*Larix*	Squared ceiling beam
	57	*Picea abies*	Squared ceiling beam
	58	*Abies alba*	Squared joist
	59	*Cupressus sempervirens*	Pole
	60	*Cupressus sempervirens*	Rectangular ceiling beam
	61	*Cupressus sempervirens*	Ceiling pole
	62	*Abies alba*	Rectangular ceiling beam
	63	*Cupressus sempervirens*	Rectangular ceiling beam
	64	*Abies alba*	Squared ceiling beam
	65	*Abies alba*	Squared joist
	66–67	*Abies alba*	Squared ceiling beam
	68	*Cupressus sempervirens*	Rectangular ceiling beam
	69	*Abies alba*	Rectangular ceiling beam
	70	*Cupressus sempervirens*	Round ceiling pole
	71	*Abies alba*	Squared ceiling beam
	72	*Juglans regia*	Squared ceiling beam
	73	*Abies alba*	Squared ceiling beam
Suburban baths—hallway N	74–95	*Abies alba*	Plank
	96	*Abies alba*	Squared joist
	97	*Abies alba*	Plank
Suburban baths—*atrium* with *impluvium*	98	*Abies alba*	Window jamb
	99	*Abies alba*	Window sill
	100	*Abies alba*	Door jamb
Suburban bath—*frigidarium*	101	*Abies alba*	Door jamb
	102	*Abies alba*	Door lintel
	103	*Abies alba*	Door jamb
Suburban baths—*tepidarium*	104	cfr. *Picea*/*Larix*	Door rail
	105	*Picea*/*Larix*	Door sunken panel
Suburban baths—*caldarium*	106	*Abies alba*	Window jamb
Antica spiaggia	107–110	*Abies alba*	Squared joist

The numbers (no.) refer to Fig. 4

Table 3 Measurements of a subsample of different timber products from Herculaneum

Element type	Taxon	Width (cm)	Thickness (cm)	Diameter (cm)
36 Squared beams	*Abies alba*	9	9	
		15	9	
		14	7	
		27	12	
		20	13	
		18	13	
		15	14	
		13	13	
		15	15	
		15	13	
		12	11	
		20	12	
		21	15	
		14	14	
		12	9	
		30	18	
		14	9	
		15	13	
		12	7	
		14	13	
		13	12	
		18	14	
		14	13	
		14	13	
		14	12	
		28	14	
		16	13	
		16	13	
		30	14	
		15	12	
		16	14	
		16	15	
		15	14	
		13	10	
		15	12	
		17	12	
1 Squared beam	*Cupressus sempervirens*	13	9	
4 Squared beams	*Picea abies*	15	15	
		18	15	
		20	15	
		17	15	
13 Squared beams	*Picea*/*Larix*	14	9	
		30	15	
		13	10	
		29	13	
		29	13	
		17	14	
		15	15	
		12	11	
		14	9	
		17	13	
		22	13	
		18	14	
		14	14	
46 Squared joists	*Abies alba*	5	4	
		10	10	
		4	3	
		8	4	
		5	4	
		9	8	
		10	5	
		20	14	
		12	11	
		10	9	
		15	13	
		15	11	
		11	8	
		6	4	
		10	6	
		9	8	
		10	7	
		11	9	
		10	9	
		17	14	
		13	12	
		16	15	
		7	6	
		8	6	
		16	11	
		11	6	
		10	7	
		10	10	
		11	7	
		14	13	
		14	12	
		8	7	
		10	8	
		9	7	
		8	4	
		10	10	
		8	6	
		4	3	
		10	8	
		11	8	
		10	7,5	
		11	7	
		14	12	
		10	9	
		16	8	
		15	12	
2 Squared joists	*Castanea sativa*	7	4	
		4	4	
1 Squared joist	*Cupressus sempervirens*	7	4	
1 Squared joist	*Juglans regia*	9	9	
1 Squared joist	*Olea europaea*	11	8	
1 Squared joist	*Picea abies*	9	8	
4 Squared joists	*Picea*/*Larix*	11	6	
		9	9	
		6	4	
		12	8	
1 Squared joist	*Pinus pinea*	10	8	
4 Squared slats	*Abies alba*	5	2	
		4	2	
		5	2	
		6	3	
1 Squared slat	dec. *Quercus*	5	3	
2 Poles	*Abies alba*			12
				10
12 Poles	*Cupressus sempervirens*			18
				6
				8
				10
				10
				6
				13
				8
				10
				13
				12
				10

Table 3 (continued)

Element type	Taxon	Width (cm)	Thickness (cm)	Diameter (cm)
27 Planks	*Abies alba*	11	4	
		13	3	
		8,5	4	
		6	2	
		6,5	2	
		11	3	
		11,5	2	
		10	4	
		16	5	
		12	3	
		10	4	
		9	1,5	
		15	4	
		11	3	
		11	2	
		10	4	
		15	4	
		13	3	
		15	8	
		17	8	
		10	3	
		9	3	
		11	8	
		18	6	
		28	15	
		20	6	
		19	5	
1 Plank	*Fagus sylvatica*	7	5	
1 Plank	*Juglans regia*	18	6	
3 Planks	*Picea abies*	13	6	
		11	4	
		10	5	
4 Planks	*Picea*/*Larix*	13	3	
		14	6	
		9	4	
		15	3	
1 Plank	*Ulmus*	26	4	
2 Tenon fragments	dec. *Quercus*	7	2	
		8	2	

For each timber product, the taxon, the width, the thickness and the diameter are given

Concerning the Vesuvius area, silver fir is found not only in Herculaneum, but also in Oplontis (Moser et al. 2013), at the Augustus Villa in Somma Vesuviana (Allevato et al. 2012) and in Pompeii (Coubray 2013; Veal 2013, 2014) for the Roman Age and in the settlement of Longola–Poggiomarino for the Bronze and Iron Age (Albore Livadie et al. 2012; Heussner 2008). The pollen records suggest a wide presence of this tree in the regional forest vegetation: silver fir is found in Pompeii (Mariotti Lippi and Bellini 2006; Mariotti Lippi and Mori Secci 1997), in Naples (Russo Ermolli et al. 2014) and in the Salerno Bay (Russo Ermolli and Di Pasquale 2002), where it first starts to decline from the Middle Ages. Cones and cone scales of silver fir are also found in the Villa Vesuvio near Scafati in the Pompeian countryside (Ciaraldi 2000). In Herculaneum, silver fir is used for most kinds of structural elements (Fig. 3), less valuable joist and planks included and in many buildings on the site, including houses attributed to the artisanal class in Herculaneum society such as the "Casa a Graticcio" (Mols 1999). Moreover, a pile of planks (almost exclusively silver fir) was found in the suburban bath and was interpreted as firewood for the baths (Pappalardo and Manderscheid 1998). The data presented here make Kuniholm's (2002) hypothesis of a provenance of the silver fir found in Pompeii and Herculaneum from the north-eastern sector of the Alpine region improbable (as already argued in Allevato et al. 2010, Allevato et al. 2012, Moser et al. 2013). Furthermore, a recent dendrochronological analysis carried out in Herculaneum (Camardo et al. 2015; Moser et al. 2012, Seiler et al. 2011) suggests that dendrochronological analysis is not a useful tool to detect the geographical provenance of silver fir in this area of Europe (see also Büngten et al. 2013). In light of all these data, silver fir seems to be a local and, until the Middle Ages, a significantly available timber resource in Campania.

Cypress can also be considered a local tree. This finding is the first proof, in Italy as well as in Western Europe, of a large use of cypress timber for building purposes during the Roman Age. These data are thus very interesting and contrast with the current use of cypress in Italy: in fact, it is nowadays used as an ornamental tree and for reforestation (Pignatti 1982). Cypress is thought to be a native of the eastern Mediterranean, where it forms natural woods (Quézel and Médail 2003; Zohary 1973) and it is considered to have been introduced to Italy by the Etruscans (Pignatti 1982) and to have been appreciated for its ornamental/symbolic value (Meiggs 1982). Cypress gradually became a characteristic element of the Mediterranean landscape (Di Pasquale et al. 2004), especially of Italy. Recent genetic analysis (Bagnoli et al. 2009) has, indeed, demonstrated the current cypress populations in the central Mediterranean being "a mosaic of recently introduced trees and remnants of ancient depauperate populations" present in Italy since the Pliocene. In particular, the southern Italian cypress population is genetically separated from the eastern Mediterranean populations and it can be considered as autochthonous. Reconstructing the history of cypress is particularly complicated, as we can only count on wood and macro-remains, since *C. sempervirens* pollen cannot be identified. Nevertheless, a good number of findings come from the Campanian region: cypress wood used as a well lining was found in the Archaic (sixth–fifth century BC) settlement of Fratte near Salerno (Colaianni et al. 2011). Many are the findings of cypress cones or cone scales in the Vesuvius area dated to the Roman Age (Ciaraldi 2000; Matterne and Derreumaux 2008; Robinson 2002). The strong presence of cypress timber in Herculaneum, as well as in Oplontis (Moser et al. 2013) and in shipwrecks found along the Tyrrenian coast of Italy (Allevato et al. 2010; Giachi et al. 2003; Sadori et al. 2015), indicates that Romans knew and appreciated its timber. Furthermore, the discovery of a large area with alignments of cypresses in pre-AD 79 eruption soils near Pompeii (Ruggiero 1879 and, more recently, Ciarallo 1990) indicates that this tree was cultivated during the Roman Imperial Age. In fact, Latin literary sources such as Pliny the Elder (*Naturalis Historia*, *XVI*, 60, 141: Bostock and Riley 1855) say that cypress was cultivated in plantation by the Romans. In addition, considering the autochthony of cypress in southern Italy (Bagnoli et al. 2009), we can perhaps bring into question the traditional idea of cypress being an exclusively cultivated tree in Italy (e.g. Pignatti 1982) and hypothesise the presence of both natural and cultivated stands of cypress in the forest landscape of Campania at least in the Roman Age.

Noteworthy is also the presence of chestnut. Chestnut is now abundantly present in the hinterland forests nearby to the investigated area, particularly on the northern slope of Mount Somma-Vesuvius, on the Lattari Mountains, on Mount Epomeo on the island of Ischia and on the hillsides of the city of Naples (Di Pasquale et al. 2010). Despite the strong role of chestnut in European forests and culture (Conedera et al. 2004), until recently, very little has been known about the history of this tree. It was generally accepted that Romans promoted its usage for fruit and its diffusion on a European scale (e.g. Pignatti 1982; Quézel and Médail 2003; Zohary and Hopf 2000), despite direct archaeobotanical evidence is missing (see Allevato et al. 2016 and references therein). Concerning Italy, chestnut pollen starts to be continuously present in the pollen spectra from the Bronze Age onwards (Mercuri et al. 2013). Nevertheless, recent studies (Buonincontri et al. 2015; Di Pasquale et al. 2014b) suggest that, at least in central Italy, the real massive diffusion of chestnut cultivation for fruit production on a landscape scale started first during the Late Middle Ages. In the Roman Age, the available data indicate that chestnut was present on the Italian peninsula, but its use was not widespread (Allevato et al. 2016 and references therein, Conedera et al. 2004). Archaeobotanical data seem to indicate, instead, a larger presence of this tree in the Vesuvius area. For the Imperial Roman Age, chestnut timber was found at Pompeii and at Boscoreale (Borgongino 2006) and, in Pompeii, it was used as fuel for funerary pyres (Coubray 2013). Several chestnut fruit shells come from the sediments of the Roman harbour of Naples, dated from the first century BC to the fifth century AD and interpreted by the authors as part of the food stock of the galleys or part of the dockworkers' diet (Allevato et al. 2016). In the other archaeological sites in the Vesuvius area, instead, findings of chestnut fruits are quite rare (Borgongino 2006; Meyer 1989). Later, chestnut was found and used as timber and as firewood, in two sites located at the northern foothills of Mount Somma-Vesuvius dated to the second to fifth century AD (Allevato et al. 2012; Di Pasquale et al. 2010), constituting the most employed timber at one of the sites. The data seem, indeed, to suggest that at least from the first century BC, chestnut was present in the Vesuvius area. The findings of its timber at Herculaneum confirm that the Romans used chestnut for its timber, while probably, the fruits were destined to the diet of the low social classes (Allevato et al. 2016).

Deciduous oak timber is also present in Herculaneum albeit with a low percentage. Despite this, it is known that deciduous oak (mainly *Q. pubescens* and *Quercus cerris*; Quézel and Médail 2003) was, like today, the main component of the regional forests during the Roman period, being the dominant taxon in all of the available pollen records (Russo Ermolli and Di Pasquale 2002; Russo Ermolli et al. 2014). Wood and charcoal data support this picture: deciduous oak timber is largely present in the Bronze-Iron Age settlement of Longola–Poggiomarino, where it constitutes the most employed taxon for building (Albore Livadie et al. 2012; Heussner 2008). For the Roman period, deciduous oak is largely used in shipbuilding (Allevato et al. 2010 and references therein), although it was also used for a cradle in Herculaneum (Mols 1999) and as firewood in Pompeii (Coubray 2013; Veal 2013, 2014). Its scarcity as building material in Herculaneum is probably due to a different use of this tree, as we will discuss in "Selection criteria in choosing timber for building" section.

Common beech and elm are also part of the local vegetation. Elm (most probably, *Ulmus minor*; Pignatti 1982) grows mainly along the rivers and in correspondence with moist areas. Its scarcity among the building materials used in Herculaneum does not surprise since it was probably destined to other uses (see "Selection criteria in choosing timber for building" section). Noteworthy, despite its low percentage is the finding of beech. Now, beech is an important element of mountain forests across the Alps and on the Apennines up to Sicily (Pignatti 1982). Today, the population nearest to the site grows on the Lattari Mounts south of Herculaneum, but several data in Italy (Bellini et al. 2009; Bertacchi et al. 2008; Colombaroli et al. 2007; Mariotti Lippi et al. 2007; Russo Ermolli and Di Pasquale 2002; discussion in Sadori et al. 2015) and in southern France (Chabal 1997; Delhon and Thiébault 2005; Figueiral et al. 2012) suggest that, in the past, it grew at lower altitudes than today (see also Pignatti 1982) in mixed deciduous forests. In the Vesuvius area, beech was found in Pompeii, where it represents the main source of fuel (Castelletti 1984; Veal 2013, 2014), this fact suggesting its large presence in the surrounding forests.

Further trees representing the local/regional landscape also include walnut, olive tree and stone pine, all typical elements of the Italian cultural landscape. Walnut grows wild in temperate deciduous forests of the Balkans, northern Turkey, the southern Caspian region and the Caucasus and in Central Asia (Zohary and Hopf 2000). Thanks to its cultivation, it is widespread in a wide area spanning from south-eastern Europe to China and the Himalayas (Aradhya et al. 2007). Still not completely understood are domestication and the patterns of diffusion (Zohary and Hopf 2000). In central and southern Italy, walnut pollen starts to be frequently present in pollen records between 3400 BP and 2000 BP, according to regional studies (Mercuri et al. 2013), but a wider distribution seems to be correlated in southern Italy to the Greek colonisation during the eighth century BC (Ravazzi et al. 2013). Concerning ancient Campania, archaeobotanical data testify to the cultivation of walnut at least since the third century BC (Amato et al. 2009). Walnut fruits are also found in Herculaneum, Oplontis and Pompeii (e.g. Borgongino 2006; Ciaraldi 2007; Meyer 1989; Murphy et al. 2013; Robinson 2002) as well as charcoal (Coubray 2013; Jashemski et al. 2002; Veal 2013, 2014) and pollen (Dimbleby 2002). In the Vesuvius area, walnut timber was also found in two villas northwards to the volcano (Allevato et al. 2012) and it was employed for shipbuilding as well (Allevato et al. 2010).

The presence of a squared joist of olive tree in Herculaneum also confirms that olive was used for timber as already documented in shipbuilding (Allevato et al. 2010). At this time in ancient Campania, olive cultivation was probably limited to small-sized oil and table olive production destined for the local market (Arthur 1991).

Stone pine is also represented by a single element in the building material of Herculaneum, namely a squared joist. It is very difficult to trace the history of this tree and to disentangle whether it is spontaneous or cultivated in the western Mediterranean basin (Quézel and Médail 2003). In Italy, botanists hypothesise that stone pine was probably introduced by the Etruscans and widely used for its fruits (Pignatti 1982; Quézel and Médail 2003) and for ornamental purposes (Meiggs 1982). Despite its low presence in Herculaneum, the use of stone pine is attested in the Vesuvius area as building material (Allevato et al. 2012) and as timber for shipbuilding (Allevato et al. 2010), and above all, the cones and seeds of stone pine are found in both Pompeii and Herculaneum (Ciaraldi 2007; Jashemski et al. 2002; Murphy et al. 2013) and in the *Neapolis* harbour sediments (Allevato et al. 2016). Stone pine charcoal was also found in the garden of the Villa Regina at Boscoreale in the Pompeian countryside (Jashemski 1994) and possibly as wood for funerary pyre in Pompeii (Coubray 2013). All these data strongly suggest the presence of stone pine in the Naples landscape and indicate that stone pine was used both for its fruits/seeds and for its timber.

Only a single piece of *Pinus* group *sylvestris* is present in the record, indicating its marginal role as timber for building in Herculaneum. Other findings of this taxon come from Oplontis (Moser et al. 2013), Pompeii (Castelletti 1984; Veal 2014) and Murecine (Gallo 2000), but they are restricted to a few pieces at all sites.

Timber trade from far regions

Norway spruce and Norway spruce/European larch samples cannot be ascribed to the vegetation of both the ancient Campania and southern Italy (Quézel and Médail 2003; Ravazzi 2002). In fact, Norway spruce and European larch are common on the Alps. In Italy, the first grows between 800 and 2300 m a.s.l., with a relict population also in the northern Apennines, whereas European larch is present only on the Alps above 1800 m a.s.l. (Pignatti 1982). Pollen data also confirm this distribution range for the whole Holocene (e.g. Ravazzi 2002; Vescovi et al. 2010). These data confirm the use of imported timber in the Vesuvius area during Roman times, as already indicated by the wooden remains of the Villa of Poppaea at Oplontis (Moser et al. 2013). The finding of Norway spruce timber in southern Italy is not very common: the sparse evidence comes from shipwrecks found in the Neapolis harbour (Allevato et al. 2010), from Pantelleria (Marchesini et al. 2009) and from Oplontis, where, however, only one beam was found. The finding of European larch is even rarer, being attested only in Herculaneum (Fioravanti and Caramiello 1999). Against this background, the higher number of these woods at Herculaneum strengthens the idea of a Roman timber trade for building purposes. The importation of European larch from the Alpine region to Rome and to Ravenna is also attested in the Latin literary sources (Pliny, *Naturalis Historia* 16, 190: Bostock and Riley 1855; Vitruvius, *De Architectura* 2, 9, 16: Rowland 1999). Lastly, we cannot exclude that together with Norway spruce and European larch, some of the silver fir timber may have had the same origin. The application of isotope analysis, in particular that of strontium stable isotopes (English et al. 2001), may assist disentangling the question in the future.

Selection criteria in choosing timber for building

The study of these building timbers allows us to advance some hypotheses about the criteria that the Romans followed when selecting wood for building.

It is noteworthy to underline that conifer timber was decisively preferred for building during the Roman period in Campania: silver fir and cypress alone represent almost 80 % of the employed timber and the conifers together reach 90 % (Fig. 2). This systematic use, documented also in shipbuilding (Allevato et al. 2010), suggests that these trees were abundantly present in the woodland vegetation during the Roman period.

Notably, the use of local broadleaves taxa is only occasional.

One of the criteria followed in selecting the taxa for building purposes seems to be the availability of the trees in the neighbouring forests. This is clearly visible for silver fir, which is used for all the types of analysed elements (Fig. 3) and in contexts not really favourable to its good preservation: silver fir is employed for window and door frames, despite its relatively high perishability if used outdoor (Giordano 1981). On the other hand, silver fir and Norway spruce are mainly used in Herculaneum for the production of squared beams and planks (Fig. 3), thus indicating that the Romans were aware of the technological properties of these woods. Their straight growth manner and their height (up to 50 m; Bernetti 2005), together with their relatively fast growth rate, make them suitable for big timber products. Moreover, these timbers can be easily cut with a saw (Giordano 1981) and are thus very useful for the production of planks.

The selective use of cypress for the production of poles (Fig. 3) is interesting. They mainly consist of elements with a diameter less than 13 cm, obtained directly from roundwood without specific manufacturing of the surface. Poles are probably obtained from cypress branches: old-aged trees, in fact, exhibit a significant number of sub-vertical branches that can be profitably used for small- to medium-sized poles (Fig. 5).

This evidence confirms the words of Pliny the Elder (*Naturalis Historia* 16, 60, 141: Bostock and Riley 1855) when he states that cypresses "are permitted to thrown out their branches, which are cut and employed for poles and props, being worth, after thirteen years' growth, a denarius a piece". A cypress pole was also found in the Pompeian countryside and interpreted as a grapevine prop (De Carolis et al. 2012). Romans largely employed cypress for pole production probably because they knew its technological properties, especially the high durability in every kind of environment and the high resistance to fungi and insects (Nardi Berti 2006). This use is nowadays missing, perhaps due to the almost complete extinction of natural cypresses from the Italian forests.

For deciduous oak, elm, beech, walnut, stone pine and olive, we can hypothesise that they were preferably used for other purposes than building. The limited use of oak timber could be explained by its large use in shipbuilding (Allevato et al. 2010). Moreover, the fruits of oak, namely acorns, were a primary source of food for animal husbandry, in particular pigs (MacKinnon 2001); for this reason, it might be that the oak forest was protected and the use of oak timber limited. Elm too was largely employed for the production of animal fodder, as attested in numerous Latin sources (e.g. Columella, *Res Rustica VI*, 3.6: Forster and Heffner 1954). Moreover, its timber is of low quality and quite perishable. The low percentage of beech timber is in agreement with its technological properties: its tendency to break and bend makes it not very suitable for timber production (Nardi Berti 2006). However, it is well known that beech is excellent for firewood and charcoal production (Nardi Berti 2006) and the Romans were surely aware of it (Veal 2013, 2014). This use of beech wood suggests that beech forests were mainly managed as coppice (see also Coubray 2013; Visser 2010), as it is also today in the Apennines (Bernetti 1995; Ciancio and Nocentini 2004), thus preventing the production of big-sized timber pieces.

Since the findings of walnut in archaeological contexts consist mainly in its nuts, in archaeobotanical studies, walnut is especially considered for its fruit (Zohary and Hopf 2000), particularly in regard to the Roman Age (Gale and Cutler 2000). However, the data available for ancient Campania (see "Local timber: forest cover in the Vesuvius area and in ancient Campania" section) clearly show that Romans were aware of the technological and aesthetic properties of its timber, which is highly valuable, hard and durable and can be easily bent (Nardi Berti 2006). Walnut, for example, is the most used taxon among the building material identified at the Roman

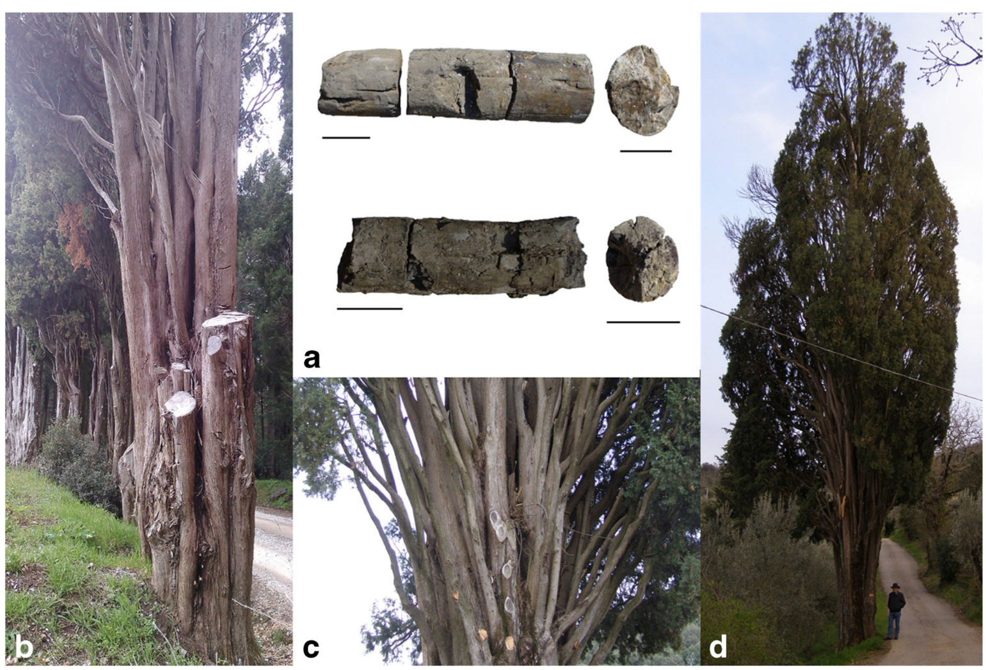

Fig. 5 **a** Charred cypress poles stored at the Casa di Granianus. The *line* indicates a measure of 10 cm. **b**–**d** Examples of centuries-old cypresses growing in central Italy (Chianti region, Tuscany) with a detailed view of the branches. Pictures by D. Moser

site of Gabia in southern Spain (Rodríguez-Ariza and Montes Moya 2010). Moreover, its attractive burls made it in ancient times, as today, an appreciated timber for furniture production (Fioravanti and Caramiello 1999), e.g. the table top of the "Casa del Mobilio Carbonizzato" in Herculaneum (Mols 1999, 2002).

The straightness of the trunk of stone pine and its light and elastic timber (Nardi Berti 2006) would also have made it a useful timber for building, even if of inferior quality with respect to other pines such as *Pinus pinaster* or *Pinus sylvestris* (Nardi Berti 2006). Nevertheless, the use of stone pine for the production of pine nuts probably made it of secondary importance for timber. The production of fruit was the main aim of olive cultivation; thus, its low presence as building material in Herculaneum is unsurprising. The Romans did use olive pruning remains for the production of treenails (Allevato et al. 2010) or as firewood (Allevato et al. 2012). Noteworthy is also the use of olive timber for the construction of a fish basket found in the Casa del Garum at Pompeii (Di Pasquale et al. in press), this use still being widespread among the fishermen of the Sorrentine peninsula.

Conclusions

The study of the wooden material from Herculaneum provided a unique opportunity to investigate the use of timber for building during the Roman period in a central area of the Roman Empire and to gain information about the Roman timber economy during the first century AD. The preservation of near complete building elements has also provided us with the opportunity to discern the utilisation of specific trees for the production of different timber products. Our data also shed more light on the landscape of ancient Campania. In summary, we conclude the following:

- Coniferous wood was by far the preferred timber for building purposes.
- Silver fir is the preferred tree, suggesting a conspicuous presence of this tree in the surrounding forests during the first century AD. The large use of silver fir for building confirms that the Late Holocene decline of this tree is most probably due to human exploitation.
- Cypress was probably selectively used for the production of poles. Data seem to indicate that it was present as a natural tree in the local vegetation, suggesting a forest type that almost completely disappeared from Italy. Cypress was also certainly cultivated for timber production near Pompeii.
- Very available forest trees, such as deciduous oak and beech, were scarcely used for building timber, suggesting a different management for other products or a strategy in the Vesuvius area that is very particular.
- Chestnut timber is not especially employed, even if data seem to indicate that it was growing on the northern slope of Mt. Vesuvius, where it was largely used in building. We hypothesise that its timber was used if available in the close surroundings, but it was not particularly sought after.
- The identification of walnut, olive and stone pine confirms their cultivation in the Vesuvius area—and not only for fruit/nut production.
- The trade of timber from forests further afield was probably limited; our data, however, indicate probable timber routes between ancient Campania and both the northern Apennines and the Alps.

The incredibly good preservation of charcoal and wood material in Herculaneum makes it an outstanding case study. Thus, we clearly see the need for future deeper and multidisciplinary studies to arrive at a sounder understanding of timber use in Roman building technology. Some of the data acquired through this study might not have only local significance but represent specific peculiarities of the technological knowledge of the Roman civilisation: the extension of building timber analysis to other Roman contexts would be very useful to clarify this question.

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