VIII

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THE POLITICS AND ECONOMICS OF ANCIENT FORESTS

TIMBER AND FUEL AS LEVERS OF GRECO-ROMAN CONTROL*

1. Introduction

Forest resources constituted a key ancient economic good. Access to forest resources was therefore of importance to various agents: regionally, at a polity level, and to individuals, rich and poor. A range of environmental, economic, and social factors influenced forest access. Ancient forests were important for the provision of wood products (timber and fuel), and non-wood products (including foodstuffs, leisure, water supply). Of these, timber and fuel were the most important economic goods. Wood could be sourced privately, but substantial forests and woodlands were state controlled. Raw wood or charcoal fuel

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were required domestically in every home, rich or poor, for cooking and heating, and especially in industries such as metal smelting and smithing; ceramics, lime and glass production; and fuelling the baths. Wood was the most important fuel in the Greco-Roman world, although non-wood fuels also played a part.[1] Together with stone and cement, wood was an essential construction material. Its abundance, or lack, could materially affect a state's ability to wage war and carry out trade. R. Meiggs' important contribution collated the ancient historical sources relating to wood, especially its use as timber, and he incorporated archaeological evidence where it was available.[2] This discussion seeks now to highlight new archaeological and scientific data, and nuance our understanding of inequalities of demand and supply of this important ancient commodity.

1.1. *Ancient forest economics: research to date*

A number of other publications (besides Meiggs) have sought to examine the environment in the classical period, although no other book has specifically examined ancient forests, let alone their economics.[3] Elsewhere I have estimated that fuel may have constituted perhaps 20% or more of the ancient Roman Gross Domestic Product (GDP).[4] Given the paucity of modern studies on ancient fuel economics at this time, it is instructive to review the classes of economic resources of modern forests,

[1] HUMPHREY / OLESON / SHERWOOD (1998) 43-44: historical references to petroleum products. Other non-wood products included animal dung and bones, agricultural plant residues, especially olive lees. See COUBRAY / ZECH-MATTERNE / MONTEIX (forthcoming); ROWAN (2015).

[2] MEIGGS (1982).

[3] HARRIS (2013b) provides a range of chapters that analyse many types of environmental data, offering a significant advance on studies mostly limited to the historical sources, such as THOMMEN (2012). DIOSONO (2008a), (2008b) focuses on wood, and combines historical and archaeological sources, but does not address economics to any great degree.

[4] VEAL (2013) 38-40.

and consider their equivalents in the ancient world. These are grouped broadly as:

a) wood products: timber, raw wood fuel, charcoal fuel;
b) non-wood products: water, leisure pursuits, foods/medicines.[5]

Our discussion here will be limited to wood products. However, non-wood forest products, (NWFPs), are not insignificant economic entities. Modern sources list very similar products to those we hear about in the ancient sources, such as: honey, fungi, berries, fruits, flowers, resins, textile plants, tubers, leaves, and bark. However, we are still at the beginning of a full appreciation of these products, (and we rarely refer to them in economic terms). In modern developing countries that are still wood dependent (such as many African countries), the value of non-wood forest products is at least 30% of the total value of forest outputs.[6] The wood types typically employed as timber or fuel are listed in the historical sources (although there are fewer mentions of fuel). In many cases, actual use corresponds with the technical performance characteristics of different wood types, (as perceived in both ancient and modern times), and agree with recommendations made by the ancient authors (especially Theophrastus and Vitruvius).[7] In some cases, especially with regard to fuel, the sources are sparse, or occasionally even contradictory, and archaeology and new scientific methods may assist us. An essential part of Meiggs' contribution has been a detailed analysis of ancient identifications of wood types for various uses, their clarity and veracity (in many cases), confusion (in others), and poor translation (for example, by Pliny the Elder, translating Theophrastus).[8] Pliny in particular mistranslates *phegos* (Greek for oak), into *Fagus* (Latin for beech). Identification issues are also problematic for the conifers which are harder to

[5] See for example, FOOD AND AGRICULTURE ORGANISATION (2003); (2013); (2016a).
[6] FOOD AND AGRICULTURE ORGANISATION (2016b).
[7] THEOPHR. *Hist. pl.*; VITR. *De arch.* (esp. Books 2 and 5).
[8] MEIGGS (1982) 410-422.

differentiate, as their cellular structures and external appearances are often close. Occasionally Theophrastus will describe different tree types (due to his observing different growth habits in different regions), while modern wood anatomists believe these may be the same species, but perhaps different sub-species. Equally, very similarly looking (but taxonomically different) woods may be listed as growing at a high altitude (in Greece), as well as on the plain (for example, beech which grew in limited mountainous areas but could not have grown extensively on the plain due to soil and climate requirements, at least in the period under consideration).[9] Mentions in the historical sources have tended to provide information on a few important wood types used in large structures.[10]

1.2. *Wood in the archaeological record*

Wood is preserved in the archaeological record in a number of ways including: dessicated, (especially in Egypt), frozen, mineralized, waterlogged, and charred.[11] Of these preservation methods, archaeological wood remains most commonly recovered are charred or waterlogged. In fact, in terms of plant use and management, archaeology provides us with four types of data: seeds, (and occasionally other macrobotanical remains, such as leaves, and nutshells); charcoal; pollen; and phytoliths. The first two are examined as macro-remains (roughly >2mm in size). The latter two are examined after extensive chemical preparation and mounting on slides.[12] These different types of

[9] Local pollen studies help us to view the tree types present in ancient Greece, see, e.g., GREIG / TURNER (1974).

[10] The Cedars of Lebanon figure strongly in the most important mentions that include, e.g. the Temple of Solomon, the coffered ceiling of the Temple of Baalbek, the roof beams of the Temple of Artemis (still reportedly intact after 400 years): MEIGGS (1982) 49-87.

[11] See ANTICO GALLINA (2011), and also ASOUTI (2004).

[12] Phytoliths are the silicaceous end remains of the breakdown of plants. Their forms (transparent geometric shapes) rarely allow specific identification of one species, (in comparison to pollen, charcoal, and seeds/nuts).

archaeobotanical materials are preserved to different degrees, and may provide differing and complementary information. For example, pollen studies will evidence lower plant types and higher plant types, while charcoal will usually show only woody (higher) plant types. Some plants will be observed in one material type (or even over-represented, such as pine pollen), and not show up at all in another. Many trees produce remains of all four types.

2. Environmental and human influences on wood resources

The influence of the environment on wood resources cannot be understated. The pejorative reputation of 'environmental determinism' has led to a poor recognition of the controlling aspects of local geological and climatic conditions in determining what wood resources could potentially grow in different parts of the ancient world. A more useful (and accurate) phrase is 'environmental possibilism'. This term, borrowed from geography allows the initial environmental constraints to be seen as a backdrop to potential human choices of adaptation. However, if an area is poorly wooded, then human interference is often presumed to be the reason. Close reading of pollen studies of the Greco-Roman period show no real overall large deforestation patterns (until the Mediaeval period), however, over-exploitation in a localized sense occurred, especially where the Romans were exploiting iron ore for smelting.[13]

Greece has many different micro-climates and geological formations. In parts of Greece, good conditions for agriculture and arboriculture existed and were contested and protected (e.g.

[13] On deforestation generally see Harris (2013a). A well-known example of deforestation is the island of Elba, which was heavily mined for iron ore, starting with the Etruscans. By *c.* the 3rd century BC, ore was being shipped to the mainland to be smelted in Populonia because woodland on Elba was exhausted: Di Pasquale *et al.* (2014).

the “borderlands” of S. Fachard — see this volume). In other places, natural conditions of poor soils and low rainfall meant that growth of large tree types was not (and is not), supported to any great extent, except in mountainous areas. Fig. 1 shows rainfall for modern Greece. Orography of Greece inhibits penetration of rainfall from the coast to the centre. Note low rainfall in Attica.

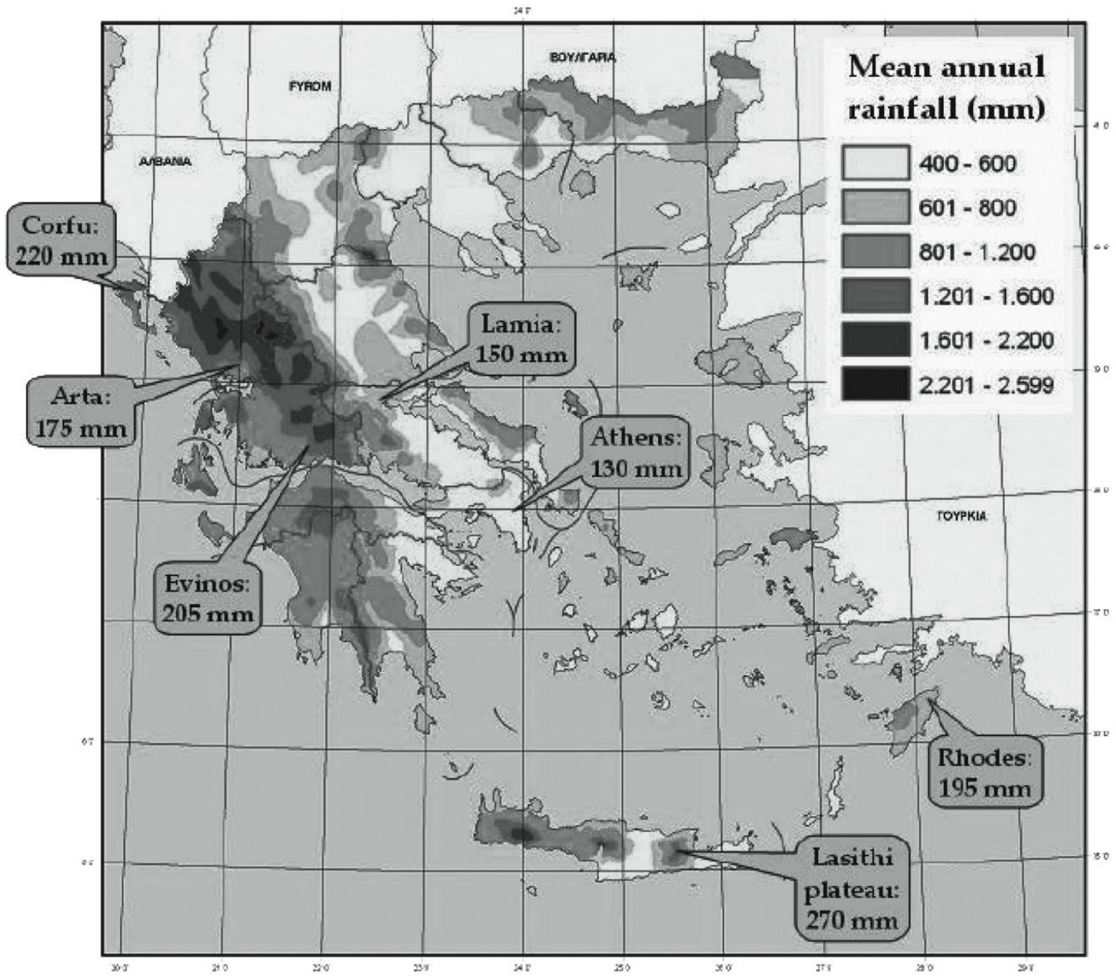

Fig. 1 – Greece (modern) rainfall (climate roughly the same as the ancient period).
Map by kind permission of Yannis Markonis, accessible at https://www.researchgate.net/publication/282733213_Floods_in_Greece/figures?lo=1

Evidence suggests climate today is not too different from that of the ancient period. These low figures (100-200mm p.a.) may be compared with Italy where the west coast has about 850mm p.a. (ranging up to 1250mm in the Apennines). This does not mean Greece had 'no trees', but rather, she had limited wood stocks, especially those that could provide long timbers. This is also true of Egypt. The optimal fertility and climate of much of Italy meant the opposite was (and still is) true. The complex interaction of humans and the environment meant trees in fertile areas were cleared for agriculture, and some laws provided incentives for this. If famine, disease or war led to abandonment of farms, deciduous and some evergreen forest trees would quickly grow back autonomously, although not in their original ratios of wood types. Few conifers grow back without reseeding. However, slow growers will be outcompeted by fast growers, and sun/heat tolerant species will tend to establish first in the Mediterranean belt.[14] Thus, by having knowledge of both ecological succession, and those main types of trees that were good colonizers, it is possible to combine co-located and co-eval archaeological charcoal and pollen studies to test for tree cover changes. Inspection of tree ring counts and curvatures in recovered charcoal fragments can provide information about cropping strategies. High curvatures indicate the use of small wood (usually a sustainable strategy for fuel provision), while flat rings usually indicate the use of wood of a diameter of perhaps 50cm or more.[15]

Complete deforestation was rare, although tree removal on a large-scale (when it occurred), led to top-soil loss. By the Roman period this was quite well recognized, and the data to date suggests more careful husbanding of top-soils in the Roman period in Italy, but perhaps less regard for its preservation in the provinces, where over-exploitation of different landscape types appears more often recorded, although it would be unwise to suggest the evidence is conclusive at this point. Longer-term

[14] SMITH *et al.* ([9]1997) 161-194, esp. 174-175.
[15] VEAL (2012).

multi-proxy studies show that patterns of human movement/ migration were preceded by climate change in the Classical to Late Antique periods.[16] The millennium of Roman rule shows a more stable climate than periods on either side. This period of stability allowed more marginal agricultural areas to be farmed, and was in part key to Rome's successful rule.[17] The very latest research in this area suggests climate changes in the last 2,500 years are strongly correlated with volcanic forcing.[18] Pollen, archaeological charcoal studies, and studies of ancient wood technology, can together reveal use of 'old wood,' as opposed to young, more quickly grown wood, and signal the exhaustion of 'old wood' supplies whilst not necessarily signifying deforestation. Such evidence is clearly seen in Roman Londinium, where large construction timbers thought to be from 'old growth timbers' (i.e. tall, large diameter slow grown wood), are observed in the period after the Boudican revolt (AD 60/61). In later centuries, old wood disappears from the archaeological record.[19] Fuel supplies, conversely, had to be sustainable in most places in the long run, or else people would be unable to cook their food or heat their homes, much less fuel their industries.

3. Wood for exercising state and regional power

3.1. *Shipbuilding, war and trade: the historical evidence*

At the highest level of political control, accessing the resources essential to winning wars was a primary goal in the ancient

[16] BÜNTGEN *et al.* (2011); MCCORMICK *et al.* (2012): pollen and other climate proxies, (including historical sources).

[17] Roman North Africa (after Carthage's destruction 146BC), and Egypt (after Actium, 31BC), provided Rome with much grain. Rain was harvested, and stored, using *foggara* technology, until the hyper-arid conditions of the AD 5th century arrived, see, e.g. WILSON (2009).

[18] SIGL *et al.* (2015). Volcanic forcing of climate occurs when stratospheric debris from a volcanic eruption spreads over a sufficient area to weaken sunlight penetration to the Earth's surface, causing temporary local cooling, thus reducing agricultural returns.

[19] BLAIR *et al.* (2006).

Mediterranean. This meant access to wood for shipbuilding, as well as for building war machines. Ships provided the means to protect and/or expand a state's interests and enabled trade, enriching the participants and further permitting ongoing control of critical resources. The ancient historical sources, especially relating to timber used in Greek shipbuilding, have been well analyzed by R. Meiggs.[20] He notes that Greece did not have trouble gaining access to wood, however most of Greece's wood supply for ships arose from access to foreign sources. A lot came from Macedonia. Later studies, such as that of S. Psoma,[21] analyze new data such as the presence of coinage as a proxy for wood supply to Athens. This supply was regularly interrupted by wars and changes of allegiance.[22] These interruptions meant that Macedonia was by no means the only supply area, and a range of evidence suggests Rhodes, Byblos, and especially Cilicia, were of importance. Psoma also finds that shipyards were co-located with wood sources occasionally, so the Athenians did not always import timber and construct their own ships, but sometimes out-sourced full construction. Timber was Athens' primary import (along with grain), and her political efforts often revolved around maintaining access to wood. Athens' pattern of critical dependence on large timber for survival mirrored that of the Egyptians beforehand. We hear less about the issues of access to, and control of wood resources for other Greek states, but they must have experienced similar challenges. A further critical resource in shipbuilding was pitch. This was made by distilling the organic volatiles of conifers, (and in particular, pines), sometimes as a by-product of making charcoal. Some forests were expressly grown for the purpose of producing resin (tapped directly from the tree and used for many purposes, as well as pitch manufacture).[23] Written evidence suggests that the

[20] MEIGGS (1982) 116-153.

[21] PSOMA (2015): Athens and its consumption of timber for shipbuilding from ca. 500 BC to the rise of Alexander III.

[22] Historical data for Greece is substantially limited to Classical Athens.

[23] MEIGGS (1982) 467-471; TRINTIGNAC (2003). I thank Sylvian Fachard for bringing the latter to my attention.

Egyptian wood supply for shipbuilding was provided by access to the Cedars of Lebanon through Byblos, although archaeological evidence for Egyptian use of cedar is predominantly limited to sarcophagi.[24] It was possible to build ships of large size and durability, due to the long, straight nature of the cedar as well as its resistance to decay.[25] Production of large fluvial boats to move cargoes down the Nile was the primary use of the timber, and it reached its height in the Bronze Age under Hatshepsut (1507-1458 BC), to carry obelisks downriver. Later, a re-equipping of the navy under Thutmose III (1479–1425 BC) saw cedar used not only for ships' frames, but also for deck beams, masts and oars, at least as recorded historically.[26]

For the Romans, timber supply was less of a problem. In the Republican period, local woods provided timber for shipbuilding and construction of large public buildings, although for warships the Romans are not attested as having a need until 311 BC (the beginning of the Punic wars). Ships and boats for coastal and fluvial inter- and intra-regional trade were built before this date, of course, as well as those destined to ply the ports of the Mediterranean.[27] Preliminary work on charcoal data from the Palatine (*c.* 4th century BC), suggests access to forests nearby.[28] Specific calls for the cutting down of forests for shipbuilding contained in the sources[29] have contributed in part to an assumption of 'deforestation' by the Romans, even of Italy, but these mentions are single anecdotes, and should not be overemphasized in terms of Italy's overall wood carrying capacity and population. Of course, as the empire grew and technological advances were made (especially in metal working), pressure on resources, especially wood resources, increased. This pressure was acute close to the largest

[24] MEIGGS (1982) 292-293 (ships), 293 (sarcophagi), and 154-187 (armies).

[25] MEIGGS (1982) 55; HEPPER (2001). The Egyptians preferred cedar to fir.

[26] GABRIEL (2009).

[27] MEIGGS (1980) 186. As he notes, THEOPHR. *Hist. pl.* 5, 8, 2 attests to the great supply of timber available at that time, and historically, in Latium.

[28] The author thanks Prof'ssa C. Pannella, (La Sapienza), for the invitation to examine these charcoals. Work is ongoing.

[29] For example: the building of the navy to confront the Carthaginians in the First Punic war (POLYB. 1, 20).

cities, especially Rome. Access to pristine conifer forests suitable for shipbuilding became more difficult in the Imperial period. Hadrian claimed the diminishing forests of the Cedars of Lebanon as Imperial property, temporarily slowing their consumption.[30]

3.2. *Archaeological evidence for shipbuilding*

Detailed archaeological evidence for Greek shipbuilding is scant in terms of wood analysis. While we have cargoes, and partially examined wrecks, the wood has not survived, or has not been analyzed very often. The Antikythera wreck (*c.* 1st century BC), had some hull planks of elm (*Ulmus* sp.), but a full study is yet to be undertaken.[31] Other data include: a small ancient Greek wreck (5th century BC) which provides us with trace hull planking of *Pinus nigra* (black pine).[32] An Israeli wreck dated AD mid 7th-8th century was made of *Pinus brutia* (another mountain pine), and tamarisk (*Tamarix* sp.).[33] A new survey in the Fournoi Archipelago (Greece) in 2015/2016 discovered 45 ancient wrecks of various ages. The survey to date has covered 15% of the area, and will continue until 2018.[34] We have cargoes of Mycenaean and Minoan wrecks, but no wood. We have no Greek triremes. Eight Byzantine wrecks (the Yenakapi wrecks), of 37 recently discovered in the area of the Theodosian Harbour, used mostly pine (*Pinus* spp.) and deciduous oaks (*Quercus* spp.), with a small quantity of plane (*Platanus orientalis*).[35]

[30] He ordered the forest be marked by inscribed boundary stones, two of which are in the museum of the American University of Beirut. Supplies were still healthy in the time of Justinian: De Giorgi (2016) 99-100.

[31] <http://www.namuseum.gr/object-month/2012/may/may12-en.html>; elm is a less preferred ship timber.

[32] Carlson (2003). Gambin (2010), also describes a Phoenician merchant vessel discovered off Gozo, Malta, dated to the 7th century BC. The wood report is not published.

[33] Polzer (2009).

[34] <http://www.ibtimes.co.uk/graveyard-ancient-greek-shipwrecks-discovered-aegean-sea-1570451>.

[35] Pulak / Ingram / Jones (2015).

In Italy wreck information is more available. One early maritime excavation (1970, off Marsala), found a vessel interpreted as a Punic warship, although no woods have yet been brought to the surface.[36] A further Punic vessel, a merchant ship, provides more data. Of the timbers that survived and were sampled, woods identified include: maple (*Acer* spp.) — floor timber and keel/sternpost; oak (*Quercus* spp.) — frame, tenons and dowels; and pine (cf. *Pinus sylvestris/nigra*, i.e. mountain pine) — planking. Small shavings and chips of other woods, thought to be carpenters' waste were also found including "a soft wood, probably cedar (*Cedrus* sp.), pistachio (*Pistacia* sp., probably *P. lentiscus*), beech (*Fagus sylvatica*)", and more oak and maple. The author infers that these arose from the building of the supraframe structures.[37] In more recent excavations under the harbor of Naples, several small coastal cargo transport vessels (AD 1st - 3rd centuries) have been examined in detail, and a synthetic article combines these results with those from the harbours of Pisa, and Rome (Portus).[38] A wide range of timbers (around 15 wood types, some identified only by genus), were found with silver fir (*Abies alba*), commonly used in planking, and cypress (*Cupressus sempervirens*), also serving in this capacity (and especially as repair planks). Oaks (both deciduous and evergreen — *Quercus* spp.) were used commonly in planking and frames. Minor quantities of strawberry tree (*Arbutus unedo*), olive, (*Olea europaea*), walnut (*Juglans regia*); and *Rhamnus/Phillyrea* (two woods which are difficult to distinguish from one another), were all found used as wooden nails. Over half of

[36] Frost (1973) 40-41.

[37] Barkai / Kahanov (2016).

[38] Allevato / Russo Ermolli / Di Pasquale (2009); Sadori *et al.* (2014). The former describes the ships found in the Naples Harbour AD 1st-3rd centuries. The latter overviews all archaeobotanical data for Roman shipwrecks found in Pisa, Portus and Naples to date. Wood types that Pisa and Portus add to the list include: ash (*Fraxinus ornus*), alder (*Alnus* cf. *glutinosa*), fig (*Ficus carica*), poplar (*Populus* sp.), willow (*Salix* sp.) and beech (*Fagus sylvatica*). These appear to have been used sporadically in supra-frame architectural elements and/or ship furniture.

the wood types were conifers. Theophrastus recommends fir or pine for the hull, and oak for the keel, and much of our evidence for those parts of ships for which we do have data concur with this recommendation.[39] Silver fir is particularly suited to shipbuilding, being light and strong, but workable, and resistant to water as well as insects. Some of the wood was identified as spruce/larch (*Picea/Larix* — two woods which are also often difficult to differentiate under the microscope). Since neither of these woods grew naturally in central Italy at the time,[40] they must have been imported from Northern Italy, or elsewhere in northern Europe. Combining all the data suggests that a much wider choice of woods was used than we may conclude from the textual sources; woods were mostly selected according to their technical qualities for a particular use, (but not always) and mostly, from those available locally. Repairs, usually easily identifiable in complete wrecks by their size and placement, were sometimes of timbers other than those used in initial construction, and occasionally of wood less technically advantageous. The study of the Pisan ships (Giachi *et al.*), provides a detailed colour-coded plan of each ship's wooden elements by location and type. This study also provides a list of *comparanda* for 26 wrecks and their timbers (to 2003), dated from the 7th century BC to the AD 12th century.[41]

In summary, the Italian wrecks consist of small to medium-sized cargo and coastal /riverine transport vessels, one fishing boat, and one small craft attested as a Punic merchant ship. Size is a limiting factor in reporting shipwrecks as larger wrecks sunk at sea are more difficult to find, and logistically very difficult to dive. This is a biased dataset, with no large craft that would have been capable of regular trans-Mediterranean travel.

[39] THEOPHR. *Hist. pl.* 5, 7, 1-3.

[40] We assert this from the co-located pollen studies: ALLEVATO / RUSSO ERMOLLI / DI PASQUALE (2009); SADORI *et al.* (2014).

[41] GIACHI *et al.* (2003) 273-274 (colour coded plans by wood type); 276-277 (summary of ancient shipwrecks by wood type).

3.3. *Looking for cedar*

In the Giachi *et al* list, cedar is noted as the main timber in a wreck from Kinneret Lake, (Israel: 1st century BC - AD 2nd century). Another Israeli wreck, (the "Athlit": 2nd century BC), also includes cedar, but only as the ramming timber. In fact, of the 26 ships/boats only five are from the East (origins: Israel and Turkey), and the rest are Italian or Gallic wrecks of Greco-Roman chronology. We are yet to find cedar in maritime archaeological sites in the quantities that the historical sources suggest should be present. It may be we need to look in new places. Theophrastus notes cedar was used more in Syria and Phoenicia, but a survey we have of these areas does not provide any wood identifications.[42] With so few wrecks from Eastern sites, the data we have are biased for location, as well as for ship size/use. Where pine is identified to species level it mostly consists of mountain pine types. Together with fir, spruce or larch, (which constitute the other high altitude conifer woods in Europe), the extraction of mountain pines implies significant effort to cut and transport the wood. Transport would have been mostly down available rivers and by sea. The timber-shipping industry must have stimulated a great amount of economic activity in terms of inward movement of experts, and outward movement of specialized conifer woods, to and from mountain areas, in agreement with N. Purcell's views of the importance of mountains as economic entities in this volume.

3.4. *Wood for armies*

R. Meiggs believes that terrestrial wars consumed more wood than shipbuilding.[43] He provides us with detailed descriptions of sieges (which often took years). War machines (e.g. catapults,

[42] KAMPBELL (2013) 91-93.
[43] MEIGGS (1982) 154-157; see also VITRUV. *De arch.* 10, 10.

mobile towers, and landing bridges), were subject to being burnt out by the besieged, and were often hurriedly rebuilt. He does not attempt an actual calculation of the relative amounts of wood used. A further consideration is the amount of iron and bronze fixtures and fittings used in making war machines, weapons (not only swords, daggers, and shields, but also ballista balls and other projectiles), and tools, etc. Metal making required the use of charcoal, which in turn required much wood for its production (discussed in more detail below).

The logistics of feeding an army were also complex. While soldiers received formal rations of basics such as meat, oil, wine and grain, they also bought supplies locally, and lived off the land. Feeding a large army implies the carriage or local supply of very large quantities of fuel. Logistically, large quantities of raw wood fuel could not be carried. Wood was gathered along the way, often being levied as part of the *annona*. Supply line provision of charcoal, rather than wood perhaps may have occurred due to its decreased weight (one-third of the equivalent volume of raw wood, but with 1.8 times the heat value). But we have no evidence. The army would have had to balance accessing local supplies with supply line provision; otherwise the local population would have been left with no fuel for its own needs.

3.5. *Large-scale construction: public buildings*

The construction of large-scale public buildings fulfilled a range of state goals, demonstrating — as in the case of coinage — the power of a state facilitating its orderly operation and providing a venue for tax collection. Construction of temples, baths, roads, bridges, *agorai* and *fora* all required large quantities of wood (and other resources). Two types of wood were required: large and long single timbers for the largest structural elements, and smaller wood for internal fit-out, and roofing. Wood was also required as fuel during construction for a range of purposes including: making/repairing of small iron or bronze tools (as for shipbuilding); making nails and other accessories for hanging and fixing things; and for making lime in mortar production. Frames were required for empanelling areas for concrete setting, and internal and external scaffolding for roof and wall construction. Smaller wood was also required for tool handle manufacture. J. DeLaine discusses the range and types of woods, *most probably* used in construction of the baths of Caracalla, and in particular details of timber sizes needed for different uses.[44] Gordion's Royal chamber brought to light pine, yew (*Taxus baccata*), Juniper (*Juniperis*), and cedar, with construction timbers originating from trees ranging from 200-800 years old.[45]

As for shipbuilding, Greece imported larger timbers for construction of public buildings, while Rome could provide from her local resources. In Rome, from the early 2nd century BC the *porticus inter lignarios* on the Tiber attests to the movement of timber upstream.[46] The presence of this way-stop for wood in the center of Rome, suggests that the most desired timber resources of Latium and the uppermost sections of the Tiber were becoming rare at lower altitudes, and that sources further afield were (also) providing timber, and possibly fuel. It is probable though that areas of northern and southern Italy with large comparative agricultural advantages for forest cultivation were the primary sources in the first instance (evidence for trans-Mediterranean trade to Italy is rare, other than for exotics). Even in the later Mediaeval period, wood required urgently to build ships was supplied from coastal southern Italy.[47]

[44] DeLaine (1997) 458-461; she bases her speculation mostly on Vitruvius.
[45] Detailed reports may be found on the Gordion website: <http://www.penn.museum/research/projects-researchers/mediterranean-section/124-gordion-archaeological-project>.
[46] Liv. 35, 41, 10.
[47] Gangemi (2000).

3.6. *Wood for industry*

Of nearly equal interest to a state, and (to private elite owners), was the healthy operation of those activities that dealt in valuable resources, and most of these required fuel. Industries consumed both raw wood and charcoal fuel, according to the exigencies of both the absolute temperature, and the level of heat control, required by the technological processes concerned. Generally, higher temperature industries required wood charcoal, while lower temperature industries used wood. Industries requiring raw wood included: ceramics, glass making, fulling, lime making, the baths, and large-scale cooking. All of these processes operated below the critical temperature of 1100°C. At about this temperature, a wood fire is harder to keep at a constant temperature for a long period, even with bellows. Ancient primary glass ingots were manufactured in a two-step process with temperatures in the range 800-1000°C.[48] Ancient ceramics were fired at various temperatures, from rough ware, to various cook and table wares (*c.* 500-950°C).[49] The most refined and highest temperature demanding ceramic was Red Slip Ware (*terra sigillata*), the best quality of which required a maximum temperature of about 1050°C.[50] As far as we know, glass and ceramics kilns were all fired with raw wood (and sometimes agricultural residues). However, for ceramics, 'direct flame furnaces' (the most commonly used), required considerably less fuel than 'indirect flame furnaces' (a later innovation). The purpose of indirect flame furnaces was to separate the waste products of combustion (ash, smoke, organic volatiles), from the ceramics to be fired, so as to provide a 'pure heat' environment. These furnaces required two to three times as much fuel for each firing, so the technological innovation of manufacturing *terra sigillata* (and also *vernice nero* and *vernice rosso*) must have seen a steep rise in fuel

[48] MEIGGS (1982) 73. Glass working and annealing (depending on the type of glass), can occur at *ca.* 700-900°C.

[49] SMIRNIOU / REHREN (2011).

[50] TITE (1969) 38-39.

demand.[51] Manufacturing of glass requires a very large amount of wood, although secondary processing into objects (located in the places to which primary glass was exported), possibly consumes more than primary production. The matter needs further investigation.

3.7. *Commercial bread production and the annona*

Bakeries were a form of large-scale food production, a portion of which was devoted to the *annona* and corresponding provision of the *frumentatis*. Republican and early Imperial food support of the poor had consisted of grain measures but over time became extended to other goods, and grain became supplied in bread form during Severus' reign. Based on the evidence from Pompeii (earlier than Severus, but still instructive for sheer numbers of bakeries), we know of around 39 commercial bakeries, with just two-thirds of the city now excavated, and a rough population of 15,000 inside the city walls. So, perhaps 60 bakeries existed to service the 15,000. However, there were roughly another 15,000 people just outside the city walls, and we can't know if they bought their bread in the city, or made their own, although most *uillae rusticae*, and larger *uillae urbanae* did have their own bread ovens. Bakers' ovens were fired up very early in the morning with wood, (or sometimes with olive pressings). The fire was stoked for 1-2 hours until hot, at which point the fuel was removed (or, potentially pushed to one side), the oven watered/washed down, whereupon baking commenced and consecutive batches of breads, cakes and other goods were cooked until the oven was cold.[52]

[51] Cuomo di Caprio (2007) 336-352.

[52] Baking bread: Cuomo di Caprio (2007); olive pressings and wood as fuel in bakeries: Monteix (2015);Coubray / Zech-Matterne / Monteix (forthcoming); Monteix *et al.* (2012); fuel in ancient food production: Veal (2017).

3.8. *Public feasting*

Large-scale public feasting as demonstrations of power and prestige, (and sometimes euergetism), are recorded in the ancient sources.[53] Little direct evidence may be found in the archaeology, as food and fuel remains tend to be scattered in secondary deposits. Soils are frequently moved around in rebuilding and renovating cities. Feasting occurred on various scales, from public celebrations of e.g major holidays such as *Saturnalia* and *Compitalia,* and Augustus' birthday, to the banquets of the *collegia.*[54] *Collegia* from the later Imperial period onwards in many cases also contributed to the *annona* in the form of baked bread. Public feasting, and commercial baking for the *annona*, both provide interesting examples of a reduction in the inequality of access to wood resources. The elite, in conducting inclusive spectacles, and supporting the *annona* controlled the resources, but in such a way as to share them from time to time.

3.9. *The public baths*

The Greco-Roman habit of bathing in public facilities required large quantities of wood (see Reger in this volume). We may presume that charcoal would be less probable as a fuel since the process required heating the stone/cement floors, and walls via a raised hypocaust to temperatures no more than a human could tolerate.[55] The environment was heated to a range of temperatures: *frigidarium* (presumably not heated), *tepidarium* (moderately heated), and the *caldarium* (perhaps heated to as high as 40°C).[56] Other rooms, if present, also required heating: the sauna, dry steam room, and *cella solaris* or *heliocaminus* (sun

[53] DONAHUE (2003).

[54] DONAHUE (2003) 873.

[55] MILIARESIS (2012). CARACUTA / FIORENTINO (2012) detail woods identified from late Roman villa baths in Faragola, SE Italy, which included predominantly deciduous oaks, and *Pistacia.*

[56] ROOK (2013) 111.

bathing room). Factors influencing the fuel consumed included: overall size of the building; volume of water; thickness of the walls/floors; outside ambient temperatures through the seasons; and the presence or absence of window coverings (glass or other materials).[57] Baths developed technologically over time, but the introduction of *tegulae mammatae* (flued wall tiles), in the AD 1st century, improved efficiency considerably.[58] They consumed a large amount of wood in the heating up phase, and required quite a lot less for temperature maintenance. Depending on seasonal temperatures, skilled *balneatores* knew when to add wood at peak use times, and when to let the fire rest.[59] We might presume they were never allowed to 'run cold', except perhaps for occasional maintenance. The written sources are silent on this matter, but archaeological evidence and physical modeling by I. Miliaresis have provided us with some data for one bath facility.[60] Public baths were relatively affordable for any freedman (or woman), and were not restricted to the elite. This relatively egalitarian access to the baths means the wood resources that underpinned this service provide another example of reduction of inequality of access to wood resources between the elite and the less well off, although slaves were not permitted to bathe.

4. Wood charcoal consuming industries

4.1. *Wood's role in the rise of metals*

The scientific requirement for the use of charcoal in iron smelting (charcoal being required due to the high smelting temperatures involved, i.e. 1100-1200°C, as well as being essential

[57] MILIARESIS (forthcoming). The Baths of Caracalla are thought to have lacked glass in the *cella solaris,* ROOK (2013) 125. Sunbathing rooms usually faced south-west. Some *caldaria* were double-glazed, e.g. the Forum Baths at Ostia, and again the Herculaneum Baths.

[58] ROOK (1978).

[59] MILIARESIS (2013). See especially: <https://www.academia.edu/8494521/Doctoral_Dissertation_Conclusions>.

[60] MILIARESIS (2013).

to the chemical reaction), has led to an estimate that around 1 ton of charcoal fuel was required to process 1 ton of iron ore.[61] The rough ratio of 1:1 was also used at a 'Roman' bloomery kiln built in Dorset, UK, in an experimental archaeology smelt conducted by the University College London, in 2015 (see Pl. 8.1, a photo montage of the ore, kiln, and bloom/slag products). This ratio will vary depending on ore quality, ambient conditions, and kiln performance. This is a very rough calculation however, as it ignores fuel used in pre-roasting of the ore, wood used to start the fire (before the charcoal is added); forging of the raw metal bloom (to remove slag and form into bars or billets); not to mention the range of 'recipes' used to make wood into charcoal for iron production. Ratios from 4:1 to 10:1, and as much as 15:1 have been estimated from archaeological remains; documented by experimental archaeology; or observed as modern practice in developing African countries.[62] During and prior to the Iron Age, metals with a lower melting temperature were also extracted by smelting.[63] Alloys, (e.g. bronze and brass), were created by full melting of the component metals. Some metal working processes did not employ full melting, and elements became malleable from being worked. In addition to copper, silver and gold, bronze and brass had lower melting/smelting temperatures (below 1100°C). However, charcoal was still the predominant fuel, as it was also required in the reduction reaction. Charcoal fires are easier to control, and better at providing a steady temperature. Wood introduces too much water, the removal of which, consumes valuable calories needed for sustaining the temperature of a furnace at 1100-1200°C.[64] Any lowering of the process temperature below the critical range produces a failed smelt.

[61] CLEERE / CROSSLEY (1985) 45.

[62] VEAL (2013) 47-48.

[63] Melting is the heating of a substance to change it from solid to liquid form. Smelting requires the metal to become "plastic" (but not molten), in order to react ("reduce") with available carbon (from the charcoal), in an oxygen-depleted atmosphere.

[64] Overview of Greco-Roman metallurgy: REHREN (2013); the definitive text on archaeometallurgy: ROBERTS / THORNTON (2014).

4.2. *Major metallic manufactures: coinage and weapons*

The manufacture of coins and weapons were two of the larger metal consuming industries that especially interested the state. These required s/melting of copper, bronze, silver and gold. A two-stage process is often attested in raw metal recovery, with preliminary production of raw metallic bars usually near the place of ore extraction.[65] These were subsequently transported around the Mediterranean for further refinement. Smithing into final products tended to occur in expert artisanal centers, often in large cities. While s/melting commanded the use of charcoal; smithing and casting occurred at lower temperatures, and may have attracted the use of raw wood or other fuel on occasion, but for iron working, the carbon in the charcoal was essential for most weapon production.[66] We are less sure about the fuel used for coin making, but when coins are made of more than one metal, full melting (casting) is required. Thus when Roman coins were significantly debased, more fuel would have been required for this reprocessing. Once blanks had been made, ovens were used to heat them sufficiently for striking. If these were being operated with the aim of holding a particular temperature over a long period to cater for continuous production (e.g. in Imperial Rome), charcoal would have been the main fuel.

5. Wood for everyday living: furniture and tools

Greco-Roman woodworking is very recognizable. Some aspects of furniture making and design of tools have changed little from antiquity.[67] Agricultural tools, wooden building elements, and

[65] Rehren (2013).

[66] The hardest and sharpest edges were made of steel. Hammering, heating and quenching of the weapon/knife, many times over, infused the cutting edge with more carbon (a process called carburization).

[67] Ulrich (2007) 13-58.

many domestic items were fashioned from the woods at hand: harder woods for tool handles, doorframes, heavy-duty furniture; and softer or more pliable woods for those requiring flexibility (spears, light furniture, tools requiring curved lengths). The archaeological data has shown that woods chosen for particular uses generally have the technical characteristics required, with the caveat, that that which is easily available in a particular location will usually be used.[68] This is true of wood-rich areas. Wood-poor areas show a different pattern, with the use of imported woods a significant phenomenon, even for everyday objects.

The use of exotic woods for the manufacture of everyday objects is rarely recorded in the literary sources, with two notable exceptions: ebony (*Diospyros ebenum* predominantly, although the name ebony is given to a number of *Diospyros* species); and citron/citrum/citrus wood (precise identification unknown, but thought to be *Tetraclinis articulata* (syn. *Callitris quadrivalvis*, *Thuja articulata*). Ebony's distinctive dark and hard wood is still coveted today (and is now protected). Citron/citrus wood (not to be confused with lemon/orange wood, despite the similarity of name), was a type of Cupressaceae, and was very fragrant. Both ebony and citron were made into elite Greek and Roman furniture, (particularly dining tables), and sourced from North Africa (and possibly other locations).[69] Both were extremely expensive, and by the 1st century veneering was becoming more common.

Knowledge of archaeological data for Mediterranean wooden artefacts is substantially dominated by remains from Herculaneum and Pompeii, and surrounds at AD 79. Some further data are obtained from an AD 2nd century roof of the Villa of Augustus.[70]

[68] GALE / CUTLER (2000) 414-489, in Tables 12-48 plant uses are detailed by: wood type, plant part, time period, geographic location, and use type.

[69] Ebony and citron wood workers were highly specialized and had their own *collegia*, VERBOVEN (2007) 884. For the qualities of these woods see ULRICH (2007) 252-253 (ebony), and 247-248 (citron).

[70] MOLS (2002) Herculaneum furniture; MOSER *et al.* (2013) charcoal study at Oplontis the so-called Villa of Poppaea), which includes furniture and fuel; ALLEVATO *et al.* (2012) review of Late Roman Campanian charcoals focusing on

Mols, examining the Herculaneum furniture, found the high use of silver fir (*Abies alba*). This is not surprising considering its lightness and workable nature as already mentioned. However, beech (*Fagus sylvatica*) figured as a major wood and is not particularly preferred in the ancient sources, while Allevato *et al.'s* study at the Villa of Augustus shows chestnut for roof timber, although its large-scale cultivation probably did not commence until the Late Antique period. Smaller quantities of oak, maple and other woods were recorded. Moser *et al.* found similar patterns in Oplontis. These patterns are complemented by other studies in fuel, and in roof timbers in Pompeii.[71] Romano-Britain is a case where water-logged construction woods are routinely found, and typically deciduous oak (*Quercus* cf. *robur/pubescens*) is a construction wood in Londinium (AD 1st century), with spruce and larch also observed.[72] In wood-rich areas, local production of wood for common use appears to have been either in the hands of individuals (small farmers who had a wood lot, or access to *ager publicus*), or potentially middlemen (*negotiatores*), who might collect wood from various sources, and resell it at *nunindae* or the local *macellum/agora.* The elite's access to such wood may have been outside the market (if their landholdings provided suitable material), except for purchase of exotics.

In wood-poor areas, the sources are silent about the supply of everyday wooden objects but archaeological evidence is most informative. One detailed case study is that of the Ports of Quseir al-Qadim in Egypt.[73] Here, a range of everyday objects was identified in the Roman period, from bowls, spoons and combs,

chestnut (*Castanea sativa*) at the Villa Augusta; MOSER / NELLE / DI PASQUALE (2016), detail the high use of silver fir in buildings at Herculaneum (AD 79).

71 See for example, COUBRAY (2013); VEAL (2012); (2014); (forthcoming-a). Fir was identified in the House of the Surgeon, as well as willow/poplar in a roof in the Porta Stabia excavations (author, unpubl.). The large presence of fir charcoal now well attested in Campania suggests its very large presence locally in the classical period, although at altitudes above about 1,000m. It is now rare.

72 See for example, GOODBURN (2005).

73 VAN DER VEEN / GALE / UBEL (2011).

to spatulas, needles, and even a wooden key.[74] Of the small artefacts, local woods accounted for about 60% of the items, which were predominantly made of tamarisk (*Tamarix* sp.) 50%; and a few monocotyledons, (either date palm (*Phoenix dactylifera*); or a type of reed (there are many), 12%; and some toothbrush shrub (*Salvadora persica*) 7.5%. A very significant 40% were exotic to Egypt, these were box (*Buxus sempervirens*) 28.5% of the total, probably imported from Europe, North Africa or the Levant; pine (cf. *Pinus sylvestris/nigra* group — i.e. hard mountain pine types) 7.5% (probably either from northern Europe or the eastern Mediterranean, and teak (*Tectona grandis*) 7.5% (from an area in present day India). This begs the question of whether exotic woods were imported by the Egyptians in timber form and then manufactured into goods, or whether finished products were brought in already manufactured. Some indications may be gleaned by correlating the fuel charcoal that was also analyzed. Fig. 2 collates and compares the wood data for marine and everyday objects, with that of the charcoal remains.

Wood type	Common name	Origin	Maritime objects	Everyday objects	Fragments as fuel
CONIFERS/Cupressaceae					
Picea/Larix / cf. *Picea/Larix*	spruce/ larch	European/ Medit.		1	3
Pinus sylvestris/ nigra	mountain pine	European/ Medit.	4	5	51
Pinus pinea/ pinaster, Pinus sp.	coastal/ plain pines	local			76
Conifer		prob. local			7

[74] The site covers a wide chronological range, but the Roman (botanical) deposits, were dated exactly to AD 1-250: van der Veen / Gale / Ubel (2011) 18 (chronology); 212-20 (wooden artefacts).

Wood type	Common name	Origin	Maritime objects	Everyday objects	Fragments as fuel
		LARGE and MEDIUM TREES			
Tectona cf. *grandis* / cf. *Tectona*	teaks	Indian	10	4	46
Quercus sp. (deciduous or undiff	oaks	European/ Medit.	2	2	8
Quercus sp. (evergreen)	oaks	European/ Medit.	7	1	2
Dalbergia sp.	African blackwood	African/ local	13	2	2
Fraxinus / cf. *Fraxinus* sp.	ash type	European/ Medit.		2	5
Ulmus sp.	elm type	European/ Medit.	2	2	32
Dipterocarpaceae	large family	Indian/ African			4
		SMALLER TREES/SHRUBS			
Acacia sp. / cf. *Acacia*	wattles	local	8	2	42
Tamarix sp.	tamarisks	local	5	11	97
Buxus sp. / cf. *Buxus*	box	European/ Medit.		9	
Moraceae / cf. Moraceae	large family incl fig	local		1	1
Ficus sp. / cf. *Ficus* sp.	fig type	local		3	1
Moringa peregrina	ben tree	local			2

Wood type	Common name	Origin	Maritime objects	Everyday objects	Fragments as fuel
		COASTAL			
Rhizophora sp./ *Bruguiera* sp.	mangrove type	local		1	20
Avicennia sp. / cf. *Avicennia*	mangrove type	local			167
Salsola sp./*Suaeda* sp.	saltwort/ coastal	local			14
		OTHER			
Monocotyledon	reed	local		3	
Leptadenia sp.	thatch/ herb	local			8
Chenopodiaceae	goosefoots (weed)	local			20
cf. Palmae	palm group	local			8
Lagenaria cf. *siceraria*	bottle gourd	cultivated locally		2	
		TOTALS	51	51	616

Fig. 2 – Wood and charcoal data collated from VAN DER VEEN / GALE / UBEL *(2011) 207, 213, 221.*
Wood types with count of only 1 have been excluded.

Results show local woods were consumed as fuel in 56% of the fragments identified (made up of a very large variety of woods, 20 or more types), of which tamarisk features as the second most common, with a type of mangrove wood (*Avicennia* sp.) as the most common; while 7% originated from imported woods from India and East Africa; and 22% from European/Mediterranean woods (and 15% were indeterminate).[75] Pine and teak as exotics appear in both wooden artefact and fuel charcoal assemblages, while box, representing 28.5% of the artefacts is not found in the fuel charcoal. Thus we may speculate that wood-working waste of exotic types may have formed part of the raw fuel consumed, but that items in finished form were also imported. It is interesting that mangrove, a hard and rather beautiful wood, is found almost solely as fuel. Fuel supply was clearly a different economy to wood supply for carpentry in this case. Several types of maple (*Acer* spp.) were also present in boat building, construction, tools, and as firewood, but did not appear as part of the domestic artefact assemblage.[76] This suggests further market differentiation for domestic items as opposed to industrial wood, even for small items.

The luxury woods of ebony and citronwood have not been found in any charcoal assemblage to date, as far as can be ascertained. More integrated studies of the quality of that at Quseir al-Qadim are needed. However, even with this one case study, a more nuanced picture of imports of wood for elite consumption, as well as imports for everyday use in a wood-poor area, arises. Less well off citizens still had access to reasonable quality wood imports, even if they could not afford the highly prized ebony and citronwood. We have no information about price that may help qualify our understanding further, but the everyday nature of the items suggests a market not limited to the elite.

6. Fuel

6.1. *Raw wood and charcoal fuels*

So far I have focused on timber for shipbuilding, construction and small object manufacture, with some mention of the use of fuel. We now turn to a more detailed discussion of fuel,

[75] Van der Veen / Gale / Ubel (2011) 221.

[76] Van der Veen / Gale / Ubel (2011) 335-336. We must recall that this is only one study.

particularly charcoal. Charcoal was made in heaps or pits of suitably cut logs or branches. These were covered and sealed with a mixture of ash, leaves and soil. The wood heap was then slowly 'charcoalified', rather than burnt. Modern ethnographic studies help to illuminate this process, which is also documented in the ancient sources.[77] Charcoal making typically took place in the forest. Charcoals were then bagged and transported to private homes or presumably nearby markets. When examining fuel in the archaeological record, discriminating charcoal that has arisen from burnt construction timber from that of fuel remains can be undertaken through analysis of the annual tree rings (where observable). Flat rings generally indicate wood arising from large timber, and tight rings indicate small wood. The archaeological context is also important, as actual burn layers are usually very recognizable. We would also like to differentiate charcoal remains of charcoal fuel from those of raw wood fuel, since the use of charcoal implies a greater consumption of forest. Such differentiation will ultimately allow us better to estimate wood fuel consumption.[78] Progress is being made with a scientific method called 'reflectance' that measures the shininess of the archaeological charcoal. This has been demonstrated to be directly related to its absolute burn temperature, and so, by measuring a range of charcoals in a context, a raw wood fire will show a 'normal' (bell-shaped) distribution curve of charcoals formed from temperatures starting at about 250°C, increasing in temperature and number of charcoal fragments from 350-550°C, and dropping off thereafter. A charcoal fuel fire will not produce low temperature charcoal remains, as all the fuel will have reached at least the temperature of the (prior) charcoal production process (about 350°C). A 'flatter' and irregular curve starting around 350°C will eventuate. This new

[77] Gathered together in VEAL (2013) 46-48.

[78] A model for the fuel consumption Pompeii has been developed and is in refinement VEAL (2012) (full discussion); the model is downloadable from <http://www.robynveal.com/a-quantitative-model-for-the-ancient-fuel-supply-to-pompeii-ad-79.html>. Application of the model to Imperial Rome has been attempted VEAL (2013), (forthcoming-b).

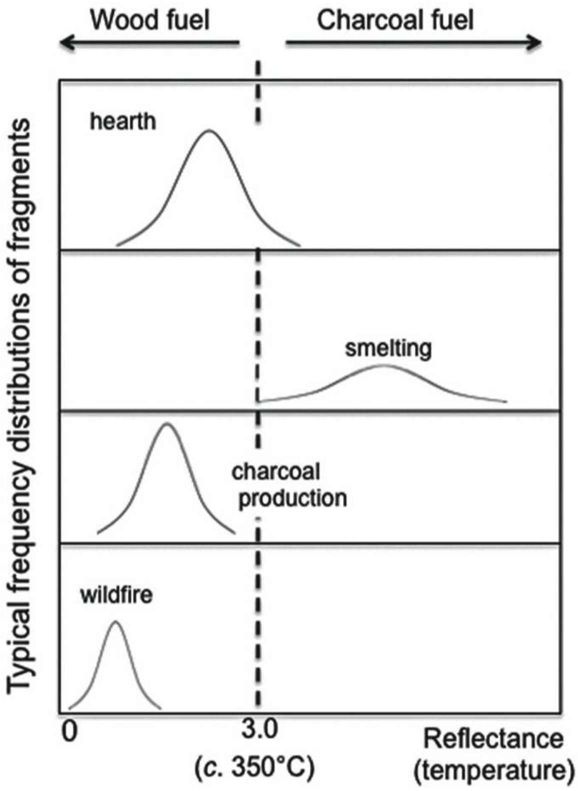

Fig. 3 – Diagrammatic fragment/temperature distributions illustrating the reflectance method.
(Figure: author, after MCPARLAND *et al. [2009].)*

method has much promise but is yet in early stages of testing.[79] Fig. 3 provides a diagrammatic representation of these differing fragment / temperature curves for different fire types.

6.2. *Marketing timber and fuel*

Price information about wood and charcoal comes mostly from Diocletian's Price Edict in AD 301, and from Delos from about the 7th century BC. In the Price Edict we find timber and charcoal fuel much more expensive than raw fuel wood, although

[79] MCPARLAND *et al.* (2009); VEAL / O'DONNELL / MCPARLAND (2016).

price comparisons for fuel types have to be interpolated through their respective transport costs.[80] Bundles of kindling had the highest value of all. Delian imports were tightly controlled, as we know, and this included supply of charcoal and wood.[81] The relative value of wood and charcoal in Greece, compared to other commodities, was very high due to its scarcity, as Bresson has argued.[82] Most ancient Greek villagers could not afford much, if any fuel. Romans on the other hand, had fairly easy access to wood due to its availability. We do not have archaeological evidence for local market supply of timber and wood for cities' use. Fuel is bulky, (and dirty), therefore sales areas may have been located away from the main market. Home delivery, at least in places like Pompeii, can also be imagined.

7. Land ownership over time: conversion of *ager publicus* to *ager priuatus*

Land types in the Roman period may be divided into *sacrum, ager publicus,* and *ager priuatus.*[83] Sacred forests (*nemus*) were perhaps less likely to be accessed for general timber or fuel production, although the matter cannot be tested archaeologically. Some scholars have suggested *nemus* were cut for the benefit of temple priests. Land laws in the Republican period attempted to protect smaller farmers' rights, but over time, *ager publicus* became *ager priuatus.*[84] The mechanism for this originated in Rome's handling of newly obtained lands in her progressive domination of the Mediterranean. Typically a defeated city may have fertile land reassigned to veterans or to the state. Forests

[80] GRASER (1959). Newer fragments of the Edict do not add more information on wood.

[81] REGER (2002) 73. ARNAOUTOGLOU (2009) questions the assumption that prices on Delos (due to its central Aegean location), represented prices throughout the Greek world (134-36).

[82] BRESSON (2016) 72-73.

[83] Following, e.g., LONG (1875) 21-27.

[84] ROSELAAR (2010).

would become part of the imperial administration, sometimes as part of the emperor's fisc. Taxes were payable in cash or kind, often in firewood, for access to the forest. Theoretically at this point, use by local citizens was still facilitated, but gradually the emperor and his tax agents leased forest (and agricultural land) to the elite, thus reducing *ager publicus*. Elites were the greatest beneficiaries of *ager publicus,* farming it directly or through tenants.[85] Texts suggesting such elite benefits increase substantially in the Late Antique period.[86]

8. State formation and urbanization

A state's progress towards political domination of the Mediterranean was moderated by the ability to gain access to, and control, the best forest resources. It is a notable pattern in history that the most successful civilizations have had long and secure access to forest resources for building and fuel. In this phenomenon, the Egyptians, the Phoenicians, and then especially the Romans, were more successful than the Greek city-states who failed to accrete as a unified power. In progress towards Empire, a type of centripetal force of attraction to Rome's larger cities developed, especially for trade. Large ancient cities became great consumers of all products, developing complex demand and supply patterns. Ever larger public buildings and elite *uillae* were constructed. Nearly all manufacturing required the use of raw wood for turning and tools, but also copious quantities of fuel, and so demand for both timber and fuel rose with increasing urbanization. Demand for fresh foodstuffs for Rome, and the rise of *pastio uillatica,* pushed the origins for the wood supply further and further away from the city. Forests in the Imperial period became more and more limited to mountain areas. Charcoal, always a preferable fuel in

[85] DUNCAN-JONES (1976) 7.
[86] Discussed by DIOSONO (2008a) 28.

a dense urban city,[87] would have experienced increasing demand with increasing population. A pattern of distant mountain supply is observable even in Pompeii (3rd century BC to AD 79).[88] The rise in sophistication of the iron and bronze industries, together with city consumer demands, must have seen a very large increase in charcoal making in Latium, and perhaps further afield, although we have no evidence either documentary, or archaeological, for the transport of large quantities of charcoal, and not much either, for the transport of wood, except in a few historical mentions.[89] Transport by road causes increasing fragmentation of charcoal, rendering less of it suitable for industrial purposes (but these 'fines' can be used domestically). Transport by river or sea would have been preferable.

9. Conclusions

Environment is the first source of inequality in access to forest resources in the ancient Mediterranean. Competition for forest resources among Mediterranean polities was strong. States with poor rainfall and larger tracts of low fertility soils had to import large timbers, especially the Egyptians and the Greeks. The Greek city-states had the further disadvantage of never forming a whole empire, and so fought among themselves, and with others for resources. The long-term ability to control forest resources depended on a polity's original ability to access timber resources to construct a fleet. Ongoing maintenance and expansion of the fleet was then critical to state and elite wealth, both for security, but also for long term access to the markets of the ancient Mediterranean. The use of predominantly conifer wood types: cedar, larch, fir, cypress, pine (and the products of pitch and resin), made environmental influence a further constraint as

[87] Since it burns with little smoke, weighs little, cf. raw wood, and provides nearly twice the number of calories.
[88] VEAL (2012); (2014).
[89] DIOSONO (2008a).

most conifer wood types do not grow back without replanting (compared with most other deciduous and evergreen woods which can regenerate naturally). The most desired conifers grew at high altitudes. Construction of large buildings also required the use of single long timbers, and conifers were also generally preferred. Other woods were important for ships' decking, furniture, and tools of all kinds. Archaeological evidence provides us with a large range of woods used for these purposes, and for the most part these were locally obtained. However, in Roman Egypt one case study we have examined shows that 40% of everyday objects were made of imported woods from Europe, the Mediterranean and modern day South Asia.[90] Evidence suggests some exotics were imported in log form and worked locally, while others may have been imported in their final product forms. The inferred quantities of everyday items made of exotic woods, suggest reasonable equality of access to this resource by elites and sub-elites alike.

Land rights dictated by the state ultimately saw increasing inequality of access to forest resources. *Ager publicus* became *ager priuatus* over time, as the Roman state leased captured agricultural lands and forests to elite favourites. The sources are silent on the long-term practical outworking of this trend on the poor tenant farmer. This inequality of access and rights to wood between rich and poor is not surprising since forest control was intricately tied up with land ownership. The elite (and state) were the great landowners, and therefore had greater access to the various types of wood for construction and fuel of which they had need. However, they could not afford to completely restrict lower socio-economic groups' access to woodland, or the workforce would have starved. Inequality of access to wood resources was also tempered by elite acts of euergetism and social display in public feasts, and the provision of public bathing.

Timber was demonstrably more valuable than fuel according to our two main sources for wood prices, Diocletian's Edict

[90] Van der Veen / Gale / Ubel (2011).

and the price data from Delos (recalling the differing dates and geographical origins of these two diverse sources). Historical evidence is mostly limited to only a few types of large timbers being traded across the Mediterranean from sources east to west (cedar, ebony and citronwood). The archaeological evidence in this regard is scant for cedar, and lacking for the latter woods. The tools of archaeology, wood and charcoal analysis, and economic modeling can be usefully combined with a re-reading of the historical texts to arrive at a much more nuanced understanding of wood commodities in the ancient world than has previously been possible. Charcoal collection should be incorporated into all classical excavations to continue progress. We hope we may see the realization of more detailed studies of shipwrecks from the East. Cedar was the most prized wood in the Mediterranean through time. Yet so far we are unable to trace archaeologically its high use as ascribed to it in the written evidence.

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DISCUSSION

S. von Reden: That was a very interesting presentation, thank you. I would like to ask one thing Robyn: you did not really mention brushwood. Brushwood consumption was also important. In Egypt land was developed for agriculture by the clearance of brushwood, in a type of symbiotic gain, presumably this was a local economy that the State may have developed. What about timber? Were these separate economies?

R. Veal: Thank you Sitta for reminding me of the importance of brushwood. Yes, brushwood was, and is an important fuel, especially in more poorly treed areas. However, it is highly flammable, and so tends to burn to completion, and not be observed in the archaeological record, although heather and gorse are occasionally found. It was used even in treed areas to start fires, and particularly in cremation. I agree it was likely to be a local product. Timber supply was the challenge for Egypt and Greece for shipbuilding and large public building construction. Woods of dimensions and types that were not locally available were required, and so these had to have been imported. Markets for timber and brushwood would presumably have been managed differently, but we have little evidence.

F. Hurlet: I'd like to know more about the relationship between 'woodland' and the 'state'. How did the Roman Imperial State control forest resources?

R. Veal: Without entering into a full discussion on Roman land rights, we can say that from the Republican period, defeated cities' and states' forested land technically became the property of the Roman State, although in practice the elite and/or communities who owned the lands still mostly retained control over, and access to them. They paid taxes to the Roman state, usually in kind (timber, fuel, resin, pitch). This is a bit of a generalization. Following aggressive defeats, (e.g. of Veii, and Cumae), no property rights were retained. Wood products from state-owned forests were put to use in construction and repair of public buildings, roads, for the baths, the army, and other public uses. Some lands and forests were 'leased', especially to senatorial families. By the Imperial period the Emperor was building up his personal land holdings through various means and the separate ownership of forests by the state and by the Emperor, seem to have become blurred. We know of the intervention of Hadrian, drawing a cordon of inscribed stones around much of the remaining forest of Lebanon. Presumably the precious cedars, and other tall conifer timbers were protected for state use. Of the leased forests, the longer a wealthy landowner held a lease, the more likely de facto ownership appears to have become the norm. Medium-sized and even subsistence landholders alike may have paid a small (i.e. affordable) access fee. This permitted them grazing and/or wood fuel collection rights. One supposes that by the Late Antique period, as Roman control broke down, woodland access may have become more costly, as elites commandeered more land without restraint. However, by this time some agricultural fields were being abandoned, and trees would have reoccupied formerly arable land (at least in part), so overall forest cover increased. More work is needed in this area.

G. Reger: You cited evidence for secular climate fluctuations in the Mediterranean. I'd like to know whether there is evidence of fluctuations in distribution of forest species in conjunction with these changes — for instance, does the range of beech extend lower on mountainsides during the wetter and cooler period in Late Antiquity. Can we see reflections of such changes in the archaeology: for instance, do we see a higher incidence of (say) beech in the archaeological record for use as fuel correlated with such periods?

R. Veal: This is an interesting question Gary, as several factors come into play. Modern ecologists believe many species of flora and fauna survived in lower altitudes in earlier time periods. Overall man's activities have pushed many species higher up, so we have in part a flawed understanding of where things might have grown, based on where they grow now (even in a similar climate). We can tell broadly, what an optimum altitudinal range might be for a particular tree type by measuring the particular climatic and soil regimes that permit maximum photosynthesis. It is difficult, however, to isolate altitude in calculating 'optimal growing conditions'. For instance, for beech, in the current climate, photosynthesis is optimized between 1200-1550m in central Italy, and we believe the overall climate was not too different in the Imperial period to today's climate.[91] Grove and Rackham propose a formula that for a 1° C drop in temperature over a century, the tree-line might drop by about 100m .[92] However, this would be difficult to observe in practice, (since neither pollen nor wood charcoal remains can tell us from where, exactly, they originated). It is also accepted now that there is a time delay in reaction to climate change, and so pollen studies need to be read with some circumspection. How great this delay may have been requires further study.

S. Fachard: Votre modèle quantitatif pour estimer les surfaces de forêts nécessaires à la consommation d'une cité est très suggestif. Si je l'applique à mes régions d'étude, je m'aperçois que les chiffres peuvent varier notablement en fonction de l'indice de productivité. Ma question est la suivante : comment estimer l'indice de productivité d'une forêt antique ?

R. Veal: Thank you Sylvian. Yes, forest productivity is a key issue. Even in a modern forest, productivity will change over time with changing weather. Thus we will always be estimating

[91] PIGNATTI (1997) 487-490.
[92] GROVE / RACKHAM (2001) 142.

a range. However, this is not an impossible task, and our aim will be to constrain our early estimates further. Modern science tells us forest productivity ranges under different climate, soil, and cultivation regimes. The woods identified in the charcoal can provide cropping indicators. Together with local pollen studies these can give us fairly closely, the makeup of the ancient forest, and how it was cultivated. Study of the ancient soils would help even more (although this is not yet routinely carried out). Difficulties also arise (even in modern studies) from reporting productivity on a 'clear cut' basis (all the wood cut down), or a sustainable basis (small wood selected, and cut as coppice or pollards). Narrower ranges may be obtainable if we collect more local data, and perhaps introduce probabilistic analyses to flesh out predicted linear ranges. Notably, macchia (common in Greece) is not necessarily always 'low productivity', although it is relatively lower than deciduous forests, as growth is slow.

C. Brélaz: I found what you said about the 'hidden economy' of forests extremely interesting. The same is true, I think, of the swamps for which secondary, small-scale activities are also attested. All swamps were not necessarily unhealthy and did not bring disease, especially when they were regenerated through fresh water. In the case of the Roman colony of Philippi in the province of Macedonia, for instance, which was settled next to a large swamp, we should assume that the colony even took advantage of this marshy environment. Fishing activities and reed cultivation must have been carried out, as was already the case in the nearby Prehistoric settlement of Dikili Tash. As Prof. Beltrán Lloris suggested in his own paper, Roman colonization did not necessarily mean an economic downturn for the local population. My question is regarding forest ownership. As you mentioned, forests seem to have been a royal monopoly in the Macedonian kingdom. Rock inscriptions from Lebanon show that some parts of the forest there, but not the whole forest, were Imperial property during the Roman period. On the other hand, it has been recently argued by A. M. Hirt, convincingly I think, that not all mines and quarries belonged to the Emperor in the Roman world. Some may have been owned and operated by local communities. What about the forests? According to what criteria was a forest considered Imperial property? Had it to do with the quality of the wood? Or did the Roman emperors only inherit the forest estates that previously belonged to Hellenistic kings?

R. Veal: Thank you Cédric. I agree with you about swamps. They were, and are, important areas of production: for collecting fruits and berries; grazing of animals; firewood provision (and pitch production — pine trees are the most common trees in coastal areas); and fishing. Coastal lagoons located in these swamp areas were also a source of large quantities of juveniles of otherwise ocean going fishes (following their parents' return to breed), as well as salt making. As to property ownership, I have looked at this broadly above in answer to Fred's question, and clearly Hadrian took action over the forests of Lebanon, precisely because these woods were very favoured for ship and public building construction. In general though in the Imperial period, the state and/or the Emperor both appear to have routinely taken over technical ownership of defeated cities' forests (regardless of makeup), whilst mostly leaving management and access to the locals, and exacting taxes in kind.

A. Bresson: Je voudrais revenir sur la question du déboisement. Sans aucun doute parler d'un déboisement universel dans le monde ancien serait méconnaître ce que l'on peut savoir sur la base de la documentation écrite et archéologique. Cependant, ne faut-il pas insister sur les différences régionales? Certaines zones très densément peuplées ou faisant l'objet d'une exploitation plus intensive (pour la production métallurgique en particulier) n'avaient-elles pas été exploitées au-delà de la capacité de reproduction naturelle? En outre, comment prendre en compte l'impact du bétail, en particulier des ovins et caprins, sur la reproduction des taillis et forêts?

R. Veal: Thank you Alain. Yes I agree deforestation is a nuanced and regional issue, although we can say with certainty from pollen studies that large-scale deforestation only started in the Mediaeval period in the Mediterranean and Europe. More difficulties existed in poorly-wooded areas (such as you have noted in Greece). Over-exploitation of areas where metal working was carried out, does appear to have occurred from time to time, for example, on Elba, (as I have discussed in my chapter), and in the provinces in places like Roman East Africa (parts of which were marginal for wood anyway). However, long-term exploitation of woodland for mining and smelting also shows highly managed forest in some cases. Scholars of Romano British metal smelting, (for example, Peter Crewes, and Henry Cleere), argue that careful coppice management was the rule, and forests were not denuded, but carefully husbanded and harvested cyclically. Forests grow back, and coppicing increases life and vigour of trees. The charcoal evidence in Romano Britain (for which many studies have been carried out) shows the use of much small round wood. We have not yet examined enough assemblages to provide a comprehensive understanding of the whole Empire.

With regard to the browsing of ovicaprids — yes they do a lot of damage, and formal woodland management for coppicing (cutting near ground level), was not possible without extensive fencing. In flatter areas of the Empire, we presume fencing was put in place (extensive documentation exists for Mediaeval Europe), however, for the steep inclines of Italy, and other similar areas, woodland management would have relied on pollarding (cutting above grazing height), or rotational clear felling (and sorting of the wood into building and fuel sizes). Both strategies are observable in modern Italian forests.

N. Purcell: I have a number of questions. Firstly, I wonder what minimum/tolerable levels of heating existed. Was 'warmth as a luxury' a social variable? Ethnographic study might be informative. For example, what do people do in winter in Greco-Roman space and time? Secondly, was fuel a macro-historical contributor to social deprivation and elite enrichment? Can we consider the contrasting cases of the urban poor, and the rural poor of Greece as outlined in Alain's book?

R. Veal: Thank you Nicholas, for so many questions of interest, and for your personal reminder about Vitruvius' *porticus post scaenam,* one place wood might be stored in a villa. Your suggestion that fuel be studied as an object of euergetism is a useful idea. Certainly we have quite a few inscriptional examples of fuel donations and tributes, as a basis for such a study. With regard to your query about the 'luxury of warmth': as the group has discussed, we have to consider not only the availability of wood, but also: the local climate, clothing, and the relative wealth of an individual. Presumably people rugged up in warmer clothing (if they had it), and purchased more fuel, probably charcoal fuel. The urban poor were assisted in part by ambient warmth that *insulae* provided in large cities. Neighbours benefitted from the fires for cooking and heating of those below them, as the heat rose. Alain's Greek rural poor, who seem far worse off, with more difficult and costly access to fuel, had to cook communally, and probably experienced worse conditions of cold in winter. So, fuel *was* a major historical influence on social deprivation and elite enrichment, since it is so tied up with land ownership, and it is an essential. As *ager publicus* gradually became *ager priuatus,* presumably access to woodland became more costly for all. This cost would not have troubled the wealthy, or even the artisanal classes, but subsistence farmers and the city poor would have been relatively burdened by such cost increases. As the Imperial population approached its maximum in the AD 2nd century, and charcoal production commensurately increased for all types of purposes, the logistics of supply would have at the very least, led to higher transport costs as woodlands became more isolated from the large cities they served. Elites were the greatest consumers, both industrially and privately, of all fuel types, so the ownership of wood resources, and their transfer to consumption zones can definitely be seen as a further example of an elite burden on the basic needs of urban populations.

P. Eich: The concept and the semantics of the term *annona* are quite complicated. Could you expand on your use of the word and the development of the *annona* in time?

R. Veal: You are right to bring this up Peter, thank you. I've only mentioned the *annona* simplistically. We know the *annona* was essentially a tax on practically every agricultural and land-based activity. This tax, often in kind, provided critical resources to provision the army, as well as to feed the city poor, among other uses. Even from the Republic, Rome had to import grain, principally from Sicily and Sardinia, and later from Egypt and North Africa, in order to feed its citizens. Over time emperors tried to limit the number of poor receiving the dole. Grain is the focus of the *annona* in the early part of Roman history. By the Late Antique period attestations of the *annona* describe a much wider variety of foodstuffs including oil, wine, and potentially fuel. My interest lies in the impact of providing the dole in bread form (from the Severan period onwards) — as opposed to raw grain. This implies the use of a considerable amount of fuel to make the bread, and so the burden to provide the dole increased. Moreover providing oil also implied a wood and fuel burden since wood was used to warm the lees to extract more oil, and of course was necessary in press building. It may be possible to take the range of estimates of numbers of people receiving the dole, and calculate the fuel required to make the grain into bread. My point is, that moving from raw grain to bread provision created a greater burden because of the fuel requirement (and of course, labour, and the opportunity cost of producing saleable items). Fuel (and timber) can be seen as almost insidious essentials — which we find inserted economically into practically every aspect of life.

F. Beltrán Lloris: Regarding forest and imperial administration, of course there could be instances of forests run by the imperial administration, but there are plenty of examples where forests remained attached to city administration as shown, for instance, in chapter 82 of the *Lex Vrsonensis*. Regarding wood sustainability and the Romans, there are cases in which the exploitation of forests during Roman times seems to have produced deforestation: the results of the study on ice cylinders from Greenland related to lead pollution show a clear peak in pollution provoked mainly by the exploitation of the silver mines in Spain (*Science* 265, 1994, 1841 ss.), mainly in the Carthago Nova area. It would be interesting to examine the effect of mining in this area in Roman times.

R. Veal: Thank you Francisco. Yes I agree in principle that local administrations often still maintained control of their forests, (the Romans rarely wanted to interfere at this level of control), but taxes were then due to the State as we have already discussed. Thank you for the specific example. The Carthago Nova mines, (modern day Cartagena), have been reinvestigated a number of times. Some of the high outputs suggested by calculations from ancient historical sources made by modern scholars, (e.g. slag output of over 15 million tons), have been debunked by extensive geo-archaeological studies, (6 million is the estimate now). Further, the Romans mined less gold/silver than previously thought, and much more copper. The wood requirements in Roman times were more like 200,000 trees p.a. (perhaps a quarter to a third of the previous estimates).[93] This is still a lot of wood, but the mine ran efficiently from about the 3rd century BC, and so renewable wood supplies had to provide part of the requirement, even if charcoal was also brought in from elsewhere. Roman mining waned there in the AD 4th century, and was not restarted on any scale until much later in history. In the 19th century new types of exploitation began 'and required more (local) wood.'[94] I infer that local woods existed then, perhaps from re-afforestation. The stark landscape of Rio Tinto is as much due to (natural and processed) sulphide dominance (i.e. poisoning) of the soils as other issues. You are right

[93] Rothenberg / Palomero (1986).
[94] *Ibid.*

Francisco we could study this more by examining the charcoals and inferring cropping strategies (i.e. more sustainable, if using small wood). Changes in the local flora may be detected by pollen studies. To my knowledge concurrent evaluation of these data has not yet occurred. Rio Tinto is probably the largest example of wood exploitation for mining in the Roman world, and it was in a province, so we might expect this to be an example of local over-exploitation.