Wood remains from archaeological excavations: A review with a Near Eastern perspective

Article *in* Israel Journal of Earth Sciences · December 2007

DOI: 10.1560/IJES.56.2-4.139

Simcha Lev-Yadun
University of Haifa

Isr. J. Earth Sci.; 56: 139–162

Wood remains from archaeological excavations: A review with a Near Eastern perspective

Simcha Lev-Yadun
Department of Biology Education, Faculty of Science and Science Education, University of Haifa—Oranim, Tivon 36006, Israel

(*Received 13 February 2008*; *accepted in revised form 4 June 2008*)

ABSTRACT

Lev-Yadun, S. 2007. Wood remains from archaeological excavations: A review with a Near Eastern perspective. Isr. J. Earth Sci. 56: 139–162.

In this review I describe and discuss the technical issues of identification of archaeological wood remains from archaeological excavations and the types of data that can emerge from studying them. I discuss uses of wood; types of wood remains (dry, charred, waterlogged, sub-fossil, fossilized); crystals from wood; the anatomical basis for wood identification, including the different anatomies of conifers, monocotyledons, and dicotyledons; regular and traumatic tissues; endogenous trends of anatomical changes related to age, size, and position within the plant; and damage by fungi and insects and their identification. Wood preservation, common microscopic methods for wood identification, wood anatomical atlases for the Levant and other relevant regions, and the lack of bark descriptions are all discussed. Wood fiber identification, statistical characters of wood anatomy, dendrochronology (tree-ring studies), and the use of stable and radioactive isotopes from wood continue. Possibilities of identification of the origin of wood by Strontium and ancient DNA and other molecular studies follow later in the review. The role of floral data emerging from studies of archaeological wood remains in planning current forests and nature conservation is discussed. In this context, an example is given of the role of wood remains in understanding the dominance of *Quercus calliprinos* (kermes oak) in the Central Coastal Plain of Israel. Geobotany and the question of identifying climatic changes, social status as reflected in the types of wood used in Masada (King Herod's palace versus Roman siege rampart), wood as an indication of ancient trade, and wood as reflecting horticulture are also discussed. Woodworking technology, the use of fire, and dealing with multidisciplinary issues and conclusions end the review. Concerning archaeological wood remains, it is impossible to exploit all theoretical and technical abilities in all studies, and scientists involved in any archaeological project have to decide about priorities. Studying archaeological wood remains is a very complicated multidisciplinary issue. Archaeological wood identification is commonly conducted by non-botanists, who have difficulties with the botanical, ecological, and environmental aspects, while evaluation of the identified plant material by botanists involves similar difficulties with archaeological and cultural issues. No scientist is able to master all relevant aspects, and such multidisciplinary issues usually require a well-balanced team to deal with them.

E-mail: levyadun@research.haifa.ac.il

0021-2164/07 $4.00

INTRODUCTION

Wood identification by various anatomical components and other methods is practiced by botanists, ecologists, archaeologists, geologists, students of evolution, foresters, wood and paper technologists, forensic scientists, students of art, and probably others. Practicing wood identification can be done at the technical level, resulting in lists of taxa, but the real scientific analysis starts in many cases only after the technical identification (which may sometimes be very complicated and tedious) is done. There are possibilities to identify wood by using pictorial wood anatomy atlases, and standard analytical wood anatomy keys for identification of some floras also exist. Several floras have computer-assisted identification packages (e.g., Gupta et al., 2001). Where the published material is insufficient, comparative anatomical slides and photographs of recent relevant material are used. Here I give an overview of the types of wood and wood-related finds, the basic methods of their identification, and the types of data that may emerge from such studies. I discuss some of the problems related to interdisciplinary studies of that kind and the geographical, ecological, and cultural aspects of drawing conclusions. I give examples from studies conducted in Israel or elsewhere in the Levant whenever possible. This review will serve all types of scientists who use data related to archaeological or other ancient wood remains, as well as geologists, forensic scientists, and people working in the wood industry.

DEALING WITH MULTIDISCIPLINARY ISSUES

There are several possible levels on which archaeological wood remains can be studied. The purpose of the study and the available resources for research may significantly influence, first, the sampling strategy during excavation, and later, the type of study conducted with the remains. Exploiting all the theoretical and technical abilities described above in all studies of wood remains is not practical, and any team involved in any given archaeological project has to decide on its priorities. In certain cases, the technical identification of the woody species or genera is sufficient. There is a clear difference between a find of a small number of wood remains such as charcoals from outdoor fire, cooking installations, or a burnt house, and an assembly of hundreds or thousands of well-preserved specimens that may reflect past floras, technological aspects, local and international trade, genetic aspects, cultural aspects, and agricultural or forestry practices. The geographical location of a site, e.g., within the hearth of a certain ecology or in a transitional area between two ecologies, is also important when geobotanical or ecological aspects are studied. The availability of previous remains from the region and period, as well as the type of archaeological site (e.g., rural, state capital, military post, trade station, port, cult center, etc.) also has a significant role in deciding how to conduct a specific study.

Some facts are not easy to digest, but scientists try to find the truth rather than please the public. In the following paragraph I deliberately present a provocative view. This view does not cover all cases of archaeobotany, but certainly discusses common limitations in this field. I refrain from discussing many specific studies because this is primarily a methodological essay and not a data review and I do not wish to be too apologetic. As discussed above, studying archaeological wood remains is a very broad and complicated issue. A single scientist cannot master all relevant aspects. I will comment on some of the difficulties related to such studies. Wood identification is commonly conducted by non-botanists, who have difficulties understanding and mastering the botanical and ecological aspects of the identified plant material. Such studies end, in certain cases, in naive models that do not fit the actual complicated ecological situations and relevant interpretations. Similarly, when botanists identify such archaeobotanical materials, their cultural interpretations may be no less problematic. Peer review of manuscripts usually does not solve the problem, as the reviewers suffer from the same limitations. While ecology is terribly complicated when the present is studied, reconstruction of the past from fragmentary, and in many cases, out-of-context finds, is even more difficult. A very important issue of studying archaeobotanical remains of any type including wood is the critical local (regional) aspect. For instance, the best experts of whatever flora are at a disadvantage when they have to identify plants belonging to other floras, and I am not referring to the technical issue of correct identification of species, but to the understanding of their ecology. A deep knowledge of a certain flora is a lifetime project. Many years of field days are needed to get a solid experience with the taxa, ecological factors, and the relevant local plant/animal/human interactions of any flora. A Ph.D. or Post-Doctoral experience, let alone a single or several summer visits to a given region, are clearly not sufficient to acquire the necessary knowledge. Moreover, there are usually critical publications published in local languages in relevant biological and archaeological issues that are not accessible to foreign visiting scientists. Broad geographical perspectives are also misleading in certain cases. For instance, for people from Spain or France, anything east of Italy may be considered Eastern Mediterranean. However, for scientists in Israel, Lebanon, Jordan and Syria, anything west of Crete may be considered Western Mediterranean. The northern Adriatic, "Eastern Mediterranean", for some (see Rossignol-Strick, 1995, and certain citations of this study) is clearly related to temperate region ecologies and not to true Eastern Mediterranean (Near-Eastern) ecologies. The erroneous botanical interpretations from such studies reflect on other studies, resulting in "paper evolution" or "paper stratigraphy" of misunderstanding. There are additional factors that may increase the complications in interpreting the significance of archaeological wood remains. Trade of timber and worked items has been common for the last several millennia. When certain tree species, e.g., *Pinus halepensis*, *Cupressus sempervirens*, *Quercus calliprinos*, *Olea europaea*, are native in several countries, it is practically impossible to distinguish between their possible local origin and import when only regular wood identification is practiced without using strontium or DNA. Vegetation changes may result from diseases that eliminate susceptible species, not less than climatic changes. It is easy to interpret such changes as a climatic change, while the change may have had nothing to do with climate.

In many cases, related studies such as palynology, seed analysis, archaeozoological, sedimentological, genetic, and historical and technological studies (plant-related archaeological installations and other finds) reflect on the interpretation of the wood material. Only multidisciplinary group efforts can permit a high level of interpretation in such complicated studies. For instance, the issue of the role of *Pinus halepensis* in the ancient landscape of Israel, which has been debated for many years, was studied for a long time under the influence of geobotanical studies conducted when herding was practiced on a very large scale everywhere in the Near East (e.g., Zohary, 1959, 1962, 1973). Moreover, all the wealth of archaeobotanical data that we have today did not exist when these monographs were written. Because of the large-scale planting of *P. halepensis* and the simultaneous dramatic decrease in herding, combined with nature protection in Israel, we have seen in the last two decades a strong process of expansion of *P. halepensis* from both plantations and natural populations into areas occupied by oak-dominated forests and maquis or other types of vegetation that, under the conditions that prevailed for generations, were unsuitable to such a process (see Lavi et al., 2005). For the common archaeobotanist it is hard to be familiar with this type of data. The difficulties reviewed above have realistic solutions if awareness of such difficulties exists—an important goal of this review. When not solved, they limit the depth and reliability of certain studies.

THE PROBLEM OF OVER-INTERPRETATION

Many scientists who have significant experience with the fragmentary archaeobotanical record are aware of its imperfect nature. Sometimes, the results of species identification are taken at face value. Caution must be taken because human preference for certain species, and differences in preservation between taxa, trade, and chance may significantly influence the finds. In many cases the number of samples is small, and statistical bias is a real risk because of sample size. A positive answer when a species is found is much safer than speculating on the species that were not found. In general, a regional picture, emerging from many archaeological sites and strata, is of a greater significance than a single find. Therefore, I warn against the risks of naive or even absurd interpretations, going far afield from the actual data, when considering analyses and discussions of archaeological wood remains. Using the Ockham's razor approach (using minimal assumptions for a certain hypothesis) may help lower such risks.

USES OF WOOD

Wood has many uses, and archaeological evidence of such uses dates back to very early in human history. Plant remains on stone tools indicate that wood was used as raw material probably already almost two million year ago (Dominguez-Rodrigo et al., 2001). Wood has been used for firewood for hundreds of thousands of years. Good evidence of long-lasting massive use of firewood exists in some ancient cave sites. In Kebara (southern Mount Carmel) and Hayonim (western Galilee) caves, the sediments were well preserved and accumulated for many meters over millennia or for many tens of thousands of years. They included many layers rich with silica (phytoliths), reflecting the burning of huge amounts of wood (Schiegl et al., 1994, 1996; Albert et al., 2000). Wood was also used for building and tool-making (e.g., Meiggs, 1982), although in smaller amounts than firewood. In general, unlike pollen or seeds that may be easily introduced into the archaeological record by chance because of their small size and high mobility, wood is not blown in the wind, does not stick to animal fur, is not brought in large chunks by animal dung, and does not roll into sediments. Therefore, in general, wood remains may represent intentional human activity more than many other types of archaeological plant remains. In many cases, specific types of wood were deliberately brought into archaeological sites because of their suitability for certain uses.

TYPES OF ARCHAEOLOGICAL WOOD REMAINS

Wood remains are found in archaeological excavations in several basic types of preservation that allow direct identification because of preservation of their "woody nature": (1) dry, (2) charred, (3) waterlogged, (4) subfossil, and (5) fossilized. In all cases, the anatomical structure of wood is generally preserved, enabling identification. Sometimes geological conditions result in pressure that twists the wood, making identification difficult, limited to genus or family, or even impossible. Biological degradation of dry and waterlogged wood by bacteria and fungi is well known at the biological, chemical, and structural levels (e.g., Blanchette, 2000; Björdal and Nilsson, 2008, and citations therein). The degree of degradation may significantly influence the taxonomic level of identification and its reliability. There are other types of wood remains or evidence of wood (e.g., crystals, tissue and chemical remains on tools, use-wear marks on tools, etc.), and they will be discussed later.

Dry wood is usually found in ancient buildings as part of the structure, furniture, or equipment, or in archaeological and natural sites in very arid hot or cold deserts. Under dry conditions, the structure of the wood is perfectly preserved, almost as in fresh material, and it enables easy identification by microscopic examination. Moreover, dendrochronological studies of the tree rings (if the wood has annual growth-rings) is commonly possible with dry wood. In Israel, dry wood in a form that sometimes even enabled tree-ring studies was found in old buildings such as Al-Aqsa and Omar (Dome of the Rock; Qubbat al-Sakhra) mosques on the Temple Mount (Lev-Yadun et al., 1984; Lev-Yadun, 1992), in Masada (Liphschitz et al., 1981; Liphschitz and Lev-Yadun, 1989), and in several other sites. Dry wood in many cases may even preserve its specific aroma for the genus, which can allow safe identification by experienced people while sawing the specimens in the field. For instance, in our region there are several conifer genera, some of which with have only one species, e.g., *Cedrus libani* (cedar of Lebanon) and *Cupressus sempervirens* (Italian cypress) with strong and specific odors that enable their immediate identification. Two other conifer genera (*Pinus* and *Juniperus*) also have special recognizable odors, but these genera have more than one species in the region, which limits the use of odor as a reliable marker only for the genus and not to the species. Charred, waterlogged, sub-fossil, and fossil material has no specific odor that can be used for field identification.

Charred wood is the most common type of wood remains in archaeological excavations in the Levant. Charred wood may be preserved as whole logs or in large chunks, but usually appears as small fragments ranging in size from a few millimeters to several centimeters. Charred specimens may maintain their microscopic structure, enabling their identification. The charcoals may be hard, and thus easy to handle, or they may turn into dust when touched, or disintegrate under the electronic beam if examined under a scanning electron microscope. When the samples disintegrate, it is possible to impregnate intact soil blocks that include such charred tissues in the field with resin and, when they harden, saw the blocks and study the charcoals in these petrographic thin sections, usually studied for sediment composition (Goldberg et al., 1994). This method was used to study plant remains in the Late Bronze Age Amarna clay tablets (Lev-Yadun, 2004). As with dry wood, dendrochronological studies of the tree rings (if they exist) is possible with wood charcoals if the remains are large enough to include a long growth-ring sequence (e.g., Friedrich et al., 2006). The physical–chemical basis for charcoal preservation and diagenesis in archaeological sediments is only partly understood (e.g., Nichols et al., 2000; Cohen-Ofri et al., 2006), and the level of physics and chemistry needed to study these processes is usually beyond that mastered by archaeologists and botanists.

Although waterlogged wood is not common in our region, some of the most important wood finds in Israel were waterlogged. Waterlogged wood may be also charred, as were some of the ca. 23,000-year-old Epi-Paleolithic site Ohalo II wood remains (Liphschitz and Nadel, 1997), or sub-fossilized, as in the 780,000-year-old material from the Acheulian site of Gesher Benot Ya'aqov (Goren-Inbar et al., 2002). Waterlogged botanical material may be well-preserved because under anaerobic conditions microbial activity is limited. However, waterlogged wood may sometimes be very soft, so soft that it is possible to insert a finger several centimeters into the wood with no effort. Such water-soaked material must be kept in water from the moment of excavation to prevent its physical collapse, shrinkage, and disintegration. Waterlogged material may be found even in the desert. For instance, waterlogged juniper wood was found in the bottom of the Hellenistic well (depth of ca. 70 m) in Be'er Sheva (Lev-Yadun et al., 1995). Several waterlogged ships and boats were found in Israel. A magnificent well-preserved 2,400-year-old ship was found near the shore at Ma'agan Mikhael (Linder and Kahanov, 2003; Kahanov and Linder, 2004). A 2,000-year-old boat was found in the Sea of Galilee (Wachsmann, 1990). Wood analysis showed this boat was composed of seven tree species (*Cedrus libani*, *Pinus halepensis*, *Crataegus* sp., *Quercus* sp., *Salix* sp., *Cercis siliquastrum*, *Ziziphus spina-christi*) (Werker, 1990).

Sub-fossil wood impregnated by aragonite was found among the waterlogged specimens in Gesher Benot Ya'aqov (Goren-Inbar et al., 2002). Fully fossilized wood from various geological periods was found in several geological formations of the Negev (Lorch, 1967, 1968), but they are much too early to be discussed in archaeological contexts.

INORGANIC CRYSTALS FROM WOOD

Wood may have two common types of crystals: calcium oxalate and silica. Both types have several defensive and physiological functions that are outside the scope of this review. Calcium oxalate crystals and silica bodies have an array of shapes, some of which are typical, enabling their use in identification (Franceschi and Horner, 1980; Rapp and Mulholland, 1992; Schiegl et al., 1994, 1996; Meunier and Colin, 2001; Canti, 2003; Nakata, 2003; Prychild et al., 2004; Franceschi and Nakata, 2005; Massey and Hartley, 2006). In addition to the use of specific shapes for identification, typical numerical relations between various shapes may also be employed (Albert et al., 2000, 2008; Tsartsidou et al., 2007, 2008).

STARCH GRAINS

Wood and bark may contain large quantities of starch. In New Guinea starch extracted from trunks of sago palms is a food staple (Diamond, 1997). Starch grains were found on prehistoric stone tools from the humid Neotropics (Panama), indicating their possible use in archaeology (Piperno and Holst, 1998; Piperno and Pearsall, 1998). In our region, prehistoric cereal starch on stone tools from Upper Palaeolithic Ohalo II has been identified (Piperno et al., 2004), indicating the potential for such studies. Starch in eastern Mediterranean woods has been studied only in relation to seasonality of wood formation (Psaras and Konsolaki, 1986). A systematic broad study of the morphology and chemistry of starch grains in Near Eastern woody and non-woody species (especially tubers) is needed in order to make progress in this issue.

THE SIGNIFICANCE OF SPECIES VERSUS GENUS OR FAMILY IDENTIFICATION

In many cases, identification of archaeobotanical material such as wood, seeds, pollen, or phytoliths only to the genus or family level has limited significance. For instance (and this is only one of dozens of possible examples) in Israel there are four deciduous oak (*Quercus*) species: *Q. ithaburensis*, *Q. boissieri*, *Q. libani*, *Q. cerris* (Feinbrun-Dothan and Danin, 1991). These four oak species have very different ecological requirements. *Quercus ithaburensis* represents a warm aspect of the region such as the upper Jordan Valley, the coastal plain, and usually low elevations but up to ca. 1,000 m asl in the Golan Heights. *Quercus boissieri* occupies higher elevations of up to ca. 1,700 m asl but is common in snow-free habitats in Israel. *Quercus libani* and *Q. cerris*, which are of northern and colder origin, reach their southern limit at Mount Hermon in habitats of 1,300–1,900 m asl which receive snow each year (Zohary, 1973). Identifying some type of archaeological remains as "deciduous oak" reflects ecological differences larger than those found throughout the Pleistocene of Israel in any type of botanical finds. Non-botanists used such types of data to propose climatic changes, agricultural issues, etc., while the data used clearly cannot indicate any of the proposed situations because of the identification of the genus rather than the species. The identification of the species and not just the genus may therefore frequently be critical.

THE ANATOMICAL BASIS FOR WOOD IDENTIFICATION

Basic types of wood of the major plant taxa

The aim of this review is to discuss methodological issues and not to serve as a review of studies on wood identification. Here I describe the principles of wood anatomy and taxonomy in relation to wood identification. Descriptions of some types of common deviations from normal anatomy will follow. There are several types of primary and secondary wood that must be known if one wishes to understand or practice wood identification. Woody vascular land plants belong to three large groups, commonly known as ferns, gymnosperms, and angiosperms. Woody ferns have not been growing in the Near East for many millions of years so I will not discuss them. Gymnosperms are a group of ca. 1,000 species of trees and shrubs that have no flowers, usually reproducing by seeds formed in cones. In the Near East, the most common gymnosperm type and a very important component in the archaeological finds of many sites are the conifers. Angiosperms comprise two large taxa: monocotyledons and dicotyledons (broadleaves). Woody monocotyledons may have only primary wood (made of vascular bundles that include primary xylem and phloem surrounded by fibers and embedded in a tissue made of parenchyma cells) even if they are tree size (e.g., palms). Some monocotyledons, not found in the native flora of the Near East (e.g., *Aloe*, *Dracaena*), produce a special type of secondary wood (Philipson et al., 1971). All gymnosperms and most dicotyledons (including small annuals) have secondary wood. Secondary wood is a three-dimensional tissue and its structure is systematically described by viewing three planes: cross section, longitudinal tangential, and longitudinal radial. The description of these three planes allows characterization and identification of the wood. For certain taxa with unique anatomical features, one or two planes may be sufficient for an experienced scientist. To obtain a reliable description of the anatomical structure, the wood or charcoal sample should usually be not smaller from 0.5 cm^3.

Gymnosperms in the Near East belong to two distinct taxa: conifers (e.g., pines, junipers, cedar, and cypress, which at maturity are usually trees although junipers may under unfavorable conditions exist as large shrubs), and several species of *Ephedra* that may be small or large shrubs or huge climbers, covering tall mature trees or houses (Zohary, 1973). Other groups of gymnosperms exist (Gifford and Foster, 1989) but not in the Near East. Dicotyledons may appear as annuals (e.g., many legumes, Asteraceae), shrubs (e.g., *Sarcopoterium spinosum*, *Calicotome villosa*), or trees (e.g., fig, olive, oaks, poplars).

Both conifers and dicotyledons have a lateral meristematic tissue, the vascular cambium, which produces secondary xylem and phloem. In many cases, the secondary xylem (wood) has annual or non-annual (false) growth rings. These growth rings are the biological foundation of tree-ring studies, known as dendrochronology (Fritts, 1976; Baillie, 1982; Lev-Yadun, 1987; Schweingruber, 1996). The wood of dicotyledons as seen in cross sections may belong to several general types: (1) ring porous wood (large vessel members are formed at the beginning of the growth ring with no vessel members formed later), (2) semi-ring porous wood (large vessel members are formed at the beginning of the growth ring and gradually become smaller later in the season), (3) diffuse porous wood (vessel members of the same size classes are distributed evenly throughout the growth ring), (4) wood with included phloem, and (5) wood with no clear annual or non-annual growth rings. There are many subtypes and combinations of these structures, and in a local flora with a relatively small number of common trees or shrubs like in Israel, some of the anatomical characters described may sometimes characterize only a single species or genus, helping in identification.

The taxa with secondary xylem (gymnosperms and dicotyledons) have two well-defined components in their wood: (1) the axial and (2) the radial systems known as the vascular rays. The axial system composes on average 90% of the wood in conifers and ca. 75% in dicotyledons (Lev-Yadun and Aloni, 1995). In conifers, the axial system is dominated by tracheids, which when they have a broad lumen, a type produced usually in the beginning of the growth season (known as earlywood), serve mostly in water transport, while towards the end of the season they have smaller lumens (known as latewood) and function mostly in mechanical support (Fahn, 1990). Tracheids are dead cells with no DNA, a factor that influences the ability to study ancient DNA from conifer wood. The gymnosperm genus *Ephedra* produces both axial tracheids and vessel members (Lev-Yadun, 1994a). Early- and latewood tracheids may not be the sole component of the axial system in conifers. Many conifers have, in addition to their axial tracheids, axial resin ducts that produce the defensive resin. In certain conifers (e.g., the ca. 110 species of the genus *Pinus*), resin ducts are formed constitutively, but these and other taxa that produce no constitutive axial resin ducts in the wood (e.g., *Cedrus*) may produce additional traumatic resin ducts after wounding (Fahn, 1979; Fahn et al., 1979). Members of the genera *Cupressus* and *Juniperus* have no resin ducts in the secondary wood and have resin ducts only in the bark, leaves, and reproductive structures. In dicotyledons, the axial system includes the water-transporting elements (tracheids and vessel members), the mechanically supporting fiber cells, and a parenchymatous component that has a major function in storage and wound healing (Fahn, 1990). In certain dicotyledon taxa axial gum ducts (the parallel of resin ducts in conifers) are formed (Fahn, 1979). Wounding may increase the number of gum ducts in dicotyledons, similar to resin ducts in conifers. In certain taxa, common in the deserts of the Near East, including annuals, shrubs, and small trees of the Chenopodiaceae (e.g., *Suaeda* sp., *Hammada* sp., *Haloxylon* sp., *Anabasis* sp.), islands of axial secondary phloem (known as included phloem) are typically formed within the secondary xylem (Fahn et al., 1986).

The radial system (the vascular rays) is usually composed of parenchyma, although other cell types such as tracheids, resin and gum ducts, radial phloem, and radial fibers may infrequently be found in the rays (Fahn, 1990; Lev-Yadun and Aloni, 1991a, 1995; Lev-Yadun, 1994b). Like the types of ring porosity mentioned above, the specific structure of the rays— (1) height in cell number, (2) width in cell number, (3) having radial resin or gum ducts, (4) having cells of only the same size and if not, their size variation, (5) having radial components such as tracheids, fibers, and phloem, and being of two size categories (huge and small) as in oaks—is used for identification (e.g., Greguss, 1955; Fahn et al., 1986; IAWA, 1989, 2004; Schweingruber, 1990). Some woody dicotyledons either never have rays in their secondary wood throughout their life, or else, as in *Suaeda monoica*, form rays only after attaining a certain thickness (Lev-Yadun and Aloni, 1991a, 1995). In conifers with no axial resin ducts in the wood, such as *Cupressus* and *Juniperus*, the living parenchyma cells of the rays are a potential source of ancient DNA.

Variation in wood anatomy related to age and position in the plant

The general description of secondary wood structure given above is only a basic one. Considerable, and even dramatic changes in wood structure occur following naturally occurring internal changes with both age and size, with position within the plant, and as a response to biotic and abiotic external factors. Most of these changes are not described or discussed in detail in the atlases of wood anatomy used for identification of archaeological wood and I will therefore address them briefly.

Roots may differ considerably in structure from stems or branches. Cell size in roots is usually larger than that of trunks. Intra-annual (false) growth rings formed in the trunk may in many cases not be produced in roots. While in roots the cells are larger than in trunks, cell size in branches is generally smaller than the corresponding cells produced at the same time in the trunk.

A general trend in cell size occurs in the wood of all plants with cambial activity and secondary growth. The trend is of increasing tracheid, vessel member, fiber, and ray size in two axes: (1) the size increases basipetal from the apex to the base of the trunk, and (2) along the radius, from the pith towards the outer layers of the wood (see Mencuccini et al., 2007). This is called “length-on-age trend” and it must be taken into consideration in many studies of wood anatomy, including those of wood from archaeological excavations. A special and common example of this general anatomical trend is juvenile wood.

Juvenile wood, or wood formed in the center of trunks (when they were young and thin), in young branches, or in young roots differs in structure from mature trunk, branch, or root wood, respectively. Juvenile wood has mainly been studied from the perspective of wood as raw material for the paper industry and timber with respect to its quality (Zobel and Sprague, 1998). General changes characterizing juvenile wood that apply to all known woody plants are: (1) the length of fibers, tracheids, and vessel members is smaller than in mature wood; (2) the vessel members and tracheids are narrower in diameter; (3) the rays are narrower and shorter in terms of cell numbers; (4) in taxa that have complicated ray structure at maturity (e.g., *Ephedra*, *Suaeda*, *Quercus*) the rays in juvenile wood are not only smaller, but much less complicated in structure (Lev-Yadun and Aloni, 1991a, 1993a, 1995). Description of the anatomical characteristics of juvenile wood with respect to identification of archaeological material is anecdotal. It is probable that many archaeobotanists are not aware of the dramatic effects of juvenility on the structure of many woody plants. For instance, in *Melia azedarach*, the rays in the juvenile wood near the pith are 1–2 cells wide, while in mature wood the rays are 5–6 cells wide, resulting in a completely different anatomy (Lev-Yadun, unpublished). Using anatomical keys constructed only for mature wood without knowing this fact may result in a wrong identification or no identification at all.

In all plants known to regularly produce secondary wood (ferns, conifers, and dicotyledons) there are changes in wood structure at branch junctions (Lev-Yadun and Aloni, 1990a, 1991b; Rothwell and

Lev-Yadun, 2005; Rothwell et al., 2008). The tissues formed there have circular patterns because of changes in the patterns of the polar auxin flow in the cambium (Sachs and Cohen, 1982). For instance, Goren-Inbar et al. (2002) found such spiral wood of *Fraxinus* sp. in the wood remains of the 780,000-year-old wood from Gesher Benot Ya'aqov.

In dry wood, and also in some samples of waterlogged wood of mature trees, a specific wood character is sometimes found. It is known as heartwood, to distinguish it from sapwood. The heartwood, which is usually darker than the sapwood (Hillis, 1987), always occupies the inner (central) parts of the wood, while the sapwood is found in the outer, more recent parts of the wood. A well-known case is the *Diospyros* (ebony) wood used in Africa for sculptures, in which the dark heartwood is black, while the sapwood is yellowish. In the Near East, a wood with dark (purple) heartwood is *Juniperus phoenicea*; very clear differences between its dark heartwood and light-colored sapwood were found in the remains from Masada (Liphschitz and Lev-Yadun, 1989). Similarly, the very dark (brown) heartwood was obvious in *Pinus nigra* logs from ancient houses in Safed (Israel), Cyprus, and Turkey (e.g., Liphschitz et al., 1979a). With the increase in girth and age of trunks, the proportion of heartwood increases. In mature trees, over 100 years in age, most of the trunk is usually composed of heartwood, while the number of live growth rings that compose the sapwood is usually 10–30 (Baillie, 1982). Heartwood is less susceptible to attack by insects and fungi than sapwood because the heartwood cells are dead (bearing on ancient DNA studies because the dead cells usually lost their DNA) and usually impregnated with defensive secondary metabolites. Ancient carpenters and builders knew this property, and in many cases they got rid of the sapwood when handling timber.

Traumatic tissues

A common case of wood that differs from the normal structure is traumatic wood. Traumas that directly change the structure of wood or the balance of regulatory factors that induce further variant anatomical development may be of biotic or abiotic origins. Common traumatic factors are fire, snow, wind storms, landslides, floods, earthquakes, volcanic activity, insect and large herbivore activity, and many types of human activities including logging, pruning, pollarding, resin tapping, chemical pollution (of soil, water, and air), and in the last century, nuclear radiation as well (e.g., Schmitt et al., 2000). All aspects of wood anatomy may be changed and I will give several common examples. Several monographs give a fuller description of traumatic wood (Timell, 1986; Larson, 1994; Fink, 1999; Schweingruber et al., 2006). Traumatic tissues in many conifers are characterized by traumatic resin ducts. *Cedrus libani* produces rows of resin ducts (Fahn et al., 1979), *Pinus halepensis* forms additional resin ducts (Fahn and Zamski, 1970; Lev-Yadun and Aloni, 1992; Lev-Yadun, 2000a), and *Pinus pinea* also forms additional traumatic resin ducts (Lev-Yadun, 2002). Similar traumatic changes in wood anatomy were found in Israeli *Ephedra* (Lev-Yadun, 1994a) and various local native and feral dicotyledons, e.g., *Ailanthus altissima*, *Ficus sycomorus*, *Quercus calliprinos*, *Q. ithaburensis*, *Rhamnus alaternus* (Lev-Yadun and Aloni, 1991b, 1992, 1993b; Lev-Yadun, 1994c, 2000ba). The many types of anatomical changes in the wood induced by traumas may present difficulties in identification of certain specimens of archaeological wood remains. However, traumatic tissues may be used with or without the combination of dendrochronology to give information on various environmental changes and human activities (Schweingruber et al., 2006).

FUNGAL AND INSECT DAMAGE AND IDENTIFICATION

Dry, charred, and waterlogged wood all sometimes show clear signs of damage by insects and fungi. Most of the data about such agents in the Levantine archaeobotanical record were published concerning insects in cereal and legume grain (e.g., Kislev, 1991; Kislev and Melamed, 2000; Kislev and Simchoni, 2007). Fungal and insect damage and the identification of the pathogenic species is a type of data that may enable the reconstruction of seasonality, duration of use of certain wooden objects, geographical origin, and technical issues such as carpentry practices. For instance, clear signs of ancient tunneling by insects were found in the cedar wood from al-Aqsa and Omar mosques on the Temple Mount. (Lev-Yadun et al., 1984; Lev-Yadun, 1992). Some of the Middle and Late Bronze Age charred oak wood samples from Tel Nami published by Lev-Yadun et al. (1996) were infested by fungal hyphae, indicating that the wood was not fresh when burnt. The fungal issue was not published, however, because the fungus was not identified. This issue has never been studied systematically in the region with respect to wood remains.

SAMPLING WOOD FROM ARCHAEOLOGICAL SEDIMENTS AND FINDS

There are several methods of extraction of wood samples from archaeological sediments, buildings, or items. Small fragments can be simply picked up during excavations. Dry sieving of excavated sediments is a very common method. Floatation in water tanks is done by putting the sediment into a container filled with water, a process that results in floating of light plant material (both charred and non-charred). Certain sediments, pottery, or clay objects may be impregnated with resin and sectioned in situ. Large wooden beams or installations may be sampled by sawing, coring with a hollow borer, or by cutting off small samples. Delicate items in museums and exhibitions cannot be sampled in a way that will visually damage them, so minute thin samples may be sliced off with a sharp razor blade.

WOOD PRESERVATION

In many cases, some type of wood preservation or specific treatment is required in order to allow the technical handling needed for identification and conservation. Some of the techniques have already been described above briefly. However, archaeological wood remains are regularly preserved for non-anatomical studies or for exhibits. A good handbook that describes various methods of preservation is Rowell and Barbour (1990). In Israel, a boat from the Sea of Galilee (Wachsmann, 1990) and the ship from Ma'agan Mikhael (Linder and Kahanov, 2003; Kahanov and Linder, 2004) are examples of archaeological wood preservation.

COMMON PREPARATION AND MICROSCOPIC METHODS USED FOR WOOD IDENTIFICATION

Several common technical methods are used in studies of wood identification according to its anatomical features. The basic technique used for dry and waterlogged wood is preparing fresh sections by hand with a sharp razor blade. The sections may be studied immediately, immersed in water, or stained with various histological stains, and mounted permanently on glass. Sections may be done with the aid of a sliding microtome for dry wood (with softening when needed) or with the aid of freezing for very soft waterlogged material. Charcoals may be embedded in paraffin and sectioned with a rotary microtome (Liphschitz, 1999). Correction fluid may be used for better visualization of vessel members (Angeles, 2001), and internal micro-casting by various elastomers may help in the study of delicate anatomical components in both charred and non-charred wood (André, 2005). Material in sediments or pottery or other clay artifacts may be embedded with suitable resins and sectioned in situ. Sections from these various preparation types are studied under regular light microscopes using bright-field or polarized illumination. Charcoals may also be studied on freshly broken surfaces or on surfaces prepared by a sharp razor blade under epi-illumination that allows viewing the cell types and their arrangements. Similarly, such surfaces may be studied under the Scanning Electron Microscope (SEM), which allows for higher magnifications of the cells and searching for unique sub-cellular features such as fringed tori in *Cedrus libani* and three-dimensional views of the tissues.

WOOD ANATOMICAL ATLASES AND RELATED PUBLICATIONS FOR THE WOODY FLORA OF THE LEVANT AND OTHER RELEVANT REGIONS

Several atlases refer to the wood anatomy of species that may be found in archaeological excavations in the Levant in general and Israel in particular. The oldest that describes the wood anatomy of various trees and shrubs from the Mediterranean region, including European species, is by Huber and Rouschal (1954). Classic atlases of conifer and dicotyledon wood were published by Greguss (1955, 1959, 1972) and include many species from all over the world. A very useful anatomy atlas of the wood of many trees and shrubs from Israel was published by Fahn et al. (1986). Anatomical descriptions of wood of desert trees and shrubs from Saudi Arabia, some of which also grow in Israel, are given in Jagiella and Kürschner (1987). Wood of wild and domesticated trees from northern Iran is described in an Iranian atlas (Pajouh and Schweingruber, 1988). Some wild trees described in this atlas also grow in the Levant, as do some domesticated fruit trees found in archaeological excavations in many regions including Israel. Schweingruber (1990), in a high-quality atlas, describes the wood anatomy of hundreds of European species. A small number of these species (e.g., olive, Aleppo pine) grow in the Levant. Moreover, many European species of trees that can be found in Levantine archaeological contexts, e.g., in ships, imported timber, or various worked wooden goods, are described in that atlas. The need for identification of European woods is clearly demonstrated by the wood found in the 2,400-year-old Ma'agan Mikhael ship (Liphschitz, 2004). Neumann et al. (2001) describe the wood anatomy of many Saharan species, some of which grow in Israel and in other parts of the Near East. Together, all these atlases provide a basic description of the wood anatomy of many wild and domesticated trees and shrubs from the region. However, none of these gives systematic data about juvenile and root wood, branch junctions, or traumatic wood. The influence of relevant growth conditions, such as forest thinning, flooding, salinity, etc., on the wood anatomy of the species is also not given. Moreover, since the critical information of the distance of the samples from the pith is almost never given, it is impossible to relate the anatomical descriptions to size and age or to agricultural practices such as irrigation.

A detailed wood-anatomical atlas of Levantine trees and shrubs that provides the full descriptions of all relevant anatomical variations as discussed above and that includes both light and SEM pictures is certainly needed. A critical type of figures needed is low magnification pictures that allow a general view of the growth rings or just large areas of the woody tissues. All atlases suffer from the dominance of microscopic figures, focusing on small areas of tissue. Since anatomical variations within the wood are a basic and non-documented character, there are repeated difficulties in using the atlases. In addition to atlases that describe many species without dealing with variability within taxa, there are some more specific publications, e.g., Grundwag and Werker (1976) for the genus *Pistacia*. Such studies may give anatomical details not given in atlases. Wood descriptions have an internationally accepted glossary that may assist in using computerized keys (IAWA, 1989, 2004).

LACK OF BARK DESCRIPTIONS

Wood in intact plants and in certain archaeological specimens is associated with bark. Bark was used in many cultures for food, tannery, as a source of fibers for textiles and cordage, in medicine, housing, boat construction, as writing material, dyes, source of poison, condiments, corking, fuel, and making of containers (Hill, 1952; Turner, 1988; Gottesfeld, 1992; Sandved et al., 1993; Zackrisson et al., 2000; Sandgathe and Hayden, 2003). Thus, there are many opportunities of introducing bark into the archaeological record. Bark remains in considerable amounts were found in the 780,000-year-old remnants from Gesher Benot Ya'aqov (Goren-Inbar et al., 2002) and in smaller amounts in Masada (Liphschitz et al., 1981; Liphschitz and Lev-Yadun, 1989) and in the 2,400-year-old Ma'agan Mikhael ship (Werker, 2003). There is no systematic description of the morphology and anatomy of the barks of trees and shrubs from the Near East and for most other woody floras of the world. This lacuna in the anatomical studies of woody plants results in difficulties in identification of bark remains. Tropical regions are rich in tree species, and the principles of bark anatomy in many tropical trees were studied and described in detail (Roth, 1981). However, even this detailed monograph cannot serve as a reference for systematic bark identification. As for wood anatomy, there are internationally accepted terms for bark tissues (Trockenbrodt, 1990; Lev-Yadun, 1991). Like in the secondary wood, there are significant changes in bark morphology and anatomy with age (Roth, 1981; Trockenbrodt, 1991; Lev-Yadun, 2001b) that have been studied to a certain extent only for a very small number of species in the Near East (e.g., Arzee et al., 1970, 1977; Arbel and Arzee, 1976; Lev-Yadun and Aloni, 1990b) or elsewhere. The dramatic changes in the morphology and structure of tree barks that occur with age, size, and according to growth conditions further complicate bark identification.

WOOD FIBER IDENTIFICATION

There are several cases where wood fiber may be critical for identification in archaeological contexts. In very degraded wood, for instance because of fungal activity, but also in charred material, especially in hearths, and in waterlogged wood or plant material in animal dung, wood structure may considerably disintegrate and only fibers may remain. Plant material was intentionally added to clay to produce pottery, and various clay items, or even clay documents. This added plant material was usually ground into small tissue fragments before mixing with the clay. Such fragmented materials are usually very hard to identify, but certain taxa have unique features that may help in identification. For several centuries, paper, commonly made of wood fibers (Hill, 1952) has been part of the archaeological record. Paper was used not only for writing and printing, but also for construction, wrapping, storage, etc. Because of the enormous economic value of paper, there are handbooks for identification of paper-making fibers including wood fibers (e.g., Ilvessalo-Pfäffli, 1995).

When the preservation of wood is bad, the fibers may allow identifying the archaeological remains only at a level of "conifer wood", dicotyledon wood, and the like (see Lev-Yadun, 2004).

STATISTICAL CHARACTERS OF WOOD ANATOMY AND ARCHAEOLOGY

Growth conditions and agricultural practices can influence the anatomical structure of wood. Measurements of vessel sizes (maximal, minimal, and size class distribution), their grouping, and other numerical factors of wood anatomy may provide information about the conditions under which a tree grew (Carlquist, 1975; Baas et al., 1983; Carlquist and Hoekman, 1986; Baas and Schweingruber, 1987; Tyree and Zimmermann, 2002; Wheeler et al., 2007). This principle was used to study olive domestication, olive orchard management, and related issues (e.g., Terral and Arnold-Simard, 1996; Terral and Mengüal, 1999; Terral, 2000; Terral and Durand, 2006). The application of ecological wood anatomy to archaeology is a great idea, opening new opportunities in the study of ancient agricultural and forestry practices. However, internal factors such as the changes in vessel characters with age and distance from the pith that were discussed above were not considered in these pioneering studies. Moreover, in some of the studies cited here and in others by the Terral group only the statistical characters of the measurements, without first presenting the real measurements, were published, thus not allowing the reader to know the actual values of cell sizes and to evaluate the meaning of the finds. A critical type of missing information is the distance of the samples from the pith. Without knowing this distance the statistical comparisons are meaningless or even misleading. This also does not allow for comparative studies with material from other sites. When these characters are measured on fragmented charcoals from archaeological excavations, usually the fragmentation does not allow measuring the distance from the pith. Sometimes, if growth-rings are seen, their curvature may allow an estimation of the age or distance from the pith of the piece of charcoal. Young material produced near the pith will be characterized by strong growth-ring curvature, while a tissue originating from the outer parts of a thick trunk will have no curvature. Without knowing at least the approximate position within the radius, fragmented charcoals should not be used for statistical analyses. I also stress that, as discussed above, wounding may change the anatomical statistics (e.g., Lev-Yadun and Aloni, 1991b, 1992, 1993b; Lev-Yadun, 1994c, 2000b, 2001a; Fink, 1999). This method does have very good prospects of illuminating various questions related to domestication, climatic changes, changes in agricultural practices, identification of pruning, etc., if the relevant endogenous anatomical changes are considered in the process.

DENDROCHRONOLOGY

Dendrochronology (dating with tree-rings) is a very important method of studying archaeological wood remains in many regions of the world. Along with the use of archaeological wood remains, dendrochronology commonly makes use of live or dead trees in forests or geological sediments. In general, many dendrochronological studies are not archaeologically oriented, but rather ecologically or climatologically. Space limitations do not allow me to outline the biological basis for dendrochronology. The same is true for the achievements of dendrochronology in a global or a Near Eastern perspective, and I will just mention some studies briefly. As stated above, annual growth-rings are the biological foundation of dendrochronology (Fritts, 1976; Baillie, 1982; Lev-Yadun, 1987; Schweingruber, 1996). Dendrochronology, when there is a reliable sequence of tree-rings, may help date archaeological and other events with precision of a year for millennia-old archaeological sites. Moreover, under ecological conditions where tree-ring formation has a precise seasonal rhythm (usually in the temperate zone), events like building a house and changing its structure may sometimes be dated to a specific month even in prehistoric sites (Baillie, 1982; Schweingruber, 1996). In regions like Europe, where wood was a common building material, and where because of climatic and soil conditions archaeological wood remains suitable for dendrochronology are very common, tree-ring analysis is conducted in many archaeological studies. In the Near East, with both mud-brick and stone building traditions and many trees that do not produce clear annual growth-rings, there are very limited opportunities to use dendrochronology in archaeological studies (e.g., Lev-Yadun et al., 1984; Lev-Yadun, 1992). However, in the Aegean and in Anatolia there are many more well-preserved archaeological wood remains with clear growth-rings that have the potential for dating various events (e.g., Kuniholm et al., 1996; Hughes et al., 2001; Manning et al., 2001; Griggs et al., 2007). Climatological aspects of tree-rings of Near Eastern old trees have also been given some attention

(Fahn et al., 1963; Liphschitz et al., 1979a, 1979b, 1987a; Lev-Yadun et al., 1981; Yakir et al., 1996; Touchan and Hughes, 1999; Touchan et al., 1999, 2003, 2005, 2007; Akkemik and Aras, 2005; Akkemik et al., 2008). Several interesting dendrochronological studies that also involved wood identification of timber from 19th and 20th century CE historical buildings were done to examine historical issues of the last 150 years by Nili Liphschitz and Gideon Biger, but because of their late period and limitation of space they will not be reviewed here.

STABLE AND RADIOACTIVE ISOTOPES

Several atoms common in wood (H, C, N, O) have stable or radioactive isotopes that may give important information about the ecological conditions under which the plants grew or may be used for dating. Most studies with stable isotopes of archaeological wood were parts of tree-ring studies (e.g., Libby, 1983; Schweingruber, 1996; McCarroll and Loader, 2004). The most important radioactive isotope in this respect is ^{14}C, commonly used for absolute dating (e.g., Boareto, 2008, this issue). The whole subject is outside the scope of this review, and only one study (Yakir et al., 1994) will be discussed in some detail in the following section.

STRONTIUM AND THE ORIGIN OF ARCHAEOLOGICAL WOOD

In certain studies the specific origin of archaeological wood may have a critical bearing on the interpretation of the data. For instance, the isotopic composition of the *Tamarix* wood from the Roman siege rampart in Masada clearly indicates that the trees grew under more humid conditions than those prevailing today in the vicinity of Masada (Yakir et al., 1994). If the wood is local, a significant climatic change probably occurred in the 1st century CE. If, however, the wood was brought from a more humid region, no climatic change occurred. Today there are two relevant available methods of identifying the region of origin of the wood. The first is to use DNA markers of current populations and examine which is genetically more similar to the DNA from the wood (will be discussed later). This method brought dramatic results in understanding the origin of individual founder crops of the Neolithic Revolution (Heun et al., 1997; Ladizinsky, 1999; Özkan et al., 2002, 2005; Salamini et al., 2002; Morrell and Clegg, 2007) and helped in the identification of the core area of the origin of agriculture within the Fertile Crescent in southeastern Turkey (Lev-Yadun et al., 2000) and in understanding the spread of agriculture from the core area (Abbo et al., 2006). The second method is based on the fact that different areas and geologies have a different level of strontium isotopes and the ratio $^{87}Sr/^{86}Sr$ in the soil is consequently reflected in the wood (Diamond, 2001). This method was used to reveal the specific origin of timber out of several possible ones in the ca. 1,000-year-old Anasazi buildings in Chaco Canyon, New Mexico, USA (English et al., 2001). One or both methods should be used to study the origin of the *Tamarix* wood from the Roman siege rampart in Masada to examine the possibility that the proposed climatic change (Yakir et al., 1994) is real or whether the wood was imported, as proposed on historical grounds (Gichon, 2000). Studies of other important archaeological timber such as the cedar, oak, and cypress wood from Al-Aqsa and Omar mosques on the Temple Mount (Lev-Yadun et al., 1984; Lev-Yadun, 1992) or from other sites will also benefit from isotopic identification the origin of the wood.

ANCIENT DNA

With the advent of DNA techniques in the last two decades there are better prospects for using ancient DNA. As mentioned above, most of the conifer wood is composed of dead tracheids that have no DNA and it may be extracted only from living ray cells or axial resin ducts. Since in old trunks (the major source of timber) of both conifers and dicotyledons most of the wood is composed of dead heartwood, there are difficulties in extracting DNA from wood. The critical technique for studying ancient DNA is called PCR (Polymerase Chain Reaction), in which minute amounts of DNA are multiplied many times in the test-tube. This method is, however, very sensitive to modern contaminations, and strict lab procedures and controls are required to conduct reliable ancient DNA studies (Pääbo et al., 2004). Plants have three genomes in their live cells (nuclear, mitochondrial, chloroplastidic) while animals have only two (nuclear, mitochondrial). It is possible to study ancient DNA of each of these genomes independently (Schlumbaum et al., 2008). Concerning ancient DNA, the biggest problem is its gradual degradation with time and its quick destruction during burning and charring. An issue of practical importance is the ability to screen for archaeological samples in which the DNA is not fully degraded without passing a large number of samples through the tedious and expensive process. Elbaum et al. (2006) found that in the woody tissues of olive pits, DNA preservation is correlated with lignin polymer preservation as measured by infrared (IR) spectroscopy. It is therefore possible to screen archaeological wood remains and select those samples with better chances of having better-preserved DNA. In any case, ancient DNA sequences can be amplified from wood (Deguilloux et al., 2002, 2004). Ancient DNA studies of archaeological plant remains in general, and of wood in particular, in the Near East have received very little attention. In the Near East, DNA has been cloned to date from two samples of ancient *Cedrus libani* wood, the first from the King Midas Tumulus (ca. 100 km west of Ankara, Turkey), and the second from the Al-Aqsa Mosque (given to the authors by me) (Rogers and Kaya, 2006). Most attention to archaeological plant DNA has been given to domesticated plants, but until the end of the year 2004, only ca. 40 papers were published on ancient plant DNA (Gugerli et al., 2005).

OTHER MOLECULAR STUDIES

DNA is not the only molecule that can be identified in archaeological biological remains. In ancient animals such as mastodon and *Tyrannosaurus rex*, proteins are sometimes preserved. Their sequencing may provide genetic data in cases where DNA was not preserved (Asara et al., 2007a). Data obtained from such studies have inherent problems due to technical difficulties (Asara et al., 2007b). Proteins and other molecules can be extracted from archaeological wood remains, especially from dry and waterlogged material. This issue has received very little attention in plants and will probably advance faster in the future.

ARCHAEOLOGICAL WOOD REMAINS— FORESTRY AND NATURE CONSERVATION

In Israel and other parts of the Mediterranean, human activity resulted in dramatic degradation of the vegetation, especially of trees (e.g., Mikesell, 1969; Zohary, 1973, 1983; Thirgood, 1981; Perlin, 1991; Lev-Yadun, 1997; Williams, 2003). In addition to the almost total deforestation of the Land of Israel during the last several millennia, several trees disappeared altogether from certain regions or all of the country. *Cupressus sempervirens* wood from ca. 15,000-year-old Natufian layers in el-Wad Cave indicate that this tree was part of the natural vegetation of Mount Carmel but disappeared from that region (Lev-Yadun and Weinstein-Evron, 1993, 1994). Similarly, *Juniperus phoenicea* was part of the natural vegetation in the mountains of the central Negev Desert ca. 10,000 years ago (Baruch and Goring-Morris, 1997). The knowledge of such species that disappeared can and should be used while planning nature protection, forestry projects, and re-introduction of lost species (as indeed has been done with birds and mammals).

The role of *Pinus halepensis* in forestry in Israel in the last 85 years due to its ease of treatment and its ability to grow under East Mediterranean conditions is well known (Bonneh, 2000; Schiller, 2000). Liphschitz et al. (1987/9), while citing selectively from the references, proposed that *P. halepensis* was not native to Israel and that it arrived in the land in the Late Bronze Age, ca. 3,500 years ago. However, the finds of archaeological wood remains published by Liphschitz (1986, 1986/7) indicated that the tree was native although not a common tree in the landscape, except for specific habitats and periods (Baruch, 1990; Weinstein-Evron and Lev-Yadun, 2000; Lev-Yadun and Weinstein-Evron, 2002). The understanding of the native character of *P. halepensis* has significant implications on decisions about its role in forestry and nature protection and concerning the proposals that all *P. halepensis* wood remnants from archaeological excavations are imported (see below on the wood trade).

DOMINANCE OF *QUERCUS CALLIPRINOS* (KERMES OAK) IN THE CENTRAL COASTAL PLAIN OF ISRAEL

The Central Coastal Plain of Israel was considered to be a typical habitat of the deciduous Mt. Tabor oak (*Quercus ithaburensis*) (Eig, 1934; Zohary, 1962). Analysis of many archaeological wood samples from several archaeological sites located in the heart of the territory showed that the dominant tree there was the evergreen kermes oak *Q. calliprinos*, followed by *Pistacia palaestina* rather than *Q. ithaburensis* (Liphschitz et al., 1987b). Such indicative data for a change in vegetation and about the primary vegetation in a certain region is one of the expected types of information emerging from studying archaeological wood remains.

GEOBOTANY AND THE QUESTION OF CLIMATIC CHANGES IN THE LIGHT OF ANCIENT WOOD REMAINS

Finds that include wood remains in considerable numbers enable us to take a close look back in time. We already have several "wooden" windows that allow us to look deep into the Pleistocene in Israel: (1) the large assembly of 780,000-year-old wood from the Acheulian site of Gesher Benot Ya'aqov (Goren-Inbar et al., 2002; Werker, 2006); (2) the 30,000–60,000-year-old Mousterian wood remains from Kebara cave (Baruch et al., 1992); (3) the 23,000-year-old wood from Ohalo II (Nadel and Werker, 1999; Nadel et al., 2006); and (4) the 15,000-year-old Natufian wood remains from el-Wad Cave (Lev-Yadun and Weinstein-Evron, 1994). All these significant finds of wood remains clearly indicate that in the Mediterranean district of Israel the vegetation in the vicinity of the sites was almost similar to the current vegetation. A similar conclusion was reached when Holocene wood remains from dozens of archaeological excavations all over Israel were analyzed (Liphschitz, 1986). This general conclusion, about a Mediterranean climate prevailing in the region for the last 800,000 years at least, does not exclude various short or long climatic fluctuations, but points to the fact that the variations were still within the Mediterranean scope. Palynological studies documenting the vegetation in the last several hundreds of thousands of years, which may be, first, more continuous, and, second, more sensitive to the climatic fluctuations than studies of wood remains, also indicate that the core of the Mediterranean zone in Israel always had a Mediterranean climate (e.g., Horowitz, 1979, 1992; Weinstein-Evron, 1983; Baruch and Bottema, 1999). This view is further supported by the fact that even a broad dramatic boreal event like the Younger Dryas is not to be taken as a significal change (if at all) in local palynological sequences (Bottema, 1995; Lev-Yadun and Weinstein-Evron, 2005). In the second half of the Holocene, human activity probably influenced the vegetation much more than climatic fluctuations (see Baruch, 1986). Such changes in plant cover must have influenced geomorphological and hydrological balances, as happened in many other parts of the world (Thirgood, 1981; Nir, 1983; Perlin, 1991; Williams, 2003; Diamond, 2005). This very well-known aspect has not usually been taken into consideration in palaeoecological studies in our region, especially those done by non-ecologists.

SOCIAL STATUS IN MASADA: THE KING'S PALACE VERSUS THE ROMAN SIEGE RAMPART

Many types of archaeological finds indicate social status but are outside the scope of this review. Concerning wood, Masada provides an excellent example of how differences in social status are reflected in the wood types. The first detailed study of wood in Masada was of the wood used by the Roman army to construct the siege rampart (Liphschitz et al., 1981). The wood used by the soldiers was dominated by *Tamarix*, a tree that grows in more humid habitats (wadis and depressions that enjoy runoff water) and oases within the desert. It is not a high-quality timber and the logs were not worked, but were cut by several blows by a sharp implement and used with no further manipulation. The picture emerging from the wood found in King Herod's palace and the other part of the royal site of Masada is of the importing of timber such as *Cedrus libani* and *Juniperus phoenicea* and delicate items made of oak wood and other non-desert trees (Liphschitz and Lev-Yadun, 1989). The social and economic gap between soldiers and royalty is clearly indicated by the wood finds.

WOOD AS AN INDICATION OF ANCIENT TRADE

We assume that a significant long-distance trade in wood did not exist in pre-agricultural periods. This is not only because of cultural/technological issues, but also because considerable parts of the Mediterranean and humid regions of the land were forested, and in arid regions groups of trees still existed in wadis and depressions that accumulated runoff water. If some small items were traded, the anecdotal preservation of wood from such early periods makes the prospects of identifying trade in wooden objects extremely low. In the last 5,500 years (since the Early Bronze Age I), the critical species used to identify international trade of timber or items made of wood is *Cedrus libani*. This tree grew in Lebanon, Cyprus, and Turkey (Mikesell, 1969; Meheshwari and Biswas, 1970) and its occurrence in Holocene archaeological contexts in ancient Israel is an indication of trade. Clear evidence for trade of wood in the archaeology of Israel emerges in the Early Bronze Age. Gophna and Liphschitz (1996) found *Cedrus libani* wood in Early Bronze Age I Ashkelon. Liphschitz (1998) reviewed the archaeological finds of wooden houshold objects from Israel and gives clear indications of import of various wooden items made of *Buxus sempervirens* that never grew in Israel. Altogether, there is clear direct evidence in the archaeobotanical record of Israel of international trade in timber and wooden items. This issue becomes very complicated when the indigenous character of several tree species is not recognized. For instance because *Pinus halepensis* (Liphschitz et al., 1987/9) and *Cupressus sempervirens* (Liphschitz and Biger, 1989, 1995) were not considered to be native to Israel, in spite of clear evidence of their being ancient elements of the flora (e.g., Lev-Yadun and Weinstein-Evron, 1993, 1994; Weinstein-Evron and Lev-Yadun, 2000), all their remains in the archaeological record were considered import (Liphschitz and Biger, 1989, 1995). There is no reason to assume that high-quality timber of certain trees that have local populations could not, in addition to local timber supply, have been traded from other regions or countries. Sites that were ports or close to ports along the coast (e.g., Votruba, 2007), or important sites such as palaces and temples were more likely to get imported timber of species such as *Cupressus sempervirens* that grew both in Israel and in other Mediterranean countries such as Lebanon (see Lev-Yadun et al., 1984, 1996), but this does not automatically turn all finds of this species found inland to imported items as proposed (Liphschitz and Biger, 1989, 1995). Clear cases of timber or wooden object trade within ancient Israel are the finds of wood of various conifers in archaeological sites in the Negev, where they could not grow (see Liphschitz and Biger, 1989, 1995; Liphschitz and Lev-Yadun, 1989; Lev-Yadun et al., 1995; Liphschitz, 1996).

WOOD AS REFLECTING HORTICULTURE

Orchards became a significant component of the agricultural system in the Chalcolithic (Zohary and Spiegel-Roy, 1975; Zohary and Hopf, 2000). Orchard trees grow and after some years they must be pruned. Old orchards suffer from considerable reduction in productivity and should be cut to the base and re-grafted or re-planted. Some of the orchard tree species produce high-quality wood that can be used for specific purposes, and indeed their wood became part of the archaeological record. Olive wood, being very hard, is suitable for producing delicate items. In addition, its pleasant burning odor made it a desired wood for cooking and heating. The broad scale of olive oil production and the frequent need to prune olive trees to keep them productive and not too tall so as to facilitate olive harvesting is reflected in the frequency of olive wood remains in the archaeological record (e.g., Liphschitz et al., 1991). *Ficus sycomorus*, which produces edible figs, was also used as a source for timber (Feliks, 1968; Galil, 1968) and this is reflected in its occurrence in the archaeological finds (e.g., Werker, 1994). The wood of several additional fruit trees is good for delicate woodworking, as indicated by the species used to manufacture furniture and other wooden items in Jericho (Cartwright, 2005).

WOOD TECHNOLOGY

Wood, being perishable, is generally under-represented in the archaeological record compared to stone artifacts. Analysis of plant remains on stone tools indicated woodworking by hominids ca. 2.0 million years ago (Dominguez-Rodrigo et al., 2001). Sometimes, because of specific site taphonomical conditions, wood is preserved for hundreds of thousands of years. The 780,000-year-old Acheulian Gesher Benot Ya'aqov wood (Goren-Inbar et al., 2002; Werker, 2006) is such a rare case. Several such unique finds indicate that delicate woodworking is a very old technique even predating our species. Among the more than 1,000 wood finds from Gesher Benot Ya'aqov, a polished *Salix* sp. wooden plank was found (Belitzky et al., 1991). Thieme (1997) found 400,000-year-old Lower Palaeolithic hunting spears in Schöningen, Germany. Again, this rare find indicates technological ability at that early period. Wooden objects from Ohalo II (23,000 cal BP), Jordan Valley, Israel, also indicate technical abilities in woodworking (Nadel et al., 2006).

Special opportunities to study woodworking techniques and carpentry are the 2,400-year-old waterlogged ship from Ma'agan Mikhael (Linder and Kahanov, 2003; Kahanov and Linder, 2004) and the 2,000-year-old boat from the Sea of Galilee (Wachsmann, 1990). The excellent preservation under the anaerobic conditions of the underwater sediments made it possible to evaluate the very high level of woodworking at that time (Steffy, 1990; Kahanov, 2003; Udell, 2003; Hillman and Liphschitz, 2004; Mor, 2004; Sitry, 2004). It should be noted that chemical changes such as sulfur and iron enrichment may occur under anaerobic conditions, especially in the outer parts of wood (Wetherall et al., 2008), which may sometimes appear as a chemical treatment of the wood.

While all previous cases of woodworking discussed above were of materials preserved as waterlogged, the contrasting conditions of the dry desert also provided well-preserved delicate wooden objects that enabled studying ancient technologies. The Neolithic Nahal Hemar cave, because of its very dry conditions, provided well-preserved delicate items made of wood (Bar-Yosef, 1985). The wood analysis (Werker, 1988) showed that the finds included items made of conifer wood (*Juniperus*), desert trees (*Tamarix*, *Pistacia*), a desert shrub (*Retama raetam*), annuals (*Salsola*), and beads made of monocotyledon wood (it may be *Phoenix* or *Hyphaene*). The Chalcolithic wood finds from the Cave of the Warrior (west of Jericho) allowed a good look into various woodworking techniques (McEwen, 1998; Schick, 1998; Sitry, 1998). Some of these well-preserved wooden objects were painted or glued, and the excellent preservation enabled the study of these woodworking-related techniques (Nissenbaum, 1998; Segal, 1998). Botanical finds in the tombs of the Second Temple period at ‘En Gedi allowed the understanding of both woodworking techniques for coffins and the types of wood used (Hadas, 1994). The wood remains from Masada were also indicative of wood technology, as many delicate small wooden items and furniture parts were found in the Palace and other buildings (Liphschitz and Lev-Yadun, 1989). The wooden beams used by the Roman soldiers to construct the siege rampart in Masada were cut with a single blow or a small number of blows and were not sawed (Liphschitz et al., 1981). For detailed discussions on ancient wood technology in our region see Sitry (2006).

THE USE OF FIRE

Several types of archaeological wood remains indicate specific cases of the use of fire. The first and the most critical is the find of 780,000-year-old charcoals (along with burnt stones) from Gesher Benot Ya’aqov, indicating very early use of fire (Goren-Inbar et al., 2004; Alperson-Afil et al., 2007). Evidence of massive use of firewood exists in Kebara and Hayonim caves through thick phytolith layers and other chemical indications for the use of fire (Schiegl et al., 1994, 1996; Albert et al., 2000). Wood charcoals give higher temperatures when burnt than dry wood, especially if air is pumped into the fire to increase oxygen supply. Charcoals were used for metal-working (Perlin, 1991; Engel, 1993), a critical technology for ancient societies. Hearths leave indicative chemical “fireprints” in the sediments that sometimes may be indicative of the type of wood used for fire (Pierce et al., 1998).

A very special and rare archaeological find are wooden implements used to light fire. Sitry (2006), who reviewed such finds in Israel, gave details of three such items (one Chalcolithic from Murabba’at Cave, an Iron Age II one from Kuntillet ‘Ajrud, and a Roman one from ‘En Rahel). These items (made of non-burnt poplar wood) had several holes with charring marks in them that were the outcome of high-speed turning of a piece of wood to cause friction and heating.

The use of fire as evident from wood charcoal analysis is related not only to well-defined archaeological sites, but also to forest clearing, ecosystem manipulation for increased productivity, accidental landscape fires, and arson as part of military or hostile actions (Clark et al., 1989; Perlin, 1991; Bowman, 1998; Kershaw et al., 2002; Williams, 2003; Diamond, 2005). Charcoals in forest floor or in nearby lake sediments may represent natural forest fires caused by lightning (Moore, 2000; Scott, 2000), or be the remnants of charcoal or tar preparation, both critical materials for ship-building and metal-working (Perlin, 1991; Outland, 2004) or else may reflect slash-and-burn agriculture (Diamond, 2005). It is not always easy or possible to distinguish between natural and man-made fires outside well-defined archaeological sites (Moore, 2000; Parshall and Foster, 2002).

A very important issue for prehistorians and to a lesser extent to other archaeologists is the reconstruction of the patterns of different activities within the area of archaeological sites. The spatial distribution of charcoal, phytoliths, burnt stones and bones, and evidence of past heating measured by TL (thermo luminescence) help in such reconstructions (Balme and Beck, 2002; Goren-Inbar et al., 2004; Karkanas et al., 2007).

WOOD CHARCOALS AND GUNPOWDER

A critical technology that enormously influenced human history in the last ca. 1,100 years is the invention of explosives, and the introduction of firearms to Europe and their gradual development (Gray et al., 1982; Diamond, 1997). The basis for this is the production of gunpowder, a product in which powder made of ground wood charcoals is one of the major constituents. There are differences among various tree species in the value of their charcoals for production of gunpowder (Gray et al., 1982). In Israel and other parts of the Near East the Mamluks, who ruled the region more than 500 years ago, began the period of the use of gunpowder (Partington, 1999). Gunpowder was used not only for weapons, but also in stone quarries for building. Home-made or workshop-made traditional (low quality) gunpowder was produced in the Judea region till about 30 years ago (Avitsur, 1976). The preferred wood charcoal for gunpowder production in the land of Israel was poplar (*Populus*), second choice was plane tree (*Platanus*), and other types of wood, and the least preferred was wood of the thorny shrub prickly burnet (*Sarcopoterium spinosum*) (Avitsur, 1976). To the best of my knowledge, ancient gunpowder was never studied in the archaeological record of Israel. Wood fragments from explosives can be used to reveal their geographical origin in certain criminal investigations (Dickison, 2000), indicating the possibility to study the origin of ancient gunpowder when found.

CONCLUSIONS

Overall, during the last several decades, because of the accumulating data from studying both archaeological wood remains and related palaeoecological studies, we are able to better understand the past vegetation and ecology of the region, the level and role of human impact on the environment, trade relations, human technology, and the establishment of agriculture in general and horticulture in particular. While for the major field crops of Near Eastern agriculture modern genetics dramatically solved various burning questions in the last decade, these modern tools have still had no significant impact where woody plants are concerned. I hope to see parallel progress in the next decade or two.

ACKNOWLEDGMENT

I thank Mina Evron, Susan Lev-Yadun, Avi Gopher, and an anonymous reviewer for their comments on the manuscript.

REFERENCES

Abbo, S., Gopher, A., Peleg, Z., Saranga, Y., Fahima, T., Salamini, F., Lev-Yadun, S. 2006. The ripples of "the big (agricultural) bang": the spread of early wheat cultivation. Genome 49: 861–863.

Akkemik, Ü., Aras, A. 2005. Reconstruction (1689–1994 AD) of April–August precipitation in the southern part of central Turkey. Int. J. Climatol. 25: 537–548.

Akkemik, Ü., D'Arrigo, R., Cherubini, P., Köse, N., Jacoby, G.C. 2008. Tree-ring reconstructions of precipitation and streamflow for north-western Turkey. Int. J. Climatol. 28: 173–183.

Albert, R.M., Weiner, S., Bar-Yosef, O., Meignen, L. 2000. Phytoliths in the Middle Palaeolithic deposits of Kebara Cave, Mt Carmel, Israel: study of the plant materials used for fuel and other purposes. J. Archaeol. Sci. 27: 931–947.

Albert, R.M., Shahack-Gross, R., Cabanes, D., Gilboa, A., Lev-Yadun, S., Portillo, M., Sharon, I., Boaretto, E., Weiner, S. 2008. Phytolith-rich layers from the Late Bronze and Iron Ages at Tel Dor (Israel): mode of formation and archaeological significance. J. Archaeol. Sci. 35: 57–75.

Alperson-Afil, N., Richter, D., Goren-Inbar, N. 2007. Phantom hearths and the use of fire at Gesher Benot Ya'aqov, Israel. PaleoAnthropology 2007: 1–15.

André, J.-P. 2005. Vascular organization of angiosperms. A new vision. Science Publishers, Inc., Enfield, New Hampshire.

Angeles, G. 2001. New techniques for the anatomical study of charcoalified wood. IAWA J. 22: 245–254.

Arbel, E., Arzee, T. 1976. Development of peripheral periderm from cork strips in *Ceratonia siliqua*. Can. J. For. Res. 6: 425–428.

Arzee, T., Waisel, Y., Liphschitz, N. 1970. Periderm development and phellogen activity in the shoots of *Acacia raddiana* Savi. New Phytol. 69: 395–398.

Arzee, T., Arbel, E., Cohen, L. 1977. Ontogeny of periderm and phellogen activity in *Ceratonia siliqua* L. Bot. Gaz. 138: 329–333.

Asara, J.M., Schweitzer, M.H., Freimark, L.M., Phillips, M., Cantley, L.C. 2007a. Protein sequences from Mastodon and *Tyrannosaurus rex* revealed by mass spectrometry. Science 316: 280–285.

Asara, J.M., Garavelli, J.S., Slatter, D.A., Schweitzer, M.H., Freimark, L.M., Phillips, M., Cantley, L.C. 2007b. Interpreting sequences from mastodon and *T. rex*. Science 317: 1324–1325.

Avitsur, S. 1976. Man and his work. Historical atlas of tools & workshops in the Holy Land. Carta, Jerusalem (in Hebrew).

Baas, P., Schweingruber, F.H. 1987. Ecological trends in the wood anatomy of trees, shrubs and climbers from Europe. IAWA Bull. n.s. 8: 245–274.

Baas, P., Werker, E., Fahn, A. 1983. Some ecological trends in vessel characters. IAWA Bull. n.s. 4: 141–159.

Baillie, M.G.L. 1982. Tree-ring dating and archaeology. University of Chicago Press, Chicago.

Balme, J., Beck, W.E. 2002. Starch and charcoal: useful measures of activity areas in archaeological rockshelters. J. Archaeol. Sci. 29: 157–166.

Baruch, U. 1986. The late Holocene vegetational history of Lake Kinneret (Sea of Galilee), Israel. Paléorient 12: 37–48.

Baruch, U. 1990. Palynological evidence of human impact on the vegetation as recorded in Late Holocene lake sediments in Israel. In: Bottema, S., Entjes-Nieborg, G., van Zeist, W., eds. Man's role in the shaping of the Eastern Mediterranean landscape. A.A. Balkema, Rotterdam, pp. 283–293.

Baruch, U., Bottema, S. 1999. A new pollen diagram from lake Hula. In: Kawanabe, H., Coulter, G.W., Roosevelt, A.C., eds. Ancient lakes: their cultural and biological diversity. Kenobi Productions, Ghent, pp. 75–86.

Baruch, U., Goring-Morris, N. 1997. The arboreal vegetation of the Central Negev Highlands, at the end of the Pleistocene: evidence from archaeological charred wood remains. Veg. Hist. Archaeobot. 6: 249–259.

Baruch, U., Werker, E., Bar-Yosef, O. 1992. Charred wood remains from Kebara cave, Israel: preliminary results. Bull. Soc. Bot. Fr. Actual. Bot. 139: 531–538.

Bar-Yosef, O. 1985. A cave in the desert: Nahal Hemar 9,000-year-old-finds. The Israel Museum, Jerusalem.

Belitzky, S., Goren-Inbar, N., Werker, E. 1991. A Middle Pleistocene wooden plank with man-made polish. J. Human Evol. 20: 349–353.

Björdal, C.G., Nilsson, T. 2008. Reburial of shipwrecks in marine sediments: a long-term study on wood degradation. J. Archaeol. Sci. 35: 862–872.

Blanchette, R.A. 2000. A review of microbial deterioration found in archaeological wood from different environments. Int. Biodeterior. Biodegrad. 46: 189–204.

Boareto, E. 2007. Determining the chronology of an archaeological site using radiocarbon: minimizing uncertainty. Isr. J. Earth Sci. 56: 207–216, this issue.

Bonneh, O. 2000. Management of planted pine forests in Israel: past, present and future. In: Ne'eman, G., Trabaud, L., eds. Ecology, biogeography and management of *Pinus halepensis* and *Pinus brutia* forest ecosystems in the Mediterranean Basin. Backhuys Publishers, Leiden, pp. 377–390.

Bottema, S. 1995. The Younger Dryas in the eastern Mediterranean. Quaternary Sci. Rev. 14: 883–892.

Bowman, D.M.J.S. 1998. The impact of Aboriginal landscape burning on the Australian biota. New Phytol. 140: 385–410.

Canti, M.G. 2003. Aspects of the chemical and microscopic characteristics of plant ashes found in archaeological soils. Catena 54: 339–361.

Carlquist, S. 1975. Ecological strategies of xylem evolution. University of California Press, Berkeley.

Carlquist, S., Hoekman, D.A. 1986. Ecological wood anatomy of the woody southern California flora. IAWA Bull. n.s. 6: 319–347.

Cartwright, C. 2005. The Bronze Age wooden tomb furniture from Jericho: the microscopical reconstruction of a distinctive carpentry tradition. P.E.Q. 137: 99–138.

Clark, J.S., Merkt, J., Müller, H. 1989. Post-glacial fire, vegetation, and human history on the northern alpine forelands, south-western Germany. J. Ecol. 77: 897–925.

Cohen-Ofri, I., Weiner, L., Boaretto, E., Mintz, G., Weiner, S. 2006. Modern and fossil charcoal: aspects of structure and diagenesis. J. Archaeol. Sci. 33: 428–439.

Deguilloux, M.-F., Pemonge, M.-H., Petit, R.J. 2002. Novel perspectives in wood certification and forensics: dry wood as a source of DNA. Proc. R. Soc. London B. 269: 1039–1046.

Deguilloux, M.-F., Pemonge, M.-H., Petit, R.J. 2004. DNA-based control of oak wood geographic origin in the context of the cooperage industry. Ann. For. Sci. 61: 97–104.

Diamond, J. 1997. Guns, germs, and steel. W. W. Norton & Company, New York.

Diamond, J. 2001. Tree trail to Chaco Canyon. Nature 413: 687–690.

Diamond, J. 2005. Collapse. How societies choose to fail or succeed. Viking, New York.

Dickison, W.C. 2000. Integrative plant anatomy. Harcourt Academic Press, San Diego.

Dominguez-Rodrigo, M., Serrallonga, J., Juan-Tresserras, J., Alcala, L., Luque, L. 2001. Woodworking activities by early humans: a plant residue analysis on both Acheulian stone tools from Peninj (Tanzania). J. Human Evol. 40: 289–299.

Eig, A. 1934. A historical-phytosociological essay on Palestinian forests of *Quercusaegilops* L. ssp. *ithaburensis* (Desc.) in past and present. Beih. Bot. Centralbl. 51: 225–272.

Elbaum, R., Melamed-Bessudo, C., Boaretto, E., Galili, E., Lev-Yadun, S., Levy, A.A., Weiner, S. 2006. Ancient olive DNA in pits: preservation, amplification and sequence analysis. J. Archaeol. Sci. 33: 77–88.

Engel, T. 1993. Charcoal remains from an Iron Age copper smelting slag heap at Feinan, Wadi Arabah (Jordan). Veget. Hist. Archaeobot. 2: 205–211.

English, N.B., Betancourt, J.L., Dean, J.S., Quade, J. 2001. Strontium isotopes reveal distant sources of architectural timber in Chaco Canyon, New Mexico. Proc. Natl. Acad. Sci., USA 98: 11891–11896.

Fahn, A. 1979. Secretory tissues in plants. Academic Press, London.

Fahn, A. 1990. Plant anatomy. 4th ed. Pergamon Press, Oxford.

Fahn, A., Zamski, E. 1970. The influence of pressure, wind, wounding and growthsubstances on the rate of resin duct formation in *Pinus halepensis* wood. Isr. J. Bot. 19: 429–446.

Fahn, A., Wachs, N., Ginzburg, C. 1963. Dendrochronological studies in the Negev. I.E.J. 13: 291–299.

Fahn, A., Werker, E., Ben-Tzur, P. 1979. Seasonal effects of wounding and growth substances on development of traumatic resin ducts in *Cedrus libani*. New Phytol. 82: 537–544.

Fahn, A., Werker, E., Baas, P. 1986. Wood anatomy and identification of trees and shrubs from Israel and adjacent regions. The Israel Academy of Sciences and Humanities, Jerusalem.

Feinbrun-Dothan, N., Danin, A. 1991. Analytical flora of Eretz-Israel. Cana Publishing House Ltd., Jerusalem (in Hebrew).

Feliks, J. 1968. Plant world of the Bible. Massada Ltd., Ramat-Gan (in Hebrew).

Fink, S. 1999. Pathological and regenerative plant anatomy. Gebrüder Borntraeger, Berlin.

Franceschi, V.R., Horner, H.T.Jr. 1980. Calcium oxalate crystals in plants. Bot. Rev. 46: 361–427.

Franceschi, V.R., Nakata, P.A. 2005. Calcium oxalate in plants: formation and function. Annu. Rev. Plant Biol. 56: 41–71.

Friedrich, W.L., Kromer, B., Friedrich, M., Heinemeier, J., Pfeiffer, T., Talamo, S. 2006. Santorini eruption radiocarbon dated to 1627–1600 B.C. Science 312: 548.

Fritts, H.C. 1976. Tree rings and climate. Academic Press, London.

Galil, J. 1968. An ancient technique for ripening sycomore fruit in east-Mediterranean countries. Econ. Bot. 22: 178–190.

Gichon, M. 2000. The siege of Masada. Les Légiones de Rome sous le Haut-Empire. Collection du Centre d'Études Romaines et Gallo-Romaines Nouvelle série 20: 541–554.

Gifford, E.M., Foster, A.S. 1989. Morphology and evolution of vascular plants. 3rd. ed. W.H. Freeman and Company, New York.

Goldberg, P., Lev-Yadun, S., Bar-Yosef., O. 1994. Petrographic thin sections of archaeological sediments: a new method for palaeobotanical studies. Geoarchaeology 9: 243–257.

Gophna, R., Liphschitz, N. 1996. The Ashkelon trough settlements in the Early Bronze Age I: new evidence of maritime trade. Tel Aviv 23: 143–153.

Goren-Inbar, N., Werker, E., Feibel, C.S., 2002. The Acheulian site of Gesher Benot Ya'aqov, Israel. I. The Wood Assemblage. Oxbow Books, Oxford.

Goren-Inbar, N., Alperson, N., Kislev, M.E., Simchoni, O., Melamed, Y., Ben-Nun, A., Werker, E. 2004. Evidence of hominin control of fire at Gesher Benot Ya'aqov, Israel. Science 304: 725–727.

Gottesfeld, L.M.J. 1992. The importance of bark products in the aboriginal economies of northwestern British Columbia, Canada. Econ. Bot. 46: 148–157.

Gray, E., Marsh, H., McLaren, M. 1982. A short history of gunpowder and the role of charcoal in its manufacture. J. Mater. Sci. 17: 3385–3400.

Greguss, P. 1955. Xylotomische Bestimmung der heute lebenden Gymnospermen. Akadémiai Kiadó, Budapest (in German).

Greguss, P. 1959. Holzanatomie der Europäischen Laubhölzer und Sträucher. Akadémiai Kiadó, Budapest (in German).

Greguss, P. 1972. Xylotomy of the living conifers. Akadémiai Kiadó, Budapest.

Griggs, C., DeGaetano, A., Kuniholm, P., Newton, M. 2007. A regional high-frequency reconstruction of May-June precipitation in the north Aegean from oak tree rings, A.D. 1089–1989. Int. J. Climatol. 27: 1075–1089.

Grundwag, M., Werker, E. 1976. Comparative wood anatomy as an aid to identification of *Pistacia* L. species. Isr. J. Bot. 25: 152–167.

Gugerli, F., Parducci, L., Petit, R.J. 2005. Ancient plant DNA: review and prospects. New Phytol. 166: 409–418.

Gupta, S., Kulshreshta, S.P., Chauhan, L. 2001. Wood anatomy information system (WAIS) a computer-assisted wood identification package from India. IAWA J. 22: 430–431.

Hadas, G. 1994. Nine tombs of the Second Temple period at "En Gedi. 'Atiqot 14: 1–65, 1*–8* (in Hebrew, English summary*).

Heun, M., Schäfer-Pregl, R., Klawan, D., Castagna, R., Accerbi, M., Borghi, B., Salamini, F. 1997. Site of einkorn wheat domestication identified by DNA fingerprinting. Science 278: 1312–1314.

Hill, A.F. 1952. Economic botany. 2nd ed. McGraw-Hill Book Company, Inc., New York.

Hillis, W.E. 1987. Heartwood and tree exudates. Springer-Verlag, Berlin.

Hillman, A., Liphschitz, N. 2004. The wood. In: Kahanov, Y., Linder, E., eds. The Ma'agan Mikhael ship. The recovery of a 2400-year-old merchantman. Final Report Vol. II. Israel Exploration Society and University of Haifa, Jerusalem, pp. 145–155.

Horowitz, A. 1979. The Quaternary of Israel. Academic Press, New York.

Horowitz, A. 1992. Palynology of arid lands. Elsevier, Amsterdam.

Huber, B., Rouschal, C. 1954. Mikrophotographischer Atlas Mediterraner Hölzer. Fritz Haller Verlag, Berlin (in German).

Hughes, M.K., Kuniholm, P.I., Eischeid, J.K., Garfin, G., Griggs, C.B., Latini, C. 2001. Aegean tree-ring signature years explained. Tree-Ring Res. 57: 67-73.

IAWA, 1989. IAWA list of microscopic features for hardwood identification. IAWA Bull. n.s. 10: 219–332.

IAWA, 2004. IAWA list of microscopic features for softwood identification. IAWA J. 25: 1–70.

Ilvessalo-Pfäffli, M.-S. 1995. Fiber atlas. Identification of papermaking fibers. Springer-Verlag, Berlin.

Jagiella, C., Kürschner, H. 1987. Atlas der Hölzer Saudi Arabiens. Dr. Ludwig Reichert Verlag, Wiesbaden.

Kahanov, Y. 2003. The hull. In: Linder, E., Kahanov, Y., eds. The Ma'agan Mikhael ship. The recovery of a 2400-year-old merchantman. Final Report Vol. I. Israel Exploration Society and University of Haifa, Jerusalem, pp. 53-129.

Kahanov, Y., Linder, E. 2004. The Ma'agan Mikhael ship. The recovery of a 2400-year-old merchantman. Final Report Vol. II. Israel Exploration Society and University of Haifa, Jerusalem.

Karkanas, P., Shahack-Gross, R., Ayalon, A., Bar-Matthews, M., Barkai, R., Frumkin, A., Gopher, A., Stiner, M.C. 2007. Evidence for habitual use of fire at the end of the Lower Paleolithic: Site-formation processes at Qesem Cave, Israel. J. Human Evol. 53: 197–212.

Kershaw, A.P., Clark, J.S., Gill, A.M., D'costa, D.M. 2002. A history of fire in Australia. In: Bradstock, R.A., Williams, J.E., Gill, M.A., eds. Flammable Australia. The fire regimes and biodiversity of a continent, Cambridge University Press, Cambridge, pp. 1–25.

Kislev, M.E. 1991. Archaeobotany and storage archaeoentomology. In: Renfrew, J.M., ed. New light on early farming: recent developments in palaeoethnobotany. Edinburgh University Press, Edinburgh, pp. 121–136.

Kislev, M.E., Melamed, Y. 2000. Ancient infested wheat and horsebean from Horbat Rosh Zayit. In: Gal, Z., Alexandre, Y., eds. Horbat Rosh Zayit. An Iron Age storage fort and village. IAA Reports, no 8. Israel Antiquities Authority, Jerusalem, pp. 206–220.

Kislev, M., Simchoni, O. 2007. Hygiene and insect damage of crops and foods at Masada. In: Masada VIII. The Yigael Yadin Excavations 1963-1965 final reports. Israel Exploration Society and The Hebrew University of Jerusalem, Jerusalem, pp. 133–170.

Kuniholm, P.I., Kromer, B., Manning, S.W., Newton, M., Latini, C.E., Bruce, M.J. 1996. Anatolian tree rings and the absolute chronology of the eastern Mediterranean, 2220–718 BC. Nature 381: 780–783.

Ladizinsky, G. 1999. Identification of the lentil's wild genetic stock. Genet. Resour. Crop Evol. 46: 115–118.

Larson, P.R. 1994. The vascular cambium. Development and structure. Springer-Verlag, Berlin.

Lavi, A., Perevolotsky, A., Kigel, J., Noy-Meir, I. 2005. Invasion of *Pinus halepensis* from plantations into adjacent natural habitats. Appl. Veg. Sci. 8: 85–92.

Lev-Yadun, S. 1987. Dendrochronology and related studies—a review. Mitekufat Haeven, J. Isr. Prehist. Soc. n.s. 20: 7–36.

Lev-Yadun, S. 1991. Terminology used in bark anatomy: additions and comments. IAWA Bull. n.s. 12: 207–209.

Lev-Yadun, S. 1992. The origin of the cedar beams from Al-Aqsa Mosque: botanical, historical and archaeological evidence. Levant 24: 201–208.

Lev-Yadun, S. 1994a. Induction of near-vessellessness in *Ephedra campylopoda* C. A. Mey. Ann. Bot. 75: 683–687.

Lev-Yadun, S. 1994b. Radial fibres in aggregate rays of *Quercus calliprinos* Webb.—evidence for radial signal flow. New Phytol. 128: 45–48.

Lev-Yadun, S. 1994c. Experimental evidence for the autonomy of ray differentiation in *Ficus sycomorus* L. New Phytol. 126: 499–504.

Lev-Yadun, S. 1997. Flora and climate in Southern Samaria: past and present. In: Finkelstein, I., Lederman, Z., Bunimovitz, S., eds. Highlands of many cultures I. The sites. Monograph Series of the Institute of Archaeology, Tel Aviv University, Tel Aviv, pp. 85–102.

Lev-Yadun, S. 2000a. Wood structure and the ecology of annual growth ring formation in *Pinus halepensis* and *Pinus brutia*. In: Ne'eman, G., Trabaud, L., eds. Ecology, biogeography and management of *Pinus halepensis* and *Pinus brutia* forest ecosystems in the Mediterranean Basin. Backhuys Publishers, Leiden, pp. 67–78.

Lev-Yadun, S. 2000b. Cellular patterns in dicotyledonous woods: their regulation. In: Savidge, R., Barnett, J., Napier, R., eds. Cell & molecular biology of wood formation. BIOS Scientific Publishers Ltd., Oxford, pp. 315–324.

Lev-Yadun, S. 2001a. Wound effects arrest wave phenomena in the secondary xylem of *Rhamnus alaternus* (Rhamnaceae). IAWA J. 22: 295–300.

Lev-Yadun, S. 2001b. Bark. In: Encyclopedia of life sciences. Nature Publishing Group, London. http://www.els.net.

Lev-Yadun, S. 2002. The distance to which wound effects influence the structure of secondary xylem of decapitated *Pinus pinea*. J. Plant Growth Regul. 21: 191–196.

Lev-Yadun, S. 2004. Vegetal remains. In: Goren, Y., Finkelstein, I., Na'aman, N., eds. Inscribed in clay. Provenance study of the Amarna tablets and other ancient Near Eastern texts. Monograph Series of the Institute of Archaeology, Tel Aviv University, Tel Aviv.

Lev-Yadun, S., Aloni, R. 1990a. Vascular differentiation in branch junctions of trees: circular patterns and functional significance. Trees 4: 49–54.

Lev-Yadun, S., Aloni, R. 1990b. Polar patterns of periderm ontogeny, their relationship to leaves and buds, and the control of cork formation. IAWA Bull. n.s. 11: 289–300.

Lev-Yadun, S., Aloni, R. 1991a. Polycentric vascular rays in *Suaeda monoica* and the control of ray initiation and spacing. Trees 5: 22–29.

Lev-Yadun, S., Aloni, R. 1991b. Natural and experimentally induced dispersion of aggregate rays in shoots of *Quercus ithaburensis* Decne. and *Q. calliprinos* Webb. Ann. Bot. 68: 85–91.

Lev-Yadun, S., Aloni, R. 1992. The role of wounding in the differentiation of vascular rays. Int. J. Plant Sci. 153: 348–357.

Lev-Yadun, S., Aloni, R. 1993a. Variant secondary growth in old stems of *Ephedra_campylopoda* C. A. Mey. Bot. J. Linn. Soc. 112: 51–58.

Lev-Yadun, S., Aloni, R. 1993b. Effect of wounding on the relations between vascular rays and vessels in *Melia azedarach* L. New Phytol. 124: 339–344.

Lev-Yadun, S., Aloni, R. 1995. Differentiation of the ray system in woody plants. Bot. Rev. 61: 45–88.

Lev-Yadun, S., Weinstein-Evron, M. 1993. Prehistoric wood remains of *Cupressus sempervirens* L. from the Natufian layers of el-Wad Cave, Mount Carmel, Israel. Tel Aviv 20: 125–131.

Lev-Yadun, S., Weinstein-Evron, M. 1994. Late Epipalaeolithic wood remains from el-Wad Cave, Mount Carmel, Israel. New Phytol. 127: 391–396.

Lev-Yadun, S., Weinstein-Evron, M. 2002. The role of *Pinus halepensis* (Aleppo pine) in the landscape of Early Bronze Age Megiddo. Tel Aviv 29: 332–343.

Lev-Yadun, S., Weinstein-Evron, M. 2005. Modeling the influence of wood use by the Natufians of el-Wad on the forest of Mount Carmel. J. Isr. Prehist. Soc. 35: 285–298.

Lev-Yadun, S., Liphschitz, N., Waisel, Y. 1981. Dendrochronological investigations in Israel: *Pinus halepensis* Mill.—The oldest living pines in Israel. La-Yaaran 31: 1–8, 49–52 (in Hebrew and English).

Lev-Yadun, S., Liphschitz, N., Waisel, Y. 1984. Ring analysis of *Cedrus libani* beams from the roof of al-Aqsa mosque. Eretz-Israel 17: 92–96, 4*–5*. The Israel Exploration Society, Jerusalem (in Hebrew, English* summary).

Lev-Yadun, S., Herzog, Z., Tsuk, T. 1995. Conifer beams of *Juniperus phoenicea* found in the well of Tel Beer-Sheba. Tel Aviv 22: 128–135.

Lev-Yadun, S., Artzy, M., Marcus, E., Stidsing, R. 1996. Wood remains from Tel Nami, a Middle Bronze IIa and Late Bronze IIb port, local exploitation of trees and Levantine cedar trade. Econ. Bot. 50: 310–317.

Lev-Yadun, S., Gopher, A., Abbo, S. 2000. The cradle of agriculture. Science 288: 1602–1603.

Libby, L.M. 1983. Past climates. Tree thermometers, commodities, and people. University of Texas Press, Austin.

Linder, E., Kahanov, Y. 2003. The Ma'agan Mikhael ship. The recovery of a 2400-year-old merchantman. Final Report Vol. I. Israel Exploration Society and University of Haifa, Jerusalem.

Liphschitz, N. 1986. The vegetational landscape and the macroclimate of Israel during prehistoric and protohistoric periods. Mitekufat Haeven. J. Isr. Prehist. Soc. 19: 80–90.

Liphschitz, N. 1986/7. Ancient vegetation of the Yarkon basin according to botanical remnants from excavations. In: Zeevy, R., ed. Israel—people and land. Eretz Israel Museum Yearbook. Vol 4. New Series, Eretz Israel Museum, Tel Aviv, pp. 101–104 (in Hebrew).

Liphschitz, N. 1996. The vegetational landscape of the Negev during antiquity as evident from archaeological wood remains. Isr. J. Plant Sci. 44: 161–179.

Liphschitz, N. 1998. Timber analysis of household objects in Israel: a comparative study. I.E.J. 48: 77–90.

Liphschitz, N. 1999. Microscopic examination of wood remains from archaeological excavations. In: Arzee, T., Schwartz, M., eds. Basic microtechniques. Tel Aviv University, Tel Aviv, pp. 107–110 (in Hebrew).

Liphschitz, N. 2004. Dendroarchaeological investigations. In: Kahanov, Y., Linder, E., eds. The Ma'agan Mikhael ship. The recovery of a 2400-year-old merchantman. Final Report Vol. II. Israel Exploration Society and University of Haifa, Jerusalem, pp. 156–163.

Liphschitz, N., Biger, G. 1989. *Cupressus sempervirens* in Israel during antiquity. Isr. J. Bot. 38: 35–45.

Liphschitz, N., Biger, G. 1995. The timber trade in ancient Palestine. Tel Aviv 22: 121–127.

Liphschitz, N., Lev-Yadun, S. 1989. The botanical remains from Masada. Identification of the plant species and the possible origin of the remnants. BASOR 274: 27–32.

Liphschitz, N., Nadel, D. 1997. Charred wood remains from Ohalo II (19,000 B.P.), Sea of Galilee, Israel. J. Isr. Prehist. Soc. 27: 5–18.

Liphschitz, N., Lev-Yadun, S., Waisel, Y. 1979a. Dendrochronological investigations in the Mediterranean basin—*Pinus nigra* of south Anatolia (Turkey). La-Yaaran 29: 3–11, 33–36 (in Hebrew and English).

Liphschitz, N., Waisel, Y., Lev-Yadun, S. 1979b. Dendrochronological investigations in Iran: *Juniperus polycarpos* of West and Central Iran. Tree Ring Bull. 39: 39–45.

Liphschitz, N., Lev-Yadun, S., Waisel, Y. 1981. Dendroarchaeological investigations in Israel: Masada. I.E.J. 31: 230–234.

Liphschitz, N., Lev-Yadun, S., Waisel, Y. 1987a. A climatic history of the Sinai peninsula in light of dendrochronological studies. In: Gvirtzman, G., Shmueli, A., Gradus, Y., Beit-Arieh, I., Har-El, M., eds. Sinai, Volume 1. Tel Aviv University, and Ministry of Defence Publishing House, Tel Aviv, pp. 525–531 (in Hebrew).

Liphschitz, N., Lev-Yadun, S., Gophna, R. 1987b. The dominance of *Quercus calliprinos* Webb. (Kermes Oak) in the Central Coastal Plain of Israel in antiquity. I.E.J. 37: 43–50.

Liphschitz, N., Biger, G., Mendel, Z. 1987/9. Did the Aleppo Pine—"Oren Yerushalaim" (*Pinus halepensis*)—cover the mountains of Eretz Israel in the past. In: Zeevy, R., ed. Israel—people and land. Eretz Israel Museum Yearbook. Vol. 5–6. New Series, Eretz Israel Museum, Tel Aviv, pp. 141–150 (in Hebrew, English abstr.).

Liphschitz, N., Gophna, R., Hartman, M., Biger, G. 1991. The beginning of olive (*Olea europaea*) cultivation in the Old World: A reassessment. J. Archaeol. Sci. 18: 441–453.

Lorch, J. 1967. A Jurassic flora of Makhtesh Ramon, Israel. Isr. J. Bot. 16: 131–155, plates 163–180.

Lorch, J. 1968. Some Jurassic conifers from Israel. J. Linn. Soc., Bot. 61: 177–188.

Manning, S.W., Kromer, B., Kuniholm, P.I., Newton, M.W. 2001. Anatolian tree rings and a new chronology for the east Mediterranean Bronze-Iron Ages. Science 294: 2532–2535.

Massey, F.P., Hartley, S.E. 2006. Experimental demonstration of the antiherbivore effects of silica in grasses: impacts on foliage digestibility and vole growth rates. Proc. R. Soc. Lond. B 273: 2299–2304.

McCarroll, D., Loader, N.J. 2004. Stable isotopes in tree rings. Quaternary Sci. Rev. 23: 771–801.

McEwen, E. 1998. The bow. In: The Cave of the Warrior. A fourth millennium burial in the Judean desert. IAA Reports no. 5. pp. 45–53.

Meheshwari, P., Biswas, C. 1970. Cedrus. Council of Scientific & Industrial Research, New Delhi.

Meiggs, R. 1982. Trees and timber in the ancient Mediterranean world. Oxford University Press, Oxford.

Mencuccini, M., Hölttä, T., Petit, G., Magnani, F. 2007. Sanio's laws revisited. Size-dependent changes in the xylem architecture of trees. Ecol. Lett. 10: 1084–1093.

Meunier, J.D., Colin, F., eds. 2001. Phytoliths: application in earth sciences and human history. A.A. Balkema Publishers, Lisse.

Mikesell, M.W. 1969. The deforestation of Mount Lebanon. Geogr. Rev. 59: 1–28.

Moore, J. 2000. Forest fire and human interaction in the early Holocene woodlands of Britain. Palaeogeography, Palaeoclimatology, Palaeoecology 164: 125–137.

Mor, H. 2004. The carpenters' tool-marks: their significance in ancient boatbuilding. In: Kahanov, Y., Linder, E., eds. The Ma'agan Mikhael ship. The recovery of a 2400-year-old merchantman. Final Report Vol. II. Israel Exploration Society and University of Haifa, Jerusalem, pp. 165–181.

Morrell, P.L., Clegg, M.T. 2007. Genetic evidence for a second domestication of barley (*Hordeum vulgare*) east of the Fertile Crescent. Proc. Natl. Acad. Sci. USA 104: 3289–3294.

Nadel, D., Werker, E. 1999. The oldest ever brush hut plant remains from Ohalo II, Jordan Valley, Israel (19,000 BP). Antiquity 73: 755–764.

Nadel, D., Grinberg, U., Boaretto, E., Werker, E. 2006. Wooden objects from Ohalo II (23,000 cal BP), Jordan Valley, Israel. J. Human Evol. 50: 644–662.

Nakata, P.A. 2003. Advances in our understanding of calcium oxalate crystal formation and function in plants. Plant Sci. 164: 901–909.

Neumann, K., Schoch, W., Détienne, P., Schweingruber, F.H. 2001. Woods of the Sahara and the Sahel. Verlag Paul Haupt, Bern.

Nichols, G.J., Cripps, J.A., Collinson, M.E., Scott, A.C. 2000. Experiments in waterlogging and sedimentology of charcoal: results and implications. Palaeogeography, Palaeoclimatology, Palaeoecology 164: 43–56.

Nir, D. 1983. Man, a geomorphological agent. Keter Publishing House, Jerusalem; and D. Reidel Publishing Company, Dordrecht.

Nissenbaum, A. 1998. Chemical analysis of organic matter associated with the bow. In: The Cave of the Warrior. A fourth millennium burial in the Judean desert. IAA Reports no. 5. pp. 107–109.

Outland, R.B. III. 2004. Tapping the pines. The naval stores industry in the American south. Louisiana State University Press, Baton Rouge.

Özkan, H., Brandolini, A., Schäfer-Pregl, R., Salamini, F. 2002. AFLP analysis of a collection of tetraploid wheats indicates the origin of emmer and hard wheat domestication in southeast Turkey. Mol. Biol. Evol. 19: 1797–1801.

Özkan, H., Brandolini, A., Pozzi, C., Effgen, S., Wunder, J., Salamini, F. 2005. A reconsideration of the domestication geography of tetraploid wheats. Theor. Appl. Genet. 110: 1052–1060.

Pääbo, S., Poinar, H., Serre, D., Jaenicke-Després, V., Hebler, J., Rohland, N., Kuch, M., Krause, J., Vigilant, L., Hofreiter, M. 2004. Genetic analyses from ancient DNA. Annu. Rev. Genet. 38: 645–679.

Pajouh, D.P., Schweingruber, F.H. 1988. Atlas des bois du nord de l'Iran. Tehran University, Tehran (in Persian and French).

Parshall, T., Foster, D.R. 2002. Fire on the New England landscape: regional and temporal variation, cultural and environmental controls. J. Biogeogr. 29: 1305–1317.

Partington, J.R. 1999. A history of Greek fire and gunpowder. Johns Hopkins University Press, Baltimore.

Perlin, J. 1991. A forest journey. The role of wood in the development of civilization. Harvard University Press, Cambridge.

Philipson, W.R., Ward, J.M., Butterfield, B.G. 1971. The vascular cambium. Its development and activity. Chapman & Hall Ltd., London.

Pierce, C., Adams, K.R., Stewart, J.D. 1998. Determining the fuel constituents of ancient hearth ash via ICP-AES analysis. J. Archaeol. Sci. 25: 493–503.

Piperno, D.R., Holst, I. 1998. The presence of starch grains on prehistoric stone tools from the humid Neotropics: indications of early tuber use and agriculture in Panama. J. Archaeol. Sci. 25: 765–776.

Piperno, D.R., Pearsall, D.M. 1998. The origins of agriculture in the lowland neotropics. Academic Press, San Diego.

Piperno, D.R., Weiss, E., Holst, I., Nadel, D. 2004. Processing of wild cereal grains in the Upper Palaeolithic revealed by starch grain analysis. Nature 430: 670–673.

Prychild, C.J., Rudall, P.J., Gregory, M. 2004. Systematics and biology of silica bodies in Monocotyledons. Bot. Rev. 69: 377–440.

Psaras, G.K., Konsolaki, M.J. 1986. The annual rhythm of cambial activity in four subshrubs common in phryganic formations of Greece. Isr. J. Bot. 35: 35–39.

Rapp, G. Jr., Mulholland, S.C. 1992. Phytolith systematics. Emerging issues. Plenum Press, New York.

Rogers, S.O., Kaya, Z. 2006. DNA from ancient cedar wood from King Midas' tomb, Turkey, and Al Aksa Mosque, Israel. Silvae Genet. 55: 54–62.

Rossignol-Strick, M. 1995. Sea-land correlation of pollen records in the Eastern Mediterranean for the Glacial-Interglacial transition: biostratigraphy versus radiometric time-scale. Quat. Sci. Rev. 14: 893–915.

Roth, I. 1981. Structural patterns of tropical barks. Gebrüder Borntraeger, Berlin.

Rothwell, G.W., Lev-Yadun, S. 2005. Evidence of polar auxin flow in 375 million-year-old fossil wood. Am. J. Bot. 92: 903–906.

Rothwell, G.W., Sanders, H., Wyatt, S.E., Lev-Yadun, S. 2008. A fossil record for growth regulation: the role of auxin in wood evolution. Ann. Missouri Bot. Gard. 95: 121–134.

Rowell, R.M., Barbour, R.J. 1990. Archaeological wood properties, chemistry, and preservation. American Chemical Society, Washington.

Sachs, T., Cohen, D. 1982. Circular vessels and the control of vascular differentiation in plants. Differentiation 21: 22–26.

Salamini, F., Özkan, H., Brandolini, A., Schäfer-Pregl, R., Martin, W. 2002. Genetics and geography of wild cereal domestication in the Near East. Nature Rev. Genet. 3: 429–441.

Sandgathe, D.M., Hayden, B. 2003. Did Neanderthals eat inner bark? Antiquity 77: 709–718.

Sandved, K.B., Prance, G.T., Prance, A.E. 1993. Bark. The formation, characteristics, and uses of bark around the world. Timber Press, Portland.

Schiegl, S., Lev-Yadun, S., Bar-Yosef, O., El Goresy, A., Weiner, S. 1994. Siliceous aggregates from prehistoric wood ash: a major component of sediments in Kebara and Hayonim caves (Israel). Isr. J. Earth Sci. 43: 267–278.

Schiegl, S., Goldberg, P., Bar-Yosef, O., Weiner, S. 1996. Ash deposits in Hayonim and Kebara Caves, Israel: macroscopic, microscopic and mineralogical observations, and their archaeological implications. J. Archaeol. Sci. 23: 763–781.

Schick, T. 1998. The arrows. In: The Cave of the Warrior. A fourth millennium burial in the Judean desert. IAA Reports no. 5. pp. 30–33.

Schiller, G. 2000. Ecophysiology of *Pinus halepensis* Mill. and *P. Brutia* Ten. In: Ne'eman, G., Trabaud, L., eds. Ecology, biogeography and management of *Pinus halepensis* and *Pinus brutia* forest ecosystems in the Mediterranean Basin. Backhuys Publishers, Leiden, pp. 51–65.

Schlumbaum, A., Tensen, M., Jaenicke-Després, V. 2008. Ancient plant DNA in archaeobotany. Veget. Hist. Archaeobot. 17: 233–244.

Schmitt, U., Grünwald, C., Eckstein, D. 2000. Xylem structure in pine trees grown near the Chernobyl nuclear power plant/Ukraine. IAWA J. 21: 379–387.

Schweingruber, F.H. 1990. Anatomy of European woods. Verlag Paul Haupt, Bern.

Schweingruber, F.H. 1996. Tree rings and environment. Dendroecology. Paul Haupt Publishers, Berne.

Schweingruber, F.H., Börner, A., Schulze, E.-D. 2006. Atlas of woody plant stems. Evolution, structure, and environmental modifications. Springer-Verlag, Berlin.

Scott, A.C. 2000. The pre-quaternary history of fire. Palaeogeography, Palaeoclimatology, Palaeoecology 164: 281–329.

Segal, I. 1998. A chemical and mineralogical study of finds. In: The Cave of the Warrior. A fourth millennium burial in the Judean desert. IAA Reports no. 5. pp. 97–99.

Sitry, Y. 1998. The wooden bowl. In: The Cave of the Warrior. A fourth millennium burial in the Judean desert. IAA Reports no. 5. pp. 54–58.

Sitry, Y. 2004. Unique wooden artifacts: a study of typology and technology. In: Kahanov, Y., Linder, E., eds. The Ma'agan Mikhael ship. The recovery of a 2400-year-old merchantman. Final Report Vol. II. Israel Exploration Society and University of Haifa, Jerusalem, pp. 183–191.

Sitry, Y. 2006. Wooden objects from Roman sites in the Land of Israel, a typological and technological study. Ph.D. thesis, Bar-Ilan University, Ramat Gan (in Hebrew with English summary).

Steffy, J.R. 1990. The boat: a preliminary study of its construction. 'Atiqot 19: 29–47.

Terral, J.-F. 2000. Exploitation and management of the olive tree during prehistoric times in Mediterranean France and Spain. J. Archaeol. Sci. 27: 127–133.

Terral, J.-F., Arnold-Simard, G. 1996. Beginnings of olive cultivation in eastern Spain in relation to Holocene bioclimatic changes. Quaternary Res. 46: 176–185.

Terral, J.-F., Durand, A. 2006. Bio-archaeological evidence of olive tree (*Olea europaea* L.) irrigation during the Middle Ages in Southern France and North Eastern Spain. J. Archaeol. Sci. 33: 718–724.

Terral, J.-F., Mengüal, X. 1999. Reconstruction of Holocene climate in southern France and eastern Spain using quantitative anatomy of olive wood and archaeological charcoal. Palaeogeography, Palaeoclimatology, Palaeoecology 153: 71–92.

Thieme, H. 1997. Lower Palaeolithic hunting spears from Germany. Nature 385: 807–810.

Thirgood, J.V. 1981. Man and the Mediterranean forest. A history of resource depletion. Academic Press, London.

Timell, T.E. 1986. Compression wood in gymnosperms. Springer-Verlag, Berlin.

Touchan, R., Hughes, M.K. 1999. Dendrochronology in Jordan. J. Arid Environ. 42: 291–303.

Touchan, R., Meko, D., Hughes, M.K. 1999. A 396-year reconstruction of precipitation in southern Jordan. J. Am. Water Resour. Assoc. 35: 49–59.

Touchan, R., Garfin, G.M., Meko, D.M., Funkhouser, G., Erkan, N., Hughes, M.K., Wallin, B.S. 2003. Preliminary reconstructions of spring precipitation in southwestern Turkey from tree-ring width. Int. J. Climatol. 23: 157–171.

Touchan, R., Xoplaki, E., Funkhouser, G., Luterbacher, J., Hughes, M.K., Erkan, N., Akkemik, Ü., Stephan, J. 2005. Reconstructions of spring/summer precipitation for the Eastern Mediterranean from tree-ring widths and its connection to large-scale atmospheric circulation. Climate Dyn. 25: 75–98.

Touchan, R., Akkemik, Ü., Hughes, M.K., Erkan, N. 2007. May-June precipitation reconstruction of southwestern Anatolia, Turkey during the last 900 years from tree rings. Quat. Res. 68: 196–202.

Trockenbrodt, M. 1990. Survey and discussion of the terminology used in bark anatomy. IAWA Bull. n.s. 11: 141–166.

Trockenbrodt, M. 1991. Qualitative structural changes during bark development in *Quercus robur*, *Ulmus glabra*, *Populus tremula* and *Betula pendula*. IAWA Bull. n.s. 12: 5–22.

Tsartsidou, G., Lev-Yadun, S., Albert, R.-M., Miller-Rosen, A., Efstratiou, N., Weiner, S. 2007. The phytolith archaeological record: strengths and weaknesses evaluated based on a quantitative modern reference collection from Greece. J. Archaeol. Sci. 34: 1262–1275.

Tsartsidou, G., Lev-Yadun, S., Efstratiou, N., Weiner, S. 2008. Ethnoarchaeological study of phytolith assemblages from an agro-pastoral village in Northern Greece (Sarakini): development and application of a Phytolith Difference Index. J. Archaeol. Sci. 35: 600–613.

Turner, N.J. 1988. Ethnobotany of coniferous trees in

Thompson and Lillooet interior Salish of British Columbia. Econ. Bot. 42: 177–194.

Tyree, M.T., Zimmermann, M.H. 2002. Xylem structure and the ascent of sap. 2nd ed. Springer-Verlag, Berlin.

Udell, M. 2003. The woodworking tools. In: Linder, E., Kahanov, Y., eds. The Ma'agan Mikhael ship. The recovery of a 2400-year-old merchantman. Final Report Vol. I. Israel Exploration Society and University of Haifa, Jerusalem, pp. 203–218.

Votruba, G.F. 2007. Imported building materials of Sebastos harbour, Israel. Int. J. Naut. Archaeol. 36: 325–335.

Wachsmann, S., ed. 1990. The excavations of an ancient boat in the Sea of Galilee (Lake Kinneret). 'Atiqot 19: 1–138.

Weinstein-Evron, M. 1983. The paleoecology of the early Würm in the Hula Basin. Paléorient 9: 5–19.

Weinstein-Evron, M., Lev-Yadun, S. 2000. Palaeoecology of *Pinus halepensis* in Israel in the light of archaeobotanical data. In: Ne'eman, G., Trabaud, L., eds. Ecology, biogeography and management of *Pinus halepensis* and *Pinus brutia* forest ecosystems in the Mediterranean Basin. Backhuys Publishers, Leiden, pp. 119–130.

Werker, E. 1988. Botanical identification of worked wood remains. 'Atiqot 18: 65–75.

Werker, E. 1990. Identification of the wood. 'Atiqot 19: 65–75.

Werker, E. 1994. Botanical identification of wood remains from the 'En Gedi excavations. 'Atiqot 24: 69–72, 10* (in Hebrew, English summary*).

Werker, E. 2003. The wood material. In: Linder, E., Kahanov, Y., eds. The Ma'agan Mikhael ship. The recovery of a 2400-year-old merchantman. Final Report Vol. I. Israel Exploration Society and University of Haifa, Jerusalem, pp. 241–243.

Werker, W. 2006. 780,000-year-old wood from Gesher Benot Ya'aqov, Israel. Isr. J. Plant Sci. 54: 291–300.

Wetherall, K.M., Moss, R.M., Jones, A.M., Smith, A.D., Skinner, T., Pickup, D.M., Goatham, S.W., Chadwick, A.V., Newport, R.J. 2008. Sulfur and iron speciation in recently recovered timbers of the *Mary Rose* revealed via X-ray absorption spectroscopy. J. Archaeol. Sci. 35: 1317–1328.

Wheeler, E.A., Baas, P., Rodgers, S. 2007. Variations in dicot wood anatomy: a global analysis based on the insidewood database. IAWA J. 28: 229–258.

Williams, M. 2003. Deforesting the earth. From Prehistory to global crisis. University of Chicago Press, Chicago.

Yakir, D., Issar, A., Gat, J., Adar, E., Trimborn, P., Lipp, J. 1994. ^{13}C and ^{18}O of wood from the Roman siege rampart in Masada, Israel (AD 70–73): Evidence for a less arid climate for the region. Geochim. Cosmochim. Acta 58: 3535–3539.

Yakir, D., Lev-Yadun, S., Zangvil, A. 1996. El Niño and tree growth near Jerusalem over the last 20 years. Global Change Biol. 2: 97–101.

Zackrisson, O., Östlund, L., Korhonen, O., Bergman, I. 2000. The ancient use of *Pinus sylvestris* L. (Scots pine) inner bark by Sami people in northern Sweden, related to cultural and ecological factors. Veg. Hist. Archaeobot. 9: 99–109.

Zobel, B.J., Sprague, J.R. 1998. Juvenile wood in forest trees. Springer-Verlag, Berlin.

Zohary, M. 1959. Geobotany. 2nd ed. Merhavia (in Hebrew).

Zohary, M. 1962. Plant life of Palestine. Israel and Jordan. The Ronald Press Company, New York.

Zohary, M. 1973. Geobotanical foundations of the Middle East. Gustav Fischer Verlag, Stuttgart.

Zohary, M. 1983. Man and vegetation in the Middle East. In: Holzner, W., Werger, M.J.A., Ikusima, I., eds. Man's impact on vegetation. Dr W Junk Publishers, The Hague, pp. 287–295.

Zohary, D., Hopf, M. 2000. Domestication of plants in the Old World. 3rd ed. Clarendon Press, Oxford.

Zohary, D., Spiegel-Roy, P. 1975. Beginnings of fruit growing in the Old World. Science 187: 319–327.