

# Reconstructing Woodland Vegetation and its Exploitation by Past Societies, based on the Analysis and Interpretation of Archaeological Wood Charcoal Macro-Remains

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## *Abstract*

In this paper the significance of the analysis of archaeological wood charcoal macro-remains as a tool for the reconstruction of woodland vegetation and its exploitation is discussed. Drawing from both older and more recent publications a number of theoretical and methodological approaches are examined. It is suggested that greater integration of charcoal and archaeological data is needed when evaluating charcoal preservation and sample composition, and that a more coherent theory of the complex ecological and cultural processes affecting species availability and firewood management needs to be developed.

*Keywords:* ARCHAEOBOTANY, CHARCOAL ANALYSIS, FUEL, SUBSISTENCE, FIREWOOD, WOODLAND VEGETATION, TAPHONOMY

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## **Introduction**

The analysis and interpretation of wood charcoal macro-remains from archaeological sites has been extensively used over the past 60 years by archaeobotanists and palaeoecologists as a means for reconstructing past vegetation and, by inference, climate patterns (see reviews in Smart and Hoffman 1988; Figueiral and Mosbrugger 2000). One such example is the detailed palaeoenvironmental sequences built for the western Mediterranean basin by archaeobotanists trained at the University of Montpellier II, France (henceforth collectively referred to as the "Montpellier school"), through the analysis of wood charcoals from multiple sites covering a wide range of time periods (e.g. Heinz and Barbaza 1998; Heinz and Thiébaud 1998). Charcoal analysis has been also successfully applied in arid environments, where wood charcoals derived from stratified archaeological deposits may represent the only reliable source of palaeoenvironmental information in the absence of well-preserved pollen sequences with adequate temporal and spatial resolution (e.g. Neumann 1992; Cartwright and

Parkington 1997; Willcox 1999; Asouti and Hather 2001; Tengberg 2002).

This proliferation of research has co-existed however with the questioning of the value of charcoal analysis, specifically its reliability as a tool for reconstructing palaeoenvironments, at least within the Anglo-American research tradition (see Smart and Hoffman 1988 for a general overview). Serious debate began in the 1940s in Britain following the publication of Salisbury and Jane's (1940) analysis of charcoals from Maiden Castle, Dorset, and the critical response to it from Godwin and Tansley (1941). The core of this debate is whether or not the observed frequencies of individual tree and shrub species in an archaeological wood charcoal assemblage reflect accurately their actual proportions in past vegetation, and could therefore be used to infer climate conditions in the past. The objection was raised that any such correlation is likely to be heavily distorted by the influence of differential wood combustion alongside ecological (e.g. structure of plant communities and species physiology) and cultural variables (wood selection), all affecting species

availability and representation. This remains a salient criticism of charcoal analysis within the field of environmental archaeology, particularly in the UK. A consequence of such criticisms, evident in many of the standard environmental archaeology textbooks, is that little explicit reference is made to charcoal analysis as a distinct discipline (e.g. Evans and O'Connor 1999) save (in older publications) for wood identification (e.g. Shackley 1981; Schoch 1986). In effect, charcoal analysis is largely dismissed as a credible area of palaeoenvironmental research.

The aim of this paper is to offer a fresh perspective into the potential of charcoal analysis in the wider context of environmental archaeology. Two particular issues will be explored in greater detail:

- A critical discussion of the interpretative models, sampling methodologies and decision-making in the field and in the laboratory that are used by charcoal analysts in order to reconstruct past environments.
- A consideration of the influences that cultural formations may exert on fuel collection and consumption practices.

It will be argued that an approach to the subject which emphasises a multi-layered interpretation of ecological processes and related human activities, may enable a more widespread recognition of the potential of charcoal analysis for the investigation of palaeoenvironments and their interaction with past societies.

## Vegetation Reconstruction from Fuel Macro-remains

Wood charcoals represent one of the most ubiquitous types of archaeobotanical remains found in archaeological sites. As such they have been used for a variety of purposes in archaeological and archaeobotanical research, including dating (radiocarbon and dendrochronology) (e.g. Kuniholm and Newton 1996), the reconstruction of woodland management practices and deforestation processes (e.g. Miller 1985; Kreuz 1992), the charting of exchange patterns for valuable timber species in antiquity (e.g. Asouti 2003a), and the analysis of the influences of fuel selection and context-related variation in the preservation of wood fuel remains (e.g. Pearsall 1983; Johannessen and Hastorf 1990; Asouti 2003b). One of the most widely recognised contributions of charcoal analysis is however the reconstruction of past woodland and forest vegetation (see references above). Vegetation reconstruction has been the main objective of specialists working in this field from its earliest stages. As early as the 1960s the French wood anatomist M. Couvert drew attention to the potential of charcoal macro-remains for providing a high

resolution picture of past vegetation at a temporal scale congruent with that of prehistoric habitation, a trait rarely shared by off-site pollen sequences that (even when adequately dated) offer a conflated picture of the local and regional woodland composition (Couvert 1968).

As most specialists working in the field of charcoal analysis recognise, the availability of woody plants in the habitation environment is one of the most important factors determining their ease of collection as fuel by prehistoric communities. Availability therefore has been widely used for developing functionalist interpretations of archaeological wood charcoal assemblages. The basis for such interpretations is the belief in the existence of a deterministic relationship between wood selection by prehistoric societies and the species composition of woodlands, known as the "Principle of Least Effort" (Tusenius 1986; Scholtz 1986; see also Prior and Price-Williams 1985; Tusenius 1989). According to this hypothesis, firewood collection in the past occurred in those wooded areas situated closest to the habitation site and all species were collected in direct proportion to their occurrence in woodland vegetation. Hence the frequencies of individual taxa in any given assemblage, allowing for potential biases introduced by differential preservation, rates of charcoal deposition and sampling strategies, can be considered as an accurate reflection of their proportions in woodland vegetation at the time of site occupation.

Based on this principle, over the last three decades the Montpellier school has developed a methodological and theoretical approach that has resulted in the construction of an elaborate model for the application of charcoal analysis as a method of palaeoenvironmental research (cf. Chabal 1988; 1992; 1997; Chabal *et al.* 1999). Two particular aspects of their approach merit mention here. First, the contention that wood charcoals fragment in a mostly uniform way. This has been expressed in the "law of fragmentation", originally formulated by L. Chabal (1988; 1992) based on the statistical analysis of complete archaeological assemblages. In essence this law states that charcoal, irrespective of species, tends to fragment by producing a high number of small fragments and a low number of large ones. That is, in an archaeological wood charcoal assemblage mass (charcoal weight) and number of fragments are correlated (Chabal 1988; 1992). Secondly, this law states that the variable effects on charcoal decay of less controlled parameters involved in combustion, such as mass reduction (which may be affected simultaneously by factors such as species anatomy, moisture content, size of the logs etc.), are independent of the overall fragmentation status of the archaeological wood charcoal assemblage. Thus, for the total mass of a charcoal assemblage retrieved

from an archaeological layer, the law of fragmentation determines the relative proportions of large and small fragments for all taxa. That mass reduction and fragmentation are separate processes is indicated by the fact that the total mass and the total number of fragments in the charcoal assemblage are correlated (see also Fig. 1. For a detailed presentation of the related statistical analyses see Chabal 1988; Chabal *et al.* 1999, 77–79). Any random biases that (although rare) might occur in species representation, as a result of mass reduction or other parameters, can be compensated for by the application of a strict sampling protocol both in the field and in the laboratory. This protocol emphasises the identification of sufficiently large assemblages; in temperate and Mediterranean Europe a minimum of 400 fragments per stratigraphic unit is recommended (Chabal 1988; Chabal *et al.* 1999).

Central to the Montpellier school approach is the recognition of the critical role that the context of deposition plays in the formation and representativeness of a wood charcoal assemblage. Chabal (1992; Chabal *et al.* 1999) has argued consistently that no sound evaluation of the composition of a charcoal assemblage is feasible, unless the type and duration of the human activities associated with fuel consumption and the presence of charcoal debris in the archaeological sediments are adequately understood. This necessitates differentiating between long- and short-lived contexts, domestic and external spaces, and different types of refuse deposits (Chabal *et al.* 1999; see also Table 1). In summary, archaeological charcoal assemblages must fulfil three criteria to qualify for the purpose of palaeoenvironmental reconstruction:

- To represent charcoal deposits accumulated over a prolonged period of time (secondary refuse, i.e. scattered charcoal), *not* short-term or episodic events (primary refuse, e.g. hearth deposits). Secondary deposits are more likely to produce a high diversity of woody taxa thus maximising the potential of analysis for vegetation reconstruction. They can also be expected to have been subject to broadly the same range of post-depositional alterations. By contrast, even if substantial quantities of charcoal are retrieved from short-term deposits and a high degree of taxonomic diversity is established, the probability that these are related to the specific circumstances of the last firing event, and do not represent a lasting trend, cannot be eliminated. Furthermore, with regard to preservation conditions, short-term deposits may have been subject to diverse post-depositional transformations.
- To be primarily the result of domestic fuel burning activities. Depending on the predicted frequency of the disposal events (day-to-day or at longer intervals), they are more likely to characterize lasting patterns of fuel-related activities.

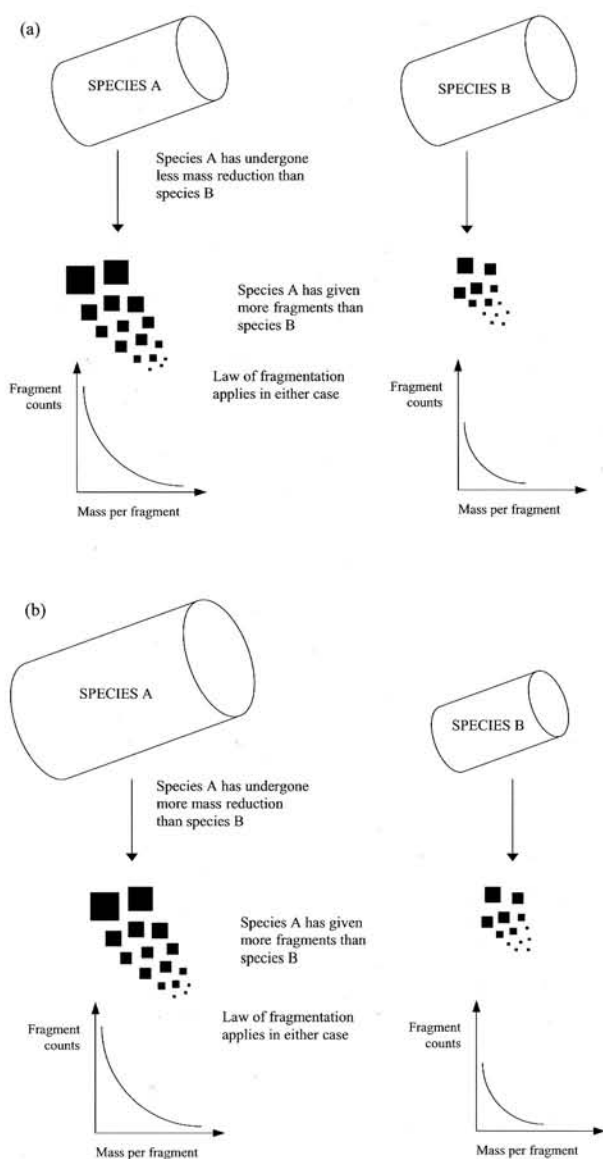


Figure 1. (a) species A was as abundant as species B but underwent less mass reduction, (b) species A was more abundant than species B but underwent more mass reduction (after Chabal 1992, 228–9).

- To contain sufficient quantities of wood charcoal to allow statistically meaningful analysis.

The impact that human selection may have on species presence and the difficulties inherent in reconstructing it accurately (particularly for prehistoric sites) is recognised in principle (Chabal 1992). Chabal however chooses to focus on burning qualities as the principal factor that may affect human choices, in order to demonstrate that ecological imperatives (i.e. availability) will eventually overtake any concept of “preferred species”. Thus she emphasises that the burning properties of each type of wood depend more on physical parameters, like pole size and

Short-term deposits	Long-term deposits
<ul style="list-style-type: none"> <li>• <u>Primary refuse</u> (e.g. hearths and fire installations, destruction levels).</li> <li>• Composition of charcoal assemblage may not reflect long-term, established patterns of fuel selection and consumption but instead the remains of their last episode of use.</li> <li>• May furnish important information on the structure and function of particular hearth types and on aspects of wood use (e.g. choice of building materials and woodworking).</li> <li>• May have been subject to diverse post-depositional alterations.</li> </ul>	<ul style="list-style-type: none"> <li>• <u>Secondary refuse</u> (charcoals likely to derive from external, non-domestic areas such as middens, fills, etc.).</li> <li>• Composition of charcoal assemblage likely to reflect lasting patterns of firewood selection and consumption.</li> <li>• May maximise the potential of the analysis for palaeoenvironmental reconstruction.</li> <li>• May allow a more precise evaluation of the effect of sedimentary conditions on overall charcoal preservation.</li> </ul>

Table 1. Advantages and disadvantages of long- and short-term deposits for charcoal analysis (drawing from descriptions provided in Chabal *et al.* 1999).

diameter, its status as fresh or deadwood, moisture content, fire temperature etc., than on the inherent characteristics (anatomical, physiological and chemical) of the species from which it derives (Chabal 1992). Based on this reasoning she argues that, for domestic firewood, the spectrum of taxonomic frequencies observed in a selected sequence of samples represents in every case a *compound* picture of the source plant communities. Therefore, it is not methodologically valid to assume that a list of taxa and their respective frequency values (measured as percentage fragment counts) can be directly translated into specific ecological units (the analogy here to research paradigms familiar from pollen analysis is evident). Such values can only be used to infer palaeoenvironmental change over time through the application of the appropriate ecological theory. The ultimate aim of the analysis is to reconstruct as accurately as possible past vegetation by removing each of the cultural, analytical and taphonomic "filters" intervening between the extant charcoal assemblage and the source area (vegetation) from which firewood derived (Chabal 1992; Chabal *et al.* 1999; see also Fig. 2).

The main critique of the approach of the Montpellier school, particularly among Anglo-American research, has focused on the perceived inappropriateness of charcoal macro-remains for reconstructing palaeovegetation based on quantitative analysis (particularly percentage fragment counts), due to the differential responses of individual taxa to the effects of burning (e.g. Zalucha 1982; Lopinot 1984, 130–1; Rossen and Olsson 1985; Smart and Hoffman 1988; Keepax 1988). Thus some researchers have promoted

different forms of quantification. One relatively common method is by weight (e.g. Miller 1985, Cartwright and Parkington 1997). However, the Montpellier school has objectively demonstrated that fragment numbers and weight measurements represent in nearly all cases co-varying parameters (see discussion above, Fig. 1). Another is by ubiquity analysis (see Willcox 1974, Smart and Hoffman 1988, Thompson 1994). There have also been suggestions for the complete rejection of quantitative methods, as they are deemed unreliable for reconstructing either past vegetation or wood use; instead the adoption of qualitative means of vegetation description is promoted (Zalucha 1982). Ubiquity analysis and qualitative vegetation descriptions may be appropriate for reconstructing past vegetation in certain environmental contexts (see below) or when considering regional assemblages that have been studied with variable sampling and analytical techniques (*cf.* Hubbard 1980). However, ubiquity analysis may also obscure patterns relating to the intensity of fuel exploitation, especially when the frequency of use of individual taxa remains broadly the same but abundance changes (*cf.* Popper 1988, 64). In other words, what the analyst may end up with is a more or less even distribution of charcoal taxa across the sampled sequence, with little, if any, information as to their relative input to sample composition. Although the influence of the charring process and related methodological issues are no less important (*cf.* Asouti 2001, 86–88), it is our opinion that approaches to the quantification of charcoal macro-remains could substantially benefit from closer scrutiny of the methodological suggestions of the

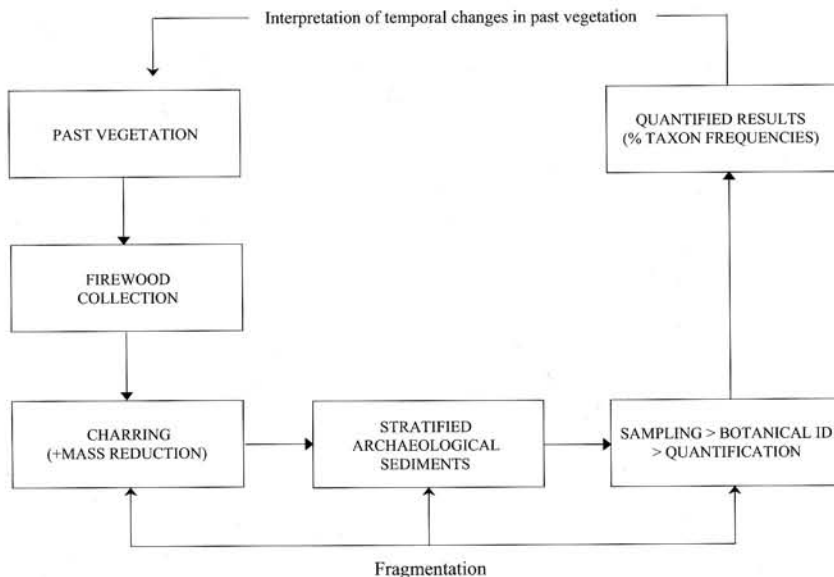


Figure 2. Schematic representation of the different stages that a given charcoal assemblage has undergone before the charcoal analyst attempts to reconstruct long-term palaeovegetation changes, as conceptualized by the Montpellier school (after Chabal 1992).

Montpellier school (particularly those concerned with sampling in the field and the number of fragments to be microscopically analysed; see below). That such an understanding has, in many cases, failed to materialise is evident in those charcoal studies that opt for an outright rejection of any quantitative approach, without considering the effects of parameters such as sample size, depositional context, and hearth type and function on taxon representation (e.g. Zaluza 1982; cf. Asouti 2001, 102–5).

Ultimately, the suitability of different quantification techniques (and hence the very utility of the method) for the purpose of vegetation reconstruction can only be assessed through the evaluation of the practical application of charcoal analysis and its actual results. In the Western Mediterranean, where the Montpellier school has been mostly active, a number of parameters have contributed in the production of reliable palaeoecological sequences from quantified charcoal macro-remains (based always on the percentage fragment counts of charcoal taxa). These can be summarised as follows:

- The adoption of a strict sampling protocol in the field, targeting long-term deposits (general charcoal scatters) and excluding short-term ones like hearths (see discussion above and Table 1).
- The sampling of a number of sites and the comparison of charcoal assemblages among sites in order to see whether common patterns emerge concerning taxon representation.
- The consideration of detailed descriptions of modern

vegetation types. These consist of the number and the autecology and synecology of species per woodland habitat type, as these can be inferred from modern ecological studies. The main aim here is to see how the ratios observed in the charcoal assemblage between individual taxa compare to those observed in known modern woodland environments.

- The availability of other sources of palaeoenvironmental information that may complement charcoal data in inferring past environmental change (mostly pollen but also snails, other archaeobotanical remains, fauna etc.).

Studies where these particular methodologies have been systematically applied in temperate Europe and west Mediterranean environments, have demonstrated that the results of charcoal analysis correlate very closely with those of off-site pollen studies (e.g. Chabal 1997; Heinz and Thiébaud 1998; Heinz and Barbaza 1998; Pernaud 2001). In addition, these studies have shown that, depending on the type of habitation site (permanent or seasonal), any differences observed between the two sources of palaeoecological information can be almost always explained adequately as the result of either localised vegetation responses to human activities (e.g. clearance), or of the predicted distance of particular woodland species and vegetation types from the habitation sites (hence explaining the absence from the charcoal record of certain taxa present in pollen diagrams). It follows that the end result of a systematic application of charcoal analysis may provide a

picture of past vegetation considerably more precise in terms of the physiognomy, composition and changes in the local vegetation catchments, than that available through off-site palynology.

This last point becomes even more pertinent for sites in arid and tropical environments. In these areas, well-preserved and dated pollen sequences are nearly universally absent, owing to sedimentary conditions and the general rarity of suitable coring sites. Particular types of vegetation communities (e.g. the oak park woodland and the woodland steppe in Southwest Asia) tend to be under-represented in regional palynological studies because many of their constituent taxa (e.g. Rosaceae) are insect-pollinated rather than wind-pollinated (Asouti and Hather 2001; Woldring and Cappers 2001). Perhaps the greatest obstacle to vegetation reconstruction in arid and, more so, in tropical regions is the high floristic diversity which can inhibit precise botanical identifications (Thompson 1994; Scheel-Ybert 2001). This aside, the methodologies followed for interpreting the frequencies of charcoal taxa derived from stratified deposits depend largely on the specific vegetation types predicted for each area under investigation. In areas where a homogeneous forest cover and/or uniform vegetation types are predicted, an approach similar to that described for temperate environments may prove productive. By contrast, for areas where there is sharp vegetation zonation (resulting for example from localised differences in rainfall and/or soil types across the territory of the site and the presence of a high diversity of microenvironments and ecotonal zones), the archaeological wood charcoal assemblages may well be very diverse, containing taxa from a series of spatially distinct woodland types. Such a pattern was identified, for example, in the analysis of charcoal from six shell-mound sites in the southeast Brazilian coast, where taxa deriving from a variety of woodland habitats and plant communities were represented in nearly equal proportions through the timespan covered by the sampled sequence (Scheel-Ybert 2001). In principle therefore, it is very likely that what will be reflected in the charcoal sequence is not so much a "dominant" vegetation type and its transformations (human and/or climate induced) through time, but instead the compound picture of a series of vegetation habitats. Provided that indicator species and/or distinct vegetation types (necessarily based on modern ecological analogues) can be securely defined, their fluctuations in the sequence are thus more likely to reflect the varying degrees and intensity with which they were exploited for fuel collection in the past, than long-term vegetation changes attributable to climate change (Willcox 2002).

An example of a similar situation is presented by the charcoal assemblage derived from the large early

Neolithic tell-site of Çatalhöyük, in the Konya plain, south-central Anatolia (Asouti and Hather 2001; Asouti in press). Given the location of the site and the complex configuration of its environs (comprising a variety of riverine, marsh, steppe and park woodland habitats), it was originally predicted that wood derived from all these different catchments could be represented in the charcoal samples. Therefore, abundance data (i.e. percentage fragment counts) were deemed largely unsuitable for defining and reconstructing woodland composition and structure, since fuel wood might have been collected from a mosaic of different vegetation types. Furthermore, with the exception of riverine trees and shrubs, most of the taxa encountered in the charcoal assemblage could have occurred in more than one vegetation type (e.g. certain members of the Rosaceae family are found in woodland steppe vegetation as well as oak park woodland; Hillman 2000). Therefore, in this case, the combined use of taxon presence data, modern analogues for community and individual species ecology, field observations and comparisons with the extant palaeoenvironmental record, seemed to be a much more useful avenue for reconstructing the composition and structure of the diverse woodland types. However, quantified taxon frequencies (percentage fragment counts) were found useful as a tool for reconstructing how intensively each of these vegetation catchments was exploited in the past, and the long-term effects of human activities and environmental change (as far as these could be disentangled) on woodland structure and composition (Asouti and Hather 2001; Asouti in press).

### Some Methodological Considerations

An important consideration in wood charcoal studies concerns the size and number of samples that are likely to provide statistically meaningful results about sample composition. In principle, optimal sample size (the number of fragments per sample required for obtaining a reliable picture of taxon presence and their relative proportions) varies depending primarily on the degree of accuracy required (*cf.* van der Veen and Fieller 1982). For charcoal analysis, some authors have suggested that (where modern vegetation communities can be studied in detail or quantitative analyses of community ecology are already available) estimating sample efficiency can be achieved through the use of the Gini-Lorenz concentration curves. These can allow the identification of standard numbers of fragments common for most types of analyses, through the estimation of generally acceptable levels of accuracy corresponding to different vegetation types (for a detailed description of its application in the analysis of west Mediterranean

assemblages see Chabal 1997). The method consists of plotting the floristic diversity of the vegetation sample against the number of charcoal samples as a "saturation curve". "Saturation curves" derive from the work of several authors who have observed that taxonomic recovery follows an exponential curve: the number of taxa present in a sample rises sharply as the first few charcoal specimens are examined and then settles down as more fragments are identified (*cf.* Keepax 1988, 44; Smart and Hoffman 1988; Chabal *et al.* 1999, 67).

For temperate environments, Keepax (1988, 120–4) has suggested that a minimum of 100 fragments per sample should be examined, which can be extended up to 300–400 fragments per stratigraphic level. Based on their experience of west Mediterranean sites, Chabal *et al.* (1999, 66) raise this lower limit to 250 fragments, with 400–500 fragments considered as the optimal subsample size per excavated level. Such differences in the recommended minimum numbers of identifications reflect of course different levels of floristic diversity between the UK and mainland Europe. For tropical regions, characterized by high floristic diversity, Scheel-Ybert (2002) has calculated the minimum subsample size in the range of 200–300 charcoal fragments per sample. Subsamples in this range gave species concentration indices similar to those found in modern vegetation units (for further details on sampling and the statistical procedures followed in this particular study see Scheel-Ybert 2002).

Other researchers have observed that the point when taxon recovery curves level off is not solely a function of the number of examined fragments, but also depends on the spatial extent of the sample population across the excavated level (Badal Garcia 1992). Provided that results are replicated across samples for each level, such a strategy may also prove useful for suggesting possible targets for sample identification. By maximising the spatial coverage of sampling within each excavated and/or stratigraphic level, it is also possible to compensate for temporary and, for that reason, largely unpredictable "levelling-off" sometimes observed in individual recovery curves (Figueiral 1992). Keepax makes a similar point when she states that "over-identification of individual samples does not compensate for insufficient sample number ... A certain number of samples must always be identified to account for between-sample variation" (Keepax 1988, 45). However, it should be kept in mind that more extensive spatial coverage may mask (if applied without careful consideration) variation between samples that could otherwise be very informative, for example when considering context-related variation in sample composition and comparing different context types.

Equally important in terms of subsample determination is the size range of the fragments chosen for analysis. Such a selection can be achieved through splitting the sample and randomly choosing a portion of it (Willcox 1974), "grab-sampling" fragments of different size and shapes (Miller 1985) or passing the dry flots through a stack of sieves of graded mesh sizes and subsampling each size fraction (Zalucha 1982, 79). Of all three methods, dry sieving is by far the most efficient for charcoal analysis. Grab-sampling suffers from a lack of standardisation thus being inherently subjective, whereas splitting the sample with a riffle-box will invariably result in further fragmentations. The use of grid systems can prove very time-consuming without also being altogether free of similar subjective elements (van der Veen and Fieller 1982). Depending on the preservation of the material, it is generally considered preferable to concentrate on the >4mm fraction of dry-sieved material as smaller fractions (>3mm – >1mm) are likely to contain too many unidentifiable fragments (due to their size) (Keepax 1988; Chabal *et al.* 1999). However research constraints or particular project requirements may necessitate including <4mm fractions if, for example, not enough fragments of >4mm are available due to preservation conditions (e.g. Asouti 2003a) or the analysis also aims at plotting the presence and frequencies of small-sized woods such as shrubs whose charcoal is more likely to be retained in <4mm fractions (e.g. Asouti and Hather 2001; Asouti *in press*).

As to the number of samples to be analysed (depending on the research objectives and the available resources), ideally the recovery from twenty-five to fifty samples on average may be considered as a reasonable minimum, whereas for more complex archaeological sites with a greater variety of depositional contexts, one hundred or more samples may be required. This may not always be possible, particularly for sites that do not have well-preserved charcoal assemblages (see Asouti 2003a). Therefore the results derived from such necessarily limited assessments of sample composition should be viewed with caution with regard to their environmental interpretation. For multi-period settlements, intra-site comparisons between contexts and/or excavated levels necessitate similar provisions (Keepax 1988, 45–47).

## Reconstructing Firewood Exploitation

Many scholars, now and in the past, have stressed the unique character of archaeological wood charcoals derived from fuel use, representing the product of purposeful human action within the period of site habitation, and have thus cautioned against their

uncritical use as climate indicators in a manner like that of off-site pollen sequences (e.g. Western 1971; Smart and Hoffman 1988; Thompson 1994; Figueiral and Mosbrugger 2000). This observation does not diminish the value of charcoal analysis as a tool for vegetation reconstruction (see previous sections). It does point however to the necessity for developing specific theoretical and methodological models that will deal with small-scale processes of vegetation-culture interactions, in order to address questions relating to local vegetation change and the interpretation of prehistoric firewood management. The rest of this paper will therefore concentrate on the issue of human selection and attempt to place it in its proper ecological and cultural context.

The availability of species for firewood exploitation is not solely a function of net species abundance. Usually it reflects a synthesis of complex ecological processes affecting species representation in ways that may be unrelated to large-scale environmental/climate change (Shackleton and Prins 1992). Ethnographic and archaeological research has established, for example, that factors such as the abundance of dry dead-wood, which poses almost minimal requirements concerning its ease of collection and transportation, may be the most influential factor in firewood collection (e.g. Heizer 1963; Ford 1979; Scheel-Ybert 2001; Asouti *in press*; Austin unpublish-

ed material; see also Fig. 3). Where this is the case it can affect the range of taxa collected as fuel, not least because different species may shed parts more readily than others, either spontaneously or due to stress of competition for light and seasonal deficiencies in ground moisture (Godwin and Tansley 1941; Millington and Chaney 1973).

Furthermore, the rate by which certain species of trees and shrubs regenerate and colonise new habitats as a response to disturbance (woodcutting, land clearance, browsing etc.) can also stimulate periodic increases in their exploitation as easily renewable firewood resources (Minnis and Ford 1977). Other important factors affecting species availability include the age and structure of the tree stands and their seasonal transformations (Austin 2000). Old-growth stands, comprising mature to over-mature trees, will provide ample quantities of dead-wood in the form of dying or dead branches in the canopy, fallen lateral branches, snags (standing dead trees)/boles and down logs (fallen trees) (Kirby 1992; Peterken 1992). Also, disturbed areas (e.g. forest gaps created by wind, fire of natural and/or anthropogenic origin, clearance etc.) will accommodate fast growing, light-demanding trees and shrubs, which could be relatively easy to harvest considering parameters such as pole size and height. They can also provide habitats characterized by increased availability of



Figure 3. Examples of preserved oak deadwood (indicated by the presence of fungal hyphae and mycelium inside vessels and on vessel walls) in wood charcoal fragments from Çatalhöyük midden samples of levels VII-IX.



herbaceous graze for woodland mammals and a higher diversity of plant and animal resources compared to undisturbed, "climax" forests (Barkham 1992; Ratcliffe 1992). Such environments are therefore amenable to exploitation for a combination of purposes including hunting, plant gathering and fuel collection, which are furthermore likely to be organised on a seasonal basis.

Species availability may also be linked to cultural perceptions of woodlands, which can actively encourage or discourage the distribution of particular species across the landscape (Unruth 1994). Trees and shrubs may be preferentially selected for their burning qualities, the physical properties and size of wood, and the cultural beliefs attached to them (Austin 2000). Smart and Hoffman (1988) also cite many examples from the ethnographic record whereby certain types of wood are seasonally collected on such a basis. Inherited perceptions or differences in social status may also exert an important influence on fuel acquisition practices among different groups (Ford 1979). A careful consideration of the charcoal record in relation to the information available on the archaeological context of the charcoal remains, and any intra- or inter-site variations in sample composition may provide a good starting point for addressing such questions from a sound factual basis (Chabal 1992).

Charcoal analysts have at their disposal an increasing body of literature describing small- to medium-scale ecological processes such as those described above, which is also complemented with a wealth of anthropological studies on human perceptions of trees and woodlands (e.g. Rival 1998). What however seems to be ill-represented in the relevant literature is a systematic concern with the construction of models for addressing the influence of cultural formations on fuel collection, consumption and discard. Important exceptions are analyses that deal with archaeological case studies of the impact of permanently settled communities on past vegetation (e.g. Miller 1985; Willcox 2002), statistical approaches to the investigation of local vegetation changes in relation to firewood management (e.g. Piqué and Barceló 2002), and methodological studies concerned with the representativeness of hearth charcoal assemblages (e.g. Ntinou 2002, 117–22). Aside from achieving a more balanced understanding of the palaeoenvironmental representativeness of archaeological charcoal assemblages, such considerations could enable the meaningful integration of charcoal macro-remains in the currently available models of ancient subsistence economies. For this purpose, it is necessary to recognise that fuel remains represent the material residues of a complex interplay between long-term environmental change, localised ecological/vegetation processes, economic produc-

tion and cultural formations.

To illustrate the value of such an approach, three general categories of subsistence adaptations (mobile hunter-gatherers, nomadic pastoralists and settled agriculturalists) are presented here. Whilst "most living peoples combine these subsistence practices in various ways" (David and Kramer 2000, 227) by focusing on these established analytical units of archaeological enquiry, such a survey can be used for developing appropriate interpretative models. It should be noted that these models have mainly heuristic value, in that they are based on a limited number of extant ethnographic and ethnoarchaeological studies concerned directly with fuel collection and consumption or, more generally, with resource procurement and the spatial organisation of fire-related activities. Future ethnoarchaeological research (backed by experimental studies on the effects of different burning environments on sample composition) would certainly enhance any predictive value held in the proposed models.

#### *Predictive model 1: mobile hunter-gatherers (Table 2)*

In general, hunter-gatherer groups can be expected to rely for their needs in firewood mainly on what is available in the immediate vicinity of the campsite and to use local vegetation on a quasi-opportunistic basis. However, differentiation within this general model could also occur, depending on the range of the exploited resources, their frequency of exploitation and patterns of mobility (cf. Binford 1980). Thus, it has been observed that "foraging" groups (characterized by high residential mobility, low-bulk inputs and regular daily forays for food procurement) are very different in this respect from "collecting" groups. The latter may be much more selective in their choice of resources, extract them in bulk quantities, and also invest in complex arrangements of resource storage and sharing (Binford 1980).

Non-permanent habitation sites may also introduce perceptions of resource "affluence" which could encourage fuel collectors to apply very selective criteria in their choice of firewood species. However, species may not be the sole or even the main criterion for choosing fuels: fuel exploitation strategies may target easily collectable wood (e.g. dry deadwood, fallen branches, driftwood etc.). It has also been observed that concepts of "preferred firewood" among hunter-gatherers are more likely to correspond to the functions of multi-purpose hearths (e.g. for lighting, smoking, cooking, protection etc.), instead of modern concepts valuing heating efficiency and the ease of ignition of individual species (Théry 2002).

General predictive model	Factors that may introduce variations in the general model	Predicted group/individual perceptions of fuel resources and definition of the concept of "preferred firewood"	Patterns of hearth structure and fuel refuse disposal
<p>Fuel collection may take place in close proximity to the campsite(s).</p> <p>Opportunistic use and consumption of fuel resources.</p>	<p>Range of exploited areas (local versus distant).</p> <p>Subsistence pattern ("foraging" versus "collecting" groups).</p>	<p>Perceptions of resource "abundance" may result in selective use of fuel species.</p> <p>Hearth function(s) may determine perceptions of "preferred firewood".</p>	<p>Hearth structure (e.g. covered versus open hearths) will affect charcoal preservation in primary contexts.</p> <p>Hearth maintenance (frequency of cleaning and patterns of disposal of fire-related debris) will affect charcoal preservation in secondary contexts.</p>

Table 2. Predictive model 1: mobile hunter-gatherers.

Most of the hearths used by mobile groups are characterized by variable lifespans and are typically located outdoors. Intermixing and displacement of deposits may occur as a result of cooking activities, shifts of activity spots, and the trampling of habitation deposits (Binford 1983, 157; O'Connell 1987). On the other hand, covered hearths are more likely to retain wood charcoals in a good state of preservation (March 1992). Fuel debris may be cleaned from hearths on a daily basis, or (for open-air hearths) at longer intervals. It may be scattered around activity areas (appearing as charcoal and ash concentrations around hearths) or beyond the limits of the living/working space (forming sometimes distinct ash dumps) (cf. O'Connell 1987; O'Connell *et al.* 1991; Bartram *et al.* 1991).

*Predictive model 2: nomadic pastoralists*  
(Table 3)

Nomadic pastoralists rely on firewood not only for satisfying daily heating and cooking requirements but also for production purposes, i.e. the preparation and processing of milk-products (Martin 1980). Converting milk into various products that can be stored for later consumption and exchange requires large amounts of firewood, preferentially gathered from areas within easy walking distance from the campsite (Cribb 1991). For example, extant estimates from northwestern Iran report that the maintenance of 250 milking animals requires some 21 tons of fuel per season most of it expended in milk processing (Horne 1994, 62–64). Given the demands in fuel of milk processing activities and their seasonal nature, what matters most from the pastoralist's viewpoint is the actual *quantity* of biomass available rather than the form or species of fuel. Fuel is collected and burnt indiscriminately and may comprise live and dead vegetation alike (Martin 1980). Such a process could

also result in the accumulation of large quantities of bulk fire debris near processing areas, especially in the case of repeated visitations to the same spots.

*Predictive model 3: settled agriculturalists*  
(Table 4)

For sedentary farming communities firewood related activities are altogether more complex. With regard to the spatial distribution of fuel waste, additional sources of patterning may represent the variable cultural contexts affecting discard practices, and the reworking of fuel debris (cf. Watson 1979, 37–39; LaMotta and Schiffer 1999). From an ecological perspective, permanent settlements exert a significant and, sometimes, irreversible impact on their environments, which is further conditioned by the range of demands placed on vegetation (e.g. for fuel, fodder, timber, pasture etc.). These demands are in turn determined by the complex set of economic activities and social relationships taking place within the community. We have isolated three main themes relevant to the understanding of the attitudes of farming communities towards woodland resources: resource ownership (determining access to woodlands), the contribution of deadwood and wood-cutting, and the seasonal scheduling of firewood collection.

*woodland accessibility and resource ownership*

In sedentary communities access to woodlands is primarily a function of ownership (individual or communal). There are several kinds of individual ownership, including household, lineage or community property, which can determine the right to own, inherit, plant or dispose of trees (cf. Horne 1982) and may include diverse units such as gardens, fields or entire woodlands (Devres Inc. 1980). Communal ownership has been far more common in societies

General predictive model	Factors that may introduce variations in the general model	Predicted group/individual perceptions of fuel resources & definition of the concept of "preferred firewood"	Patterns of hearth structure and fuel refuse disposal
<p>Collection of the largest amount of biomass available at the shortest possible distance from the camp.</p> <p>Opportunistic use and consumption of fuel resources.</p>	<p>Hearth function(s) (preparation and processing of milk products, heating, cooking).</p> <p>Duration of fuel consumption activities at camp location.</p>	Total quantity of the biomass available more important than the form or species of fuel.	Accumulation of large quantities of bulk fire debris near processing areas.

Table 3. Predictive model 2: nomadic pastoralists.

General predictive model	Factors that may introduce variations in the general model	Predicted group/individual perceptions of fuel resources and definition of the concept of "preferred firewood"	Patterns of hearth structure and fuel refuse disposal
<p>Fuel collection may take place at variable distances from the settlement site.</p> <p>Scheduled use and consumption of fuel resources.</p>	<p>Range and types of activities involving the use of fire (domestic, industrial, ritual).</p> <p>Range and type of activities resulting in the generation of quantities of wood fuel (by-products of timber processing, woodland management, prunings from cultivated species, etc.).</p> <p>Seasonal scheduling of activities and wood storage.</p> <p>Resource ownership (individual/communal).</p> <p>Regulation of access to woodlands.</p> <p>"Economic" behaviour (conservation of fuel resources).</p>	Fuel selection may be a function of burning qualities, ease of collection, distance of collection point from the settlement, tool type, and conservation of woodland resources.	<p>Complex range of hearth types (domestic, manufacturing, industrial, ritual, etc.).</p> <p>Regular clearing of fire debris from domestic fire installations and disposal at a spatially removed location (midden, fill, abandoned structure, etc.).</p>

Table 4. Predictive model 3: settled agriculturalists.

where the institution of "common lands" exists (reserved for firewood, grazing, hunting, fodder provisioning, wild plant foods, timber, medicinal plants etc.) (Devres Inc. 1980; Michael Arnold 1997; Scherr 1997). Restrictions on woodland exploitation can be realised through the exertion of authoritative, religious or hereditary rights, which aim at the preservation of woodland resources (e.g. Dei 1992; Unruth 1994; Smith *et al.* 1996). Conservation practices may also incorporate notions of recycling and economic behaviour (e.g. through the re-use of defunct structural timber as fuel, the adjustment of cooking practices in order to minimise loss of heat, and the proscription of burning objects fashioned in

wood) (*cf.* Chapman 1948; Devres Inc. 1980; van Beek and Banga 1992). Hearths may be used for composite purposes too such as cooking, food processing and small-scale industries (Devres Inc. 1980; Horne 1994).

#### *the relative contribution of deadwood and wood harvesting*

Burning qualities and ease of collection may influence agriculturalists in choosing which species or even plant parts will be harvested as firewood. There seems to be a universal agreement concerning the qualities of "ideal" firewood (dense, burning with a strong hot flame, and drying rapidly), but there may also exist several variations with regard

to the ease of collection of particular types of wood. Deadwood (fallen branches and trunks) is always highly ranked, followed by twigs and live branches and, when communities are faced with severe fuel shortages, cutting of saplings and trees proper. Deadwood may be "manufactured" by girdling or ring-barking trees when insufficient quantities of it are naturally available, or groups face official restrictions (Devres Inc. 1980). Practical considerations can also dictate the size of the firewood gathered, such as the type of tools used and the distance of the collection point from the settlement. When tree cutting is deemed necessary, species cut may be those at the pole stage, which is also likely to enhance woodland regeneration and stimulate biomass production (Shankar *et al.* 1998).

#### *seasonality and scheduling of firewood collection*

Fuel gathering may be combined with seasonal tasks such as land clearance and fodder collection (Ben Salem and van Nao 1981; Horne 1982; Townsend and Guest 1980; Ertuğ-Yaras 1997, 183–4). In arid environments the dry season, after harvest, may be the preferred period (wooded areas are easier to access, days are longer and dry wood is more abundant) (Devres Inc. 1980). In temperate regions the preferred season is late winter or early spring, particularly where pruning, coppicing and pollarding are involved, in order to avoid damage to trees during the growing season (in arid regions the growing season may be further constrained by extremely dry summers). Fuel collected on a seasonal basis is commonly stored for consumption during the rest of the year. Small amounts of firewood (twigs, branches and bark) can be collected and brought back to the settlement throughout the year (Fleuret and Fleuret 1978).

## Archaeological Case Studies

To demonstrate how a multi-layered approach to the reconstruction of past vegetation and firewood collection practices may be applied to archaeological material, two case studies are presented in which an explicit attempt to incorporate these principles in the analysis and interpretation of the archaeological charcoal assemblages was made. The sites selected are two Anatolian Neolithic sites that conform to predictive models 1, 3 (mobile hunter-gatherer, pastoralist) and 2 (permanent agricultural settlement). These are, respectively, a complex of seasonally occupied campsites at Pınarbaşı (Watkins 1996; Asouti 2003b) and the tell site of Çatalhöyük (Mellaart 1967; Hodder 1996; Asouti and Hather 2001; Asouti *in press*). A further advantage for selecting these sites was that they occupy broadly the same environmental setting (the open woodland/steppe/wetlands

ecotone of the south-central Anatolian plateau) thus offering an opportunity for a meaningful comparison of their results.

#### *Mobile hunter-gatherer/pastoralist settlement: Pınarbaşı (PN)*

The PN wood charcoal assemblage comprised 7,197 fragments derived from 36 flotation samples. Two sites (PN A – an open-air site situated on a lakeside location and, nearby, PN B – a rockshelter facing PN A) were sampled, with the majority of samples originating in PN B. The characterisation of PN A as a hunting and PN B as a hunting and pastoralist campsite has been based primarily on the lack of substantial architectural remains and the results of faunal analysis (Watkins 1996; D. Carruthers *pers. comm.*).

#### *taphonomy*

The earliest Neolithic deposits (PN A) were extremely poor in charcoal. The most likely explanation for poor preservation is the sedimentary environment (limestone, responsible for the abundance of mineral precipitates in the charcoal fragments) and bioturbation. Therefore the frequency values of the taxa found in these samples were not considered as reliable indicators of the proportions of taxa burnt in the past. By contrast, in PN B the late Neolithic (discarded bulk charred debris and animal bone derived from the infill of a dry-stone revetment wall, and from activity areas external to the wall) and the Chalcolithic deposits (activity spots and fire installations) gave enormous quantities of wood charcoal. The faunal analysis has indicated that the rockshelter hosted a seasonal camp, inhabited for short periods of time (D. Carruthers *pers. comm.*). A few slab-covered hearths (Chalcolithic) preserved in very low quantities rare taxa such as juniper, wild plum and oak. The frequency of occurrence of reeds and small sized woods (e.g. low shrubs), all likely to have been consumed entirely in open fires, was also very low.

#### *woodland vegetation and exploitation*

Sample composition was uniform across phases, particularly with regard to the frequencies of the dominant taxa (terebinth and almond, followed by rose and tamarisk) (see Fig. 4). The fact that the rockshelter was used only as a temporary station may explain the absence of evidence for any medium- to long-term impact on local vegetation (a mixture of open woodland steppe and lakeside halophytic vegetation). The charcoal evidence suggests an opportunistic pattern of woodland exploitation, centred on the irregular collection of readily available branch wood (both cut and collected as fallen and/or standing deadwood; see Asouti 2003b, 1199).

Permanent agricultural settlement:  
Çatalhöyük (CH)

In CH 28,959 fragments of charcoal were examined, derived from 126 flotation samples belonging to various context types. Given the enormous contextual variation, it was decided to prioritise for analysis midden samples that could furnish reliable information on long-term patterns of vegetation

change and fuel exploitation. Midden areas have been identified in CH as the main communal repository of domestic refuse. By contrast, very low densities of charred debris were obtained from built spaces and other context types such as external areas used for the burning and preparation of lime plaster, domestic hearths, feature and building infills etc.

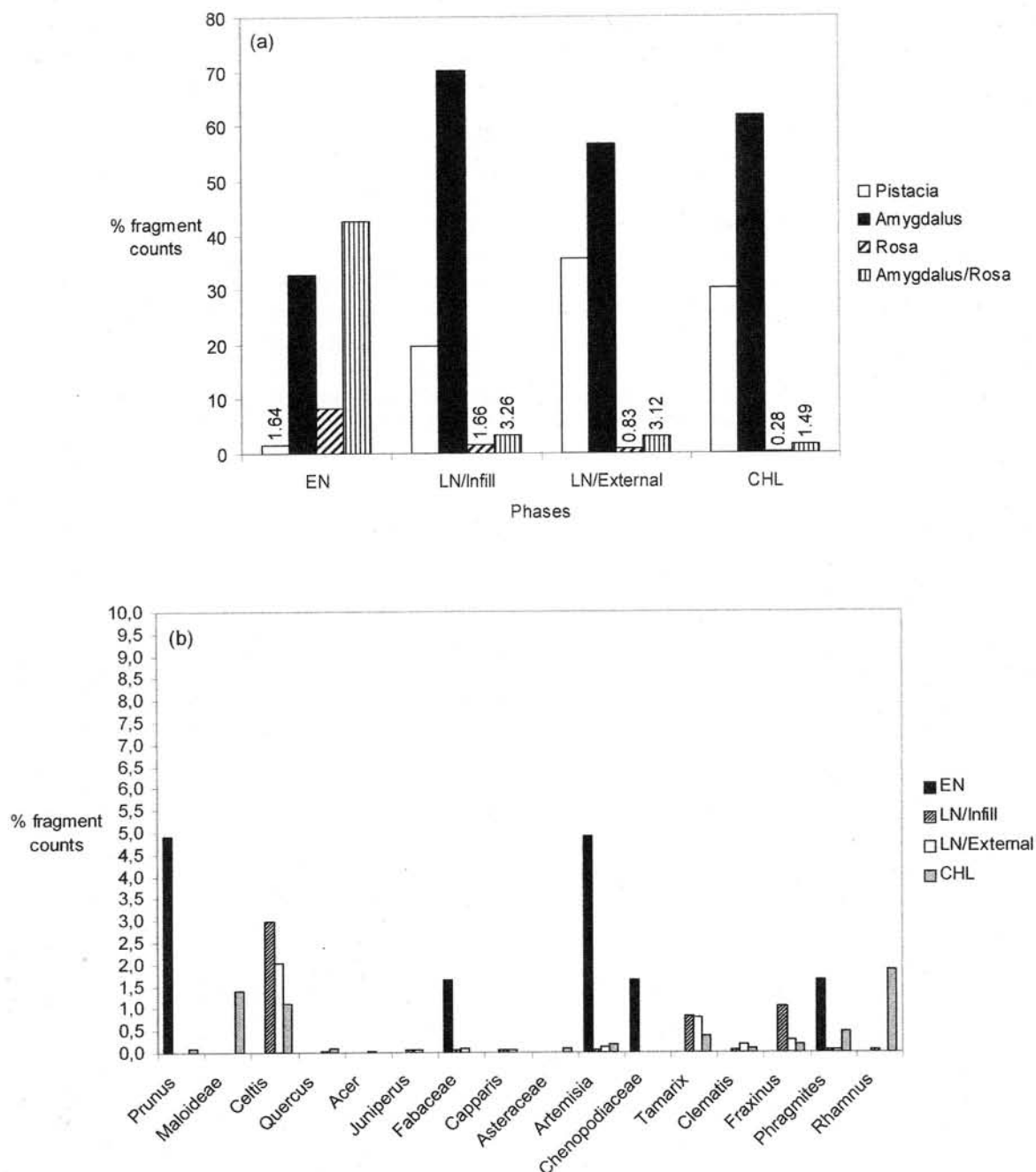


Figure 4. Percentage fragment counts from all examined charcoal samples from Pınarbaşı. EN=Early Neolithic (2 samples, 139 fragments), LN/Infill=Late Neolithic Infill (9 samples, 1800 fragments), LN/External=Late Neolithic External (19 samples, 3800 fragments), CHL=Chalcolithic (8 samples, 1458 fragments). (a) frequency values of the major taxa, (b) values for the less frequent taxa (data presented in Asouti 2003b).

### taphonomy

Midden samples were the richest and most consistent in terms of taxonomic composition. Their reliability, compared to other deposits, was also higher: a high number of taxa were retrieved (see Fig. 5) whereas taxon proportions between samples were also established to be approximately the same (Asouti in press). It thus seems likely that the charcoal from midden samples is a reliable indicator of the relative proportions of the different taxa used as fuel by the Neolithic inhabitants of CH. Such consistency was not achieved for samples deriving from short-lived and/or specialised context types (details on the different preservation regimes encountered in CH and their quantitative description are given in Asouti in press).

### woodland vegetation and exploitation

With the sole exception of wetland plants (e.g. willow/poplar) all other tree and shrub taxa present in the CH samples belong to drier vegetation types such as oak park woodland, steppe and woodland steppe (modelling of vegetation distributions was based on soil maps, geomorphological and pollen reconstructions, and modern vegetation analogues; for full references to the sources used see Asouti and Hather 2001; Asouti in press). The co-occurrence in the archaeobotanical samples of fruits from the same range of tree taxa, as well as independent evidence for the long-distance procurement of game and seasonal variations in grazing patterns (Fairbairn *et al.* 2002; in press; Russell and Martin in press) suggest a pattern of seasonal variations in resource exploitation that could have accommodated firewood collection as well, taking place at variable distances from the settlement. That dung fuel was consistently used alongside wood throughout the lifetime of the settlement may further underline the relative distance of the settlement from dry woodland vegetation (e.g. oak park woodland). Distance therefore could have hindered the exploitation of drier areas on a day-to-day basis. No direct evidence was obtained concerning fuel storage although it remains plausible: deadwood (particularly from oak and wet woodland species such as willow/poplar) was commonly present, thus indicating non-destructive patterns of woodland exploitation and/or at least some opportunistic exploitation of the local riverine environments (through the removal of dead vegetation in the event of river floods). This factor may also be responsible for the lack of evidence for soil erosion and large-scale deforestation in the local pollen diagrams and sedimentary records covering the early-middle Holocene period (*cf.* Roberts *et al.* 1996).

An important temporal change was observed in the taxonomic composition of midden samples approximately halfway through the lifetime of the

settlement (Fig. 5). This manifested as a clear increase in the presence and frequencies of oak charcoal (much of it appearing in the form of deadwood) and a simultaneous decrease of riverine taxa. The rise in oak frequencies has been interpreted (based on the charcoal, stratigraphic and off-site palaeoecological evidence) as the result of the spatial expansion of human activities on the hill zone, possibly due to the overexploitation of the riverine vegetation (Asouti in press), which is further suggested by other lines of subsistence-related evidence (Russell and Martin in press). Archaeological evidence from the same levels has indicated that oak and juniper timbers were frequently re-used, and their abundance may also reflect episodes of timber recycling (possibly when defunct timber was used as fuel). Many of the less frequent taxa were only present in the late (post-8,000 BP) assemblages, thus indicating a greater diversity of collected wood species (see Fig. 5). The gradual increase in the proportions of juniper and shrubs (legumes, chenopods, labiates etc.) may also indicate increasing human impact on the landscape (through animal grazing on the plains and selective oak logging on the hills) albeit one of relatively low intensity compared to large-scale deforestation (*cf.* Asouti and Hather 2001; Asouti in press).

## Conclusion

In closing this paper we wish to emphasise the following points:

- Charcoal analysis is a viable methodology for investigating past vegetation and its exploitation by human societies, provided that the appropriate sampling, subsampling and analytical procedures are followed with due consideration of the settlement pattern, context of deposition, and the duration and types of activities associated with fuel use (domestic, industrial etc.). Also important is evaluating the likely post-depositional disturbances in sedimentary matrices that may have been unfavourable to charcoal preservation.
- In most cases, charcoals retrieved from archaeological contexts are a product of purposeful human action. In this they diverge crucially from off-site pollen cores in that they present a composite picture of local vegetation and related human activities contemporary to the period of site use. These properties allow the detailed reconstruction of past vegetation and people-environment interactions at a timescale congruent with that of the human habitation.
- Following from the previous point, as the examination of the ethnographic record and the review of the archaeobotanical case studies indicate, at the site level the environmental (availability, form and distribution of woodland vegetation) and cultural

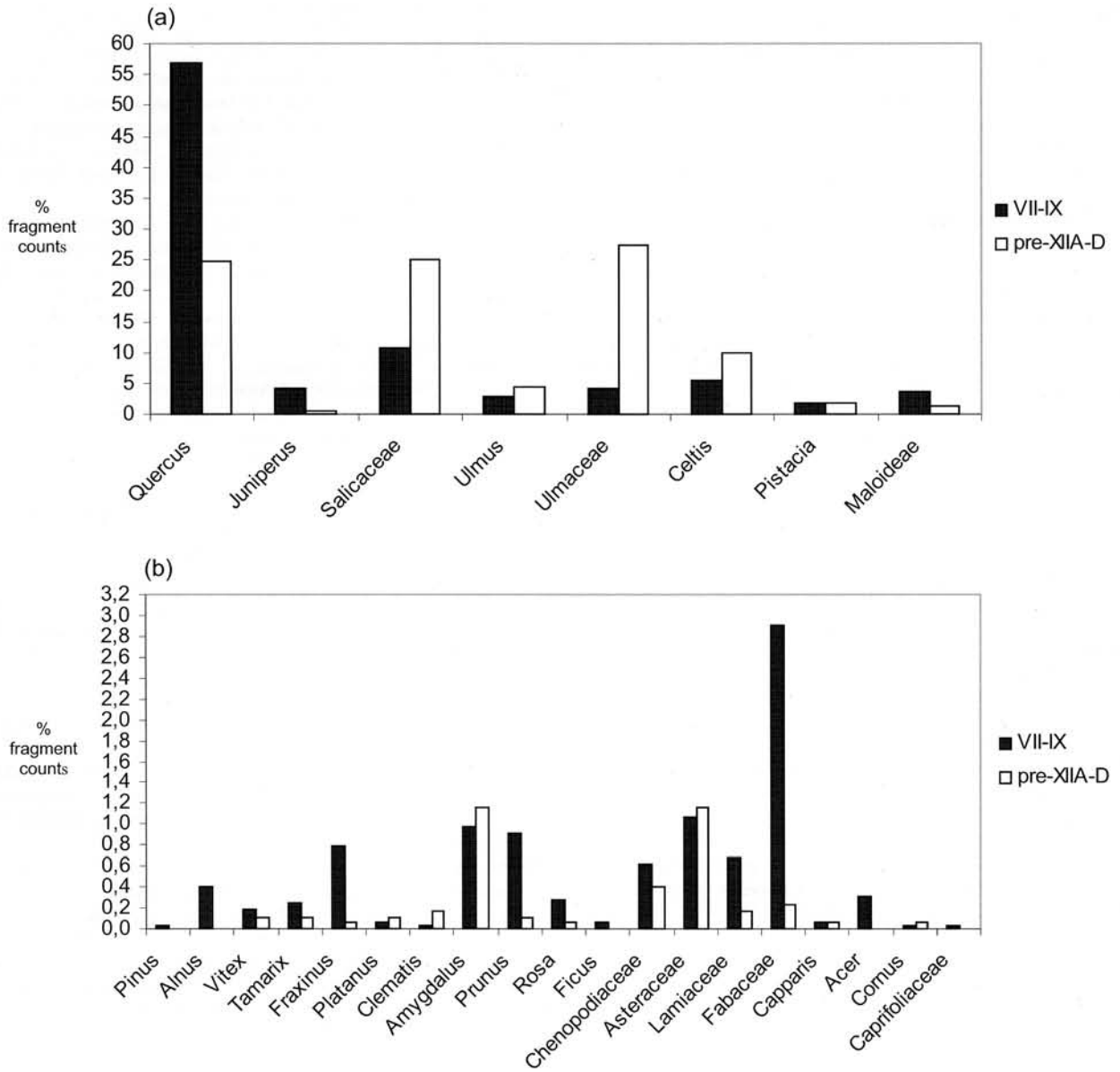


Figure 5. Percentage fragment counts from all midden charcoal samples of Çatalhöyük. Levels VII-IX (post-8,000 BP) middens (28 samples, 4,050 fragments), pre-level XII (pre-8,000 BP) middens (21 samples, 2,940 fragments). (a) frequency values for the major taxa, (b) values for the less frequent taxa (data presented in Asouti in press).

(subsistence economy) aspects of fuel collection and consumption are interlinked. In order to attempt long-term vegetation reconstructions, it would be preferable to obtain fuel remains derived from long stratified sequences or multiple sites belonging to different periods, particularly when inferences about regional climate change are sought from the charcoal record.

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