Modeling wood acquisition strategies from archaeological charcoal remains

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A B S T R A C T

Archaeological charcoal remains are often used to reconstruct local woodland composition in the past, but rarely address how and why people may have selected specific woody taxa for particular purposes. Models from the field of human behavioral ecology predict that people forage for wood resources by taking into account the relative usefulness, abundance, and handling time related to procuring different wood types. Archaeological and ecological data from the site of Gordion, in Central Anatolia (modern Turkey), were used to test expectations associated with such models. Results suggest that inhabitants of Gordion used wood types for fuel in proportion to their local availability, but that they selected specific, more distant woods for construction. In most occupation periods pine was preferred for construction, perhaps because it produces long, straight timbers for roofing, despite the distance at which it grows from the site. This case study demonstrates that behavioral ecology modeling can help to distinguish between multiple wood acquisition strategies potentially used in the past and improve our understanding of wood use from archaeological charcoal remains.

1. Introduction

The challenge of understanding human relationships with environments of the past is a central theme in contemporary archaeological discourse. One specific question in this area of inquiry is how archaeological wood charcoal remains reflect the ways in which people utilized wood resources. The field of charcoal analysis, or anthracology, began in the 1940s as a way to investigate how people used wood in the past and how woodland ecology has changed between that time and the present (Asouti and Austin, 2005; Chabal et al., 1999; Godwin and Tansley, 1941; Salisbury and Jane, 1940).

While the methods for ecological interpretation of charcoal remains are well established, few studies successfully incorporate human decision making into their interpretation of wood use. Models from human behavioral ecology, the study of how ecological and social environments influence behavior (Bird and O'Connell, 2006; Winterhalder and Smith, 2000), offer considerable potential for improving our understanding of the ways in which human populations utilize woodland resources. This study explores constituent variables of these foraging models and applies them to a wood charcoal assemblage from the multi-period site of Gordion in Central Anatolia (modern Turkey) to interpret wood acquisition strategies employed by its inhabitants over a span of 2000 years.

2. Modeling wood use through charcoal analysis

The identification and spatial analysis of archaeological charcoal have been used widely to make inferences regarding human wood use and forest ecology in the past (Asouti and Austin, 2005; Chabal et al., 1999; Dufraisse, 2006; Thiébault, 2002). This research usually compares the proportions of woody taxa in archaeological charcoal assemblages to modern local woodland composition and then aims to interpret differences as the result of climatic or geomorphological change (e.g., Chabal, 1992; Delhon, 2006; Newton, 2005) or human-induced landscape modification, including selective harvesting and widespread deforestation (e.g., Miller, 1985; Pearsall, 1983; Willcox, 1974, 2002). Models that attempt to explain archaeological charcoal assemblages typically rely on the “principle of least effort,” which predicts that charcoal frequency tracks the presence of woody taxa with a direct correspondence (Shackleton and Prins, 1992). The situation may be more complicated as environmental circumstances and human decision-making processes render the principle of least effort more or less likely to apply to a given archaeological situation (Shackleton and Prins, 1992). The situation may be more complicated as environmental circumstances and human decision-making processes render the principle of least effort more or less likely to apply to a given archaeological situation (Shackleton and Prins, 1992). Such research approaches may make use of ethnographic studies of wood use (e.g., Ludemann, 2006; Thiébault, 2006) to determine the most likely uses of wood in the past.

Models generated from the discipline of human behavioral ecology can be applied to the interpretation of archaeological remains to create a more explicit connection between general patterns of human behavior and the static record of specific events.
recovered through the practice of archaeology (Bird and O’Connell, 2006). The most basic of these models is the prey choice model, also termed the diet breadth model, which relates the availability of resources to their use value and handling cost to predict which resources will be preferred by a forager in a given environment (Emlen, 1966; Krebs, 1978; MacArthur and Pianka, 1966; Stephens and Krebs, 1986). An alternate model, the patch choice model, describes how individuals forage for resources in a coarse-grained environment in which patch resources can be depleted, based on the marginal value theorem of diminishing returns (Charnov, 1976; Cowie, 1977; Parker, 1978; Parker and Stuart, 1976). When the patch choice model is extended to foragers that collect more than one prey item on each foraging trip from a central place, it becomes known as the central place foraging model (Orians and Pearson, 1979). All three models can be combined, resulting a series of common expectations about diet breadth and patch residence time (Stephens and Krebs, 1986).

Of these foraging models, the prey choice model has been applied most widely to ethnographic and archaeological cases of human foraging, focusing primarily on the hunting or gathering of wild animal and plant food resources (Bird et al., 2006; Broughton, 1994, 1997; Gremillion, 2004; Kennett, 2005; Smith, 1991; Winterhalder and Smith, 1981), although patch choice and central place models have been employed as well (Bird et al., 2005; Keegan, 1986; Zeanah, 2004). Recent work has expanded the application of these models to explain transitions to agriculture in various parts of the world (Gremillion, 2006; Kennett and Winterhalder, 2006; Piperno and Pearsall, 1998; Winterhalder and Goland, 1997). Although such models originate in the study of food acquisition, they can be applied equally well to the acquisition of other resources where the foraging process includes an analogous cost/benefit structure and the resources sought can influence the fitness of the individual. Similar foraging models have been applied to such diverse topics as how scholars search for resources online (Sandstrom, 1994) and how customers chose among brands in a store (Foxall et al., 2004).

This study deconstructs these models and explores their primary constituent variables as a mechanism for understanding how people made decisions about wood acquisition in the arid steppe plateau of Central Anatolia and how those choices can be reconstructed from an archaeological charcoal assemblage. These conclusions are compared with ecological data on woodland structure in the region and inferences about changes in this structure throughout the occupation history of the region. Results of these analyses suggest that behavioral ecology principles and models hold considerable potential for the behavioral analysis of archaeological remains in circumstances where ethnographic analogy does not provide a close parallel for the economic and social structures of ancient societies.

3. Archaeological and ecological context

Central Anatolia is characterized by a temperate climate and seasonal rainfall that supports an open steppe grassland with concentrations of trees extending into canopy forest above 1000 m (Atalay, 1997; Zohary, 1973). A major settlement in the northwestern corner of the plateau is the mound archaeological site of Gordion, a multi-period urban settlement dating from the Early Bronze Age (3rd millennium BCE) through the Medieval Period (14th century CE) (Sams, 2005). Gordion sits near the confluence of the Porsuk and Sakarya rivers (Fig. 1), which rendered it a major trade center in Central Anatolia until the rise of Roman Ankara in the first millennium CE. Gordion reached its height of wealth and influence as the capital of the indigenous Phrygian state between c. 850 and 550 BCE, when it was ruled by monarchs including the historical King Midas and controlled much of Central Anatolia. Survey at the site has revealed that the city reached its greatest areal extent between c. 800 and 550 BCE (Kealhofer, 2005; Voigt, 2002). Settlement at Gordion was nearly continuous from the Late Bronze Age through the beginning of the first millennium CE, and excavations since 1988 have produced wood charcoal remains spanning this entire occupation period through the later Medieval settlement at the site, mostly dating to the 12th and 13th centuries CE (Voigt, 1993).

The Central Anatolian plateau includes both Indo-Turanian steppe plants and Xeroc-Euxinian forest elements, with local differences in response to changes in elevation and soil composition. Zohary (1973) refers to this vegetation association as “steppe-forest,” although forested areas are generally restricted to elevations above 1000 m. The major plant associations in the Gordion region include a xeric steppe grassland with occasional scattered trees, a scrub oak-juniper forest above 900 m, and canopy forest dominated by pine or juniper above 1300 m. The banks of the Porsuk and Sakarya rivers support a variety of hydrophilous vegetation dominated by willow, poplar, and tamarisk trees.

Dominant tree species in the region include scrub oak (Quercus pubescens) and juniper (Juniperus oxycedrus); canopy forest of oak (Quercus cerris), juniper (Juniperus excelsa), and pine (Pinus nigra); and poplar (Populus nigra), willow (Salix alba), and tamarisk (Tamarix spp.) in wet areas. Many components of the steppe-forest woodland include wild pear (Pyrus eleagnifolia), wild plum (Prunus divaricata), wild almond (Prunus orientalis, syn. Amygdalus orientalis), elm (Ulmus minor and Ulmus glabra), barberry (Berberis cf. crataegina), hawthorn (Crataegus pontica), sumac (Rhus coriaria), ash (Fraxinus excelsior), plane (Platanus orientalis), Russian olive (Elaeagnus angustifolia), colutea (Colutea arborescens), and Christ’s thorn (Paliurus spina-christi). Woody shrubs include restharrow (Ononis spinosa), bramble (Rubus sp.), and several low woody plants in the families Asteraceae and Chenopodiaceae. Walnut (Juglans regia) may be native to the area, but is usually found planted in domestic compounds, as are domestic grape (Vitis vinifera), apricot (Prunus armeniaca), sour cherry (Prunus cerasus), pear (Pyrus communis), apple (Malus domestica), and mulberry (Morus nigra and Morus alba). These domestic fruit trees, save mulberry, have a long history in Anatolia and may well have been cultivated at the site in antiquity (Zohary and Hopf, 2000). These trees and shrubs form the set of wood resources locally available to residents of Gordion and their distribution and frequency are primary variables in behavioral ecology models relevant to wood acquisition, as described below.

4. Foraging models and wood acquisition

Behavioral ecology assumes that behavior is optimizing — that people assess costs and benefits for a set of possible decisions, and prefer the outcome with the greatest benefit for the least cost (Stephens and Krebs, 1986). This assumption makes possible the construction of simple models for predicting decision making under a given set of conditions, such as resource foraging. Foraging models require the identification of the foraging goal, the currency in which the forager measures value, environmental constraints (biological or social), and potential alternative strategies. In this study, two goals for wood use are contrasted: construction and combustion. These two use goals require that wood be valued with different currencies, as characteristics differ between good fuel and good construction material. Constraints and alternative strategies are considered later in this paper and address the potentially problematic issue of how cultural change shapes human behavior independent of natural environmental cues.

Foraging models predict that an individual will choose to add different types of resources to its diet based on their value and the amount of time needed to process them (Charnov, 1976; Emlen, 1966; MacArthur and Pianka, 1966). This leads to a ranking of
resource types, with the most valuable and easiest to handle becoming top-ranked resources. The models assume that a forager is capable of estimating values for these variables and thus operates with a ranked list when foraging. The forager’s diet is based on the encounter frequency with resources of different rank values. Foraging models, and the prey choice model in particular, relate these three variables (value, handling time, and frequency) and predict that under certain conditions foragers will specialize only on top-ranked resources (Stephens and Krebs, 1986).

Archaeologists have used ethnographic data to create prey lists for human hunters and foragers and then tested them against the archaeological record (Broughton, 1997; Diehl and Waters, 2006; Zeanah, 2004). One of the challenges in testing foraging models using archaeological data is that it is rarely possible to quantify accurately all variables for all potential resource types. Instead authors turn to proxy measures for value (Bird et al., 2009; Broughton, 1994, 1997; Ugan, 2005) or computer simulations (Zeanah, 2004). As a result, most archaeological studies do not test a foraging model in its entirety, but rather explore whether assumptions or components of the model hold for the particular archaeological case, the approach adopted here.

This study independently investigates three variables common to foraging models by constructing separate rank orders of resource types based on their value, handling time, and frequency. Each is tested individually against the archaeological data to assess the relative contribution of each variable to the behavioral patterns leading to wood gathering at Gordion. Two separate value lists distinguish between alternate currencies for wood use related to the alternative goals of construction and combustion, which can be distinguished archaeologically. The archaeological correlate of construction is burned structure collapse, which was identified during excavation by the presence of large amounts of decayed mudbrick and occasional roof tiles within foundation courses of buildings that appear to have been destroyed by fire. Wood charcoal from these contexts was originally used as supporting posts and roof beams. The archaeological features corresponding to the use of wood as fuel are hearths, ovens, kilns, and furnaces, which here are collectively termed “pyrotechnic features.” The sample size was insufficient to distinguish further between domestic and industrial features, but similar types of charcoal appear in both. To produce meaningful sample sizes between features and across time periods, charcoal from all samples belonging to each context type was grouped together as representing the product of the wood acquisition process relating to each of the two goals.

Different currencies are associated with the two activities of construction and combustion. For construction, long, straight, durable trunks are desired. For combustion, the energy content of the wood is most important, which is a factor of the density, water content, and resin/oil content of the wood (Hall and Dickerman, 1942). Given these parameters, different tree species produce woods that are more or less useful for the two activities. Rank-ordered lists of the fifteen potentially local tree taxa identified archaeologically at Gordion (Table 1) were constructed based on data from botanical survey, regional biogeography, and experimental analysis (Bets, 1913; Campbell, 1918; Davis, 1965–2000; Fisher, 1908; Graves, 1919; Hale, 1933; Hall and Dickerman, 1942; Krishna and Ramaswami, 1932; Marsh, 2005; Miller, 1999, in press; Panshin and de Zeeuw, 1970; Parr and Davidson, 1922; Reynolds and Pierson, 1942; Zohary, 1973). The rank order for fuel woods is based on experimental data from American and European species.

Fig. 1. Map of the Gordion region. Contours are 50-m intervals.
Table 1
List of wood taxa identified from archaeological contexts at Gordion (data from this study; Marston, 2003; Miller, in press; Simpson and Spirydowicz, 1999).

<table>
<thead>
<tr>
<th>Family</th>
<th>Taxon</th>
<th>English name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aceraceae</td>
<td>Acer sp.¹ ²</td>
<td>Maple</td>
</tr>
<tr>
<td>Betulaceae</td>
<td>Alnus viridis</td>
<td>Alder</td>
</tr>
<tr>
<td>Betulaceae</td>
<td>Carpinus betulus</td>
<td>Hornbeam</td>
</tr>
<tr>
<td>Buxaceae</td>
<td>Rusus sp.¹ ²</td>
<td>Boxwood</td>
</tr>
<tr>
<td>Chenopodiaceae</td>
<td>– ³</td>
<td>Chenopod family</td>
</tr>
<tr>
<td>Cornaceae</td>
<td>Cornus sp.¹</td>
<td>Dogwood, Cornelian Cherry</td>
</tr>
<tr>
<td>Cupressaceae</td>
<td>Junipers sp.¹ ²</td>
<td>Juniper</td>
</tr>
<tr>
<td>Fagaceae</td>
<td>Quercus sp. ³ ⁴</td>
<td>Oak</td>
</tr>
<tr>
<td>Juglandaceae</td>
<td>Juglas sp.¹ ² ³ ⁴</td>
<td>Walnut</td>
</tr>
<tr>
<td>Oleaceae</td>
<td>Fraxinus sp.</td>
<td>Ash</td>
</tr>
<tr>
<td>Pinaceae</td>
<td>Cedrus libani ³ ⁴</td>
<td>Cedar</td>
</tr>
<tr>
<td>Pinaceae</td>
<td>Pinus sp.¹ ²</td>
<td>Pine</td>
</tr>
<tr>
<td>Poaceae</td>
<td>Phragmites sp.</td>
<td>Reed</td>
</tr>
<tr>
<td>Rhamnaceae</td>
<td>Rhamnus sp. ³ ⁴</td>
<td>Buckthorn</td>
</tr>
<tr>
<td>Rosaceae</td>
<td>Maloidea</td>
<td>Hawthorn, Pear, Apple</td>
</tr>
<tr>
<td>Rosaceae</td>
<td>Prunus sp.</td>
<td>Apricot, Peach, Almond, Plum</td>
</tr>
<tr>
<td>Salicaceae</td>
<td>Populus sp.</td>
<td>Pooplar</td>
</tr>
<tr>
<td>Salicaceae</td>
<td>Salix sp.</td>
<td>Willow</td>
</tr>
<tr>
<td>Tamaricaceae</td>
<td>Tamarix sp.</td>
<td>Tamarisk</td>
</tr>
<tr>
<td>Ulmaceae</td>
<td>Celtis sp.</td>
<td>Hackberry</td>
</tr>
<tr>
<td>Ulmaceae</td>
<td>Ulmus sp.</td>
<td>Elm</td>
</tr>
</tbody>
</table>

¹ Taxa not identified in this study (from Marston, 2003; Miller, in press; Simpson and Spirydowicz, 1999).
² Taxa identified from furniture in burial tumuli at Gordion (Simpson and Spirydowicz, 1999).
³ Estimated from specific heat values given by Fisher, 1908.
⁴ Taxa identified from the wood type preference of “suitability for construction” (Davis, 1965–2000).
⁵ Mean values for all species reported by Graves, 1919; Hale, 1933; Hall and Dickerman, 1942; The Heat Shed, n.d.; units are million B.t.u. per air dried cord.
⁶ Mean values for all species reported by Campbell, 1918; Graves, 1919; Reynolds and Pierson, 1942; units are coal equivalents per air dried cord (coal – 100).
⁷ Mean values for all species reported by Betts, 1913; Krishna and Ramaswami, 1932; Parr and Davidson, 1922; units are B.t.u. per pound of oven dried wood.
⁸ Estimated from specific heat values given by Fisher, 1908.

Table 2
Rank orders for wood fuel value by volume (density-dependent) and by weight (density-independent), based on mean published caloric values of wood taxa from the sources listed above. Standardized values were calculated as multiples of the value of oak to render different units comparable. Rank by volume is based on the average of the standardized values of the two density-dependent surveys. Missing values indicate that information was not available for those taxa in the sources listed.

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Mean¹</th>
<th>Standard values (oak – 1)</th>
<th>Rank by volume</th>
<th>Mean²</th>
<th>Standard values (oak – 1)</th>
<th>Rank by Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carpinus</td>
<td>1.08</td>
<td>95.0 0.99</td>
<td>2</td>
<td>1.15⁵</td>
<td>8529 1.04</td>
<td>5</td>
</tr>
<tr>
<td>Maloidea</td>
<td>1.02</td>
<td>95.0 0.99</td>
<td>2</td>
<td>1.10</td>
<td>8529 1.04</td>
<td>5</td>
</tr>
<tr>
<td>Quercus</td>
<td>2.44</td>
<td>95.7 1.00</td>
<td>3</td>
<td>8196 1.00</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Ulmus</td>
<td>2.20</td>
<td>88.8 0.93</td>
<td>4</td>
<td>9194 1.12</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Aler</td>
<td>2.10</td>
<td>87.2 0.91</td>
<td>5</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Fraxinus</td>
<td>2.14</td>
<td>83.1 0.87</td>
<td>6</td>
<td>8329 1.04</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Juglas</td>
<td>0.85</td>
<td>80.0 0.84</td>
<td>7</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Celtis</td>
<td>19.1</td>
<td>73.0 0.76</td>
<td>8</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Juniperus</td>
<td>18.7</td>
<td>63.0 0.66</td>
<td>9</td>
<td>9892 1.21</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Prunus</td>
<td>16.8</td>
<td>69.4 0.73</td>
<td>10</td>
<td>7860 0.96</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Pinus</td>
<td>20.2</td>
<td>49.0 0.51</td>
<td>12</td>
<td>8295 1.01</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Rhamnus</td>
<td>15.0</td>
<td>57.8 0.60</td>
<td>13</td>
<td>8429 1.03</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Salix</td>
<td>13.8</td>
<td>56.0 0.59</td>
<td>14</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Tamarix</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>8768 1.07</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>

¹ Mean values for all species reported by Graves, 1919; Hale, 1933; Hall and Dickerman, 1942; The Heat Shed, n.d.; units are million B.t.u. per air dried cord.
² Mean values for all species reported by Campbell, 1918; Graves, 1919; Reynolds and Pierson, 1942; units are coal equivalents per air dried cord (coal – 100).
³ Mean values for all species reported by Betts, 1913; Krishna and Ramaswami, 1932; Parr and Davidson, 1922; units are B.t.u. per pound of oven dried wood.
measures are, not surprisingly, highly correlated for this assemblage and give similar results. Only construction debris and pyrotechnic features were included to ensure distinction of these two uses, which resulted in the inclusion of only short-lived structures and features and the exclusion of longer-term occupation debris and midden deposits that might be considered more representative of ongoing behavioral patterns. This potential limitation is mitigated by the long duration of site use represented by the features sampled, a span of 2000 years.

In order to test the expectation that variables used in foraging models, namely value, frequency, and/or handling time, should correlate with intensity of use for a given taxon, the taxa were ranked by weight and by ubiquity, and those ranks were compared to ranks predicted by the three variables (Tables 5 and 6). Correspondence between the expected and observed rank orders was calculated using a bivariate correlation test and quantified with Kendall’s τ-b coefficient, which is an appropriate correlation coefficient for ordinal rank data on a variable scale with ties present in the ranks (Kendall, 1938). The values of the τ coefficient can range from 1.0 (perfect positive correlation) to −1.0 (perfect negative correlation). Values of Kendall’s τ-b and the two-tailed significance of the tests are given in Tables 5 and 6 for each pairwise rank correlation. Calculations of Kendall’s τ-b and its estimated significance were made using SPSS 16.0 software for Macintosh.

6. Results

In both data sets weight and ubiquity rankings were strongly positively correlated, with Kendall’s τ-b values of 0.593 for fuel woods and 0.867 for construction woods (p < 0.05). Due to this correlation, in all but one case statistical inferences made on the weight-ranked and ubiquity-ranked charcoal data were substantively the same (Tables 5 and 6).

The results of the tests for construction collapse woods are presented in Table 5. The rank order of charcoal remains by weight and by ubiquity did not show a statistically significant correlation to either of the proposed construction durability rank orders at the 0.05 level. The frequency rank order did show a statistically significant positive correlation to the archaeological charcoal remains when ranked by weight (0.788, p < 0.05) and a similar, nearly significant, correlation when ranked by ubiquity (0.645, p < 0.08). Surprisingly, both rank orders for archaeological charcoal were strongly negatively correlated with the distance rank order (−0.856, p < 0.05), indicating that more distant woods were preferred over closer woody species. These results suggest that wood durability was not a significant factor when procuring wood for construction at Gordion, but that wood frequency was, irrespective of the distance at which that wood was available.

Test results from archaeological wood charcoal from pyrotechnic features are presented in Table 6. Results were the same whether the charcoal was ranked by weight or ubiquity. Both rank orders by fuel value (ranked by caloric value per unit of weight or volume) were not significantly correlated to the archaeological charcoal rank orders; correlation with distance was also not significant. The frequency rank order was significantly positively correlated with the archaeological data, however, both by weight (0.906, p < 0.05) and by ubiquity (0.695, p < 0.05). These results suggest that the relative frequency of tree taxa was the primary determinant of wood selection for fuel use.

7. Discussion

One expectation of foraging models is that resource types will be chosen based on their relative value and handling time when encountered, with top-ranked resources chosen whenever encountered. While this does not predict the frequency of use for specific taxa, as that is dependent on the encounter rate with top-ranked resources, it does yield the expectation that, of similarly available wood types, the higher-ranked types should be taken more often. My results appear to refute this expectation: not only were construction durability and fuel value rank orders not significantly correlated with archaeological charcoal representing those uses, but common, high-value woods were used less frequently than lower-ranked alternatives in pyrotechnic features (i.e., pine is more common than juniper). As a result, there is no evidence that inhabitants of Gordion took into account the relative value of specific woody taxa, as hypothesized above, when acquiring wood for either use.

Even more surprising is that charcoal representing construction episodes is negatively correlated with distance to the wood resource, which directly opposes the proposed hypothesis that closer woods would be used more frequently and thus comprise a greater proportion of the archaeological charcoal assemblage. This might imply that distance transport costs were marginal, and thus distance is a poor proxy of handling time. That interpretation seems unlikely, however, as significant numbers of pine timbers
were imported from a distance of 30 km overland to the site. Another possibility is that distribution of trees in antiquity was substantially different from that observed today, a situation explored in more detail below but one unlikely to have driven this effect. A more likely explanation of this unexpected correlation, however, is the fact that, for construction woods only, frequency and distance ranks were significantly negatively correlated ($-0.856, p < 0.05$). As a result, the observed correspondence between observed and distance rank orders may be a product of the positive correlation of observed and frequency rank orders and the negative correlation of frequency and distance rank orders.

The primary conclusion of these data is that the ancient inhabitants of Gordion, in both fuel and construction use contexts, utilized wood types that are most frequent in their environment to a far greater extent than rarer wood taxa, regardless of distance to those resources. This corresponds with the conclusions of Miller (1999) based on her earlier work at Gordion, which identified some combination of oak, pine, and juniper as the primary wood types in all periods of inquiry. It also matches the expectations of the “principle of least effort” (Shackleton and Prins, 1992) and scholars of the “Montpellier school” (Chabal, 1992; Chabal et al., 1999), as well as the implicit assumptions of other authors (e.g., Asouti and Hather, 2001; Pearsall, 1983; Willcox, 1974), that archaeological charcoal assemblages mirror (though perhaps imperfectly) the distribution of tree species in the natural surroundings due to the fact that people generally use local resources to a degree roughly proportional with their frequency. The lack of concern for distance is surprising, however, suggesting that either pine grew substantially closer to the site in antiquity or that pine was specifically sought out for construction reasons other than durability.

It is possible that pine grew closer to Gordion in pre-modern periods. Geomorphological data suggest that large-scale deforestation may have occurred in the region during the first millennium BCE (Marsh, 1999, 2005). Diachronic changes in wood use at Gordion show a clear trend of diminishing juniper use over the course of occupation at the site, and variable use of pine between periods but no clear trend of increasing or decreasing use; the availability of other tree species appears to have remained relatively stable (Miller, 1999). Although the closest pine canopy forest to Gordion today lies in the direction of Mhaliççık, some 30 km NW of the site, ...
individual Pinus nigra trees were found on the upper slopes of Çile Dağı within 20 km of the site during survey in 2008. A denser pine forest on that mountain in antiquity is certainly possible, although substituting a value of 20 km for the distance rank order in Table 4 results in a strong negative correlation similar to that identified earlier (\( r = -0.775, p = 0.05 \)). It is improbable that pine, which today grows as low as 900 m in well-watered valleys, could have grown closer than 20 km to Gordion at any point during the late Holocene, a relatively stable climatic period in Central Anatolia (Bottema and Woldring, 1984; Bottema et al., 1994; Roberts et al., 1999; van Zeist and Bottema, 1991).

Although durability of specific wood types was not a significant factor in structural wood acquisition strategies at Gordion, wood for construction may have been chosen for other reasons. Large buildings require long timbers for use as roof beams, and pine grows substantially taller than juniper or oak, the other dominant trees in the region today. Archaeological data from the site support this conclusion. Juniper is preferred as a construction wood in the earliest structures at Gordion (Kuniholm, 1977; Miller, 1999), perhaps due to its greater durability, but its use declines abruptly beginning in the Phrygian period c. 950 BCE (Miller, 1999) and continues only in elite burial contexts (Liebhart and Johnson, 2005; Simpson and Spyridowicz, 1999). Miller (1999) has argued that this is the result of over-harvesting of the local juniper species suitable for construction (J. excelsa) and subsequent depression of the local availability of this slow-growing species.

Pine, while less durable than juniper, allows larger spaces to be roofed and was more accessible in the periods addressed in this study. The two large public buildings included in the roof collapse contexts identified in this study both show a clear preference for pine, so do contemporary large buildings reported by Miller (1999) and Kuniholm (1977) from earlier excavations at Gordion. The negative correlation between the distance rank order and wood charcoal from construction contexts is a result of a landscape in which trees of a height suitable for roofing large buildings grow at a distance from the site.

The selective use of wood for fuel based on calorific value was not demonstrated in this study, although many trees infrequent in the present landscape (e.g., Colutea, Rhus) and spiny trees and shrubs, including Elaeagnus, Berberis, Ononis, and Rubus, are entirely absent from the archaeological assemblage, as foraging models predict for low-ranked resources outside of the optimal diet breadth (Stephens and Krebs, 1986). It appears that for fuel use the overriding criterion for wood choice was taxon frequency, as predicted by the principle of least effort (Shackleton and Prins, 1992).

8. Conclusions

The aim of this paper was to evaluate whether principles of behavioral ecology modeling could enhance the ability of charcoal analysis to consider the role that human decision-making processes play in wood selection. Several alternate test implications derived from component variables of foraging models were investigated, including resource value, handling time, and frequency. The results showed that no value-based selection occurred at Gordion for fuel woods, which were collected in proportion to their relative frequency in the landscape. Selection for construction does appear to have occurred, although not as a systematic preference for durable woods as originally hypothesized. The variable of primary importance instead appears to have been the length of timber that can be obtained from a given tree taxon, leading to preferential selection of pine that grows relatively far from the site today and likely similarly far in antiquity as well. The negative correlation of distance with construction wood use may be due to this preference, or alternately may be an effect of the interaction between frequency and distance ranks, since frequency is also significantly correlated with construction wood use.

This study shows the benefits of working with behavioral ecology models. By separating several component variables of these models and testing them individually, it was possible to investigate both the degree to which wood was selected and what selection criteria may have been used in antiquity. The difference between the expected and observed results in selection for construction wood is of particular interest because the apparent selection criterion is related not to the proposed currency of the activity (that is, to have strong and durable supports) but rather the constraints of the activity (the limited number of tree taxa that produce long, straight beams needed to roof large public buildings). Behavioral ecology modeling requires consideration of both currencies and constraints, as well as ultimate goals and alternative behavioral strategies, and this study shows the necessity of considering these multiple components together to make plausible inferences about human behavior in the past.

In considering the ecological and social constraints on the inhabitants of Gordion, it is necessary to consider the limitations of this study as well. While this data set represents thousands of pieces of wood gathered during the occupation of the site, it does not include pending analysis of systematically collected charcoal pieces from flotation samples, which are more likely to fully represent the original spectrum of wood use (Asouti and Austin, 2005; Chabal et al., 1999). This larger sample size will allow further investigation of possible shifts in wood acquisition strategies between occupation periods, which the current data set does not permit. A more fundamental challenge to the approach employed here, however, is that it is impossible to relate archaeological charcoal samples to individual foraging episodes, as is commonly done in quantitative behavioral ecology research with modern populations (e.g., Bird et al., 2009; Bird and Bliege Bird, 1997; Hill et al., 1987; Smith, 1991). As such, there is no way to test directly the expectations of the model with regard to decision making on the scale of the individual or even on the scale of years or decades based on these data. Instead, this research speaks to long-term trends in the Gordion region and argues that climatic stability, slow geomorphological change, and consistent wood use requirements led to the maintenance of similar wood acquisition strategies over the span of two millennia. This may not have been the case for other activities in the region, such as agriculture, or for wood acquisition strategies in other parts of the world, where application of human behavioral ecology models to similar archaeological problems may also yield new findings about human decision-making processes in the past.

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