Weed ecology as a method for the archaeobotanical recognition of crop husbandry practices

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ABSTRACT. This paper reviews the methods used to reconstruct past crop husbandry practices from the ecology of the weed species associated with archaeobotanical crop remains. The contributions of phytosociology and Ellenberg numbers, in particular, are reviewed and critiqued, and an alternative approach using the functional ecology of weed species is proposed. This approach uses functional attributes, which measure the ecological characteristics of weed species, and is not dependent on the co-occurrence of particular species or the reliability of field observations to indicate species preferences. Functional attributes permit the 'translation' of present-day ecological data to archaeobotanically attested species and, through an understanding of ecological processes, provide the means to disentangle the separate effects of different husbandry practices, so allowing the identification of novel combinations of practices in the past. An understanding of the, often complex, functional relationships between husbandry practices and weed floras also enables a more sophisticated approach to the interpretation of archaeological weeds through a consideration of attribute suites, or species functional types, as a reflection of the combined effects of different ecological factors.

KEY WORDS: archaeobotany, crop husbandary, weed ecology, phytosociology, functional ecology

INTRODUCTION

It has long been recognised that the crop weeds in archaeobotanical samples provide a potentially useful source of evidence for past agricultural activities. Their quantities in relation to crop remains (grain and chaff), for example, have been used as a means of distinguishing crop processing products and by-products (Hillman 1981, Dennell 1974, G. Jones 1988). More specifically, the types of weed seeds associated with crop remains have proved useful for identifying particular stages in the crop processing sequence (Hillman 1984, G. Jones 1984, 1987). Through a consideration of their ecology, weeds also have potential for the identification of husbandry practices applied to growing crops before they are harvested. This paper reviews the different approaches that have been applied to archaeobotanical data in attempt to use weed ecology in the identification of husbandry

practices such as tillage method, time of sowing, irrigation/drainage, fallowing/rotation, manuring and weeding. In all three of the areas considered below, the pioneering work of Krystyna Wasylikowa can be identified.

PHYTOSOCIOLOGY

One of the most frequently used ecological approaches is that of phytosociology. This hierarchical method of classifying plant communities relies on the co-occurrence of species in the field and on the presence of diagnostic species (character species) which are relatively restricted to one community (association) or group of communities in the hierarchy (Westhoff & van der Maarel 1973). This approach has the great advantage that phytosociological data have been accumulated for a large num-

ber of plant communities over a wide geographic area, particularly central Europe (e.g. Braun-Blanquet 1936, Tüxen 1950, Hüppe & Hofmeister 1990, Oberdorfer 1994). In archaeobotany, this approach has been used in two rather different ways: (1) attempts have been made to identify modern phytosociological associations in archaeological assemblages (e.g., for grassland communities, Greig 1988) or to reconstruct ancient weed associations (e.g. Knörzer 1971), (2) phytosociological character species have been used as indicators of the ecological conditions associated with the community (or higher phytosociological group) as a whole (e.g. G. Jones 1992).

Several authors have pointed out the disadvantages of the first method in particular (e.g. M. Jones 1988, Behre & Jacomet 1991, Küster 1991, G. Jones 1992, van der Veen 1992). First, such associations tend to be particularly unstable through time. While changes in the ecological preferences and characteristics of individual species are a problem underlying all attempts to apply modern weed ecology to archaeobotanical species, this problem is compounded for the identification of ancient communities by the fact that species which now occur together may have been geographically isolated in the past (Holzner 1978). Secondly, the archaeobotanical record of crop weeds is at best partial: weeds may shed their seeds before the harvest or set seed after the harvest; depending on the harvesting method employed, species in seed may be selectively harvested with, for example, only the taller weeds being collected (Knörzer 1971); subsequent stages of crop processing will selectively remove certain categories of weed seed (Hillman 1981, 1984, G. Jones 1984), and preservation by charring will introduce a bias against the most fragile species (Wilson 1984). Again, while this partial preservation poses problems for all attempts to use weed seeds as indicators of past crop husbandry methods, it is particularly detrimental to the reconstruction of intact phytosociological communities. Finally, character species of different plant communities may become mixed together in an archaeobotanical assemblage, and it is difficult to distinguish such mixtures from genuinely novel, but extinct, ancient plant communities.

Nevertheless, phytosociology has provided useful insights into agricultural practices especially when combined with ecological infor-

mation on the groups involved (e.g. van Zeist 1974, van Zeist et al. 1986, Wasylikowa 1978, 1981, Willerding 1979, 1983, Knörzer 1984, 1987, Jacomet 1987, Jacomet et al. 1989, Behre & Jacomet 1991, Karg 1995, Rösch 1998). This second method of using phytosociological data will be discussed further below but has proved most successful when applied to the higher phytosociological groups (e.g. alliances, orders or classes): the character species at these levels indicate relatively broad ecological conditions, and so tend to be (a) more stable through time and (b) relevant over a larger geographical area than phytosociological associations (Westhoff & van der Maarel 1973, Willerding 1983).

AUTECOLOGY AND ELLENBERG NUMBERS

The alternative to the phytosociological approach is to use some form of autecology, that is the ecology of individual plant species. Autecology in general has the advantage that it does not rely on the same combinations of species occurring in the past as in the present nor does it assume that species found together in an archaeobotanical assemblage necessarily grew together – weed species with different requirements found together may be interpreted as resulting from the mixing of crops cultivated under different conditions. The absence of certain species also poses fewer problems provided interpretations are not based on negative evidence. Unfortunately, detailed autecological records (such as those of Grime et al. 1988) are unavailable for many weed species. In fact, this is probably one of the main reasons why archaeobotanists have used the second phytosociological method mentioned above: relating individual character species to the environment of the group as a whole is a form of 'poor man's autecology' in that it is used in lieu of the individual species' own autecological account. The assumption is made that the preferences of the character species correspond to the environment in which the group as a whole is found. This assumption may not be unjustified since character species are identified on the basis of their restricted occurrence and so are likely to have rather specific ecological requirements.

The most comprehensive autecological

coverage of weed species is provided by the work of Ellenberg (1950, 1979, Ellenberg et al. 1991) who recorded species according to their response to a number of climatic (light, temperature, continentality) and edaphic (soil moisture, pH, nitrogen) factors. This work provides a database, comparable in scope to the phytosociological accounts, in which species are coded (usually on a scale from 1 to 9) for each factor independently. These 'Ellenberg numbers' are based partly on controlled laboratory experiments but primarily on observations in the field and, as such, take into account the effects of inter-species competition as well as the optimal growing requirements of the individual species. This can be both an advantage and a disadvantage: plants are frequently found in suboptimal conditions, due to the effects of competition, and so field observations seem to provide a more 'realistic' expectation of where species may be found; on the other hand, competition between species is itself variable and cannot be treated as a 'constant' in all ecological situations.

Whether based on Ellenberg numbers, or on individual autecological accounts, there are two rather different ways in which autecological information on the environmental preferences of weed species can be used. The first involves the use of individual species, which have a narrow ecological amplitude for at least one environmental factor, and so act as 'indicators' for particular conditions (e.g. M. Jones 1977 and many later examples). The second uses the spectrum of variation for a particular factor in a whole assemblage of species, for which Ellenberg numbers are particularly well suited (e.g. Wasylikowa 1978, 1981, 1989, Willerding 1978, 1980, 1983, Gluza 1983, van Zeist et al. 1986, Jacomet 1987, Jacomet et al. 1989, Kreuz 1990, Behre 1991, van der Veen 1992, Lempiäinen & Behre 1997). The use of species assemblages is attractive because 'indicator' species are relatively rare and so, in an already restricted archaeobotanical dataset (see above), it seems sensible to use information derived from all the available species. In practice, however, the inclusion of catholic species, that may grow under a variety of different conditions, or species that include ecotypes, each adapted to a different ecological niche, may not be as advantageous as it seems. The most influential species in a particular assemblage are likely to be those with extreme values for a particular factor. These will themselves tend to be 'indicator' species (and, quite possibly, also the character species of a corresponding phytosociological group).

Nevertheless, because the use of groups allows ecological inferences to be based on a larger number of species, it is more archaeologically reliable than the use of indicator species for two reasons. First, though the ecological preferences of individual species may have changed through time, it is relatively unlikely that all the species in a group will have changed their preferences in the same direction (G. Jones 1992). Secondly, reliance on a single species (especially if in low numbers) in an archaeological context is unreliable due to the possibility of mixing from a non-crop source, even in assemblages which have been identified as primarily derived from a crop processing product or by-product. Ecological groups based on Ellenberg numbers (Ellenberg 1979), or a similar classification, have been used on their own or in combination with a phytosociological classification (e.g. Wasylikowa 1981, Lange 1990, Jacomet 1987, Jacomet et al. 1989, Karg 1995).

FUNCTIONAL AUTECOLOGY

All of the methods described so far rely primarily on field observations and so address the issue of where a species is found rather than why it is there. Since plants respond to a large number of environmental factors (including competition with other species), these methods provide no means for disentangling the effects of different crop husbandry practices on the composition of the weed flora (Charles et al. 1997). In addition, it cannot be assumed that the same weed species will be available in different geographic areas or at different time periods, even if the husbandry practices applied to the crops are identical (Charles et al. 1997), which makes it difficult to apply modern ecological observations to the past. This second problem is very similar to that encountered in archaeobotany when trying to identify crop processing stages on the basis of weed seeds, and has been overcome in this case by considering the physical characteristics of weed species (such as seed size, weight etc.) that have bearing on their removal at different stages in the crop processing

sequence (Hillman 1984, G. Jones 1984, 1987). For the identification of specific husbandry practices, therefore, it is necessary to consider the ecological principles underlying weed species distribution and to identify relevant characteristics that enable species to thrive under particular ecological conditions.

In fact, archaeobotanists have regularly used one such characteristic in their interpretations of past weed floras, and it is common to find weeds in archaeobotanical reports classified according to their life history: summer annual, winter annual or perennial. Following Ellenberg (1950), summer and winter annuals have usually been taken to indicate the season in which the crop was sown, with a predominance of summer annuals indicating a spring-sown crop, and winter annuals an autumn-sown crop (e.g. M. Jones 1977, 1981, Groenman van Waateringe 1979, Wasylikowa 1981, van der Veen 1992, Kroll 1997). Community affinities have sometimes been used in place autecological information on life history, however, and a note of caution has been sounded, especially when interpreting early weed floras, where distinctive summer and winter weed communities may not yet have developed (Brombacher & Jacomet 1997, Maier 1999) or, in all periods, where poor tillage may have failed to eradicate winter weeds from spring sown cereals (Bakels & Rousselle 1985, van Zeist & Palfenier-Vegter 1993/4, Karg 1995). The presence of perennials has similarly been interpreted as indicating tillage with an ard (rather than mouldboard) plough and/or the practice of fallowing (e.g. Hillman 1981, Karg 1995, Behre 1999, Schibler & Jacomet 1999); and their absence as evidence for intensive tillage by hoeing and digging (e.g. G. Jones 1992, Maier 1999) or, at least, the cultivation of fixed plots (as opposed to shifting cultivation, Bogaard 2002).

To extend this approach to the identification of a greater range of husbandry practices, other relevant ecological characteristics must be used but, unlike life history, which is known for most species, most other ecological characteristics are slow and time-consuming to measure. Relevant data are therefore unavailable for the majority of arable weeds but the 'Functional Interpretation of Botanical Surveys' (FIBS) offers a means of generating such data reasonably easily. This method was developed at the Unit of Comparative Plant Eco-

logy (UCPE) to investigate the role of ecological processes on species distribution in a wide range of habitats (Hodgson 1989, 1990, 1991, Hodgson & Grime 1990). It utilises easy-to-measure functional attributes which are direct or indirect measures of plant ecological characteristics. For example, species with a high specific leaf area (leaf area/leaf weight) are fast-growing species able to compete well in highly productive environments. The principle underlying this method is that species tolerant of (or advantaged by) a particular ecological factor tend to share a suite of adaptive characteristics, i.e. they are of a particular 'functional type'. Functional attributes measure the potential of species rather than the performance of individual plants and so are readily applicable in an archaeobotanical context.

Using these attributes, recent research on present-day weed floras has explored the causal relationships between various crop husbandry practices, such as irrigation (G. Jones et al. 1995, Charles et al. 1997, Charles & Hoppé in press, Charles et al. in press), fallowing and rotation (Palmer 1998, Bogaard et al. 1999), tillage, manuring and weeding (G. Jones et al. 1999, 2000), sowing time (Bogaard et al. 2001), and the weed species which characterize them. This research has established the utility of weed functional attributes as successful indicators of husbandry practice by identifying suites of attributes which are associated with particular practices. For example, attributes indicative of site productivity (such as canopy height and leaf area) were particularly associated with methods for restoring soil fertility (e.g. through manuring – G. Jones et al. 2000 – or fallowing – Bogaard et al. 1999) or, in combination with water-related attributes (e.g. stomatal density or cell size), for improving soil moisture (e.g. through irrigation – Charles et al. 1997, in press). Disturbance attributes (such as length of flowering period and capacity for vegetative regeneration) were indicative of practices such as bare fallowing (Bogaard et al. 1999) or weeding (G. Jones et al. 2000), and seasonality attributes (such as the timing and duration of the flowering period) were more useful than life history for identifying crop sowing time (Bogaard et al. 2001).

These functional attributes therefore allow us to achieve two goals essential for the application of the method in archaeobotany:

(1) the identification of crop husbandry practices on the basis of plant characteristics rather than particular species, thus allowing the established relationship between husbandry methods and weeds in (one location in) the present-day to be applied to (another location in) the past;

(2) an understanding of the ecological principles determining why particular species are associated with particular husbandry regimes, which enables specific elements of the regime to be identified and so opens up the possibility of recognizing novel combinations of practices in the archaeological record.

In some respects the investigation of the relationship between weed functional attributes and the husbandry practices applied to crops has raised as many problems as it solves. Most of these, however, are common to all attempts to apply weed ecology to the past and are not specific to the use of functional attributes. What these studies have highlighted is the complex relationships that exist between different ecological factors, and the impact these have on the species composition of arable weed communities. First, the same attributes may be indicative of somewhat different ecological conditions. For example, attributes indicating high productivity (e.g. high specific leaf area or canopy height) are characteristic of both highly fertile sites and those with high water input. The weeds of the latter sites, however, should also possess attributes, such as small roots or large cell size, specifically indicating a plentiful water supply (Charles et al. 1997, in press).

Secondly, ecological factors may interact with one another so that different combinations of factors advantage species with particular attributes. For example, attributes indicative of high productivity are advantageous in highly fertile sites but, for some of these attributes (e.g. canopy height), this applies only if the sites are also relatively undisturbed. In these cases there may be a gradient from very short canopies (where disturbance is high and fertility low) to very tall canopies (where disturbance is low and fertility high), while medium canopy size may be ambiguous, indicating either medium fertility or high fertility with high disturbance (Bogaard et al. 1998). Other fertility attributes, less affected by disturbance (e.g. leaf area), may permit a distinction in this case (G. Jones et al. 2000).

Thirdly, certain functional types may possess suites of attributes relating to more than one ecological factor. For example, fast-growing warm season weed species will possess both attributes indicating spring sowing of crops (e.g. late flowering) and those normally characteristic of high productivity (e.g. high specific leaf area). So the weed flora of a spring-sown crop is inherently likely to possess attributes suggestive of fertile conditions and vice versa for weeds of autumn-sown crops. In this case it may be necessary to assess sowing time before attempting to identify other practices relating to soil fertility (Bogaard et al. 2001).

Lastly, ecological specialisation may be achieved by more than one route so, for example, species which are able to avoid summer drought by flowering early have little need of drought tolerance attributes (such as small stomatal size) and, conversely, species growing late in the season may require drought tolerance attributes even when growing in irrigated fields. Again, it may be necessary first to assess whether the weed flora is dominated by species flowering at a particular time of year before evaluating other drought avoidance or drought tolerance attributes (Charles et al. in press). In essence, some of these problems can be overcome by considering suites of attributes, or species functional types, and others by considering ecological factors in combination or in sequence.

DISCUSSION

Several points of interest emerge from this discussion. First, some of the difficulties encountered in using weed ecology to identify crop husbandry practices apply only to particular methods. For example, the instability of species associations is a particular problem for phytosociology, and the non-specificity of field data for the use of Ellenberg numbers. Other difficulties equally affect all methods, and the advantage of the functional ecological approach in this respect is that, by investigating the causal links between practices and weed composition, it provides an understanding of the complex interactions between species and the environmental conditions created by different husbandry methods. This allows us to develop ways of circumventing, or

at least allowing for, these interactions. Most other methods consider only the 'end result' of such interactions, in terms of species associations or environmental preferences, and so preclude their detailed investigation. This may explain why the use of weed ecology in the identification of husbandry practices has somewhat stalled since the original optimism of the 1980s.

Secondly, for all methods, it is advantageous to consider groups of species, as this provides the opportunity to look for shared preferences or ecological characteristics and so strengthens the ecological, and ultimately archaeological, interpretations. Nevertheless all methods rely primarily on those species which have very specific ecological preferences or tolerances, and so possess the ecological characteristics which enable them to thrive in these conditions. So 'indicator species', phytosociological character species, and species with 'extreme' values for certain functional attributes will always be the most useful for the identification of crop husbandry. The use of species groups also minimises the effects of ecological change through time and archaeological contamination.

Thirdly, the functional ecological approach lends itself very readily to archaeological application. It allows present-day ecological data for one set of species to be 'translated' via functional attributes to a completely different set of species in the past. Because it offers the opportunity to disentangle the separate ecological effects of different husbandry practices, unexpected combinations of practices may be identified in the archaeobotanical record, extending the range of possible agricultural interpretations beyond our modern experience. In addition, because functional attributes are relatively easily measured, it should be possible to build up a database of functional attributes comparable in size to those existing for phytosociological data and Ellenberg numbers.

The possibility also exists for applying functional data to archaeobotanical taxa identified only to higher taxonomic groups. Current research (Hynd pers. comm.) is exploring which functional attributes are most constant within taxonomic groups and therefore useable archaeologically at the level of the genus or higher. Constant attributes and taxonomic groups will also be those most likely to have

remained unchanged through time. The challenge here is to balance the precision of the most adaptable taxa as ecological indicators with the applicability to the past of the more conservative taxa. Since weeds are also affected by crop processing, archaeological applications must take these effects into account before applying ecological studies to the archaeobotanical data. This is best achieved by first establishing the processing stage from which individual archaeobotanical crop samples are derived, and then comparing only the products or by-products of the same stage in terms of their ecological characteristics (G. Jones 1987, 1992).

Initial attempts to apply functional ecological data in the identification of husbandry practices are promising. A test case to demonstrate the geographical applicability of the approach, using the present-day weeds of spelt wheat in northern Spain, has been successful in correctly identifying the crop as intensively cultivated and winter-sown, based on attribute suites characterising cultivation intensity and sowing time in Greece and Germany respectively (Charles et al. 2002). Archaeological applications, using locally measured attributes, are also shedding light on irrigation agriculture in the Islamic period in Jordan (Hoppé 1999) and early cultivation methods in the central European LBK (Bogaard pers. comm.).

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