Journal of Ethnobiology 20(2): 303-325 Winter 2000

A CLADISTIC APPROACH TO COMPARATIVE ETHNOBOTANY: DYE PLANTS OF THE SOUTHWESTERN UNITED STATES

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ABSTRACT.—An intensive review of the ethnobotanical literature on dye plants used by 11 indigenous tribes in the Southwestern region of the United States revealed that 108 plants have been used to manufacture dyes for coloring wool, leather, cotton and other plant fibers. Some plant species are also used to obtain pigments for pottery and body paint while others are used to color food. Of the 11 different plant dye traditions evaluated in this study, the Navajos use the greatest number of plants (n=69) for dye purposes. Considering innovations in dye plant traditions shared among tribes to be analogous to shared derived characters in phylogenetic analyses (termed "synapomorphies"), a cladistic analysis shows that traditions of dye plants are most derived among the Navajo and Hopi tribes. The traditions of dye plants of these two tribes are also more closely related to each other than either tradition is to dye plant traditions from other tribes. The cladistic approach of analyzing shared derived technologies appears to be a useful way of generating hypotheses concerning cultural diffusion of plant uses in other ethnobotanical studies.

Key words: cladistics, dye plants, ethnobotany, Southwestern Native Americans.

RESUMEN.—Una revisión intensiva de la literatura enthnobotanical en las plantas del tinte usados por 11 tribus indígenas en la región al sudoeste de los Estados Unidos reveló que 108 plantas se han utilizado para fabricar los tintes para las lanas del colorante, el cuero, el algodón, y otras fibras de la planta. Un ciertas especies de la planta también se utilizan para obtener los pigmentos para la cerámica y la pintura de cuerpo mientras que otras se utilizan para colorear el alimento. De las 11 tribus evaluadas para este estudio, la tribu de Navajo utiliza el número más grande de las plantas (n=69) para los propósitos del tinte. Considerando innovaciones en las plantas del tinte compartidas entre las tribus para ser el equivalente del termo cladistico se dice "synamorphies," un análisis cladistic mostró que las aplicaciones del tribus de Navajo y de Hopi son derivados más de las plantas del tinte. Estas dos tribus también se relacionan más de cerca el uno al otro en sus aplicaciones de la planta del tinte que están a cualquier otra tribu. El acercamiento cladistic de analizar tecnologías derivadas compartidas aparece ser una manera útil de generar hipótesis referentes a la difusión cultural de las aplicaciones de la planta en otros estudios ethnobotanical.

RÉSUMÉ.—Une revue approfondie de la literature ethnobotanique est presenté sur 108 plantes utilisées comme teintures par 11 tribus indigènes à la region suroeste des Etats Unis. Elles sont utilisées pour teindre de la laine, le cuir, le coton, et quelques autres fibres vegetales. La tribu Navajo utilis le plus grand nombre des plantes comme teintures (n = 69). Une analyse cladistique indique que les tribus Hopi et Navajo sont les plus développées en ce que concerne utilization de plantes comme teintures et aussi elles sont plus similares entre se.

INTRODUCTION

The Southwestern region of the United States is considered ethnobotanically to be "the best studied area in the world" (Ford 1985:401). In this region, comprehensive studies have been made of the plants used by indigenous people for medicine, food, clothing, and art (Bell and Castetter 1937; Castetter, Bell and Grove 1938; Dennis 1939; Dunmire and Tierney 1995; Fewkes 1896; Kent 1957; Palmer 1878; Sauer 1950; Standley 1911; Winter 1974). Other studies have focused on the ethnobotany of particular tribes (Castetter and Underhill 1953; Cook 1930; Elmore 1943; Ford 1968; Hough 1897; Jones 1931, 1948; Mathews 1886; Reagan 1929; Robbins, Harrington and Freire-Marreco 1916; Stevenson 1915; Swank 1932; Vestal 1952; White 1945; Whiting 1939; Wyman and Harris 1941, 1951). However, comparative ethnobotanical studies are rare. In the early 1960's, Whiting identified an urgent need for "summary reports, comparative historical studies, and broadly based reviews of comparable data throughout the area" (Whiting 1966:318). Doebley (1984) responded to this call with comparative studies of wild grasses, yet few other similar studies have been done. Twenty years after Whiting made his statement, Richard Ford (1985) and Robert Bye (1985) both noted that there remains a void in the area of comparative work.

We have compared use of plants for dyes and paint among different southwestern indigenous tribes based on historical and contemporary accounts. For this purpose we considered all plants used to color wool, cotton, and leather, for food coloring, as well as for pigments for body and pottery paint. The purpose of our study is two-fold: (1) to provide a comprehensive review and comparison of dye plants used by southwestern Amerindians, and (2) to show how cladistic analyses may be used to generate hypotheses concerning cultural diffusion of plant uses between tribes.

Linguists, systematists, and biogeographers have previously used cladistic techniques to study common origins of languages, biological species, and biogeographical regions respectively. Unlike comparative methods that rely on overall similarity, such as phenetics, cladistic analyses generate relationship diagrams (also know as cladograms) based on shared derived features or characters (synapomorphies). Thus, although phenetic schemes might suggest crocodiles and lizards are more closely related to each other than either are to birds because of overall similarity, cladistic analyses group birds with crocodiles because of shared derived features of skull anatomy (Ridley 1993). In biology, characters used for cladistic analyses can be different features of anatomy, molecular sequence, behavior, physiology and so forth.

We believe that cladistic analysis might be a useful method for cross-cultural ethnobotanical comparisons. A unique technological innovation that is subsequently shared by different cultures could be considered a shared derived feature, called in cladistic terminology a "synapomorphy." For example, if use of a particular plant as a medicine originated with a single individual, but subsequently spread to different cultures through time, that use could be considered to be a synapomorphy for those cultures. Synapomorphies are used in cladistic analyses to indicate possible branching patterns in cladistic trees. Such shared derived innovations can then be used to generate relationship trees for the technology of interest (such as dye plants, medicinal plants, crop varieties, etc.). Diagrams of these relationships, presented as trees, are termed "cladograms."

Technological features in common to different cultures that do not share a common unique derivation could be termed "symplesiomorphies." For example, the use of conifers as firewood is probably common to all cultures where conifers occur, but likely cannot be traced to a single unique innovation, and hence is an example of a symplesiomorphy. Symplesiomorphies unfortunately, are of little or no value in determining relationship trees or cladograms.

Some cultures may produce technological innovations that do not spread to other cultures. Such unique unshared innovations are termed "autapomorphies." For example, use of an endemic species of algae by the Hawaiian people cannot possibly have spread to other islands, and hence could be considered an autapomorphy. Autapomorphies, while interesting for a particular culture, do not shed light on relationships to other cultures.

Characters used for cladistic analyses in cross-cultural ethnobotanical studies could include technological, medicinal, artistic, architectural, ritual innovations. It is not necessary to compare biological entities; we here study plant uses because as ethnobotanists our interests are focused on the interactions between plants and people. Cladistic studies require that observable information is translated into discrete characters (Kitching et al. 1998). In cross-cultural ethnobotanical studies one can easily identify plants as used or not used, making such characters prime candidates for cladistic analyses. Thus, we are proposing to evaluate relationships between uses of plants by different tribes based on shared technological innovations of dye plant use rather than grouping these uses on the basis of overall similarity. It is important to note that we are not, however, attempting to consider genetic or cultural relationships of the tribes themselves. It is only the plant uses, and not the people themselves, which are the objects of our analysis. Thus, while our diagrams of plant use relationships are not intended to suggest genetic or cultural relationships between different tribes, they can be used to generate hypotheses of how different discoveries of new dye plants might have spread through various cultures.

While cladistic techniques are simple, and for a limited number of different traditions of plant use (three or four) can easily be done by hand, the number of possible alternative relationships trees (and hence the number of calculations) increases exponentially with the number of tribes. As a result, we have had to use a computer program to evaluate the number of trees. As will be described shortly, the program basically determines which, of all possible relationship trees, is the most parsimonious- the one requiring the least number of steps of culture transmission, parallel innovation, and culture loss. This most parsimonious tree is then proposed as a candidate for evaluation by other researchers. Often, with a large number of taxa (here considered to be different tribal traditions of plant dye use), different trees of equal number of steps are discovered during the computer algorithm. We have here chosen to present a summary of the features in which all of these most simple trees agree: such a diagram is called a strict consensus tree. Further information on cladistic techinques can be obtained from a variety of textbooks in systematic biology.

METHODS

General Comparison.—As a means of understanding native American traditions of dye plants use, we conducted interviews with Navajo weavers on the Navajo reservation in Southern Utah and Northern Arizona and observed some collections of dye species and dying techniques. We then expanded our study to a regional basis by conducting an intensive literature review, compiling ethnobotanical information on 11 different tribes: Eastern Keres, Hopi, Jemez (Towa), Navajo, Papago, Pima, Southern Tiwa, Tewa, Western Apache, Western Keres (Acoma and Laguna), and Zuni. We chose to study the dye plant traditions of these tribes because of the geographical proximity of the tribes to each other, their pattern of cross-cultural interactions, and the availability of previous ethnobotanical studies.

Some of the dye plants used in the past are no longer used today, yet for our analysis we include both historical and contemporary uses with no effort to distinguish between the two. In our study we selected from literature accounts only those plants identified to the level of both genus and species, since records from different tribes of a plant identified only by a generic epithet might conflate different species, skewing our analysis. For consistency, plants identified beyond the species level to the varietal level were truncated to species. Appendix 1 lists each plant and the tribes that used it. Figure 1 illustrates approximate tribal boundaries and the number of dye plants used by each tribe. Our definition of tribal boundaries is somewhat arbitrary since these boundaries have never been static but vary in time with changes in culture, modes of transportation, and the colonization/reservation boundaries forced upon different indigenous groups. For this reason, we used a slightly modified version of regional boundaries defined in *The Handbook of North American Indians* (Ortiz 1983).

Cladistic Analysis.—A cladistic analysis based on shared derived characters (synapomorphies), in this case, shared cultural innovations in use of dye plants, was performed by coding each of the 108 dye plant species as either used or not used for each of the 11 tribes. Our data matrix is provided in Appendix 2. No effort was made to differentiate between plants used to dye wool or other materials for two reasons: (1) we are presuming that one plant used for one particular material would most likely be tried on other materials as well, therefore not be exclusive to wool, cotton, leather, or other materials, and (2) literature accounts tend to focus on the plants used rather than on the types of materials dyed. Our coded data

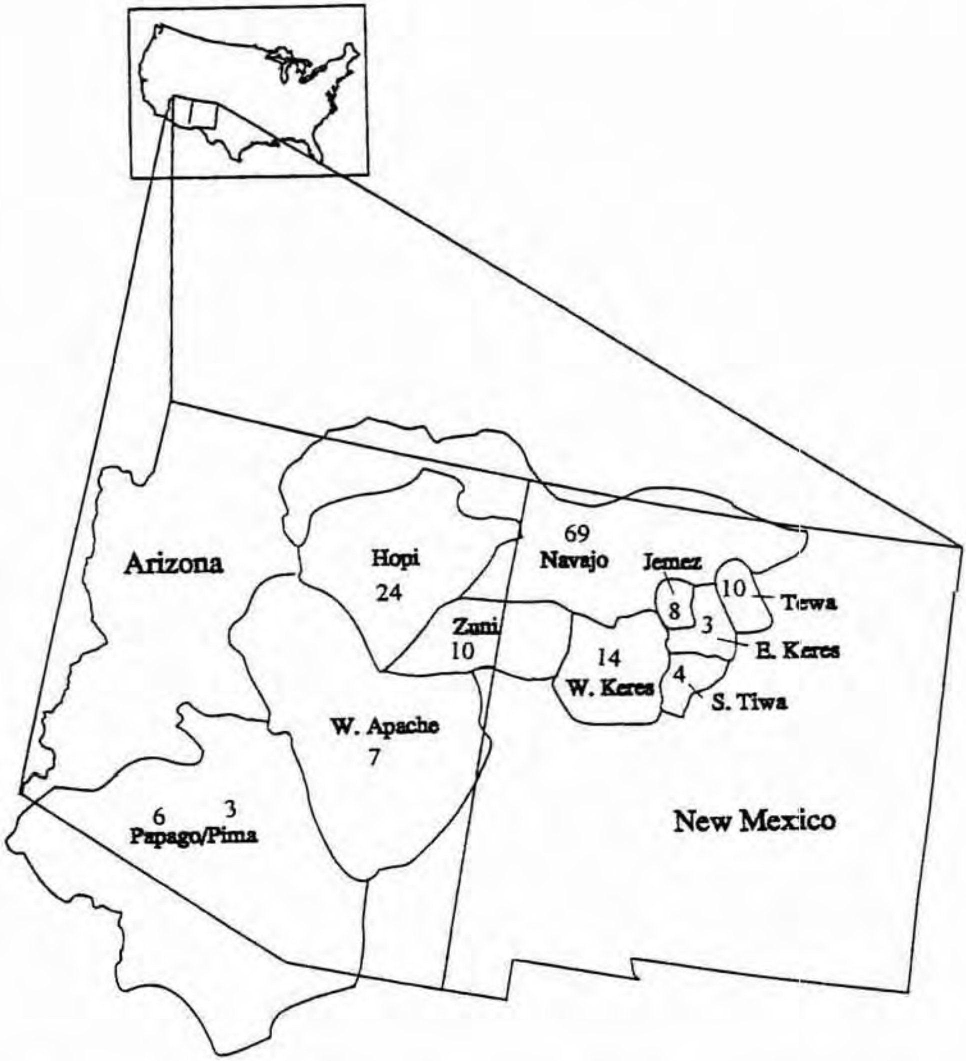

FIGURE 1.—Map showing the geographic proximity of tribal regions. Number of dye plant species used by each tribe are indicated (adapted from Ortiz 1983).

matrix was analyzed with the computer program HENNIG86 (Farris 1988). In the analysis we gave each dye plant species an initial weight of one and selected the non-additive option. The complete search algorithm, implicit enumeration (ie), was used to generate relationship trees of minimal length. A strict consensus tree was obtained for the trees obtained from implicit enumeration of the unweighted characters (Figure 2). We then found equally parsimonious trees by using the *xsteps* command with the *w* option utilized, thus applying species weights according to their fit to the trees. Weights applied were calculated by the program as the product of character consistency index, *ci* (Kluge & Farris 1969) and the retention index, *ri* (Farris 1989a, 1989b). Weightings were applied in successive rounds of implicit enumeration until no changes in tree length, consistency index, or retention index could be obtained from successive rounds. We then obtained a strict consensus tree for the weighted sample.

In a strict cladistic sense, we make no claim about the monophyletic nature of the traditions we have here analyzed; in fact the uses we analyze may be paraphyletic because 1) we do not know if all of these plant dye uses can somehow be traced back to a singular innovation in the uses of plants as dyes, and hence share the same ancestral tradition, and 2) it is doubtful if we have here included all possible traditions derived from an ancestral tradition; little is known, for example, about Anasazi use of dye plants.

In cladistic analyses, often an outgroup possessing the "primitive" state is chosen in order to determine character polarities. Not wishing to make any statement about relative age and technological status of any of the 11 tribes we studied by claiming that one tribe's use of a plant somehow preceded or was ancestral to another tribe's use of the same plant, we rooted our analysis in the uses of plants by a hypothetical tribe that has never used any dye plants: hence all character

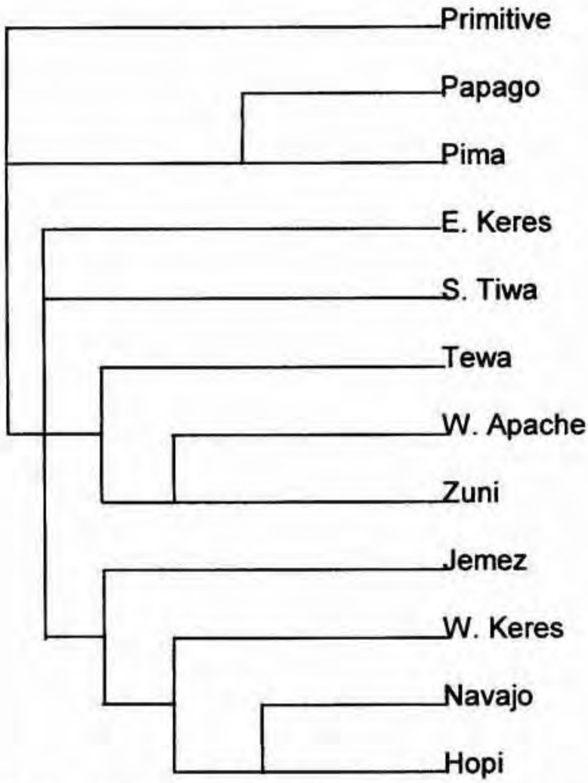

FIGURE 2.— Cladistic relationships of dye plant traditions of southwestern Amerindian tribes; strict consensus tree of unweighted characters, length= 131, consistency index = 0.82; retention index = 0.51

states begin at zero. We note that alternative methods of cladistic analysis that include unrooted networks are available, but such analyses do not change the topology of our resultant trees, and we believe our postulation of a zero-use cultural antecedent to current Amerindian dye uses is, by *reductio ad absurdum* true: if we were to go back far enough in time (at the extreme, the first aboriginal immigrants to North America), we would eventually find a group of people who did not use any North American plants for dyes. This group would be the most "primitive" group as far as dye technology is considered. Our subsequent analysis assumes that knowledge of how to use dye plants is passed from generation to generation rather than being independently recreated *de novo* each generation–the cultural equivalent of recurrent homoplasy in the cladistic sense.

RESULTS

Enumeration of Dye Plant Species.—A total of 108 species, including 103 vascular plants, two fungi and three lichens, have been recorded as sources of dye pigments for wool, cotton, leather, body and pottery paints, and the coloring of food by the 11 tribes (Appendix 1). The 103 vascular plants represent 38 different families. The majority of the dye plant species are used to dye wool. Of these 108 species, the Navajo use 69, the Hopi use 24, the Western Keres use 14, the Tewa and Zuni use 10, the Jemez use eight, the Western Apache use seven, the Papago use six, the Southern Tiwa use four, and the Eastern Keres and Pima both use three species (Figure 1).

Cladistic Analysis.—Our cladistic analysis based on shared cultural innovation (synapomorphies) in use of dye plant species initially resulted in nine trees, each requiring 131 steps, a consistency index of 0.82 and a retention index of 0.51. A strict consensus tree, which presents all features on which these nine trees agree, showed a basal unresolved trichotomy, but we sought to improve the consistency and retention indices by successive character weightings. We then performed two rounds of successive approximations weighting which was analyzed by implicit enumeration, and seven trees of different topologies (Figure 2) were obtained with

TABLE 1.—The 11 most commonly used dye plants and the associated tribes that use those plants.

Plant species	Tribes that use them
Alnus tenuifolia	Jemez, Navajo, S. Tiwa, Tewa, W. Apache, W. Keres, Zuni
Cercocarpus montanus	E. Keres, Jemez, Navajo, S. Tiwa, W. Keres
Chrysothamnus nauseous	Navajo, Tewa, W. Apache, W. Keres, Zuni
Cleome serrulata	E. Keres, Navajo, S. Tiwa, Tewa, Zuni
Pinus edulis	Hopi, Jemez, Navajo, W. Keres
Atriplex canescens	Hopi, Navajo, Tewa
Betula occidentalis	Hopi, Jemez, Tewa
Castilleja integra	Navajo, W. Apache, Zuni
Descurainia pinnata	Hopi, Jemez, Tewa
Psilotrophe tagetina	W. Apache, W. Keres, Zuni
Rhus aromatica	Hopi, Navajo, W. Keres

a higher consistency index of 0.98 and a retention index of 0.90, all with 940 steps. Although the strict consensus tree of the weighted samples reduced resolution from the unweighted analysis by collapsing the original basal trichotomy into a basal hexatomy, all other topological features of the tree remained the same as the unweighted tree (in fact, the tree produced from character weighting, is, topologically, still a subset of the unweighted tree.). We note that the consistency index (but not the retention index) may be an overestimate of the robustness of our analysis since this statistic is sensitive to autapomorphies (characters restricted to one tribe, in our analysis, uniquely derived plant uses not shared with other tribes), in which some traditions we studied, particularly that of the Navajo, abound.

Of the 108 plant species used as characters, only 27 are synapomorphies. This level of autapomorphy which, as mentioned above, does affect the consistency

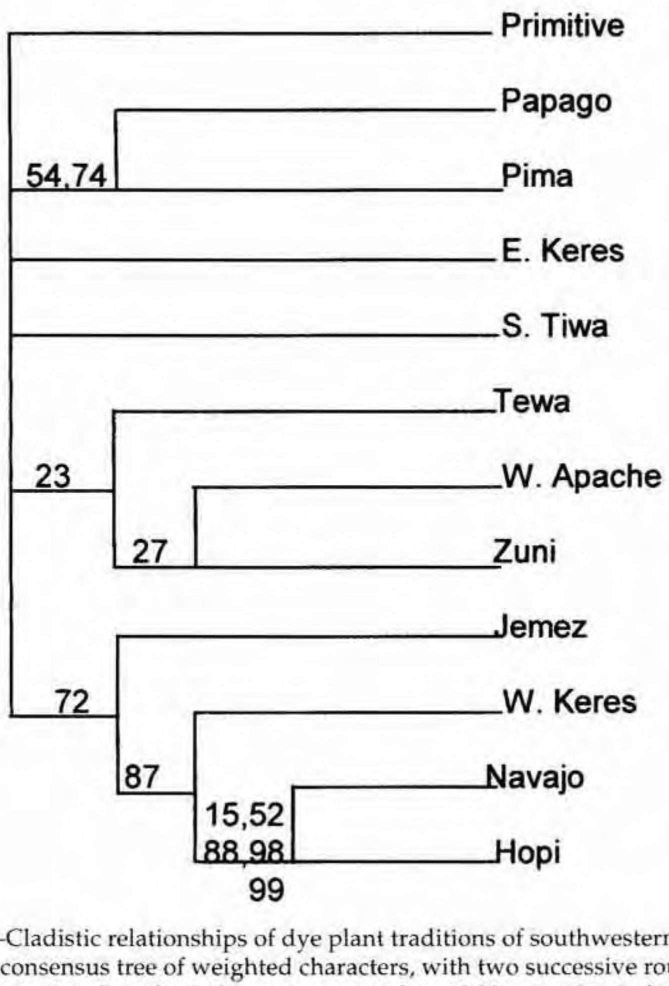

FIGURE 3.—Cladistic relationships of dye plant traditions of southwestern Amerindian tribes; strict consensus tree of weighted characters, with two successive rounds of implict enumeration; length= 940, consistency index = 0.98; retention index = 0.90. The synapomorphies are indicated by a number which refers to specific plant species as identified in Appendix 1.

index. Yet, including all of the data does not affect global parsimony or successive weighting methods, and, of course, leaves the tree morphology unaltered. However, many of the nodes of the consensus tree are supported by a relatively few number of synapomorphies, so it is conceivable that the topology of the consensus tree could change as plant uses from other additional tribes outside of our study area are added to the sample.

A strict consensus tree (Figure 3), which combines the features on which that all of the seven most parsimonious trees agree, shows dye plant use of the Hopi and the Navajo to be more closely related to each other than the use of plants by either tribe is to their sister group, plant used among the Western Keres. Synapomorphies (shared characters or innovation in use of a plant species for dye) linking the Hopi and Navajo include *Carthamus tinctorius* (an introduced species), *Juniperus osteosperma*, *Rumex hymenosepalus*, *Thelesperma megapotamicum*, and *Thelesperma subnudum*. Dye use among members of the larger clade consisting of the Navajo, Hopi, and Western Keres was more closely related to dye use among the Jemez than to any of the other tribes considered. The synapomorphy (shared innovation) linking the clade composed of the Navajo, Hopi, and Western Keres is *Rhus aromatica*. Dye use among the clade consisting of the Navajo, Hopi, Western Keres, and Jemez was more closely related to each other than to all other tribes on the basis of *Pinus edulis* as a synapomorphy. The other clades consistently grouped in the strict consensus tree were the Western Apache and Zuni linked by the synapomorphy of *Coreopsis cardaminefolia*. Use of *Chysothamnus nauseosus* link the Western Apache, Zuni, and Tewa, although our analysis indicates an independent origin for the use of this species among the Navajo and Western Keres. A less parsimonious solution is, of course, that the other tribes lost this knowledge. Such homoplasy may disappear from the cladogram as plant used for dyes from more tribes are added to the data set, and, in an adapation of cladistic biogeography, as comparative cladograms for plants used for different purposes (i.e. medicinal, ritual, etc.) are overlaid with dye plant use. The Papago and Pima share two synapomorphies—*Krameria parviflora* and *Prosopis velutina*. However, the pattern of branching cannot be resolved in the strict consensus tree for the Eastern Keres and Southern Tiwa. However, in the unweighted tree they form a sister group to the Papago and Pima.

DISCUSSION

Enumeration of Dye Plant Species.—Certain questions are raised from our study in both the enumeration of plant uses and in the subsequent cladistic analysis. Why do the Navajo use so many unique plants (cultural autapomorphies), especially in comparison to the other tribes? We believe that the importance of dye plants in the Navajo economy, specifically in weaving, creates an incentive for Navajos to use more dye plants. For the Navajo, weaving has been, and continues to be, an important source of income (Hedlund 1992; Roessel 1983). Weaving as a source of commercial income for the Navajo was established by 1900 (Wheat 1979). Indeed, at that time the Navajo rug was the only handwoven good from natives of the Southwest that still had significant trade value (Minge 1979). The Navajo have been praised for the highest quality of weaving observed among regional indigenous groups. Some have estimated that the Navajos emerged as premier weavers by the 1800's (Mathews 1891; Wheat 1979). The Navajo adopted weaving about 300 years ago and yet they didn't use a great number of dye plants until the beginning of the 20th century (Hedlund 1992). Indeed, one of the earliest recordings of dye plant use among the Navajo only mentions seven dye plants (Mathews 1891). Aniline dyes were also employed during the early part of this century, but by the 1930's there was a resurgence of interest in natural dyes (Reichard 1936), and in today's market a weaver can get a better price for a rug made with vegetal dyes than one that is made with aniline dyes. For these reasons we believe the Navajo have a stronger incentive to use vegetal dyes and to continue experimenting and finding more plants that produce good dyes, even looking outside their own cultural knowledge of dye plant use. This incentive may have also contributed to the Navajo looking to Anglo/Western sources for plant dye information, as found in Amsden's *Navajo Weaving* (1940). Our interviews with different weavers and traders show a general consensus that experimentation with new plants to find new dyes is common today. This is also supported in the literature (Hedlund 1992; Jones 1948). Hence there is an economic motivation for use of plant dyes. This motivation may be a determining factor in the continued use of natural dyes and may contribute to the fact that many weavers today are continually experimenting with new plants and combinations of plants for unique dyes. This economic incentive may be significant in the large difference of dye plants used between the Navajo and other tribes.

Tribal population size could also influence the variation in dye flora sizes among tribes assuming that larger tribes, having more people, had greater collective knowledge about what plants make good dye plants. If this were the case, we would expect larger tribes to use more plants. Today the Navajo tribe is the largest of the tribes studied, but it is difficult to assess and correlate fluctuations in tribal size with fluctuations in dye plant use.

Cladistic Analysis.—Of interest in the cladistic analysis is the absence of symplesiomorphies common to all tribes, i.e., dye plants that all 11 tribes use and were derived from some earlier tradition of use or people not included in our analyses. The most commonly used plant is *Alnus tenuifolia*. Seven of the 11 tribes use this plant. The four tribes that do not use it are the Hopi, Eastern Keres, Papago, and Pima. Table 1 shows the 11 most commonly used plants and which tribes use them.

Does the absence of symplesiomorphies mean that different clades (tribes) independently invented the use of dye plants, or some tribes lost the use of a particular plant, or that each tribe merely utilized those plants that were most common and therefore readily available? Obviously the latter hypothesis cannot be true for every tribe, especially when the use of non-native species is considered. But for those tribes only using a few dye plants, independent development of plant dyes is possible. The absence of symplesiomorphies could indicate that different tribes lost the use of a particular plant as acculturation through the influence of Western culture increased with the movement of more European-Americans into their regions. In the case of *Alnus tenuifolia* we can assume that each of the seven tribes independently invented the use of this plant, but a more parsimonious hypothesis would be that *Alnus tenuifolia* is actually a symplesiomorphy which was "lost" four separate times by the Eastern Keres, Hopi, Papago and Pima.

As we consider other commonly used plants like *Cercocarpus montanus* or *Cleome serrulata*, the question becomes more problematic. These two plants are used by five of the 11 tribes. Were they each once used by all tribes, thus being a symplesiomorphy? If so, the knowledge would have been lost six times. Or is it more likely that the five tribes independently came to use these two plants? Use and diffusion of plant knowledge of such plants may be difficult to assess. Yet some plants lend themselves to easier consideration. *Chrysothamnus nauseosus* could easily be placed on the cladogram below the Tewa, and use of it could have been lost by both the Jemez and Hopi.

The Navajo have 51 autapomorphies (plants used by only that tribe—a uniquely derived, but unshared, innovation). The rest of the tribes have noticeably fewer autapomorphies and are as follows: Hopi–12, Western Keres–six, Tewa–four, Papago–three, Western Apache and Jemez–two, Pima–one, Eastern Keres, Southern Tiwa and Zuni–zero. The presence of unique cultural uses of dye plants suggests that some indigenous groups are putting more energy into finding dye plants, while others are content to use fewer plants and have less variety in their range of color for dyed materials. The large number of autapomorphies that the Navajo have correlates well with their cultural and economic emphasis on woven rugs as discussed above.

This cladistic analysis provides some hypotheses on the cross-cultural diffusion of dye plant use/knowledge. It seems plausible that the Navajo and Hopi would be closely related in dye plant use because of their geographical proximity to each other and the similarity of the environment in which they live. It is feasible that as the Navajo people migrated into the southwestern region they learned about plant use from their nearest neighbors—the Hopi. Clearly, some knowledge was being shared between tribes—the Navajo learned to weave from the Pueblo people. And through their contact with other southwestern tribes, like the Hopi, it is likely that the Navajo learned about plant use, in this case dye plant use.

The relationship between the Western Apache and Zuni plant dye use is surprising at first, given their distinct language differences. But as one closely examines their environments, both live within the White Mountain range which contains a distinctly different flora from the high plateau deserts where tribes that are culturally more similar live. Thus their shared relationship in dye plant use appears to be a function of their shared environment, rather than a closely shared culture.

The Papago and Pima relationship of plant dye use is no surprise—their tribal regions are much further west and south than the Pueblo tribes and the Navajo/Western Apache. It would be expected that their flora is the most different of all tribes studied based on the ecology of their homeland. Indeed, of all the tribes studied, they have the smallest potential dye flora within their ecological boundaries. Also, the Papago and Pima come from the Uto-Aztecan language stock, as do the Hopi, but the Hopi live in much closer proximity to the Puebloan tribes and share many cultural traditions with them. The Papago and Pima are more unique in their cultural background and it would be expected that they would emerge as more closely related to each other in dye plant use than to other tribes.

CONCLUSIONS

This comparative study shows a wide range of plants used by Native Americans for dye purposes. Such variation suggests several scenarios in the evolution of dye plant use: (1) those tribes that place a greater emphasis on dyeing, due to factors such as the economics of dyed materials or cultural significance, may have actively sought to find plants that yield pigments and thus increased their overall dye flora, (2) some tribes may have lost dye plant knowledge through acculturation and assimilation into the Western culture, (3) some tribes could have independently invented the use of certain plants for dyes, and (4) larger tribes may have retained more information about their tribal dye flora whereas dye plant use may decrease as tribal size decreases over time. Most likely, a combination of these factors account for the variation seen among the eleven tribes considered in this study.

The fact that some tribes use very few plants is as telling as those tribes that use many dye plants. The cultural importance of weaving, dyeing and painting varies between tribes. We might assume that those tribes that place a higher significance on such activities will have a larger dye flora. And conversely, those tribes who use few plants may place a lesser value on weaving and dyeing. By comparing plant use in other areas, we could piece together potential cultural values for each tribe, based on size of flora used for different means (medicinal, agricultural, ceremonial/ritual, building, etc.). Dye use is merely one piece of a larger picture that helps us understand not only cultural uses of plants, but those things that are important in different cultures as well.

Cladistic analyses can generate hypotheses of cross-cultural diffusion of dye plant use hat might not be readily apparent if one were to limit cultural comparisons to overall similarities. Again, we reiterate that this analysis does not suggest overall cultural relationships between the eleven tribes studied since we considered only one small aspect of material culture: dye plant use. Our analysis does, however, suggest hypotheses on how dye plant knowledge may have spread between the different tribes and which tribes were sharing ethnobotanical knowledge. We find a strong ethnobotanical link between the Hopi and Navajo, the Zuni and Western Apache, and the Papago and Pima. These different indigenous groups could have been sharing information about dye plants with each other, both potentially enlarging their own dye flora from the others' ethnobotanical knowledge. The exact history of use and knowledge will not be known, but hypothetical situations can be generated by cladistic studies which are amenable to falsification by archaeological or ethnohistorical data.

Further cladistic analyses on different ethnobotanical uses—such as medicinal and agricultural plants, plants used for clothing, shelter and tools, and plants with ritual significance—could be overlaid in the same way that vicariate biogeographers overlay different plant and animal phylogenies to discover relationships between diverse geographical areas. Such iterative cladistic analyses (towards which our study is only a small step) could provide fascinating clues and trends into ethnobotanical cross-cultural interactions. By overlaying such analyses we might generate hypotheses of cultural interactions that may not be readily apparent otherwise.

As indigenous knowledge systems throughout the world continue to disappear, it is important to understand how ethnobotanical knowledge diffuses across cultural boundaries. Using plants as shared innovations and comparing tribal use of plant species using cladistic analyses may provide one key to understanding such knowledge transfer. It is a simple technique that can clarify relationships between indigenous cultures and elucidate the exchange of knowledge and technologies. Cladistic analyses may also render insights on plant technologies that were independently invented versus those that were exchanged across cultural boundaries.

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APPENDIX 1.—Plants used for dye purposes and corresponding tribes that use(d) them. Plants are used to dye wool, unless otherwise indicated. Numbers in each box refer to reference(s) that indicated tribal use of each plant.*

	Eastern Keres	Hopi	Jemez (Towa)	Navajo	Papago	Pima	Southern Tiwa	Tewa	Western Apache	Western Keres	Zuni
ASTERACEAE 1. *Actinea gaillardia*				37							
2. *Actinea leptoclada*				37							
SCROPHULARIACEAE 3. *Adenostegia wrightii*		34 body paint									
BETULACEAE 4. *Alnus tenuifolia*			6 leather	1,7,9,12, 15,19,20 22,24,28 32,37			16	7,11, 25	7,23	7,30 leather	7,23 leather
AMARANTHACEAE 5. *Amaranthus cruentus*		10,31, 34 wafer bread									29 wafer bread
6. *Amaranthus palmeri*		13,14 wafer bread									7 wafer bread
ASTERACEAE 7. *Artemisia tridentata*				37							
GRAMINEAE 8. *Arundo donax*					4,7						
CHENOPODIACEAE 9. *Atriplex canescens*		7,13, 14 wafer bread		18,32, 37				7,25			
10.*Atriplex rosea*				18							
BERBERIDACEAE 11.*Berberis fremontii*				20							7,29
12.*Berberis repens*				20,37							8
BETULACEAE 13.*Betula occidentalis*		7,14 leather	6 leather					14 leather			
ASTERACEAE 14.*Carduus occidentalis*				1							
15.*Carthamus tinctorius* (introduced)		7,10,13, 14,32,34 wafer bread		7							
SCROPHULARIACEAE 16.*Castilleja integra*				37					23		7,29 leather
17.*Castilleja linariaefolia*		34									

	Eastern Keres	Hopi	Jemez (Towa)	Navajo	Papago	Pima	Southern Tiwa	Tewa	Western Apache	Western Keres	Zuni
LINACEAE 18.*Cathartolinum puberulum*										7,30 paint	
ULMACEAE 19.*Celtis reticulata*				7,9							
ROSACEAE 20.*Cercocarpus breviflorus*		5,34									
21.*Cercocarpus montanus*	33		6 leather	1,7,9,12 15,18,19 20,22,24 28,32,37			16 leather			30 leathe r	
ASTERACEAE 22.*Chrysothamnus latisquamena*				7,37							
23.*Chrysothamnus nauseosus*				1,7,9,12, 15,18,19 20,32,37				11	7,23	7,25	7,29
24.*Chrysothamnus parryi*		10 body paint									
25.*Chrysothamnus viscidiflorus*				9 plant materia							
CAPPARACEAE 26.*Cleome serrulata*	33			20,37			16,33	7,11, 25,35 paint			7,29
ASTERACEAE 27.*Coreopsis cardaminefolia*									7,23		7,29
ROSACEAE 28.*Cowania mexicana*				7,9,20, 24,37							
CUCURBITACEAE 29.*Cucumis melo* (introduced)		34 body paint									
30.*Cucurbita foetidissima*									7,23 sand paint		
CHENOPODIACEAE 31.*Cycloloma atriplicifolium*		34									
RANUNCULACEAE 32.*Delphinium scaposum*				24,37							
CRUCIFERAE 33.*Descurainia pinnata*		7,10, 34	8 paint					7,25 genus only			

	Eastern Keres	Hopi	Jemez (Towa)	Navajo	Papago	Pima	Southern Tiwa	Tewa	Western Apache	Western Keres	Zuni
ASTERACEAE 34.*Encelia farinosa*					4,7						
35.*Endothia singularis* (fungus)				17							
GNETACEAE 36.*Ephedra trifurca*				9,12							
37.*Ephedra viridis*				37							
CRUCIFERAE 38.*Erysimum capitatum*										8,30	
OLEACEAE 39.*Forestiera neomexicana*			6 body paint	37							
ERICACEAE 40.*Gaultheria humifusa*				7,9							
ASTERACEAE 41.*Gutierrezia sarothrae*				18							
42.*Helenium hoopesii*				12,24, 37							
43.*Helianthus annuus*				9							
44.*Helianthus petiolaris*		7,13, 14									
SAXIFRAGACEAE 45.*Heuchera bracteata*				7,9,24							
ASTERACEAE 46.*Hymenoxys metcalfei*				7,37							
IRIDACEAE 47.*Iris missouriensis*				20							
JUGLANDACEAE 48.*Juglans major*				7,9,37							
49.*Juglans regia* (introduced)				9							
CUPRESSACEAE 50.*Juniperus deppeana*				18							

	Eastern Keres	Hopi	Jemez (Towa)	Navajo	Papago	Pima	Southern Tiwa	Tewa	Western Apache	Western Keres	Zuni
51.*Juniperus monosperma*				1,7,9,22, 24,28,32 37						30 leathe r	
52.*Juniperus osteosperma*		34 body paint		9,28							
53.*Juniperus scopulorum*										30	
FABACEAE 54.*Krameria parvifolia*					4,7 cotton, leather	7,26 leather					
ZYGOPHYLLACEAE 55.*Larrea tridentata*	7				4,7 tattoo						
56.*Letharia vulpina* (lichen)									7,21		
FABACEAE 57.*Lupinus kingii*				37							
58.*Medicago sativa* (cultivated)				9							
NYCTAGINACEAE 59.*Mirabilis multiflora*				20							
LILIACEAE 60.*Nolina microcarpa*				16							
CACTACEAE 61.*Opuntia engelmannii*										30 paint	
62.*Opuntia phaecantha*				20							
63.*Opuntia polycantha*				9,24, 37							
64.*Parmelia molliuscula* (lichen)				1,9,37							
FABACEAE 65.*Parryella filifolia*		13,14 wafer bread									
AMPELIDACEAE 66.*Parthenocissus vitacea*			6 body paint								
ASTERACEAE 67.*Pectis angustifolia*		5									
68.*Petradoria pumila*				9							

	Eastern Keres	Hopi	Jemez (Towa)	Navajo	Papago	Pima	Southern Tiwa	Tewa	Western Apache	Western Keres	Zuni
FABACEAE 69.*Phaseolus vulgaris* (cultivated)		3,5,34									
LORANTHACEAE 70.*Phoradendron juniperinum*				9,23							
PINACEAE 71.*Picea pungens*				9							
72.*Pinus edulis*		34	6	1,9,15, 19,20, 22,32, 37						30	
CAPPARACEAE 73.*Polanisia trachysperma*								8,25			
FABACEAE 74.*Prosopis velutina*					7,10 paint	2,7 paint, hair dye					
ROSACEAE 75.*Prunus americana*				7,9,37			16 leather				
76.*Prunus emarginata*				9							
77.*Prunus melanocarpa*				37							
78.*Prunus persica* (introduced)				9							
79.*Prunus virginiana*				20							
UMBELLIFERAE 80.*Pseudocymopterus montanus*				37							
ASTERACEAE 81.*Psilotrophe tagetina*									23	8,30	7,8,29
MONOTROPACEAE 82.*Pterospora andromedea*				37							
PYROLACEAE 83.*Pyrola chlorantha*				36 paint							
ROSACEAE 84.*Pyrus malus*				9							
FAGACEAE 85.*Quercus gambelii*				20,37							

	Eastern Keres	Hopi	Jemez (Towa)	Navajo	Papago	Pima	Southern Tiwa	Tewa	Western Apache	Western Keres	Zuni
86.*Quercus pungens*				7,36							
ANACARDIACEAE 87.*Rhus aromatica*		5,33		1,7,9,15, 18,19,22 24,27, 31,35,36						7	
POLYGONACEAE 88.*Rumex hymenosepalus*		5,8,34		1,7,9,12, 15,18,19 24,32,37							
SALICACEAE 89.*Salix irrorata*								7,25 body paint			
CHENOPODIACEAE 90.*Salsola kali*				37							
91.*Sacrobatus vermiculatus*				20							
ASTERACEAE 92.*Senecio douglasii*				24							
MALVACEAE 93.*Sphaeralcea angustifolia*								7 body paint			
CRUCIFERAE 94.*Stanleyella wrightii*								7,25			
ASTERACEAE 95.*Tagetes micrantha*				9,37							
96.*Taraxacum officinale*					4 paint						
97.*Tetradymia canescens*				18							
98.*Thelesperma megapotamicum*		5,7,10, 13,14, 34		18,32, 37							
99.*Thelesperma subnudum*		5,34		9							
TYPHACEAE 100.*Typha angustifolia*						7					
101.*Ustilago zeae* (fungus)		34 body paint									
ERICACEAE 102.*Vaccinium humifusum*				9							

	Eastern Keres	Hopi	Jemez (Towa)	Navajo	Papago	Pima	Southern Tiwa	Tewa	Western Apache	Western Keres	Zuni
AMPELIDACEAE 103. *Vitis arizonica*			6 body paint								
ASTERACEAE 104. *Xanthium commune*										30 body paint	
105. *Xanthoparmelia conspersa* (lichen)				18,32							
LILIACEAE 106. *Yucca glauca*				18,32							
GRAMINEAE 107. *Zea mays* (cultivated)		5,34									
ASTERACEAE 108. *Zinnia grandiflora*										30	

* References of specific citations of each plant used among different tribes. See literature cited for full citation.

1. Amsden 1949
2. Bell and Castetter 1937
3. Carter 1945
4. Castetter and Underhill 1953
5. Colton 1965
6. Cook 1930
7. Dennis 1939
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11. Ford 1968
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21. Palmer 1878
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23. Reagan 1929
24. Reichard 1936
25. Robbins, Harrington and Freire-Marreco 1916
26. Russel 1908
27. Sauer 1950
28. Standley 1911
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30. Swank 1932
31. Vestal 1940
32. Vestal 1952
33. White 1945
34. Whiting 1939
35. Winter 1974
36. Wyman and Harris 1951
37. Young 1940

	Zuni	W. Keres	W. Apache	Tewa	S. Tiwa	Pima	Papago	Navajo	Jemez	Hopi	E. Keres	Primitive
1								1				
2								1				
3										1		
4	1	1	1	1	1			1	1			
5	1									1		
6	1									1		
7								1				
8							1					
9				1				1		1		
10								1				
11	1							1				
12	1							1				
13				1					1	1		
14								1				
15								1		1		
16	1		1					1				
17										1		
18		1										
19								1				
20										1		
21		1			1			1	1		1	
22								1				
23	1	1	1	1				1				
24										1		
25								1				
26	1			1	1			1			1	
27	1		1									
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106								1				
107										1		
108		1										

APPENDIX 2.—Data matrix for cladistic analysis. Characters are represented by individual plant species as numbered in Appendix 1. A blank cell denotes plant not used by tribe, a "1" denotes plant used.