The Big Sandy problem: Projectile morphometrics and cultural transmission at the end of the Younger Dryas in the mid-south

By

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Hafted bifaces known as ‘Big Sandys’ are side-notched lithic tools that are present in Early and Late Archaic contexts, limiting their utility as temporally diagnostic artifacts. I used Cultural Transmission theory to derive an initial expectation that there should be discernable variation due to the incongruous presence of Big Sandys throughout the Archaic and the millennia of time separating the production of these artifacts. I used Geometric Morphometrics to detect potential differences between the haft elements of Early and Late Archaic side-notched points. Statistical analysis of the morphometric data revealed there are differences in the morphology of the haft element between Early and Late Archaic varieties. However, larger sample sizes are necessary to reliably classify a Big Sandy biface from unknown context as belonging to either the Early or Late varieties using morphometrics.
DEDICATION

To my friends and family, I want to express my gratitude for your continuous support.
ACKNOWLEDGEMENTS

This thesis was made possible by the contributions of many people. My first mentor in archaeology, Dr. Andrew Agha, showed me that a career in archaeology was possible, and for that I am extremely grateful.

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CHAPTER I

INTRODUCTION

Side-notched bifaces, regionally identified in the Mid-South as ‘Big Sandys,’ are characterized by a triangular body, excurvate side edges, an incurvate basal edge, and narrow notches that are perpendicular to the long axis of the point (Kneberg 1956). However, there is a glaring problem with using this projectile point type as a temporally diagnostic artifact (Figure 1.1): at the Hester site in Mississippi (Brookes 1979) and Dust Cave in Northern Alabama (Sherwood et al. 2004; Thulman 2017) the side-notched tradition is associated with Late Paleoindian/Early-Archaic contexts that date to the end of the Younger Dryas (12,850-11,900 cal yr BP; Anderson and Sassaman 2012:5), whereas at the Eva site in Tennessee, the side-notched tradition is associated with a Late Archaic context (7422-6679 cal yr BP; Bissett 2014:239, Bissett 2016:90).

Using cultural transmission theory (Boyd and Richerson 2006; Cavalli-Sforza and Feldman 1981) and an analysis using geometric morphometrics (Shott and Trail 2010; Zelditch et al. 2012), this thesis will test whether or not the points from the side-notched horizons of these sites can be separated into early and late traditions. The outcome of this analysis shows that morphometrics is a viable methodology for separating the Early and Late Archaic Big Sandys. Cultural Transmission Theory provides the expectation that there will be separable differences due to loss of learning networks, and morphometrics provides the means of discerning the minute amount of variation which separates the early from late forms.
With this goal in mind, refining the Big Sandy point type is especially important because the early tradition of this point type appears at the end of the Younger Dryas during a period of rapid warming (Randall 2002; Sherwood et al. 2004), and the latter tradition coincides with some of the earliest evidence for regional trade networks and intergroup violence in the Mid-South (Anderson et al. 2007; Bissett 2014; Miller 2014). Being able to accurately separate early and late side-notched forms will allow archaeologists to use them as temporally diagnostic artifacts from a larger number of sites that do not have radiocarbon dates.

![Figure 1.1](image)

**Figure 1.1** Calibrated radiocarbon dates from side-notched horizons at Dust Cave, Hester, and Eva. Circles represent the mean ages.

**Hypotheses**

The null hypothesis for this study is that there are no statistically significant differences in the shapes of side-notched points, and therefore, a morphometric analysis cannot distinguish Early Archaic side-notched points from Late Archaic side-notched points. For this hypothesis to
be supported, statistical analysis would not be able to separate Hester and Dust Cave (Early Archaic) points from points of Eva (Late Archaic), and would likely result in a few statistical clusters that do not conform to their respective sites/time period. Alternatively, there may be statistically different clusters, but they do not correspond to differences between Early and Late forms of side-notched points. Finally, a third outcome would be that there are statistically significant differences between Early Archaic and Late Archaic side-notched points. This would allow archaeologists using a morphometric approach to classify this tool type definitively as a temporally diagnostic artifact. For this alternative hypothesis to be supported, the point clusters for Hester and Dust Cave would be statistically discrete from the point clusters at Eva.

**Research Background**

As an artifact class, the Big Sandy point has limited utility as a temporally diagnostic artifact in part because of its appearance in both the Early and Late Holocene. Additionally this point type has become a “default category” for side-notched points in the Mid-South with inclusions of points into the type that do not match the original definition set forth by Madeline Kneberg (1956) to describe “specimens from the Big Sandy site in Henry County, Tennessee” (O’Brien and Lyman 2000:217).

Combined, these factors have led archaeologists to the point where a reassessment of the utility of the Big Sandy point type is needed. Kneberg’s (1956) original description of the Big Sandy form as having a triangular body, excursive side edges, an incurvate basal edge, and narrow notches was simple and general. Over time, additional features such as “full haft grinding” became qualifiers for the Big Sandy point type, with the caveat that “specimens lacking grinding are not atypical” (Justice 1987:61). Specifically, ground versus non-ground basal edges and notches became the attribute which originally diversified this point type to create
Big Sandy I and Big Sandy II varieties (Cambron and Hulse 1964:15; Justice 1987:61). The importance of this distinction for this study is that the latter, unground Big Sandy II variety was found with the Three Mile component at the Eva site (Kneberg 1959).

More recent type descriptions have included additional attributes but still describe the same broad spectrum of points. For example, when describing the basal features of the Big Sandy, Justice (1987:61) notes that “basal ears are usually squared but may be slightly rounded,” and “the basal edge of Big Sandy varies from nearly straight to deeply concave.” In an attempt to be more specific about defining what characterizes the Big Sandy form, the definition has actually become more inclusive and vaguer, resulting in a wider variety of points fitting the Big Sandy type description.

Cambron and Hulse (1964) attempted to address the variation of the Big Sandy point type by creating three sub-types, which include “wide base, contracted base, and auriculate base.” Regional handbooks for identifying projectile point types use attributes to define what constitutes a particular point type based on its morphological and metric values. This practice continues to be used in analysis of projectile points, includes basic measurements of length, width, thickness and ratios of these values; but recently has included more type specific attributes such as “notch type” and “auricle type” (Randall 2002:69) or “between notch width” and “auricle height” (Bridgeman Sweeney 2013:99).

Randall (2002) tested to see if there was any pattern in the spatial distribution of the Big Sandy sub-types defined by the Cambron and Hulse typology based on the three sites he was analyzing; Dust Cave, Stanfield-Worley, and 1FR311. Time was removed as a variable from his analysis of basal variation in order to ascertain a spatial extent of the Big Sandy varieties. What Randall found was that the modal type, defined by Cambron and Hulse as ‘Big Sandy’, occurs at
the highest frequency in all of his study sites, with almost no ‘Big Sandy Auriculate’ points present in his dataset. The only site with an auriculate variant of the Big Sandy was Dust Cave. His interpretation of this finding was that the auriculate variant might be time dependent, such that it only occurs “in earlier or later context” (Randall 2002:96).

Bridgeman Sweeney (2013) examined the spatial relationship of side-notched points on a much larger scale, examining point collections from seven separate river drainages throughout the Coastal Plain in the Southeast. While Randall used base types for his analysis, Sweeney compared single attributes across the geographic region. What she found was that certain basal attributes such as “between notch width” are highly concentrated within drainages and vary considerably throughout the region, suggesting that there are spatially separable technological traditions that can be detected using qualitative data and statistical analysis (Bridgeman Sweeney 2013:180).

Despite the attempt to be unbiased, most traditional quantitative methods using calipers still contain a degree of error that can significantly skew the representation of an artifact (Grosman et al. 2008). However, applying a more exact form of measurement which minimizes user input and accurately captures the variation that is present in side-notched points is not enough address the Big Sandy problem. Since there is a discontinuity in the temporal sequence of Big Sandy points, with a disappearance of the form for several thousand years that has yet to be addressed (Bissett 2016; Thulman 2017; Table 1), this thesis aims at creating a problem-oriented classification scheme to separate the early and late Big Sandy forms. The previous studies are encouraging for this thesis because their findings demonstrate that there are attributes which are separable across time and space. If it is possible to distinguish changes that occurred
after the initial disappearance of the form, side-notched points found in the Mid-South can be effective as temporally diagnostic artifacts.

**Environmental Background**

At the end of the Pleistocene, the rapid cooling event known as the Younger Dryas represents the geologic transition into the warmer and wetter Holocene (Russell et al. 2009). Meltzer and Holliday (2010) and Meltzer and Bar-Yosef (2012) argued that is likely that there was a considerable amount of regional variation in the degree to which this climatic event was felt, and it is unlikely that the temperature drop during the Younger Dryas was so sudden or extreme that it affected the behavior of populations moving into North America in a way that was significantly different from their response to general seasonality. However, the effects of climate change are not limited to cooler temperatures. Late Pleistocene boreal forests continued to move north and were replaced by a combination of “mixed coniferous/broadleaf deciduous” species that are not present in the mid-to-late Holocene forests (Delcourt and Delcourt 1985) while at the onset of the Younger Dryas megafauna went extinct (Grayson 1987). These environmental factors precede the earliest context for side-notched points around 11,000 calBP during the Early Holocene (Table 1), which coincides with the end of the Younger Dryas during the warming inter-glacial period in the Southeast.

During the transition from the Early to Mid-Holocene, there was an increase in temperature and greater seasonal variation (Russell et al. 2009, Viau et al. 2006). One of the most important impacts of the environmental changes that occurred during the Mid-Holocene was the expansion of pine forest, which began to replace oak and hickory forest around 8000 cal yr BP (Anderson et al. 2007). The effect of this shift was a decrease in accessibility to mast producing trees, which effectively changed the food resources that were exploited by humans at
that time. However, in the Mid-South, pollen from oak and hickory trees is significantly more abundant during the Mid-Holocene (Delcourt and Delcourt 1985), leading Gardner (1997) to argue that this shift may have provided an optimal environment for white-tailed deer. Support for Gardener’s hypothesis is reflected by a higher frequency of deer in Mid-Holocene archaeological assemblages relative to assemblages that date to the Early Holocene (e.g., Styles and Klippel 1996). Additionally, there is evidence that intensive exploitation of plant resources also occurred in the Southeast during the Early and Mid-Holocene (Hollenbach 2009; Hollenbach and Walker 2010), with signs of morphological changes indicative of domestication by the Late Archaic for local plant species such as “sunflower, sumpweed, goosefoot, maygrass, knotweed, little barley, and local cucurbits or gourds” (Anderson et al. 2007:463). These environmental changes, expressed in the paleobotanical and zooarchaeological data, coincide with the latter tradition of side-notched points in the Mid-South.

**Study Sample**

Three sites, Eva, Hester and Dust Cave, were chosen for this analysis, because each has Big Sandy side-notched points from reliable context with associated radiocarbon dates (Bissett 2014:239, 2016:90; Strawn 2019:41; Thulman 2017a:170). Importantly, the three sites used here represent the temporal span associated with Big Sandys: Dust Cave and Hester represent Early Holocene occupation with side-notched points, whereas at Eva, side-notched points are associated with the Late Archaic Big Sandy horizon.
Table 1.2  Metadata for calibrated radiocarbon dates associated with early and late side-notched traditions.

<table>
<thead>
<tr>
<th>Oxcal Reference</th>
<th>Uncalibrated Mean and Sample Error</th>
<th>calBP µ</th>
<th>Sample Material</th>
<th>Sample Number</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eva</td>
<td>5865±63</td>
<td>6,679</td>
<td>ANTLER</td>
<td>AA90404</td>
<td>Bisset 2014:239, 2016:90</td>
</tr>
<tr>
<td>Eva</td>
<td>6514±66</td>
<td>7,422</td>
<td>ANTLER</td>
<td>AA90405</td>
<td>Bisset 2014:239, 2016:90</td>
</tr>
<tr>
<td>Hester</td>
<td>9589±32</td>
<td>10,931</td>
<td>WOOD</td>
<td>AA111479</td>
<td>Strawn 2019:41</td>
</tr>
<tr>
<td>Dust Cave</td>
<td>9720±70</td>
<td>11,084</td>
<td>ORGANIC SEDIMENT</td>
<td>Beta-81606</td>
<td>Sherwood 2004:539</td>
</tr>
<tr>
<td>Dust Cave</td>
<td>10070±60</td>
<td>11,617</td>
<td>CHARRED MATERIAL</td>
<td>Beta-81602</td>
<td>Sherwood 2004:539</td>
</tr>
</tbody>
</table>

**Eva**

The Eva site is located in Benton County, Tennessee on an ancient riverbank of the Tennessee River. Lewis and Lewis (1961) suggest that the initial occupation of the site began 8,000 years ago and that it was occupied over a period of several thousand years. This site contains five discrete stratigraphic layers, where Stratum II contains the Three Mile component with Big Sandy and “Side Notch Undifferentiated” projectile points. Lewis and Lewis estimated that Stratum II began to accumulate about 6,000 years ago and ended about 4,000 years ago based on a single radiocarbon date from the bottom of Stratum I. Bissett (2016) has since refined the chronology of Stratum II using samples from the top and bottom of the stratum, the deepest yielding a date of 7354-7488 cal years BP and the upper yielding a date of 6598-6760 cal years BP. Lewis and Lewis summarized Stratum II as containing the “greatest number of burials and artifacts” as well as the heaviest shell and ash contents (1961:9). Based on this information, their interpretation was that Stratum II represents the “longest and most intensive occupation of the
site” (Lewis and Lewis 1961:9). The subsistence-related data from Stratum II also are unique in several ways.

Despite Stratum II representing the most intensive occupation of the site, the preceding stratum contained “five times as much bone” (Lewis & Lewis 1961:17). The faunal data also reveal that Stratum II contains the greatest number of non-mammalian specimens such as birds, turtles, and fish. In addition, this stratum also contains the greatest density of mussel shells, suggesting during the Three Mile occupation, there was “a great dependence upon mussels for food” (Lewis & Lewis 1961:17). Another unique aspect of the faunal record at the Eva site is that, despite the differences in frequency and total bone counts between the stratum, Stratum II contains just as many bone awls and needles as any other stratum containing earlier, Eva-component materials. They suggest that bone and antler tool technology associated with leather working activities persisted even though subsistence strategies had shifted towards aquatic resources. This shift in subsistence strategy can be seen in the frequency of bone tool types, as Stratum II contains 10 of the 15 fishhooks found at the Eva site.

Collectively, the changes in diet and mortuary practices during the Three Mile phase at Eva represent a significant change in behavior at that time. The presence of shell middens, the clear reduction in the amount of deer bone, and the increased number of water fowl remains in Stratum II suggest a shift of attention to aquatic species during the occupation. At the same time, the site was being used more intensively as a burial ground (Lewis & Lewis 1961: 107).

**Dust Cave**

Dust Cave, is a cave site in the uplands of the Tennessee River Valley located in Lauderdale County, Alabama. The initial occupation of the cave began 12,000 years ago, and it was occupied for approximately 5,000 years. The early side-notched horizon at this site has an
estimated age of 10,000 to 9,000 B.P. These temporal estimates are based on radiocarbon assays, while the “overall linear pattern of positive correlation of depth with antiquity results from fairly consistent horizontal bedding of deposits” (Driskell 1996:318; see also Sherwood et al. 2004). The protected cave environment has preserved organic remains in the cave. The early side-notched horizon contains the “greatest diversity of food plants” (Gardner 1994:203) and “surprisingly, relatively high frequencies of aquatic and small terrestrial birds and mammals […] and small numbers of deer” (Grover 1994:127; Walker 1998). Additionally, due to the relatively limited amount of bioturbation and other disturbance, Dust Cave contains discretely stratified cultural horizons. For the purposes of this summary it should also be noted that, based on the density and volume of lithic flakes, 40% of the entire site’s lithic debitage is associated with the early side-notched component of the site (Driskell 1996).

**Hester**

Hester, representative of one of the Early Archaic side-notched horizons, is located in Monroe County, Mississippi, in an alluvial floodplain of the Tombigbee River. A preliminary site report (Brookes 1979) gives descriptions of four distinct soil zones. Zone II, containing the Early Archaic occupation, is made up of reddish-brown oxidized sand. This site suffers from a lack of information concerning subsistence, yet is plentiful in information concerning stone artifacts. Brookes also mentions the crux of “the Big Sandy problem” in the Hester report (Brookes 1979), noting that at the Eva site side-notched points are larger, have narrower notches, and are found in levels dating to the Late Holocene. His explanation for the later side-notched horizon at Eva and an earlier side-notched horizon at Hester is that there must be an early and a late side-notched tradition in the Southeast.
CHAPTER II
CULTURAL TRANSMISSION

Archaeologists use CT as a theoretical framework to examine changes in the “cultural composition of a population through time” (Richerson and Boyd 1992:63) and to address some of the elements which create stylistic variability in time. Cavalli-Sforza and Feldman (1981) outline some of the differences between genetic and cultural transmission, pointing out that while cultural information can be shared ‘vertically’—from parent to offspring and from offspring to parent, it can also be shared ‘horizontally’—between peers. They point out that, information can be shared one-on-one, from many-to-one, or from one-to-many, and additionally individuals can choose who they receive information from and they can use it, modify it, or even ignore it.

As information accumulates within an individual over a lifetime, it can be passed on to another individual or a group of individuals, and “because culture is acquired by copying the phenotype, culture allows the inheritance of acquired [or guided] variation” (Richerson and Boyd 1992:64). CT is considered an evolutionary theory because it considers the selective forces that work on guided variations to explain how cultural adaptations occur at a rate that is quicker than biological evolution (Eerkens and Lipo 2007).

However, modes of cultural transmission are not random, and individuals’ choices are not solely determined by environmental cues for maximizing caloric return. For example, guided variation involves unbiased transmission and environmental cues to assess alternative choices. There are additional non-environmental variables known as transmission biases that affect
individuals. An example of one of these biases is conformist bias, which assumes that people will copy the most common practices or behaviors whether they perceive it as the most advantageous or not. This transmission bias describes how traits and behaviors that are exhibited by a majority of the population will likely become adopted by learners and stay relevant. Likewise, an individual may choose to copy an individual’s behavior that he or she perceives to be successful, or in Darwinian terms, ‘fit.’ However, this “prestige” bias may result in an individual copying behaviors and traits that have nothing to do with successful or adaptive behavior (Boyd and Richerson 2006; Henrich 2001; Richerdson and Boyd 1992). This emphasizes why distinguishing between functional and stylistic traits is crucial for analyzing variability in the archaeological record (Dunnell 1978).

In describing local or regional material culture, stylistic variability provides a “means of explaining the archaeological record in terms of time and contact among populations [and so] style has an inherent link to cultural transmission” (Eerkens and Lipo 2007). Dunnell (1978:199) defined style as “forms that do not have detectable selective values,” indicating that stylistic traits are neutral traits. The other half of this dichotomy considers functional traits as those “forms that directly affect the Darwinian fitness of the populations in which they occur” (Dunnell 1978:199), indicating that these are the traits upon which selective forces work.

For these purposes, it may be useful to think of style as a neutral trait within a range of equivalent traits “where variability represents equal cost alternatives” (Eerkens and Lipo 2007). For example, if there is no performance difference between hafting a projectile point with basal or side notching, and they both require the same amount of time and energy during the flintknapping process, we can say that both of these styles are equal cost alternatives. However, for archaeologists, this assumes that we know exactly how these artifacts were made, used, and
what they were used for. We must also consider that certain traits may be packaged together, and spread through a process of hitchhiking, where stylistic traits may be transmitted along with functional ones (O’Brien and Lyman 2003).

As an example, in the transition from hunting megafauna to smaller game in North America, projectile points may have gotten smaller because the decreasing size of these points may have had a functional advantage over larger ones (Buchanan et al. 2011). However, if a master flintknapper is side-notching projectile points and teaching others how to flintknap and hunt, the people learning may equate this style of notching with successful hunting practices even if an equal-cost alternative would have been equally as successful. In this example, the conformist bias may account for the prevalence of side-notched points within this group, even though successful hunting forays may be the result of environmental fluctuations, group strategies, etc. From this example, it becomes clear that information can be packaged with multiple behaviors and technologies, which can be a source of variability of the archaeological record.

**Geometric Morphometrics, Projectile Points and Cultural Transmission Theory**

Metric and morphological attributes have often been used to create artifact classes and paradigmatic classifications (Lyman and O’Brien 2002). These classification schemes have recently been used in conjunction with geometric morphometrics (O’Brien et al. 2016; Thulman 2012). One advantage of using geometric morphometrics (GM) for analyzing projectile points is that it captures “fine elements of blade and basal concavity curvatures that could potentially contribute to the description of overall tool shape” in ways that traditional methods of morphological analysis could not (Smith et al. 2015:164). In addition to more accurately
capturing the irregular shape of lithic artifacts, using GM also allows the user to create a
“reliable, reproducible, and standardized method for lithic analysis” (Grosman et al. 2008:3109).

Applications of GM have ranged from 2-D scans of complete Clovis points from Florida
(Thulman 2012) to 3-D scans of lithic debitage from Upper Paleolithic sites in Syria (Bretzke
and Conrad 2012). These scans can be presented visually to analyze a variety of complex
attributes, from flake platform area (Clarkson and Hiscock 2011) to the surface area of cortical
surfaces (Lin et al. 2010). Oftentimes, analysts using GM will utilize landmarks (Bookstein
1991) to designate points for measurement and illustrate variation of these landmarks within
their dataset using “thin plate splines” (Shott and Trail 2010:212) or landmark “superposition”
(Eren et al. 2015:163). One commonality of research designs using GM is that they are always
used in conjunction with various forms of statistical analyses.

Combining geometric morphometrics and cultural transmission theory has the potential to
be able to determine expected ranges of variation and identify sources of variation which
coincide with discrete/integrated learning networks that have resulted in an array of projectile
point forms. Smith et al. (2015) used GM to produce an expected range of variation for Clovis
points from well-dated Clovis sites across North America. They then compared these data with
sites which contained Clovis-like points, and grouped these sites into several sub-regions. Their
results showed that the ‘Far Northeastern Subgroup’ was an outlier whose Clovis-like points had
shapes statistically outside of the range of expected variation. Eren et al. (2015) achieved a
similar result on a smaller scale, revealing statistically significant differences among Clovis
points near three different stone outcrops in modern-day Indiana, Ohio, and Kentucky using GM.
Their regional study was also able to offer a testable explanation for the variation in their dataset
using cultural transmission theory.
Eren et al. (2015:160) argue that there are several principal processes that have been proposed as the source for regional variation, which include resource availability, copying error, and groups adapting their hunting equipment to the characteristics of prey and local habitat. These possible explanations are not mutually exclusive, and in fact, make more sense if one thinks of them as being intertwined. As distance increases between groups, contact diminishes and the likelihood of cultural drift increases; likewise, as distances increase between groups, there is also a greater likelihood that environmental differences are encountered which may select for different tool forms. One the other hand, Eren et al. (2015) argue that locations such as chert outcrops provide context for interaction between groups that could lead to “biased-learning strategies” and therefore account for the general uniformity of some regional assemblages (Eren et al. 2015:160). Based on their findings, stone outcrops provided more than a raw material, but also were hubs for learning and creating the tools that could account for the relatively standard forms which create all point ‘types.’ In other words, uniformity of assemblages could be the reflection of individuals copying others (with error) instead of the time consuming and potentially inefficient process of individual learning or experimentation.

An experiment by Schillinger et al. (2014) compares the rate of shape copy error between reductive and additive practices and offers an explanation for why cultural drift is likely a predominant factor when trying to explain variation in a collection of similar projectile points. Not surprisingly, this experiment showed significantly greater levels of shape-copying error for processes that are reductive and irreversible. It makes sense that a reductive process such as flintknapping will lead to more copying errors than, say, ceramic vessel production where wet clay can be re-worked and new clay can be added. In addition to the research of Eren et al.
(2015), this experiment supplements a convincing argument for copy error being a major cause for variation in projectile points within an assemblage or geographic region.

Returning to the Big Sandy problem and the potential sources of variation that may distinguish early and late traditions of making side-notched points, two main reasons become apparent. First, if more intragroup interaction centered on raw material outcrops led to less intergroup interaction over time, and accepting that reductive processes tend to inherently create drift in form, then a highly sensitive form of measurement such as GM could be able to consistently detect the unique learning networks of people making Big Sandy points during the Early and Late Archaic periods (e.g. Thulman 2012). Second, during the 3,500 years which separate the early and late side-notched traditions, there were major environmental changes which affected diet breadth (e.g., Styles and Klippel 1996). From the Early to Middle Holocene deer became the primary focus of faunal exploitation (e.g., Garner 1997, Styles and Klippel 1996), for example. The new environment also becomes a selective force which affects projectile point form which could be detectable with GM
CHAPTER III
METHODS

In order to determine if geometric morphometrics can resolve the “Big Sandy Problem,” I examined bifaces from the Dust Cave (n=39), Eva (n=17), and Hester sites (n=8). Given the breadth of time that elapsed between the Early Archaic side-notched occupations at Dust Cave and Hester and the Later Archaic occupation at Eva, I expected that there were also distinct learning networks around these sites which would create separable variation. Due to the substantial difference in time (approximately 3,500 years), variation in the artifacts’ forms caused by drift should be detectable using morphometrics. My research incorporated a landmark-based approach to morphometric analysis, specifically on the half elements of Big Sandy points (Lipo et al. 2015; Thulman 2012; White 2016). Similar to other studies (Bissett 2003; Randall 2002; Bridgman Sweeney 2013; Thulman 2012; White 2016), my research limited the scope of landmark placement to the bases of these projectile points because the base can be representative of a blueprint, mental template, or ideal form that is diffused through various forms of cultural transmission. This mental template is preserved in the base since it is within the hafting element and unlikely to be subjected to re-sharpening. Another reason I chose to only analyze bases is to avoid detecting change that may occur throughout the tool’s use life from reduction practices, which eventually could create a side-notched scraper (Keeley 1982). A third reason to only analyze point bases is because doing so potentially increases the sample size by including broken points or proximal halves.
Next Engine 3D Laser Scanner

To obtain a 3-D scan of the points, I used the NextEngine portable laser scanner in conjunction with the proprietary “ScanStudio” software. I selected six scan intervals with the highest possible number of points per square inch, in monochrome which took about an hour and a half per scan. This scanner also offers a range of settings which I tested to effectively capture the complex and irregular shape of chipped stone tools. I used these settings as a compromise between scan time and high resolution.

One of the notable features of this device is its portability and ease of use. This hardware allowed for a reliable and replicable scanning process after traveling to different curation facilities to obtain scans. Notably, the NextEngine includes an AutoPositioner which held the object steady during the scanning process, and automatically rotated the object based on the pre-programed number of scanning intervals. The Next Engine user-guide suggests that modeling clay can be used in addition to the gripper arm, however, modeling clay was intentionally avoided as a medium for holding the projectile point in place due to the fact that it may mask certain important attributes such as basal concavity during the scan, and, the owners of the collection may not want the projectile point to be in contact with a foreign substance and be contaminated for future analysis. I was able to avoid a stabilizing medium altogether, relying on the tension of the gripper arm to hold the Big Sandy onto the rotating base.

Another benefit of using the NextEngine Scanner is the associated editing software ScanStudio. This software’s functions are trimming, aligning, and fusing to create a finished model which is ready for analysis. The ‘mesh’ viewing function ensures that only the rubber-tipped gripper arm and rotating base plate were trimmed. For some models the automated
alignment was significantly inaccurate, essentially ‘butterflying’ the model where the digital model would look as though it was turned inside-out (Figure 4.1).

![Figure 3.1 NextEngine auto-alignment error, before recalibration.](image)

I rectified this issue by using the ‘recalibrate alignment’ feature. Experimentation with manual and automatic alignment resulted in negligible difference for the final model, so the automatic feature was used to reduce the time spent post-processing. In an effort to maintain the visibility of flake scars and other details, I used texture blending at its lowest possible setting when fusing the scans. Overall, the major benefit of using the NextEngine scanner is that the majority of the scanning, aligning, and fusing actions can be automated.

I compared each model to a picture, automatically taken by the Next Engine scanner before each scan interval, to ensure that the model was an adequate representation of the actual artifact and that no features were misrepresented or missing. Once I deemed the model to be
adequate, I exported it from NextEngine as a binary .ply file to be used in Landmark for the next step of analysis.

**Landmark**

Landmark is software created by the University of California-Davis (Wiley et al. 2007). While the software interface is intuitive and easy to use, updates and troubleshooting for the program are no longer supported. The major benefit of using this program is that landmarks can placed in a way that is easily replicable, and the data can be converted to a file type which is accepted by MorphoJ, a popular statistical software for geometric morphometrics which was used for this analysis. I placed a total of 11 landmarks were placed on each specimen (Figure 3.2).

Determining where to put these landmarks was based on being able to replicate the pattern on all of the 3D models. For each of the notches, I placed landmarks where the notch and blade edge intersect, and at the deepest point of the notch. It was more difficult to design a consistent methodology for landmark placement along the basal edge, simply because the landmarks had to embody straight, incurvate, and excurvate bases. To represent this variability accurately, I treated incurvate basal edges the same as notches; with a landmark at the deepest part of the basal edge and where the basal concavity intersects with the basal edge. Excurvate bases were done the same way, except I placed a landmark on the basal edge which was farthest from the distal tip. Lastly, straight bases had landmarks where the basal edge intersects with each auricle, and a third landmark centered between them. These data could easily be used to attain typical metrics associated with lithic studies, such as notch height, neck width, auricle height, maximum width, thickness, width of basal edge, etc.
It is also worth mentioning that the number of landmarks used is equally important as where the landmarks are placed. For instance, if each notch is assigned three landmarks and the basal edge is assigned five landmarks, variation of the basal edge will be oversampled. With this in mind, assigning three landmarks to each notch and basal edge allowed for an even representation of the haft shape. In terms of capturing variation related to thickness, I placed a landmark as close as possible to the halfway point between the notches on either side of the model. In hindsight, this was a mistake which will be addressed in the exploratory data analysis section; in sum, the placement of the thickness-related landmarks was not easily replicable and
were not aligned with one another. The placement of all landmarks is extremely important, so once all specimens received landmarks, each specimen was reloaded and double-checked to insure consistent and accurate placement. Once all landmarks were placed with accuracy, each specimen was related to the atlas to prepare the data for export.

**MorphoJ**

The landmark data was converted to a NTSYS format so that it could be used for statistical analyses in a program called “MorphoJ” (Klingenberg 2011). One of the major benefits of using MorphoJ is that it is easy to use and rewards users who have systematically named all of their samples. This information is retained during import to MorphoJ and can be used to classify information in analysis. Furthermore, if there are inconsistencies in the landmark data, MorphoJ provides features which can rectify some issues after import. Another major reason why MorphoJ was chosen for this analysis is because all of the statistical tests I wanted to conduct were easily available in a single program.

**Statistical Analysis in MorphoJ**

The statistical analysis in MorphoJ began by generating a new Procrustes fit (Klingenberg and McIntyre 1998). The Procrustes analysis eliminates size as a source of variation by scaling and orienting all specimens the same so that detectable variation is only related to differences in shape. The result is a superimposition of all the datasets’ landmarks, clustered around a set of landmarks which represent the average shape in the data (Figure 3.3). This is not to say that size is not an important variable to consider, but in order to fully utilize the morphometric approach, the Procrustes coordinates used here will only consider variation in shape that is generated by the landmarks.
A new Procrustes Fit has to be generated first, since MorphoJ generates covariance matrices from datasets of shape data after Procrustes superimposition. These covariance matrices are the building blocks for all statistical tests that follow. Principal Component Analysis (PCA) was run on the covariance matrices in order to reduce the number of variables so that broad patterns of shape variation can be seen within a dataset, and between datasets (Pavlicev et al. 2009). For this study, PCA was specifically used as an exploratory analysis to identify how much variation was present within the sample of points from each site, and to understand how the mean shape from each group of Big Sandys compares with the others.

A Discriminate Function Analysis (DFA) was conducted after the PCA in order to find separable differences between two groups of observations (Lachenbruch 1967). These groups are known a priori, and the DFA only works on two groups at a time. In this case, the ‘groups’
corresponded to the sample of side-notched points from each of the three sites. To assess the reliability of the DFA at assigning group membership, cross validation results indicate what percentage of observations were correctly assigned to their respective group. While there is no ‘line-in-the-sand’ for what constitutes a good cross-validation score, if 80% of the Big Sandys could be assigned to their respective site I deemed it a result which would reject the null hypothesis (David Thulman, personal communication 2019).

Finally, a Canonical Variate Analysis (CVA) was used in order to visualize differences in shape features which separate groups in the sample (Klingenberg and Monterio 2005). These groups are also known a priori, and correspond to the sample of Big Sandys from each of the three sites. The differences in shape features can be seen in two separate graphical outputs known as lollipop graphs. These graphs can be easily interpreted to see the degree and direction of variation associated with canonical variates 1 and 2. After carefully observing the variation seen in the lollipop graphs, the shape-related trends which were observed can be related to the CVA scatterplot. To determine how the variations in shape relate to the overall sample, the CVA scatterplot shows how CV1 and CV2 relate to Big Sandys from all three sites. There is not a nominal result which can be a ‘line-in-the-sand’ for assessing the CVA results. The only metric that can be used to discuss ‘relatedness’ between the three groups are the Mahalanobis distances. To do this, Mahalanobis distances simply indicate an average distance to each Procrustes coordinate from the centroid of the entire point cloud.

**Landmark Configurations**

As a part of an exploratory data analysis, various configurations of landmarks were also tested using the same statistical methods. These alternative landmark configurations were titled ‘subsets’ of the combined dataset “e/h/dc.” This analysis was conducted in order to examine the
properties of different landmark configurations, yet these subsets maintain the same qualities of the original landmark placement in that the basal concavity and notches are equally represented. However, since capturing the curvature of notches is believed to be a “very important variable when trying to characterize the shape of the haft element” (Goodale et al. 2015), I wanted to create several ways of testing the notches and basal edge in order to explore different ways of testing variability in the haft elements. The different landmark configurations can be seen in Figures 3.2-3.9, where landmarks are indicated by solid blue circles and hollow blue circles indicate landmarks which were excluded from that subset.

Table 3.2 Landmark subsets; see Figures 3.4-3.9

<table>
<thead>
<tr>
<th>Subset #</th>
<th>Rationale</th>
<th>Landmarks Excluded</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>to reduce the number of landmarks and evenly distribute those landmarks across the basal edge and notches</td>
<td>12, 14, 15, 16, 17, 19, 20, 22, 23, 24, 25, 27, 28, 30, 31, 32, 33, 35</td>
</tr>
<tr>
<td>2</td>
<td>the vertex of each notch and basal concavity is emphasized</td>
<td>12, 13, 15, 16, 18, 19, 20, 21, 23, 24, 26, 27, 28, 29, 31, 32, 34, 35</td>
</tr>
<tr>
<td>3</td>
<td>placed greater emphasis on the ‘exits’ of each notch and basal concavities</td>
<td>13, 14, 15, 16, 17, 18, 21, 22, 23, 24, 25, 26, 29, 30, 31, 31, 33, 34</td>
</tr>
<tr>
<td>4</td>
<td>to absolutely minimize the number of landmarks [also the layout of the original landmark placement]</td>
<td>12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35</td>
</tr>
<tr>
<td>5</td>
<td>to remove thickness as a variable for the raw data</td>
<td>10,11</td>
</tr>
<tr>
<td>6</td>
<td>testing thickness using one versus two landmarks</td>
<td>11</td>
</tr>
<tr>
<td>Raw</td>
<td>semi-landmarks were generated based on initial landmark placement--see subset 4</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Figure 3.4  Subset 1 Landmark Placement; semi-landmark reduction with even distribution

Figure 3.5  Subset 2 Landmark Placement; semi-landmark reduction with vertexes emphasized
Figure 3.6  Subset 3 Landmark Placement; semi-landmark reduction with notch ‘exits’ emphasized

Figure 3.7  Subset 4 Landmark Placement; all semi-landmarks omitted
Figure 3.8  Subset 5 Landmark Placement; both thickness-related landmarks omitted

Figure 3.9  Subset 6 Landmark Placement; single thickness-related landmark omitted
**Sampling Solution with Artificial Data?**

Sample size was a major concern for this project. Since there are differences in sample size between the three sites, it is possible that the probabilities of correctly assigning observations to their respective groups are different between the three sites. For instance, the probability that the Dust Cave points will be correctly assigned is greater than the probability of the Hester points, by virtue of the fact that there are simply more Dust Cave points in my combined sample. To account for this discrepancy, in an excel spreadsheet provided by Dr. David Thulman, Cohen’s Kappa (McHugh 2012) values were calculated for the raw statistically significant discriminate functions to see how well the test fairs compared to random chance. Since the percentage of observations which were correctly assigned for the two statistically significant raw discriminate functions were the same (74% & 52%), the Cohen’s Kappa score was also the same at .26; which essentially means that these tests do 26% better than random chance would at assigning points to their respective sites.

Since the number of specimens for the Dust Cave sample outnumbered the sample size of Eva and Hester, the effect of this imbalance was tested by artificially creating specimens for the latter sites. In Excel, the specimens from Eva and Hester have x, y, z coordinates listed for every landmark on each projectile point, in the order in which they appear. The x, y, and z coordinates were shortened to the first two decimal places, then the shortened coordinate was concatenated with a random four-digit number. This formula combined the first two decimal places for the real x, y, and z coordinates and the random number to create a similar yet different specimen (Appendix A). This process was repeated using the concatenated coordinates in order to build up a sample size for Eva and Hester, until these samples were equal to the Dust Cave sample.
CHAPTER IV
RESULTS

Principal Component Analysis

A Principal Component Analysis (PCA) was conducted in order to examine how morphological variation can be related to just a few principal components. In other words, the distribution of principal components indicates how many dimensions account for the most amount of variation in the data. For this analysis, I used PCA to get a preliminary impression of the relationship between the mean shape for each site. To do this, PC1 was plotted against PC2, and confidence ellipses were created for each mean shape (Figure 4.1).

Figure 4.1  Principal Component scatterplot for the combined raw dataset with mean shapes.
PCA plot uses two dimensions which account for most of the variation within the entire raw dataset (Figure 4.1). Principal Components 1 and 2 account for 49.752% of the total variation (Figure 4.2).

| Principal Component Analysis: PCA: CovMatrix, e/h/dc, Symmetric component |
|--------------------------------------------------|------------------|------------------|
| Eigenvalues | % Variance | Cumulative % |
| 1. 0.00776355 | 26.452 | 26.452 |
| 2. 0.00534921 | 26.293 | 52.745 |
| 3. 0.00135797 | 13.422 | 66.167 |
| 4. 0.00234799 | 6.907 | 73.074 |
| 5. 0.00219972 | 8.345 | 81.419 |
| 6. 0.00105550 | 4.804 | 86.223 |
| 7. 0.00076597 | 2.995 | 89.219 |
| 8. 0.00062188 | 2.358 | 91.777 |
| 9. 0.00047184 | 1.798 | 93.567 |
| 10. 0.00042082 | 1.596 | 95.164 |
| 11. 0.00034732 | 1.318 | 96.481 |
| 12. 0.00032329 | 0.882 | 95.363 |
| 13. 0.00026621 | 0.782 | 96.146 |
| 14. 0.00019355 | 0.734 | 96.880 |
| 15. 0.00014838 | 0.565 | 97.445 |
| 16. 0.00010849 | 0.412 | 97.856 |
| 17. 0.00010054 | 0.381 | 98.238 |
| 18. 0.00008405 | 0.319 | 98.556 |
| 19. 0.00006641 | 0.246 | 98.802 |
| 20. 0.00005724 | 0.217 | 99.019 |
| 21. 0.00004964 | 0.188 | 99.208 |
| 22. 0.00003379 | 0.128 | 99.336 |
| 23. 0.00002743 | 0.104 | 99.440 |
| 24. 0.00002555 | 0.097 | 99.537 |
| 25. 0.00001853 | 0.078 | 99.609 |
| 26. 0.00001619 | 0.061 | 99.666 |
| 27. 0.00001262 | 0.048 | 99.716 |
| 28. 0.00001233 | 0.047 | 99.763 |
| 29. 0.00000945 | 0.036 | 99.799 |
| 30. 0.00000757 | 0.029 | 99.828 |
| 31. 0.00000705 | 0.027 | 99.855 |
| 32. 0.00000621 | 0.024 | 99.878 |
| 33. 0.00000570 | 0.022 | 99.900 |
| 34. 0.00000446 | 0.017 | 99.917 |
| 35. 0.00000372 | 0.014 | 99.931 |
| 36. 0.00000286 | 0.011 | 99.942 |
| 37. 0.00000248 | 0.009 | 99.951 |
| 38. 0.00000134 | 0.007 | 99.956 |
| 39. 0.00000178 | 0.007 | 99.963 |
| 40. 0.00000164 | 0.006 | 99.971 |
| 41. 0.00000140 | 0.005 | 99.977 |
| 42. 0.00000181 | 0.004 | 99.981 |
| 43. 0.00000190 | 0.004 | 99.984 |
| 44. 0.00000074 | 0.003 | 99.987 |
| 45. 0.00000002 | 0.002 | 99.999 |
| 46. 0.00000008 | 0.002 | 99.999 |
| 47. 0.00000002 | 0.002 | 99.994 |
| 48. 0.00000001 | 0.001 | 99.999 |
| 49. 0.00000005 | 0.001 | 99.999 |
| 50. 0.00000000 | 0.001 | 99.998 |

Figure 4.2   Eigenvalues from PCA of the combined raw dataset.
However, the shape space of this dataset has more than just two dimensions, so they may be separated in other dimensions or some combination of them. With this in mind, the plot suggests that on the axes described by PC1 and PC2, the populations broadly overlap. Since there is a significant overlap in the confidence ellipses, we can see some individuals are not as close to the mean of their own population as they are to the mean of a different population. The effect of differing sample sizes can also be seen in the PCA. The larger the sample size, the more the confidence interval around the mean shape contracts, which is best illustrated by Dust Cave having the smallest confidence ellipse and Hester having such a broad one.

The important takeaway from the PCA is that the mean shape of side-notched points from Eva and Dust Cave minimally overlap, while the small sample size of the Hester population overlaps broadly with the other two populations (Figure 4.1). As a preliminary test, it suggests two important trends. First, the PCA illustrates the problematic nature of the Hester sample size which creates a very broad mean shape. Second, the result shows that if the Hester data were omitted, the mean shape of Early Archaic side-notched population would minimally overlap with the mean shape of the Late Archaic population.

**Discriminate Function Analysis**

Next a Discriminate Function Analysis (DFA) was used to determine whether points can be ‘discriminated’ into two populations and in doing so, statistically separate Early from Late Archaic side notched points. These populations are known a-priori, so even though there are three sites being used, only two populations will be pooled at a time. To assess the reliability of the DFA to differentiate between the two populations, we use cross-validation results. While there is no standard metric for what constitutes a ‘good’ cross-validation result, ‘80%’ correct assignment was a deemed a decent standard (David Thulman, personal communication 2019).
There were three groups of data that were tested using the DFA: 1) the combined raw data, 2) the raw data subsets of different landmark configurations, and 3) the datasets which incorporated artificial data. The results indicate that none of the raw data could be discriminated with statistical significance (Table 4.2). However, there were statistically significant results in the artificial dataset, as well as Subsets 3 and 4. Considering that the DFA using the raw data was not statistically significant, yet the results using artificial data were, implies that an uneven sample size is a limiting factor for this experiment. However, one of the goals for using the DFA on the artificial dataset was to see what the results would be like if sample sizes were the same from all three sites. With statistically significant p-values for all three combinations of sites in the artificial dataset, the results of the DFA suggest that obtaining more data from Hester and Eva is necessary if we aim to properly address the Big Sandy Problem using morphometrics.

Table 4.2 Cross Validation Results for the Raw Data

<table>
<thead>
<tr>
<th>Raw Data</th>
<th>Comparison</th>
<th>Group 1</th>
<th>n</th>
<th>Cross Validation Correct</th>
<th>% Correct</th>
<th>Group 2</th>
<th>n</th>
<th>Cross Validation Correct</th>
<th>% Correct</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Dust Cave/Eva</td>
<td>Dust Cave</td>
<td>39</td>
<td>23</td>
<td>59</td>
<td>Eva</td>
<td></td>
<td>1</td>
<td>10</td>
<td>59</td>
</tr>
<tr>
<td>B</td>
<td>Dust Cave/Hester</td>
<td>Dust Cave</td>
<td>39</td>
<td>29</td>
<td>74</td>
<td>Hester</td>
<td>8</td>
<td>4</td>
<td>50</td>
<td>0.96</td>
</tr>
<tr>
<td>C</td>
<td>Eva/Hester</td>
<td>Eva</td>
<td>17</td>
<td>14</td>
<td>82</td>
<td>Hester</td>
<td>8</td>
<td>5</td>
<td>63</td>
<td>0.92</td>
</tr>
</tbody>
</table>

For the comparison of Eva and Hester using a dataset augmented with artificial data to counteract the effects of differential sample size, there is perfect cross-validation (Table 4.3 C). Since the DFA was able to perfectly discriminate the artificial data to their respective groups (100% for Eva and 100% for Hester), this result suggests that the artificial data are effectively similar to their respective parent data.
Table 4.3  Cross Validation Results for the Artificial Data

<table>
<thead>
<tr>
<th>Artificial Data</th>
<th>Comparison</th>
<th>Group 1</th>
<th>n</th>
<th>Cross Validation Correct</th>
<th>% Correct</th>
<th>Group 2</th>
<th>n</th>
<th>Cross Validation Correct</th>
<th>% Correct</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Dust Cave /Eva Cave</td>
<td>39</td>
<td>20</td>
<td>51</td>
<td>Eva</td>
<td>39</td>
<td>32</td>
<td>89</td>
<td>0.0007</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Dust Cave /Hester Cave</td>
<td>39</td>
<td>23</td>
<td>59</td>
<td>Hester</td>
<td>39</td>
<td>35</td>
<td>90</td>
<td>&lt;.0001</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Eva /Hester</td>
<td>39</td>
<td>39</td>
<td>100</td>
<td>Hester</td>
<td>39</td>
<td>39</td>
<td>100</td>
<td>&lt;.0001</td>
<td></td>
</tr>
</tbody>
</table>

The comparison between the Dust Cave and Eva using artificial data (Table 4.3A) and between Dust Cave and Hester (Table 4.3B) had cross validation scores which did not entirely surpass the 80% mark. While the artificial datasets for Hester and Eva reached the 80% discrimination standard, in both iterations of the DFA, Dust Cave had less than 60% of its side-notched points correctly assigned. These results may suggest that using artificial data to counteract the effect of limited sample size may allow for the cross-validation results that are sensitive enough to discriminate between the samples. However, considering that the Dust Cave sample did not include any artificial data and subsequently had the worst cross-validation results, the statistical significance of these results may be overstated. This result could also be the byproduct of producing samples that are too similar to the original samples, and therefore not capturing the entire range of variation actually present in the real archaeological assemblage. In sum, using artificial data for the DFA may not be reliable for discerning Early from Late Archaic side-notched points.

Looking at the datasets which used a subset of the landmarks which were all included in the raw dataset, the trends are similar with a few notable exceptions. Most of the DFA results for the subset data were not statistically significant (Table 4.4, 4.5, 4.8, 4.9). Though these results
are not statistically significant, they are important for understanding the distinguishing characteristics of Early and Late Archaic side-notched points.

Subsets 5 and 6 (Figure 3.8-3.9) were created in order to understand the variation associated with the thickness of Big Sandys. The results of the DFA for subset 5 shows that when thickness is removed as a variable, the results are poor (Table 4.9 A/B/C), suggesting that the shapes of the haft elements are very similar. Additionally, subset 6 was created in order to test the effectiveness of using two landmarks to capture variation related to thickness. The only difference between subset 6 and the raw data is that subset 6 uses 1 landmark instead of two. When comparing the DFA results for the raw data with subset 6, the results are very similar (Table 4.2, Table 4.9). This implies that using two thickness landmarks did not dramatically affect the results of any other tests.

Subsets 1 and 2 differ from the other subsets in that variation is emphasized near the apex of each notch. The DFA results for these subsets (Table 4.4, Table 4.5) were not significant, suggesting that there is not distinguishable variation associated with the apex of each notch. In considering why variation seems muted in this portion of the haft element, it may be that the shape of the apex of the notches are constrained by the tool being used to create it. For instance, if antler tines are used as notching tools, the apex of the notches may be similar due to the commonality of the tool being used. However, instead of just focusing on one portion of the haft element, these subsets were designed to capture variation along the basal edge, too. The DFA results stem for a combination of all landmarks being used, so attributing the results to only one portion of the haft element is unwise. While not all of the DFA results from these subsets were statistically significant, as a part of exploratory analysis, these subsets provide insights as to which regions of the haft element might be useful for discrimination.
Table 4.4  Cross Validation Results for Subset 1

<table>
<thead>
<tr>
<th>Subset 1</th>
<th>Comparison</th>
<th>Group 1</th>
<th>n</th>
<th>Cross Validation Correct</th>
<th>% Correct</th>
<th>Group 2</th>
<th>n</th>
<th>Cross Validation Correct</th>
<th>% Correct</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Dust Cave</td>
<td>Dust Cave</td>
<td>39</td>
<td>26</td>
<td>67</td>
<td>Eva</td>
<td>17</td>
<td>9</td>
<td>53</td>
<td>0.08</td>
</tr>
<tr>
<td>B</td>
<td>Dust Cave</td>
<td>Dust Cave</td>
<td>39</td>
<td>26</td>
<td>67</td>
<td>Hester</td>
<td>8</td>
<td>4</td>
<td>50</td>
<td>0.15</td>
</tr>
<tr>
<td>C</td>
<td>Eva/Hester</td>
<td>Eva</td>
<td>17</td>
<td>12</td>
<td>71</td>
<td>Hester</td>
<td>8</td>
<td>3</td>
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</tr>
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Table 4.5  Cross Validation Results for Subset 2

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<th>% Correct</th>
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<th>n</th>
<th>Cross Validation Correct</th>
<th>% Correct</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Dust Cave</td>
<td>Dust Cave</td>
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<td>Eva</td>
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<td>7</td>
<td>41</td>
<td>0.12</td>
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<td>B</td>
<td>Dust Cave</td>
<td>Dust Cave</td>
<td>39</td>
<td>32</td>
<td>82</td>
<td>Hester</td>
<td>8</td>
<td>4</td>
<td>50</td>
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<tr>
<td>C</td>
<td>Eva/Hester</td>
<td>Eva</td>
<td>17</td>
<td>12</td>
<td>71</td>
<td>Hester</td>
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Table 4.6  Cross Validation Results for Subset 3

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<th>Group 2</th>
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<th>Cross Validation Correct</th>
<th>% Correct</th>
<th>p</th>
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<td>29</td>
<td>74</td>
<td>Eva</td>
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<td>Dust Cave</td>
<td>Dust Cave</td>
<td>39</td>
<td>28</td>
<td>72</td>
<td>Hester</td>
<td>8</td>
<td>3</td>
<td>38</td>
<td>0.31</td>
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<td>C</td>
<td>Eva/Hester</td>
<td>Eva</td>
<td>17</td>
<td>13</td>
<td>75</td>
<td>Hester</td>
<td>8</td>
<td>3</td>
<td>38</td>
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Table 4.7  Cross Validation Results for Subset 4

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<th>Cross Validation Correct</th>
<th>% Correct</th>
<th>Group 2</th>
<th>n</th>
<th>Cross Validation Correct</th>
<th>% Correct</th>
<th>p</th>
</tr>
</thead>
<tbody>
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<td>A</td>
<td>Dust Cave</td>
<td>Dust Cave</td>
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<td>29</td>
<td>74</td>
<td>Eva</td>
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<td>9</td>
<td>53</td>
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<td>B</td>
<td>Dust Cave</td>
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<td>39</td>
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<td>Hester</td>
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<td>13</td>
<td>0.11</td>
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<tr>
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<td>9</td>
<td>53</td>
<td>Hester</td>
<td>8</td>
<td>4</td>
<td>50</td>
<td>0.19</td>
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36
Table 4.8  Cross Validation Results for Subset 5

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<thead>
<tr>
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<th>Cross Validation Correct</th>
<th>% Correct</th>
<th>Group 2</th>
<th>n</th>
<th>Cross Validation Correct</th>
<th>% Correct</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Dust Cave /Eva Cave</td>
<td>Dust Cave</td>
<td>39</td>
<td>0</td>
<td>0</td>
<td>Eva</td>
<td>17</td>
<td>1</td>
<td>6</td>
<td>0.93</td>
</tr>
<tr>
<td>B Dust Cave /Hester Cave</td>
<td>Dust Cave</td>
<td>39</td>
<td>8</td>
<td>21</td>
<td>Hester</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0.98</td>
</tr>
<tr>
<td>C Eva/Hester Cave</td>
<td>Eva</td>
<td>17</td>
<td>14</td>
<td>82</td>
<td>Hester</td>
<td>8</td>
<td>4</td>
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<td>0.90</td>
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Table 4.9  Cross Validation Results for Subset 6

<table>
<thead>
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<th>Cross Validation Correct</th>
<th>% Correct</th>
<th>Group 2</th>
<th>n</th>
<th>Cross Validation Correct</th>
<th>% Correct</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Dust Cave /Eva Cave</td>
<td>Dust Cave</td>
<td>39</td>
<td>29</td>
<td>74</td>
<td>Eva</td>
<td>17</td>
<td>10</td>
<td>59</td>
<td>0.99</td>
</tr>
<tr>
<td>B Dust Cave /Hester Cave</td>
<td>Dust Cave</td>
<td>39</td>
<td>32</td>
<td>82</td>
<td>Hester</td>
<td>8</td>
<td>3</td>
<td>38</td>
<td>0.99</td>
</tr>
<tr>
<td>C Eva/Hester Cave</td>
<td>Eva</td>
<td>17</td>
<td>14</td>
<td>82</td>
<td>Hester</td>
<td>8</td>
<td>5</td>
<td>63</td>
<td>0.91</td>
</tr>
</tbody>
</table>

However, DFA from the subset data also produced several statistically significant results, which suggests that there are actually differences in the data with different landmark orientations that the raw data, which contains data from all of the recorded landmarks, was not able to capture. For example, Subset 3 emphasizes the area where the notch intersects with the blade edge, and Subset 4 minimizes the number of landmarks by omitting all semi-landmarks. This result is interesting in that both of these subsets emphasize variation found where the blade edges intersect with the notches. Both of these datasets had the same cross validation scores (Tables 4.6, 4.7). Additionally, a common trend between these two datasets is that Dust Cave and Eva were the two sites which could be discriminated with statistical significance. Despite the fact that the cross-validation scores do not reach the 80% benchmark, the result suggests that the variation
that exists within these populations is statistically separable. This indicates distinguishable differences between Early and Late Archaic side-notched points using morphometrics.

**Canonical Variate Analysis**

As an alternative means of expressing the separable variation between Early and Late Archaic side-notched points, the Canonical Variate Analysis (CVA) shows where variation occurs in relation to the average shape of the entire point cloud of all three sites. This is visualized through lollipop graphs which show the direction and degree of variation which can then be related to the scatterplots for inter-site comparison. CVA is different from other tests in that it uses dimensions which maximize differences between group means, instead of intra-site variation.

Since this variation is in relation to the mean shapes derived from the Procrustes coordinates, in each of the scatterplots, the confidence ellipses are centered around the mean shape for each site. These scatterplots indicate where variation occurs for each site’s point cloud, but not necessarily how closely related these point clouds are. In order to get an understanding of relatedness, Mahalanobis distances provided by the Canonical Variate Analysis are used. These metrics indicate an average distance to each Procrustes coordinate from the centroid of the point cloud. For this application, the Mahalanobis Distances are used just to get an initial impression of relatedness. Based on the Mahalanobis Distances for this dataset (Table 4.3), the lowest value is expressed for Hester and Dust Cave, these two Early Archaic sites have the most similar populations. On the other hand, the Mahalanobis Distance for Dust Cave and Eva is not much higher than Dust Cave and Hester.
Table 4.10  Mahalanobis distances from raw CVA results

<table>
<thead>
<tr>
<th>Mahalanobis Distances</th>
<th>Dust Cave</th>
<th>Eva</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eva</td>
<td>13.3543</td>
<td>/</td>
</tr>
<tr>
<td>Hester</td>
<td>13.1082</td>
<td>16.967</td>
</tr>
</tbody>
</table>

To interpret the lollipop graph, I simply look to see the extent and direction of the ‘stem’ from the landmarks. In Figure 4.3, CV1 expresses variation in several directions with the most noticeable variation in CV1 being related to the concavity of the basal edge and the shape of the auricles. In Figure 4.4, CV2 expresses variation that is related to the overall width of the haft element, and in particular, landmarks 1, 3, 4, 6, 7, and 9 which extend outward and away from each other. Additionally, CV2 expresses a direction of variation that can be thought of as the width between notches, which also may be related to the overall width of the haft element.

Figure 4.3  Lollipop Graph, Canonical Variate 1, Raw Data
Figure 4.4  Lollipop Graph, Canonical Variate 2, Raw Data

Figure 4.5  Canonical Variate Analysis, Raw Data
CHAPTER V
DISCUSSION

Cultural transmission theory generated the initial expectation that differences in Big Sandy morphology would be present based on the millennia in which these side-notched bifaces are absent from the archaeological record before re-appearing. This generated expectations for the null hypothesis that there are no statistically significant differences between Early and Late Archaic side-notched points; and alternative hypotheses, that there may be statistically different clusters which do not correspond to their respective site/time period, or that there are statistically significant differences in shape between Early Archaic and Late Archaic side-notched points.

Based on the data presented here, there are statistically significant differences between Early Archaic and Late Archaic side-notched points, which can be differentiated using morphometrics. This is true in so far that the DFA results showed that Big Sandys from Eva and Dust Cave could be discriminated using landmark subsets 3 and 4. I demonstrated that sample size likely contributed to Hester not being discriminated with any iteration of raw data. Looking at the Mahalanobis distances from the CVA results, it is clear that the point cloud from Hester is more closely related to the point cloud from Dust Cave, and dissimilar from the point cloud from Eva. This data gives credence to the interpretation that Big Sandys from Dust Cave and Hester are morphologically more similar than either are to Eva, while points from Dust Cave and Eva may have commonalities in other aspects which are related to raw material.
Specifically, the variation that is expressed in CV1 by landmarks 3, 4, 6, and 7 (Figure 4.3) can be thought of as differences in the shape of the haft element, similar to variation that Cambron and Hulse (1964) describe as rounded versus squared auricles. Additionally, landmarks 3 and 7 of CV1 indicate variation in the direction which is related to the height of the notches. Furthermore, looking at all of the landmarks along the basal edge, it is clear that the width and depth of the basal concavity is also expressed by CV1. This interpretation of CV1 suggests that a key feature which separates the Early and Late Archaic side-notched forms is the shape of the auricles, the height of the notches, and the extent basal concavity. We know this because CV1 is what separates the Early Archaic sites, Dust Cave and Hester (positive loading), from the Late Archaic site, Eva (negative loadings), in Figure 4.5.

As such, the CV 2 axis (Figure 4.4) illustrates variation related to the overall width of the haft element, as the lollipops extend out and away from one another for landmarks 1,3,4,6,7,9. Unlike CV1, variation expressed in CV2 can be thought of as related to differences in raw material, as both the Eva and Dust Cave points come from larger tabular formations and the Hester points come from smaller gravel cherts. In other words, part of the variation that CV2 detected is related and constrained by the toolstone that was being used. While raw material types were not included in this analysis, incorporating this line of data in the future would bolster the interpretation of CV2. Additionally, when looking at the landmarks along the notches, there is obvious variation in the direction associated with a wider versus narrower neck of the haft element. This is likely related to raw material constraints as well.

The CVA findings seem to be commensurate with the variation which previous studies defined as being significant. Considering Randall’s (2002) conclusion that the auriculate varieties Cambron and Hulse outlined correlate to site-specific side-notched traditions, it is not
surprising that the lollipop graphs from the CVA results (Figure 4.3) illustrated variation around auricles. Additionally, the CVA results (Figure 4.4) also align with Bridgeman Sweeney’s (2013) conclusion that between notch width was an effective metric to separate geographically derived trends. Overall, this is an important insight because it suggests that sometimes traditional measurements can detect the essence of significant variation. In sum, it seems as though the variation the CVA detected is meaningful for the purpose of separating Early and Late Archaic side-notched traditions, yet problems with sample size prevented this distinction from being made using PCA and DFA.
CHAPTER VI
CONCLUSION

One conclusion of this study is that the data presented here could not be used to confidently assign a side-notched point to its respective site. The PCA results clearly indicate that some individuals are not as close to the mean of their own population as they are to the mean of a different population in shape space. However, the PCA also revealed that larger samples produced smaller confidence ellipses around its respective mean shape. For Dust Cave and Eva, these confidence ellipses barely overlapped (Figure 4.1), and with a larger sample from Eva, there would likely be no overlap at all. Similarly, if the Hester sample size was larger, the confidence ellipse around its mean shape would be smaller. Knowing if a reduced mean ellipse from the Hester sample overlapped with Dust Cave would indicate if there truly is a distinct Early Archaic variety of Big Sandys. However, the results of the PCA support the alternative hypothesis that while Eva and Dust Cave seem to have discrete means, the confidence ellipse for the Hester sample overlaps the others such that we can say that the cluster seen the PCA results do not conform to their respective time periods.

The DFA results also clearly indicated that unequal sample sizes had an effect on the findings, which required introduction of artificially created data as a solution to overcome this issue. While the artificial data produced statistically significant results, the DFA suggests that the variation that exists within the combined pool may be too great for the DFA to accurately assign an individual to a group. With that in mind, the results of the DFA support the null hypothesis in
that none of the raw data could be significantly discriminated. That being said, using subsets 3 and 4, there seems to be potential for correctly discriminating the hafted bifaces to their respective group. Being able to interpret what counts as a ‘good’ or ‘bad’ cross-validation percentage would be a way of truly assessing the effectiveness of the DFA for separating Early and Late Archaic Big Sandys.

Considering how the results of the CVA dovetail with previous research, the alternative hypothesis can be supported; there are statistically significant differences between the morphologies of Early and Late Archaic Big Sandys that the CVA detected. While this interpretation can be made based on the combination of the CVA scatterplot and lollipop graphs, it is unclear how major or minor those differences are based on the Mahalanobis distances.

Overall, this study revealed that using geometric morphometrics is potentially a productive means for solving the Big Sandy problem. I have demonstrated that despite issues with sample sizes, there is morphological variation associated with Early and Late Archaic side-notched traditions can be separated with this methodology. Hopefully this project can be a foundation for future work, with larger samples.

**Future Directions**

While the NextEngine scanner is portable, the scanning process was very time consuming. In retrospect, my research design could have been achieved using a 2D approach. However, now that I have obtained the 3D data, there is more research potential in the dataset for anyone who is interested in using it in the future. Furthermore, the statistical software which I used is one of several possible options. The statistical tests themselves have variants which are different between software packages. In the future, I would recommend using a statistical package, such as R (Adams et al. 2013), that has the capability to run all of the required tests
without having to move data across statistical packages. Moreover, I would discourage the use of Landmark since it is no longer supported by its developers.

Having unequal sample sizes makes it very difficult to be certain about any result. Being able to include the Big Sandys from Hester which were obtained by Samuel Brooks during his original excavations at Hester would be a beneficial aid to supplement this study. Additionally, it would be great to increase the Eva sample by including more of the points Lewis and Lewis categorized as ‘undifferentiated side-notched’ (Lewis and Lewis 1961:37). While some of these points were included in my study, not all of them were due to time constraints. Including additional points from Eva and Hester would provide a way to determine the effect of small and unequal sample sizes found in this study, as well as an independent means to determine how realistic the artificial data is when compared to actual points from the same assemblage.

Ideally though, this experiment could be recreated with more sites. Specifically, it would be beneficial to include another Late Archaic sample, such as the side notched points from the Big Sandy site (Osborne 1942, Bissett 2014). Using sites where the manufacturing process is more visible (Smallwood 2012) may reveal that variation within the Chaine operatoire is greater than variation in shape space. Pairing the morphometric data with raw material data is another potential avenue for exploring the sources of the variation encountered in this study.

Unquestionably, larger sample sizes are needed in order to bolster results without the aid of artificial data. However, despite the sample size issue in this experiment, I do feel confident that the methodology used to artificially inflate my sample did so without causing drastic deviations from the mean shape of a population in shape space. This is certainly a positive takeaway, which could be used for future morphometric studies.
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Driskell, Boyce  

Dunnell, R.C.  
Eerkens, Jelmer, and Carl Lipo

Eren, Metin I., Briggs Buchanan, and Michael J. O’Brien

Gardner, Paul

Goodale, Nathan, William Andrefsky, Curtis Osterhoudt, Lara Cueni, and Ian Kuijt

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APPENDIX A

CREATING ARTIFICIAL MORPHOMETRIC DATA IN EXCEL
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<th>C</th>
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<td>Rounded Landmark</td>
<td>Random Number</td>
<td>Concatenate</td>
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<td>28.130283</td>
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<td>28.146629</td>
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<td>28.130283</td>
<td>28.14</td>
<td>6629</td>
<td>28.146629</td>
</tr>
</tbody>
</table>

- `=ROUNDUP(A1)`
- `=RANDBETWEEN(999,9999)`
- `=CONCATENATE(B1,C1)`