Lithic Morphological Organisation: Gahagan Bifaces from the Southern Caddo Area

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Abstract

This analysis of Gahagan biface morphology enlists the three largest samples of Gahagan bifaces, to include that of the type site (Gahagan Mound) as well as the Mounds Plantation and George C. Davis sites. Results indicate a significant difference in Gahagan biface morphology at the Mounds Plantation site when compared with Gahagan bifaces from the Gahagan Mound and George C. Davis sites. Tests for allometry and asymmetry were not significant. The test of morphological disparity indicates that Gahagan bifaces produced at the Mounds Plantation site occupy a more restricted range of morphospace than those produced at Gahagan Mound, providing indirect evidence for standardisation and diversity in Caddo biface production. While the sample includes a wide range of morphological variability, the test of morphological integration indicates that Gahagan bifaces are significantly integrated, meaning that those traits used to characterise their shape (blade and base) vary in a coordinated manner. These results articulate with a shift in Caddo bottle morphology over the same geography, potentially indicating two previously unrecognised and morphologically-distinct lithic and ceramic production areas.

Keywords: American Southeast, Caddo, 3D, geometric morphometrics, morphological integration, morphological disparity, virtual archaeology

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1. Gahagan bifaces

Newell & Krieger (1949, 173-174) originally termed the large thin bifaces from tomb contexts at the George C. Davis site to be similar in form, but not technology, to the Copena points discovered in northern Alabama and described by Webb & DeJarnette (1942, 301-306). The chronological placement of Gahagan bifaces is Late Prehistoric with a distribution that includes central, east-central, and east Texas with a limited presence in south Texas and Louisiana (Turner et al., 2011, 230). Previous mortuary occurrences of Gahagan bifaces have been reported from Gahagan Mound (Webb & Dodd, 1939) and Mounds Plantation (Moore, 1912) in northwestern Louisiana (Figure 1). Clarence H. Webb later suggested Gahagan as a typological term to replace Copena at the 1970 Caddo Conference (Shafer, 1973, 229); however, it was not until 2006 that a morphological and technological description was advanced (Shafer, 2006, 22):

Gahagan bases are either slightly concave or straight, and the lateral edges are slightly recurved, contracting slightly below the base and reaching maximum width about mid-length on the less-reduced examples. Lateral edges are finished and retouched by fine pressure flaking. Thinning flakes expand out from the platform and terminate near the middle of the blade rather than carrying across, indicating well-controlled thinning skill. Cross sections are faintly lenticular to almost flat. Retouching reduces the size and curvature of the blade to the extent that the blades may become almost triangular but usually retain the recurved blade form. Bevelling along the lower part of the left edge is a rare, uncharacteristic method of resharpening. The knives may display moderate to extensive use wear in the form of microflake damage or ‘nicking’ and edge abrasion. The overall size depends largely on the degree of retouch.

Researchers initially considered the majority of Gahagan bifaces to be man-

Figure 1: Location of the Gahagan Mound, Mounds Plantation, and George C. Davis sites in the Southern Caddo Area.

unfactured of Edwards chert but subsequent studies of those bifaces from Davis
 30 (Shafer, 2006), Mounds Plantation (Webb & McKinney, 1975) and other loca-
 tions (Banks & Winters, 1975) have documented a surprising diversity of raw
 materials in addition to Edwards. Other raw materials represented include chert
 sources in the Kiamichi Mountains of southeastern Oklahoma, and Woodford,
 Battiest, Big Fork and Ogallala cherts (Banks & Winters, 1975).

35 Given the significance of blade and base shape to the definition of the Ga-
 hagan type, only intact or reconstructed specimens were used in this analysis
 (Table 1). While comparisons and reference to these three assemblages of Ga-
 hagan bifaces occur in the gray literature (Denton, 1983; Gadus et al., 2006;
 McClurkan, 1968; Quigg et al., 2014), these specimens have not previously been
 40 aggregated for a comprehensive morphological analysis. Preliminary observa-
 tions point to significant morphological differences between Gahagan bifaces

recovered from Mounds Plantation and those found at the Gahagan Mound and George C. Davis sites. Given the importance of these bifaces to defining components of Caddo sites that may articulate with Formative or Early Caddo occupations, additional tests for morphological disparity, and morphological integration of the base and blade were used to further expound upon the quiddity of the Gahagan biface type.

Table 1: Sample of Gahagan bifaces included in the study.

Specimen	Trinomial	Context	Site Name	Repository
3Ba90	16CD12	Burial Pit 1	Mounds Plantation	LSEM
3Bb1	16CD12	Burial Pit 2	Mounds Plantation	LSEM
3Bb3	16CD12	Burial Pit 2	Mounds Plantation	LSEM
3Bb4	16CD12	Burial Pit 2	Mounds Plantation	LSEM
3Bb5	16CD12	Burial Pit 2	Mounds Plantation	LSEM
3Bb6	16CD12	Burial Pit 2	Mounds Plantation	LSEM
3Bb7	16CD12	Burial Pit 2	Mounds Plantation	LSEM
3Bb8	16CD12	Burial Pit 5	Mounds Plantation	LSEM
BlkThn	16CD12	Burial Pit 2	Mounds Plantation	LSEM
Case2LG	16CD12	Burial Pit 2	Mounds Plantation	LSEM
Case2SM	16CD12	Burial Pit 5	Mounds Plantation	LSEM
LGGray	16CD12	Burial Pit 8	Mounds Plantation	LSEM
489	16RR1	Burial Pit 2	Gahagan Mound	LSEM
490	16RR1	Burial Pit 2	Gahagan Mound	LSEM
532	16RR1	Burial Pit 2	Gahagan Mound	LSEM
533	16RR1	Burial Pit 2	Gahagan Mound	LSEM
541	16RR1	Burial Pit 2	Gahagan Mound	LSEM
542	16RR1	Burial Pit 2	Gahagan Mound	LSEM
543	16RR1	Burial Pit 2	Gahagan Mound	LSEM
544	16RR1	Burial Pit 2	Gahagan Mound	LSEM
545	16RR1	Burial Pit 2	Gahagan Mound	LSEM
546	16RR1	Burial Pit 2	Gahagan Mound	LSEM
547	16RR1	Burial Pit 2	Gahagan Mound	LSEM
548	16RR1	Burial Pit 2	Gahagan Mound	LSEM
549	16RR1	Burial Pit 2	Gahagan Mound	LSEM
550	16RR1	Burial Pit 2	Gahagan Mound	LSEM

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Table 1 – continued from previous page

Specimen	Trinomial	Context	Site Name	Repository
551	16RR1	Burial Pit 2	Gahagan Mound	WMNSU
569	16RR1	Burial Pit 2	Gahagan Mound	LSEM
593	16RR1	Burial Pit 3	Gahagan Mound	LSEM
605	16RR1	Burial Pit 3	Gahagan Mound	LSEM
606	16RR1	Burial Pit 3	Gahagan Mound	LSEM
607	16RR1	Burial Pit 3	Gahagan Mound	LSEM
608	16RR1	Burial Pit 3	Gahagan Mound	LSEM
609	16RR1	Burial Pit 3	Gahagan Mound	LSEM
610	16RR1	Burial Pit 3	Gahagan Mound	LSEM
611	16RR1	Burial Pit 3	Gahagan Mound	LSEM
612	16RR1	Burial Pit 3	Gahagan Mound	LSEM
613	16RR1	Burial Pit 3	Gahagan Mound	LSEM
614	16RR1	Burial Pit 3	Gahagan Mound	LSEM
622	16RR1	Burial Pit 3	Gahagan Mound	LSEM
666	16RR1	Burial Pit 3	Gahagan Mound	LSEM
ET221-993	41CE19	6L3	George C. Davis	TARL
ET221-1016	41CE19	F3	George C. Davis	TARL
ET221-1260A	41CE19	21R14	George C. Davis	TARL
4078-8	41CE19	F134	George C. Davis	TARL
4078-9	41CE19	F134	George C. Davis	TARL
4078-11	41CE19	F134	George C. Davis	TARL
4078-12	41CE19	F134	George C. Davis	TARL
4078-13	41CE19	F134	George C. Davis	TARL
4078-14	41CE19	F134	George C. Davis	TARL
4078-14B	41CE19	F134	George C. Davis	TARL
4078-22	41CE19	F134	George C. Davis	TARL
4078-30	41CE19	F134	George C. Davis	TARL
4078-32	41CE19	F134	George C. Davis	TARL
4078-45	41CE19	F134	George C. Davis	TARL
4078-72	41CE19	F134	George C. Davis	TARL
424-33	41CE19	F119	George C. Davis	TARL
424-39	41CE19	F119	George C. Davis	TARL
424-40	41CE19	F119	George C. Davis	TARL
424-41	41CE19	F119	George C. Davis	TARL
424-50	41CE19	F119	George C. Davis	TARL

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Table 1 – continued from previous page

Specimen	Trinomial	Context	Site Name	Repository
424-53	41CE19	F119	George C. Davis	TARL
424-133	41CE19	F119	George C. Davis	TARL
424-169	41CE19	F119	George C. Davis	TARL
424-218	41CE19	F119	George C. Davis	TARL
424-221	41CE19	F119	George C. Davis	TARL
424-230	41CE19	F119	George C. Davis	TARL
463-1	41CE19	F119	George C. Davis	TARL
463-16	41CE19	F119	George C. Davis	TARL
463-23	41CE19	F119	George C. Davis	TARL

LSEM, Louisiana State Exhibit Museum; WMNSU, Williamson Museum at Northwestern State University; TARL, Texas Archeological Research Laboratory.

50 2. Geometric morphometric analyses of stone tools

Analyses of lithic shape are neither new or novel, and it is not surprising that geometric morphometrics (GM) (sensu Corti (1993)) has captivated analysts of material culture due to the substantive contribution of morphology to lithic typologies (Fox, 2015; Thulman, 2012; Wilczek et al., 2015). The first application
55 of GM to archaeologically-recovered artefacts was an analysis of irregular shapes by elliptic Fourier analysis (EFA) (Gero & Mazzullo, 1984), and the adoption of the method by the archaeological community has continued.

EFA has been increasingly employed in lithic analyses, where analysts continue are developing novel approaches that advance archaeological applications
60 (Cardillo, 2010; Fox, 2015; Ioviță, 2009, 2010, 2011; Ioviță & McPherron, 2011; Smith et al., 2014; Gingerich et al., 2014; Sholts et al., 2012; Wilczek et al., 2015). Numerous creative research designs have also been presented that address some of the very real challenges associated with the oft-fractured and incomplete specimens abundant in the archaeological record (Byrne et al., 2016;
65 Rezek et al., 2011; Smith, 2010; Smith & DeWitt, 2016). This approach is particularly useful in instances where homologous landmarks cannot be readily

identified; for instance, in cases where both lanceolate and stemmed projectile points are employed in the same analysis.

Landmark-based approaches, like the one applied here, articulate with the
70 rise of the Procrustes paradigm ([Adams et al., 2013](#), 8), which have proven
utility in archaeological application. This includes a 2D study of blade shape
differences in Paleoindian projectile point types where a novel approach to in-
vestigating allometry was applied through the use of median point area and
size grades to compare shape and size distributions, demonstrating that it is
75 possible to discriminate between some types based upon blade shape "independ-
ent of allometry, raw material quality, and resharpening effects" ([Buchanan &
Collard, 2010](#), 357), thus representing a rejection of the reduction thesis ([Shott,
2005](#)). [Charlin & González-José \(2012\)](#) demonstrated that while reduction is
important, it has a greater effect on shape than on size; an observation that
80 is more apparent on blades than on bases, concluding that the two point types
used in their study could be successfully segregated despite reduction. Similarly,
[Thulman \(2012\)](#) analysed three Paleoindian projectile points from Florida and
found that the types used in his study did not represent continuous variation;
rather, they are representative of three discrete groups.

85 Like those studies mentioned above, this analysis enlists a landmark-based
approach aimed at capitalising upon the variability that occurs along a sin-
gle plane (widest biface edge); however, 3D data were required to consistently
identify the widest edge. Procrustes ANOVAs were used to test whether the
intra-type morphology of Gahagan bifaces varies by size and site, a test of mor-
90 phological disparity to determine relative standardisation and diversity in the
sample, and a test of morphological integration to determine whether biface
blade and base shapes covary. Additionally, a variety of landmark and semi-
landmark configurations are in development that will allow for a more robust
analysis of 3D morphology associated with specific elements of Gahagan biface
95 morphology.

3. Methods

Each of the Gahagan bifaces was scanned with a Creaform GoSCAN 20 at a 0.3 mm resolution in VElements. Scanner calibration was optimised prior to each scan with positioning targets required for increased accuracy and shutter speed reconfigured in each instance. A clipping plane was established to reduce the amount of superfluous data collected. Following data collection, the resolution of each mesh was increased to 0.1 mm, and the point cloud was transferred to VXmodel where the mesh was rendered following application of the *clean mesh* function, used to remove isolated patches, self-intersections, spikes, small holes, singular vertices, creased edges, narrow triangles, outcropping triangles, narrow bridges, and non-manifold triangles prior to decimation and export as ASCII stl and ASCII ply. The stl functions as a 3D print-ready backup of the scan data, and the ply file was subsequently imported to Geomagic Design X (Dx).

There is a residue adhering to seven of the Gahagan bifaces from the George C. Davis site (Figure 2) that occurs at variable thicknesses. Shafer (1973, 228) posits that this residue potentially represents the remains of a sheath. While an interesting aside, the residue does pose a problem for an analysis of 3D geometry. The initial research design (3D) was thus revisited, leading to a reconfiguration of the analysis as a 2D geometric morphometric study that enlisted a landmark configuration similar to that used by Buchanan & Collard (2010, Figure 2), Buchanan et al. (2011, Figure 2), and Ragan & Buchanan (2018, Figure 1). The residue does not occur on all of the George C. Davis specimens, and none of the Gahagan bifaces from the Mounds Plantation or Gahagan Mound sites include a similar residue on their surfaces, making it possible to compare a greater range of surface morphology between those samples. While beyond the scope of this present study, that is an avenue of inquiry worth pursuing should differences in Gahagan biface shape be found to differ among the three sites.

Figure 2: Residue adhering to Gahagan bifaces from Feature 134 at the George C. Davis site; a, 4078-8; b, 4078-9; c, 4078-11; d, 4078-13; e, 4078-72; f, 4078-14B; and g, 4078-14.

3.1. Alignment and reference geometry

125 Following transfer to Dx, each mesh was subjected to a second quality check to eliminate non-manifold poly-vertices, folded poly-faces, dangling poly-faces, small clusters, small poly-faces, non-manifold poly-faces, crossing poly-faces, and small tunnels. The principal assumption in constructing the reference geometry is a reference vector. A sampling ratio of 100 percent was used to extract
130 the reference vector, after which a reference point was added by projecting it atop the mesh surface at the location where the reference vector exits the base of the biface. Each element of reference geometry (vector and point) was then used in an interactive 3-2-1 alignment where the biface was aligned to a global origin, then to the extremes of the lateral edges.

135 The widest profile was defined as the location on the mesh that lies furthest from the point at which the reference vector exits the base. To identify that point, a mesh sketch was generated using the planar method—employing the plane located at the base of the biface as the base plane—to sketch a circle around the biface from the top view where the whole of the biface profile was

140 included in the circumference. A 3D surface (cylinder) was extruded around the biface, and the *accuracy analyzer* was used to identify the point on the biface with the lowest deviation from the extruded surface. A plane (MPlane) was then inserted coplanar to the vector and oriented to the widest point, thus bisecting the biface at the location of the widest profile.

145 Using the MPlane as the basis for a third sketch, a spline was populated along the entirety of the silhouetted profile, and split at the location of each landmark (Table 2). Four splits were added that include the tip, juncture of the blade/base (widest profile), centre base, and opposing blade/base. Those landmark locations identified at the two points of highest curvature enlist the
150 *curvature* function in Dx, and do not represent arbitrary locations.

Table 2: Landmarks used in the analysis.

Landmark	Location	Definition
Point01	Tip	Horizontal tangent
Point20	Blade/Base	Point of highest curvature on widest side of biface
Point24	CentreBase	Intersection of vector and external surface of the 3D mesh
Point28	Blade/Base	Point of highest curvature

Two specimens in the George C. Davis sample (4078-8 and 4078-72), both from Feature 134, are missing small sections of their lateral edges (Figure 2a, e). For the purpose of the GM analysis, these two areas were modelled, where the spline was cut behind the area of highest curvature above and below the
155 missing piece, and a line was inserted to connect the lateral edge above and below the missing piece. This ensures that the spline provides a model that is closer to the (assumed) original intent of the maker.

Due to the paucity of homologous landmarks or points of morphological correspondence on stone artefacts (Lycett, 2009, 81), reference geometry was
160 constructed around each specimen in a manner that yields a replicable configuration of three landmarks, and 43 equidistant semilandmarks. Landmarks and semilandmarks were populated along the spline, always beginning on the side of the biface determined to include the widest point. Divisions between each

section articulate with those of the spline splits, where landmarks were placed
 165 at each of the points in Table 2, with a series of equidistant semilandmarks
 between (18 for each blade section, and three between each of the basal land-
 marks; Figure 3). This constellation of landmarks and semilandmarks allows
 for tests of morphological integration between the blade and base as well as a
 test of directional asymmetry (Bookstein, 1991; Klingenberg & McIntyre, 1998;
 170 Klingenberg et al., 2002; Mardia, 2000).

Figure 3: Landmark (blue) and semilandmark (white) placement.

3.2. Analysis

Landmarks and equidistant semilandmarks were exported as x, y, and z co-
 ordinate data from Dx. Those data were aligned to a global coordinate system
 (Kendall, 1981, 1984; Slice, 2001), achieved through generalised Procrustes su-
 175 perimposition (Rohlf & Slice, 1990) performed in R 3.4.4 (R Core Development
 Team., 2017) using the *geomorph* library v.3.0.5 (Adams et al., 2017; Adams &
 Otárola-Castillo, 2013). Procrustes superimposition translates, scales, and ro-
 tates the coordinate data to allow for comparisons among objects (Gower, 1975;
 Rohlf & Slice, 1990). The *geomorph* package uses a partial Procrustes superim-
 180 position that projects the aligned specimens into tangent space subsequent to
 alignment in preparation for the use of multivariate methods that assume linear
 space (Rohlf, 1999; Slice, 2001).

Principal components analysis (Jolliffe, 2002) was used to visualise shape variation among the bifaces. The shape changes described by each principal axis are commonly visualised using thin-plate spline warping of a reference 3D mesh (Klingenberg, 2013; Sherratt et al., 2014). A residual randomisation permutation procedure (RRPP; n=1000 permutations) was used for all Procrustes ANOVAs (Adams & Collyer, 2015), which has higher statistical power and a greater ability to identify patterns in the data should they be present (Anderson & Ter Braak, 2003). To assess whether shape changes with size (allometry), and differs by group (types and sites), Procrustes ANOVAs (Goodall, 1991) were also run that enlist effect-sizes (z-scores) computed as standard deviates of the generated sampling distributions (Collyer et al., 2015).

A Procrustes ANOVA and pairwise test was used to identify sites where biface shapes differ. The pairwise test is conceptually similar to trajectory analysis (Adams & Collyer, 2007, 2009; Collyer & Adams, 2007, 2013) in that pairwise statistics are vector lengths between vectors, but differs since a factorial model is not explicitly needed to contrast vectors between point factor levels nested within group factor levels (Adams et al., 2017). Procrustes variance was used to discriminate between groups and compare the amount of shape variation (morphological disparity) across sites (Zelditch et al., 2004), which is estimated as the Procrustes variance using residuals of linear model fit (Adams et al., 2017).

Morphological integration was tested using a two-block partial least-squares (2B-PLS) analysis to evaluate relationships for two (or more) blocks of variables collected from the same specimens (Bookstein et al., 2003; Rohlf & Corti, 2000; Wold, 1966). Using shape coordinates in all blocks of variables, 2B-PLS can be used to assess morphological integration (Bastir & Rosas, 2006; Bookstein et al., 2003; Gunz & Harvati, 2007). This analysis includes blade shape (Block 1) and base shape (Block 2), allowing for a test of morphological integration between the blocks.

4. Results

The mean consensus configuration and Procrustes residuals were calculated for each site by means of a generalised Procrustes analysis (GPA) (Mitteroecker & Gunz, 2009, Figure 3) (Figure 4). This initial view of the dataset demonstrates the degree of variation that occurs at each site and in the combined sample. As an exploratory measure, GM methods—to include GPA—aid in clarifying shape differences associated with each population and in the production of novel *a posteriori* hypotheses (Mitteroecker & Gunz, 2009).

Figure 4: Mean consensus configuration (black) with Procrustes residuals (gray) superimposed by generalised Procrustes analysis for a, Mounds Plantation; b, Gahagan Mound; c, George C. Davis; and d, all specimens.

The mean consensus configuration for the sample from each site points toward a potentially significant difference in Gahagan biface morphology at the Mounds Plantation site. It may also be the case that the Gahagan bifaces produced at Mounds Plantation occupy a smaller range of morphospace than those recovered at Gahagan Mound and George C. Davis. While the mean consensus configurations for Gahagan bifaces from Gahagan Mound and George C. Davis

do appear to be similar, there are some notable differences. The bifaces from Gahagan Mound generally include less recurve in the blade, and a base that is more convex than that of the bifaces from George C. Davis, where the mean consensus configuration of the base is slightly concave.

230 Principal components analysis (PCA) was conducted on scaled, translated, and rotated landmarks, and demonstrates that the first two PCs account for 76 (PC1) and nine (PC2) percent of the variation in Gahagan biface shape (Table 3 and Figure 5). Together, PC1 and PC2 account for over 86 percent of shape variation for Gahagan bifaces, with each remaining PC representing
235 less than five percent of the variation (Table 3). The first two PCs are plotted in Figure 5, where warp grids represent the shape changes along PC1 and PC2. This plot indicates that shape changes associated with PC1 articulate most readily with blades that range from broader at the minimum to narrow at the maximum, and base shapes that range from more concave at the minimum
240 to flat or slightly convex at the maximum. Those shape changes associated with PC2 are dominated by differences in base shapes that range from narrow at minimum to broad at maximum, and blade shapes that are broader at minimum to narrower at maximum.

A Procrustes ANOVA was then used to test whether there was a significant
245 difference in biface shape by site. Results of the ANOVA indicate a significant difference in biface shape by site ($RRPP = 1000$; $Rsq = 0.33044$; $Pr(>F) = 0.001$), and a pairwise test of shapes between groups designated by site confirms a significant difference in Gahagan biface shape at the Mounds Plantation site when compared with Gahagan Mound and George C. Davis (Table 4).

250 The test of morphological disparity indicates that while bifaces at both Gahagan Mound and George C. Davis display a greater range of shape variation among individuals relative to other groups, the Gahagan bifaces from Gahagan Mound occupy a significantly greater range of morphospace than those from Mounds Plantation (Table 5). This indicates that those bifaces at the Gahagan
255 Mound site encompass a greater range of morphological variability than those produced at the Mounds Plantation site, meaning that Caddo makers at the

Table 3: Results of principal components analysis for first 10 PCs (> 98 percent of total variance explained).

	SD	PVE	CVE
PC1	0.05939	0.76305	0.76305
PC2	0.02132	0.09829	0.86135
PC3	0.01504	0.04891	0.91026
PC4	0.01041	0.02347	0.93373
PC5	0.009359	0.018950	0.952680
PC6	0.007708	0.012850	0.965540
PC7	0.007231	0.011310	0.976850
PC8	0.004334	0.004060	0.980910
PC9	0.003663	0.002900	0.983810
PC10	0.003434	0.002550	0.986370

SD - standard deviation; PVE - percentage variance explained; CVE - cumulative variance explained.

Mounds Plantation site were participating in a more morphologically-restricted method of biface manufacture.

A two-block partial least-squares (2B-PLS) analysis was used to test for morphological integration between base and blade shape of the Gahagan biface sample. The results indicate significant morphological integration (1000 random permutations; r-PLS = 0.805; P-value = 0.001), indicating that blade shape and base shape vary in a coordinated manner (Figure 6). In general terms, longer and thinner bifaces were found to articulate with a slightly convex base, while shorter and broader bifaces articulate with a slightly concave base.

A comparison of mean consensus configurations was used to further characterise the intra-site shape variation of Gahagan bifaces from Mounds Plantation, Gahagan Mound, and George C. Davis (Figure 7). While those comparisons visualised in Figure 7a and b were found to represent significant differences in biface morphology, the comparison in Figure 7c was not. The subsequent test of directional asymmetry yielded results that were not significant.

Figure 5: Principal components analysis plot (PC1/PC2) for Gahagan bifaces by site; green, Mounds Plantation; black, Gahagan Mound; red, George C. Davis.

5. Discussion

This comparison of the three largest assemblages of Gahagan bifaces from the Southern Caddo Area demonstrates a significant difference in the shape of bifaces produced at Mounds Plantation when compared with Gahagan Mound and George C. Davis. The test of morphological disparity revealed that Gahagan bifaces from the Gahagan Mound site include a significantly greater range of shapes than the Mounds Plantation sample, and the test of morphological integration indicated that the base and blade shapes of Gahagan bifaces vary in a coordinated manner. Lastly, the comparison of mean consensus configurations highlights that Gahagan bifaces from the Gahagan Mound site generally exhibit a lower degree of blade recurvature and a less convex base than those from the George C. Davis site.

If it is assumed that Gahagan bifaces were produced at or near their location of recovery (an assertion that may differ for the George C. Davis assemblage (Shafer, 1973)), then results demonstrate that those bifaces produced at Mounds Plantation differ significantly in shape from the other assemblages (Table 4

Table 4: P-values, effect sizes, and least-squares mean distance matrix for advanced Procrustes ANOVA and pairwise test (RRPP = 1000) of Gahagan biface shape.

	Gahagan Mound	George C Davis	Mounds Plantation
Gahagan Mound	1.000 <i>0.0000000</i> (0.00000000)		
George C Davis	0.343 <i>0.1620967</i> (0.01783345)	1.000 <i>0.0000000</i> (0.00000000)	
Mounds Plantation	0.001 <i>6.3816976</i> (0.09244913)	0.001 <i>7.8954687</i> (0.10820597)	1.000 <i>0.0000000</i> (0.00000000)

Significant differences in bold; effect sizes (z) in italics; least-squares means distance matrix in parentheses.

and Figure 5), and occupy a more restricted range of morphospace than those produced at the type site (Table 5 and Figure 7). Results imply spatial
290 production differences in northern (above the confluence of Cypress Bayou and the Red River) and southern (below) Caddo sites that align with recent findings associated with Hickory Engraved and Smithport Plain Caddo bottles from the same area (Selden Jr., 2018a,b), and also demonstrate that Caddo makers at the Mounds Plantation site were enlisting a more standardised approach to the

Table 5: P-values and pairwise absolute differences between variances for the test of morphological disparity (RRPP = 1000).

	Gahagan Mound	George C Davis	Mounds Plantation
Gahagan Mound	1.000 <i>0.0000000000</i>		
George C Davis	0.640 <i>0.0007943556</i>	1.000 <i>0.0000000000</i>	
Mounds Plantation	0.039 <i>0.0041492880</i>	0.089 <i>0.0033549324</i>	1.000 <i>0.0000000000</i>

Significant differences in bold; pairwise absolute differences between variances in italics.

Figure 6: Two-block partial least-squares analysis for morphological integration of blade and base shape with singular warps illustrated.

295 manufacture of Gahagan bifaces (Table 5). This would similarly imply that Caddo makers at the Gahagan Mound site were producing Gahagan bifaces with a significantly greater range of morphological diversity (Table 5 and Figure 8). However variable, the morphology of Gahagan bifaces is not without pattern, as blade and base shapes can be said to covary throughout the sample (Figure 300 6). While additional research is warranted, this result implies that retouch of Gahagan bifaces was not arbitrary; rather, it was a practice constrained to a suite of blade and base shapes that vary in a coordinated manner.

"Standardization refers to homogeneity in ... materials, ... shape, and/or decoration" (Costin & Hagstrum, 1995, 622), while diversity "can be most gener- 305 ally considered as the opposite of standardization" (Rice, 1991, 273). Standardisation is relative (Costin, 2001; Sinopoli, 1988), and seen as a cultural marker that may have utility in a variety of interpretations. Attributes associated with standardisation may prove dynamic, potentially indicating periods of standardised production as well as periods of creativity that more readily articulate with 310 diversity (Kenoyer et al., 1991). In production contexts, standardisation might

Figure 7: Comparison of mean consensus configurations for Gahagan biface shape by site at; a, Mounds Plantation (gray) and Gahagan Mound; b, Mounds Plantation (gray) and George C. Davis; c, Gahagan Mound (gray) and George C. Davis.

be seen as the result of minimised labour costs and improvements in efficiency (Sinopoli, 1988). Both standardisation and diversity have utility in characterising tolerance, where a greater range of shapes may be indicative of a higher tolerance, and where lower tolerances can be demonstrated by production where variation is decreased (Eerkins & Bettinger, 2001). In this application, those bifaces from the Mounds Plantation site potentially represent production under a model of lower tolerance than those produced at the Gahagan Mound site, where the tolerance to morphological diversity appears higher.

Production activities are more likely to be localised than exchange systems, and are assumed to leave a clearer signature (Costin, 1991); in this case, those variables used in the analysis are the products themselves. The morphological

Figure 8: Illustrated sample of Gahagan bifaces from the Gahagan Mound site demonstrating the morphological variation that occurs in Gahagan biface shape at the type site.

attributes are representative of *intentional attributes* (Costin, 2005) related to morphological characteristics; in this instance, the blade and base of Gahagan bifaces. Dimensional standardisation has utility in identifying the range of variation and the overlap of product morphology within and between communities (Arnold III, 1991). In this study, the relative dimensional standardisation exhibited at the Mounds Plantation site may imply a smaller number of production units (sensu Costin (1991)) contrasted with a larger number of production units at the Gahagan Mound site.

6. Conclusion

Through the use of morphological attributes associated with the blade and base shapes of Gahagan bifaces, a significant difference in morphology was found to occur at the Mounds Plantation site, where the range of morphological variation is also significantly more restricted when compared with Gahagan bifaces from the Gahagan Mound site. These results point toward a lower threshold for morphological variability at the Mounds Plantation site, which may indicate a smaller number of production units. While additional research is warranted, these findings articulate with a shift in Hickory Engraved and Smithport Plain bottle morphology over the same (north-south) geography (Selden Jr., 2018a,b), potentially indicating two previously unrecognised and morphologically-distinct

Caddo lithic and ceramic production areas.

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