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Perdiz arrow points from Caddo burial contexts aid in defining discrete behavioral regions

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Abstract Recent research into Caddo bottle and biface morphology yielded evidence for two distinct behavioral regions, across which material culture from Caddo burials expresses significant morphological differences. This study asks whether Perdiz arrow points from Caddo burials differ across the same geography, which would extend the pattern of morphological differences to a third category of Caddo material culture. Perdiz arrow points collected from the geographies of the northern and southern Caddo behavioral regions were employed to test the hypothesis that morphological attributes differ, and are predictable, between the two communities. The analysis of linear metrics indicated a significant difference in morphology by behavioral region. Using the linear metrics combined with the tools of machine learning, a predictive model—support vector machine—was designed to assess the degree to which community differences could be predicted, achieving a receiver operator curve score of 97 percent, and an accuracy score of 94 percent. The subsequent landmark geometric morphometric analysis identified significant differences in Perdiz arrow point shape and size between the behavioral regions—one characterized

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by a comparatively smaller blade and larger stem (north), and the other by a comparatively larger blade and smaller stem (south)—coupled with significant results for modularity and morphological integration. These findings build directly upon recent investigations that posited two discrete Caddo behavioral regions defined on the basis of discernible morphological differences, which is expanded here to include a third category of Caddo material culture.

Keywords American Southeast · Caddo · NAGPRA · computational archaeology · archaeoinformatics · machine learning · museum studies · digital humanities · non-Western art history · STEM · STEAM ·

1 Introduction

Perdiz arrow points are considered the epitome of the Late Prehistoric Toyah lithic assemblage in Texas—which also includes convex end scrapers or unifaces, prismatic blades, as well as two- and four-beveled bifacial knives—and are representative of the Late Prehistoric transition to the Protohistoric (Arnn III 2012a). This technological assemblage is typically attributed to groups of highly mobile bison hunters, and has been documented across the geographic extent of Texas. Our present understanding of the Toyah tool kit indicates that it was successfully implemented in a broad-spectrum of hunting and foraging lifeways that included not only bison (*Bison bison*), but deer (*Odocoileus spp.*) and numerous other animal prey species (Arnn III 2012a; Dering 2008).

The Toyah tool kit has been recognized as a potential contributor to discussions of Late Prehistoric social and cultural identity. Initially identified by J. Charles Kelley on the basis of technological and morphological differences in material culture, the Toyah Phase (CE 1300 - 1700) occurrs between the Protohistoric and the preceding Austin Phase of the Late Prehistoric Period (Kelley 1947a, 1947b). As noted by Arnn:

> Toyah represents something of a paradox in which archaeologists have identified *one archaeological or material culture* in the same region where historians have documented numerous Native American groups and significant cultural diversity (Arnn III 2012a, 47).

Stemming from the observations of Kelley, as well as later researchers who viewed Toyah as a cultural entity, technological origins became a point of further interest and debate from which two schools of thought emerged regarding Toyah cultural manifestations: 1) that Toyah represented the technology of Plains groups moving into Texas following the bison herds (Prewitt 1981, 1985), or 2) a technocomplex or suite of artifacts adopted by multiple groups across Texas as they participated in bison hunting (Black 1986; Collins 1995; Ricklis 2017). In both interpretations, primary agency is environmental (Arnn III 2012a); either people followed the bison from elsewhere, or the influx of bison spurred adoption of the technology among the numerous groups in Texas.

Research by Arnn (Arnn III 2005, 2007, 2012a, 2012b) emphasized aspects of Toyah social identity, social fields, and agency, as well as the archaeological visibility of these phenomena. Arnn recognized three important scales of identity and interaction in his work: community/band, marriage/linguistic group, and long-distance social networks (Arnn III 2012a). His ideas are important here because they supplant a simple monocausal environmental explanation of material culture variability with a multi-causal and scaled concept that includes social identity.

1.1 Perdiz arrow points

Perdiz arrow points generally follow two manufacturing trajectories—one that enlists flakes, and the other, blade flakes (Dockall et al. 2020; Johnson 1994; Ricklis 1994; Selden Jr et al. 2021)—and are known to encompass a greater range of variation in shape and size than most arrow point types in Texas (Suhm and Jelks 1962; Turner, Hester, and McReynolds 2011). Lithic tool stone in the ancestral Caddo area of northeast Texas is relatively sparse (Selden Jr et al. 2021, fig. 2), consists primarily of chert, quartzite, and silicified wood characteristic of the local geological formations, which may contribute to local variation in shape and size (Selden Jr et al. 2021; Banks 1990). It has been demonstrated elsewhere that the morphological attributes of Perdiz arrow points from northeast Texas vary significantly by time, raw material, and burial context (Selden Jr et al. 2021). In outline, Perdiz arrow points possess a:

> [t]riangular blade with edges usually quite straight but sometimes slightly convex or concave. Shoulders sometimes at right angles to stem but usually well barbed. Stem contracted, often quite sharp at base, but may be somewhat rounded. Occasionally, specimen may be worked on one face only or mainly on one face ... [w]orkmanship generally good, sometimes exceedingly fine with minutely serrated blade edges (Suhm, Krieger, and Jelks 1954, 504).

A social network analysis of diagnostic artifacts from Historic Caddo (post-CE 1680) sites in northeast Texas, which included Perdiz arrow points, demonstrated two spatially discrete behavioral regions based upon the co-presence of diagnostic types (Selden Jr. 2021a, fig. 12.4). The network analysis was limited to Historic Caddo types; however, Formative/Early Caddo (CE 800 – 1200) Gahagan bifaces and Caddo bottle types have been found to express significant morphological differences across the same spatial extent as the behavioral regions (Selden Jr. 2018a, 2018b, 2019, 2021b), extending the prehistoric longevity for the behavioral regions based on local alterity. Gahagan bifaces from the ancestral Caddo area also differ significantly in shape, size, and form compared with those recovered from central Texas sites (Selden Jr., Dockall, and Dubied 2020), suggesting a second shape boundary between the ancestral Caddo area and central Texas.

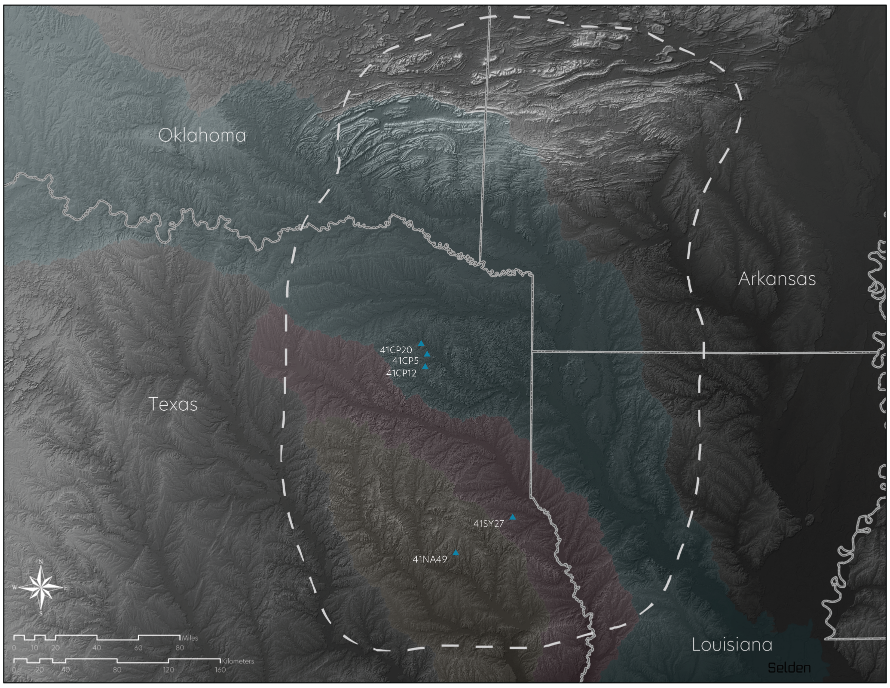

Fig. 1 Location of Caddo sites with Perdiz arrow points used in this study, the extent of the ancestral Caddo area (white), and the Red River basin (blue), Sabine River basin (maroon), and Angelina River basin (brown).

The goal of this exploratory endeavor was to assess whether metrics collected for Perdiz arrow points support the shape boundary posited in recent social network and geometric morphometric analyses, to determine whether linear metrics and shape variables might be useful predictors of regional membership, and—if so—to identify those morphological features that articulate with each behavioral region. Should the analysis yield significant results, it would bolster the argument for at least two discrete Caddo behavioral regions in northeast Texas; each empirically defined by discernible morphological differences across three discrete categories of Caddo material culture (Figure 1).

1.2 Caddo behavioral regions

In a June 18, 1937 Works Progress Administration interview with Lillian Cassaway, Sadie Bedoka—a Caddo-Delaware woman raised with the Caddo—stated that:

> Each [Caddo] clan had its own shape to make its pottery. One clan never thought of making anything the same pattern of another clan. ***You could tell who made the pottery by the shape*** (Cassaway 1937, 395).

General differences in Caddo ceramic forms have been noted elsewhere (Krieger 1946; Selden Jr., Perttula, and O'Brien 2014); however, the study of the Clarence H. Webb collection was the first to illustrate a significant north-south geographic shape difference among Hickory Engraved and Smithport Plain Caddo bottle types (Selden Jr. 2019). That exploratory aperçu was later confirmed using more robust samples of Hickory Engraved and Smithport Plain bottles (Selden Jr. 2018a, 2018b), and was subsequently expanded to include a greater variety of Caddo bottle types across a larger spatial and temporal extent (Selden Jr. 2021b).

The co-presence of diagnostic artifact and attribute types was leveraged in defining Caddo phases and periods, which serve as a heuristic tool that aids archaeologists in the explanation and retrojection of the local cultural landscape, whilst simultaneously highlighting the regional alterity that occurs between landscapes. The Historic Caddo network expands those efforts, augmenting the previously-defined phases and periods, and emphasizing the dynamic and manifold relational connections that reinforce and transcend current epistemic categories (Selden Jr. 2021a). This was achieved by enlisting a multi-scalar methodological approach (Knappett 2011; Mills et al. 2015), where northern and southern communities were parsed into constituent groups using the co-presence of diagnostic types paired with a modularity algorithm (Blondel et al. 2008; Lambiotte, Delvenne, and Barahona 2014). Most constituent groups identified in the network analysis were found to articulate with known Caddo polities (Selden Jr. 2021a).

A subsequent analysis of Gahagan bifaces confirmed that a second category of Caddo material culture expressed significant morphological differences across the same geography as the Hickory Engraved and Smithport Plain bottles (Selden Jr., Dockall, and Shafer 2018). The morphology of Gahagan bifaces from sites in central Texas has also been found to differ significantly from those recovered from the Caddo region (Selden Jr., Dockall, and Dubied 2020). That Gahagan bifaces were found to differ across *two* spatial boundaries was noteworthy, particularly since it is regularly assumed that these large bifaces were manufactured in central Texas and arrived in the ancestral Caddo area as products of trade and/or exchange (Selden Jr., Dockall, and Dubied 2020; Selden Jr., Dockall, and Shafer 2018). Further, that Gahagan bifaces were found to differ across the same geography as those communities posited in the Historic Caddo network analysis suggested that the temporal range of the shape boundary might extend to the Formative/Early Caddo period (CE 800 - 1250); a hypothesis that was later confirmed in a more comprehensive analysis of Caddo bottles (Selden Jr. 2021b).

2 Methods and results

Sixty seven whole/intact Perdiz arrow points recovered from Caddo burial contexts in Camp, Nacogdoches, and Shelby counties comprise the basis of this study (supplementary materials). A standard suite of linear metrics were collected for each specimen, including maximum length, width, thickness, stem length, and stem width (Table @ref{tab:table1}). Following collection, data were imported to R (Team 2021), where boxplots were produced, along with a principal components analysis (PCA), followed by a permutational multivariate analysis of variance (perMANOVA) to test whether the morphology of Perdiz arrow points differs between the behavioral regions (supplementary materials).

Table 1: Sample overview: Linear metrics and categorical variables used in the study, which include maximum length (MaxL), width (MaxW), thickness (MaxTh), stem length (MaxStL), and stem width (MaxStW).

ID	Site	Region	MaxL	MaxW	MaxTh	MaxStl	MaxStw
554	41cp12	north	25.40	12.18	3.82	5.75	3.84
555	41cp12	north	22.92	12.87	3.54	3.71	3.69
556	41cp12	north	24.09	11.87	3.61	5.15	4.78
559	41cp12	north	25.01	10.57	3.50	5.84	3.88
562	41cp12	north	22.10	10.45	3.47	3.77	3.43
565	41cp12	north	20.31	10.53	3.08	2.01	3.07
591	41cp12	north	25.49	13.37	4.42	7.04	4.95
646	41cp5	north	16.37	10.46	2.63	3.85	4.03
649	41cp5	north	23.38	13.88	4.11	7.33	5.54
651	41cp5	north	22.86	13.84	4.61	6.16	5.02
652	41cp5	north	22.51	12.67	3.37	6.33	4.39
653	41cp5	north	27.55	17.05	3.08	6.83	4.60
654	41cp5	north	17.01	10.90	2.35	4.64	3.64
655	41cp5	north	26.86	13.06	2.50	6.10	3.99
656	41cp5	north	25.79	12.52	2.96	5.43	3.97
657	41cp5	north	27.36	12.41	3.04	6.56	4.26
659	41cp5	north	23.10	11.42	2.14	4.74	4.21
660	41cp5	north	20.23	9.64	1.89	5.70	2.66
661	41cp5	north	21.73	10.67	2.27	4.91	3.13
665	41cp12	north	27.34	15.77	4.10	4.69	4.60
677	41cp20	north	24.72	13.70	2.52	6.98	3.76
678	41cp20	north	24.98	13.33	3.26	4.19	3.54
na49-1	41na49	south	47.74	15.14	4.52	6.82	6.22
na49-10	41na49	south	22.88	12.13	3.68	5.73	5.49
na49-11	41na49	south	24.09	12.52	3.27	5.36	4.81
na49-12	41na49	south	21.41	10.31	3.48	4.64	3.82
na49-13	41na49	south	24.84	11.21	3.51	5.19	4.97
na49-14	41na49	south	21.92	9.35	2.62	5.22	4.85
na49-2	41na49	south	32.49	12.78	3.80	6.80	4.78
na49-3	41na49	south	27.72	13.05	4.19	5.99	5.88
na49-4	41na49	south	26.20	10.60	3.30	4.67	4.92

ID	Site	Region	MaxL	MaxW	MaxTh	MaxStl	MaxStw
na49-7	41na49	south	24.25	12.01	2.92	6.01	4.93
na49-8	41na49	south	22.06	14.51	2.92	5.67	5.17
na49-9	41na49	south	25.44	13.86	3.44	4.74	4.81
f2-g2-5	41sy27	south	24.92	16.16	3.57	4.44	4.25
f2-g2-10	41sy27	south	34.69	16.40	3.29	6.12	4.14
f2-g2-15	41sy27	south	34.17	20.00	3.09	8.34	5.68
f2-g2-9	41sy27	south	39.39	16.73	2.95	6.28	4.90
f2-g2-14	41sy27	south	30.36	15.72	2.58	6.11	4.51
f2-g2-2	41sy27	south	29.32	15.47	2.94	5.59	4.18
f2-g2-1	41sy27	south	30.83	16.80	2.96	5.83	5.21
f2-g2-11	41sy27	south	31.10	15.33	2.92	5.60	4.78
f2-g2-3	41sy27	south	23.30	15.31	3.09	3.87	4.31
f2-g2-13	41sy27	south	29.33	18.59	3.13	5.54	4.52
f2-g2-7	41sy27	south	24.78	15.68	3.20	4.60	4.23
f2-g2-8	41sy27	south	28.17	18.24	3.01	5.99	4.72
f2-g2-12	41sy27	south	33.53	15.83	3.18	5.55	4.23
f2-g2-6	41sy27	south	23.74	16.12	2.92	5.53	4.34
f2-g1-20	41sy27	south	37.46	16.78	3.28	7.53	5.54
f2-g1-10	41sy27	south	27.32	18.39	3.10	5.37	4.54
f2-g1-19	41sy27	south	31.44	19.62	3.13	5.44	5.75
f2-g1-17	41sy27	south	32.75	19.34	3.34	6.29	5.31
f2-g1-16	41sy27	south	34.97	16.81	3.39	5.90	5.49
f2-g1-11	41sy27	south	33.18	17.45	3.36	6.47	5.12
f2-g1-13	41sy27	south	31.61	18.57	3.07	5.75	5.04
f2-g1-15	41sy27	south	38.50	20.34	3.40	8.85	6.16
f2-g1-18	41sy27	south	30.02	17.33	3.21	7.05	5.18
f2-g1-3	41sy27	south	29.45	18.84	3.16	5.58	5.32
f2-g1-7	41sy27	south	32.44	18.20	3.28	5.80	4.76
f2-g1-4	41sy27	south	28.33	17.49	2.98	7.29	4.83
f2-g1-12	41sy27	south	32.17	18.47	3.47	5.44	5.20
f2-g1-8	41sy27	south	31.03	17.05	3.10	7.41	5.11
f2-g1-9	41sy27	south	27.56	21.12	3.47	6.84	5.07
f2-g3-1	41sy27	south	27.21	17.41	3.52	7.70	5.35
f2-g3-3	41sy27	south	24.31	16.35	3.00	7.08	5.10
f2-g3-6	41sy27	south	30.58	18.03	3.56	7.37	4.81
f2-g3-2	41sy27	south	27.63	17.74	2.99	8.23	4.82

Boxplots illustrate the distribution and mean for each of the five linear variables (Figure 2a-e), and the PCA (Figure 2f) illustrates over 92 percent of the variation in the sample among PC1 (84.65 percent) and PC2 (11.71 percent). The perMANOVA demonstrated that linear metrics for Perdiz arrow points differ significantly by behavioral region (permutations = 10,000; Rsq = 0.29485; Pr(>F) = 1e-04) (supplementary materials).

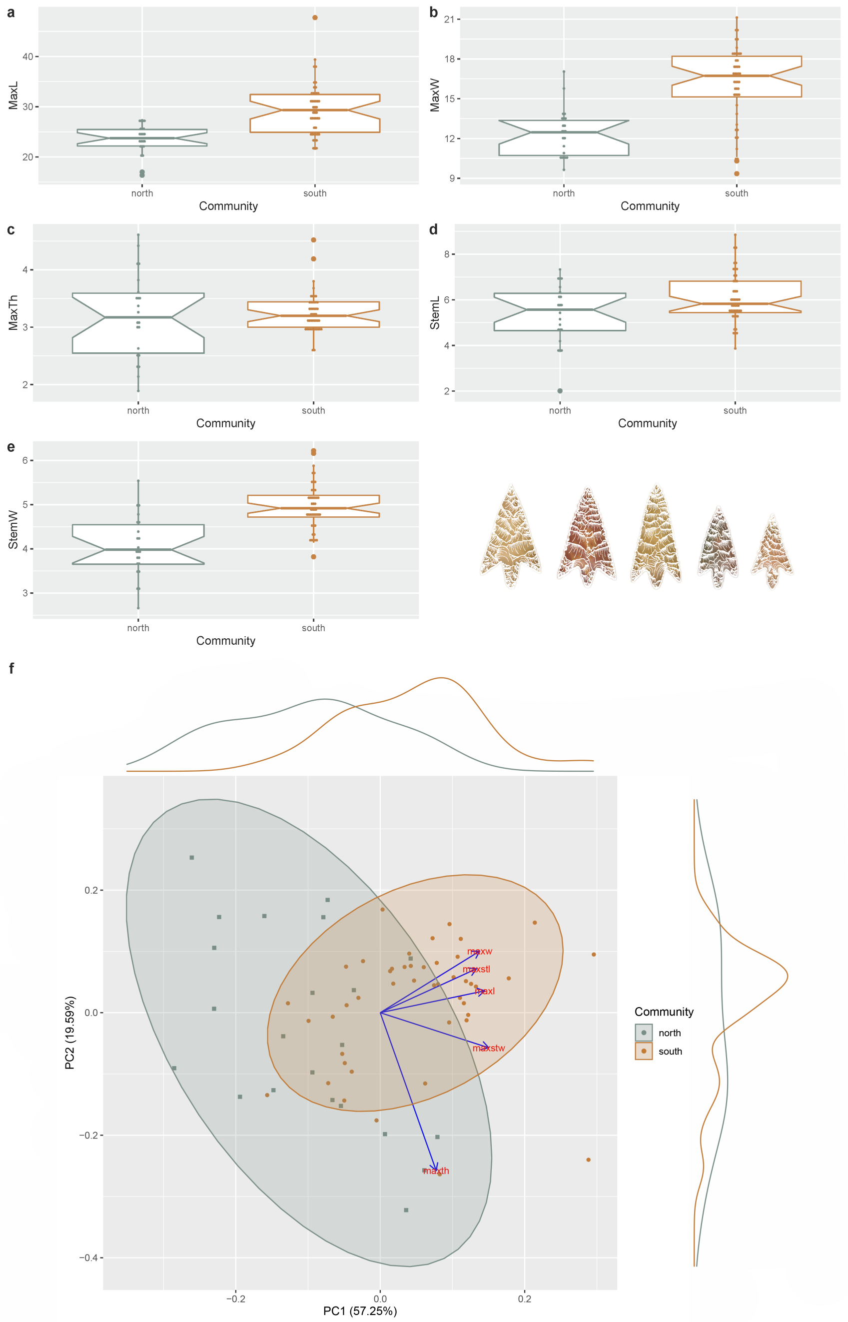

Fig. 2 Boxplots for a, maximum length; b, maximum width; c, maximum thickness; d, stem length; e, stem width, and f, PCA [on correlation matrix] for linear metrics associated with the Perdiz arrow points. Additional information related to the analysis, including all linear data and the code needed to reproduce these results, can be found in the supplemental materials at https://seldenlab.github.io/perdiz3/.

2.1 Predictive model

A *support vector machine* is a supervised machine learning model regularly used in classifying archaeological materials (Bhatt and Patalia 2017; Monna et al. 2020; Febriawan et al. 2020; Kadhim and Abed 2021; Zhang 2013; Elliot et al. 2021), which has utility in comparing and classifying datasets aggregated from digital repositories, comparative collections, open access reports, as well as other digital assets. For this effort, linear data were imported and modeled using the `scikit-learn` package in Python (Pedregosa et al. 2011; Buitinck et al. 2013) (supplementary materials), and subsequently split into training (75 percent) and testing (25 percent) subsets. A standard scaler was used to decrease the sensitivity of the algorithm to outliers by standardizing features, and a nested cross validation of the training set was used to achieve unbiased estimates of model performance, resulting in a mean cross validation score of 86 percent (supplementary materials). The model was subsequently fit on the training set, yielding a receiver operator curve score of 97 percent, and an accuracy score of 94 percent (supplementary materials).

2.2 Geometric morphometrics

Each of the arrow points was imaged using a flatbed scanner (HP Scanjet G4050) at 600 dpi. The landmarking protocol developed for this study (supplementary materials) included six landmarks and 24 equidistant semilandmarks to characterize Perdiz arrow point shape, and were applied using the `StereoMorph` package in R (Olsen and Westneat 2015). The characteristic points and tangents used in the landmarking protocol were inspired by the work of Birkhoff (Birkhoff 1933).

Landmarks were aligned to a global coordinate system (Kendall 1981, 1984; Slice 2001), achieved through generalized Procrustes superimposition (Rohlf and Slice 1990), performed in R 4.1.1 (Team 2021) using the `geomorph` package v4.0.1 (Dean C. Adams and Otarola-Castillo 2013; Baken et al. 2021) (Figure 3). Procrustes superimposition translates, scales, and rotates the coordinate data allowing for comparisons among objects (Gower 1975; Rohlf and Slice 1990). The `geomorph` package uses a partial Procrustes superimposition that projects the aligned specimens into tangent space subsequent to alignment in preparation for the use of multivariate methods that assume linear space Slice (2001).

Principal components analysis (Jolliffe 2002; Revell 2009) was used to visualize shape variation among the arrow points (Figure 4). Shape changes described by each principal axis are commonly visualized using thin-plate spline warping of a reference image or 3D mesh (Klingenberg 2013; Sherratt et al. 2014). A residual randomization permutation procedure (RRPP; n = 10,000 permutations) was used for all Procrustes ANOVAs (Dean C. Adams and Collyer 2015; Michael L. Collyer and Adams 2018), which has higher statistical power and a greater ability to identify patterns in the data should they

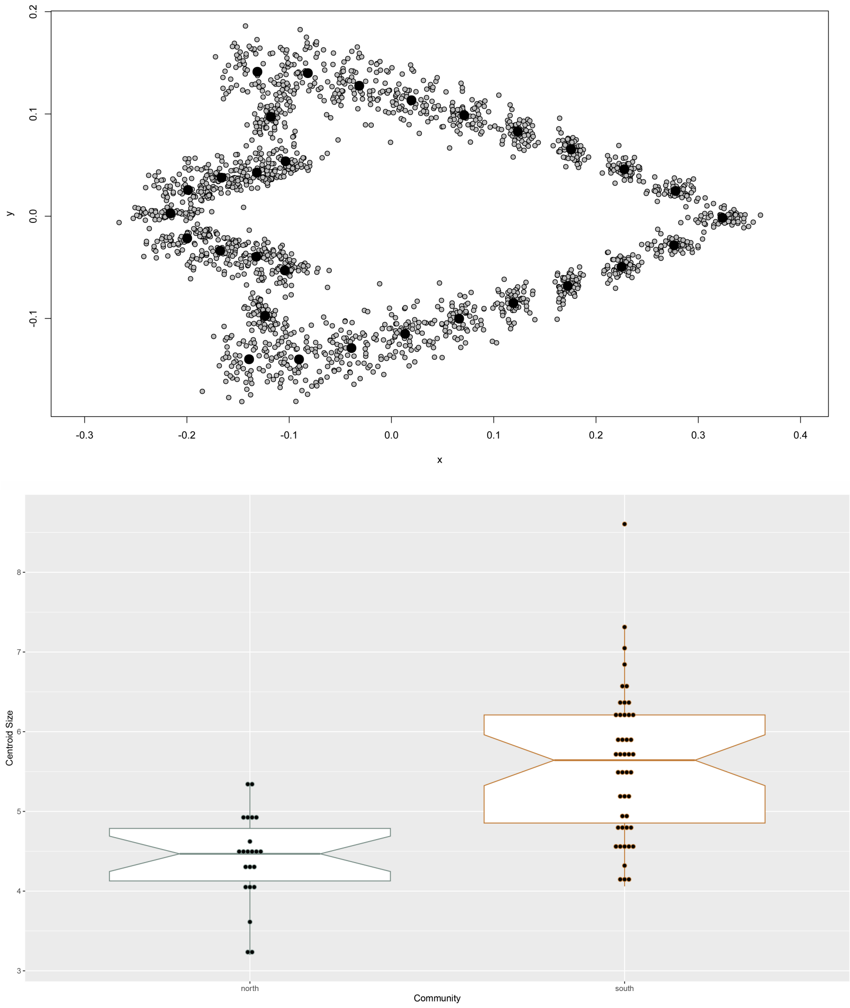

Fig. 3 Results of generalized Procrustes analysis, illustrating mean shape (black) and all specimens in the sample (gray), as well as the difference in centroid size for Perdiz arrow points from the two behavioral regions. Additional information related to the GPA, including all data and code needed to reproduce these results, can be found in the supplemental materials at https://seldenlab.github.io/perdiz3/.

be present (Anderson and Ter Braak 2003). To assess whether shape differs by group (region), Procrustes ANOVAs (Goodall 1991) were also run that enlist effect-sizes (z-scores) computed as standard deviates of the generated sampling distributions (M. L. Collyer, Sekora, and Adams 2015). Procrustes variance was used to discriminate between regions and compare the amount of shape variation (morphological disparity) (Zelditch et al. 2004), estimated as Procrustes variance using residuals of linear model fit (Dean C. Adams

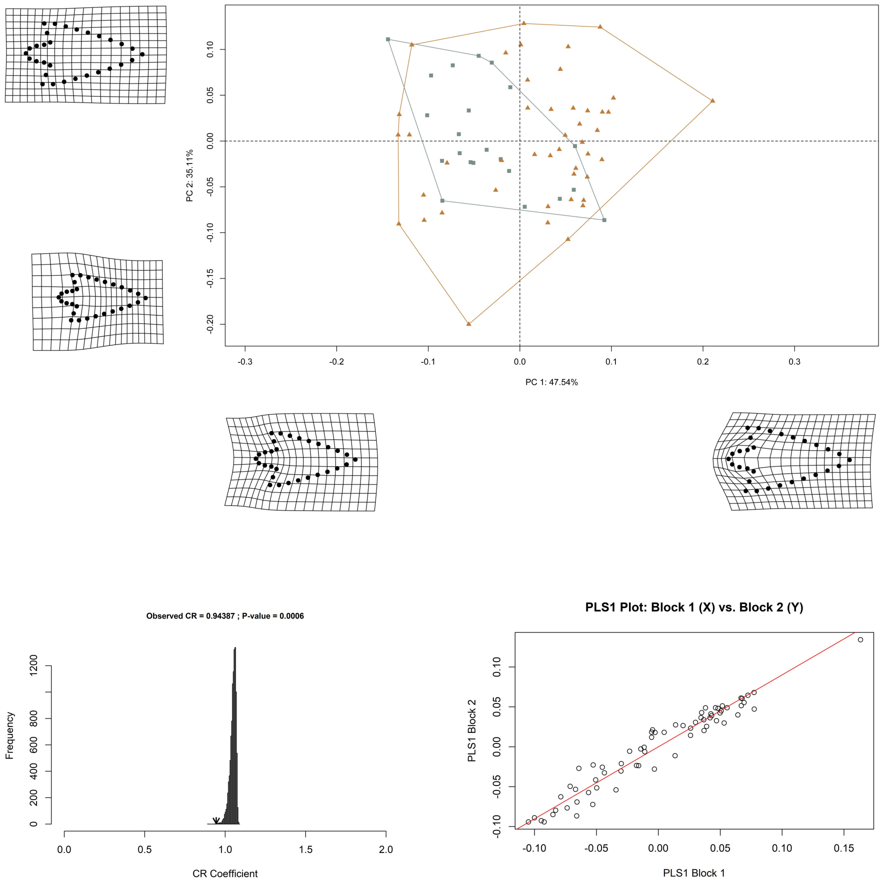

Fig. 4 Principal components analysis plot (PC1/PC2) for Perdiz arrow points by behavioral region/community (top; gray squares, north; orange triangles, south), and results of modularity (bottom left) and blade/base morphological integration (bottom right) analyses. Additional information related to the PCA, including the full listing of results and all data and code needed to reproduce these results, can be found in the supplemental materials at https://seldenlab.github.io/perdiz3/.

et al. 2018). A pairwise comparison of morphological integration was used to test the strength of integration between blade and basal morphology using a z-score (Bookstein et al. 2003; M. L. Collyer, Sekora, and Adams 2015; Dean C. Adams and Collyer 2016; D. C. Adams and Collyer 2019).

A Procrustes ANOVA was used to test for a difference in Perdiz arrow point (centroid) size by behavioral region (RRPP = 10,000; Rsq = 0.30681; Pr(>F) = 1e-04), followed by a second to test for a difference in arrow point shape (RRPP = 10,000; Rsq = 0.0536; Pr(>F) = 0.0161). While shape and size differ significantly between behavioral regions, the Rsq value for size is just under six times larger than that for shape (smaller in the north; larger in the south), suggesting that between-region differences in Perdiz arrow point *size* may be more visually apparent than differences in *shape*. A comparison of mean consensus configurations was used to illustrate shape differences from the northern and southern behavioral regions. Diacritical morphology is characterized by a comparatively smaller blade and larger stem in the north, and by a comparatively larger blade and smaller stem in the south. Further, the angle between the shoulder and base is more acute, with a base that is generally shorter and narrower in the southern behavioral region (supplementary materials).

The analysis of modularity, which compares within-module covariation of landmarks against between-module covariation was significant (see Figure 4 and supplementary materials) (D. C. Adams and Collyer 2019; Dean C. Adams and Peres-Neto 2016), demonstrating that Perdiz arrow point blades and bases are, in fact, modular. The test for morphological integration was also significant (see Figure 4 and supplementary materials), indicating that the blades and bases of Perdiz arrow points are integrated. These results demonstrate that blade and base shapes for Perdiz arrow points are predictable; a finding that would have utility in subsequent studies of Perdiz arrow point morphology that incorporate fragmentary specimens.

3 Discussion

The shape boundary empirically delineates two discrete behavioral regions in the ancestral Caddo area. That Perdiz arrow points recovered from Caddo burials north and south of the shape boundary were found to differ significantly, expands the scope of the behavioral regions to include three classes of material culture (Caddo bottles, bifaces, and—now—arrow points) (Selden Jr. 2018a, 2018b, 2019, 2021b; Selden Jr., Dockall, and Dubied 2020; Selden Jr., Dockall, and Shafer 2018; Selden 2022). Thus, for material culture included in burial contexts north and south of the shape boundary, the Caddo were selecting for significant morphological differences in bottles, bifaces, and arrow points (Figure 5a-d). Results clearly illustrate that morphological differences among Perdiz arrow points found in the northern and southern behavioral regions (Figure 5d) are predictable (supplementary materials), and can be disaggregated using a standard suite of linear metrics regularly collected in the course of cultural resource management endeavors.

The geometric morphometric analysis demonstrated significant morphological differences for Perdiz arrow points recovered north and south of the shape boundary, where the most pronounced difference was found to occur in basal morphology (see Figure 5d). This finding provides evidence in support of the argument that Perdiz arrow point morphology is labile (Selden Jr et al. 2021). The character of those morphological differences found to occur in Perdiz arrow points (basal morphology and size) is potentially suggestive of differential approaches to hafting.

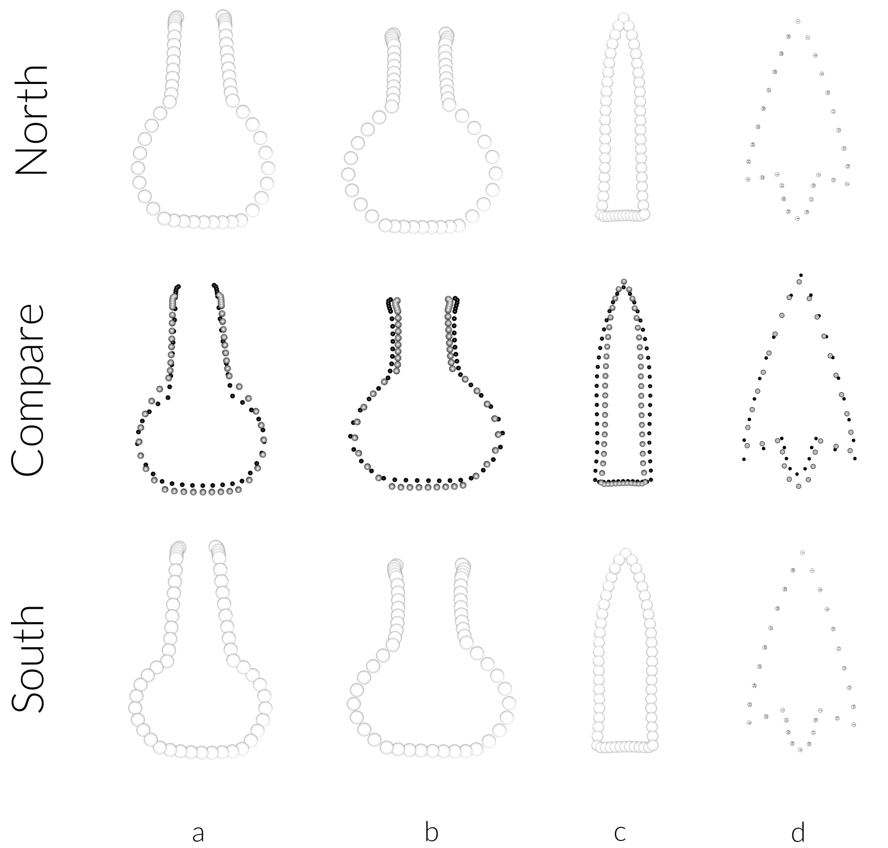

Fig. 5 Mean shapes and comparisons for a, Formative/Early and b, Late/Historic bottles; c, Formative/Early Gahagan bifaces; and d, Middle/Late Perdiz arrow points from Caddo burial contexts in the northern and southern behavioral regions. In the comparisons of mean shape, the northern population appears in gray, and the southern population appears in black.

Blades and bases of Perdiz arrow points were found to be both modular and morphologically integrated. This indicates that each module functions independently, and that basal shape is a predictor of blade shape, and vice-versa. Further work is warranted to assess whether Perdiz arrow points from groups within the boundaries of the northern and southern behavioral regions may express unique morphologies, aiding in further delimiting local boundaries associated with constituent Caddo groups.

3.1 Morphologically-distinct behavioral regions

In considering the role/s of material culture as aspects of social identity, it is important not to lose sight of the fact that people and their possessions are active agents in the production and maintenance of social identity/ies. All three categories of material culture (bottles, bifaces, and arrow points) contribute to local and regional communities of identity and communities of practice (Eckert, Schleher, and James 2015). Generally, this concept may be more easily applied to bottles since those were manufactured and used by individuals sharing collective Caddo identities. Bifaces and arrow points potentially represent multiple identities—those being the Caddo, as users; and non-Caddo, as producers—at least with regard to chipped stone tools incorporated in mortuary contexts. This concept lends defensible credence to the notion of morphologically-distinct behavioral regions among the Caddo, while integrating the possibility of understanding interactions between Caddo and non-Caddo groups, to include the movement of material culture between Caddo behavioral regions.

Three categories of Caddo material culture have been demonstrated to differ north and south of the shape boundary, indicating a haecceity of regional perspectives related to production (bottles), and aesthetic choice/cultural interaction (bifaces and arrow points). These differing perspectives incorporate normative group decisions that include shape, size, form, and decorative expression, which likely represent the culmination of generational perspectives (Stark 2006). Simply stated, such perspectives are representative of tradition. Eckert and colleagues (Eckert, Schleher, and James 2015) indicate that provenance, the origin or source of an item, is a significant component of understanding the interrelatedness of communities of identity and communities of practice. A second shape boundary demonstrates that Gahagan bifaces differ significantly between the ancestral Caddo region and central Texas, where they are currently thought to have been manufactured. This suggests that those communities of practice that articulate with the *production* of chipped stone artifacts recovered from Caddo internments, may not have been Caddo.

It is also entirely possible that there are no communities of practice for chipped stone artifacts recovered from Caddo mortuary contexts. However, there do appear to have been communities of practice associated with Perdiz arrow points recovered from non-mortuary contexts in the ancestral Caddo area, which may more readily reflect retouch or resharpening approaches used by Caddo knappers (Selden Jr et al. 2021; Shafer 1974; Selden 2022). Similar interpretations can be applied to the Gahagan bifaces, as few have been reported outside of Caddo mortuary contexts. It may be more fitting to perceive of Perdiz arrow points and Gahagan bifaces as indicative of communities of identity rather than communities of practice, due to the contextual discrepancy evinced through mortuary and non-mortuary settings. The provenance of bifaces from Caddo mortuary contexts can most assuredly be considered nonlocal, or produced outside of the ancestral Caddo region, based on multiple factors that include raw material, workmanship, morphology, and context.

4 Conclusion

This study demonstrated that linear metrics and shape variables collected for Perdiz arrow points support the shape boundary posited in recent social network and geometric morphometric analyses, and determined that those same metrics can be used to predict regional membership. Morphological features that discriminate between Perdiz arrow points recovered from each behavioral region were identified using geometric morphometrics, with substantive differences found to occur in size and basal morphology. Blade and base shape were found to be both modular and morphologically integrated, suggesting that blade and base shapes are predictable. While evidence from one category—Caddo bottles—supports discussions of Caddo production, the other two—bifaces and arrow points—may articulate with production activities outside of the region by non-Caddo makers. Such production activity is more likely to be localized than exchange systems, thus assumed to leave a clearer signature (Costin 1991).

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7 Data Management

The data and analysis code associated with this project can be accessed through the GitHub repository (`https://github.com/seldenlab/perdiz3`) or the supplementary materials (`https://seldenlab.github.io/perdiz3/`); which are digitally curated on the Open Science Framework (DOI: 10.17605/OSF.IO/VZHJR). Images of all Perdiz arrow points used in this study were made available in an open access comparative collection (`https://scholarworks.sfasu.edu/ita-perdiz/`), with permission from the Caddo Nation of Oklahoma. These supplementary materials include all analysis data and code used in the study, providing a means for others to reproduce (exactly) those results discussed and expounded upon in this article. The replicable nature of this undertaking provides others with the means to critically assess and evaluate the various analytical components of this study, which is a necessary requirement for the production of reliable knowledge (Gray and Marwick 2019; Peng 2011; Gandrud 2014).

Reproducibility projects in psychology and cancer biology are impacting current research practices across all domains. Examples of reproducible research are becoming more abundant in archaeology (Marwick 2016; Ivanovaitė et al. 2020; Selden Jr., Dockall, and Dubied 2020; Selden Jr et al. 2021; Selden 2022), and the next generation of archaeologists are learning those tools and methods needed to reproduce and/or replicate research results (Marwick et al. 2019). Reproducible and replicable research work flows are often employed at the highest levels of humanities-based inquiries to mitigate concern or doubt regarding proper execution, and is of particular import should the results have—explicitly or implicitly—a major impact on scientific progress (Peels and Bouter 2018).

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