

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

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**Abstract** Recent research in the ancestral Caddo area yielded evidence for distinct *behavioral regions*, across which material culture from Caddo burials—bottles and Gahagan bifaces—has been found to express significant morphological differences. This inquiry assesses whether Perdiz arrow points from Caddo burials, assumed to reflect design intent, may differ across the same geography, and extend the pattern of shape differences to a third category of Caddo material culture. Perdiz arrow points collected from the geographies of the northern and southern Caddo *behavioral regions* defined in a recent social network analysis were employed to test the hypothesis that morphological attributes differ, and are predictable, between the two communities. Results indicate significant between-community differences in maximum length, width, stem length, and stem width, but not thickness. Using the same traditional 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 geometric morphometric analysis identified significant differences in Perdiz arrow point shape, size, and

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allometry, coupled with significant results for modularity and morphological integration. These findings bolster recent arguments that established two discrete *behavioral regions* in the ancestral Caddo area defined on the basis of discernible morphological differences across three categories of Caddo material culture.

**Keywords** American Southeast · Caddo · Texas · archaeoinformatics · computational archaeology · machine learning · museum studies · digital humanities · STEM ·

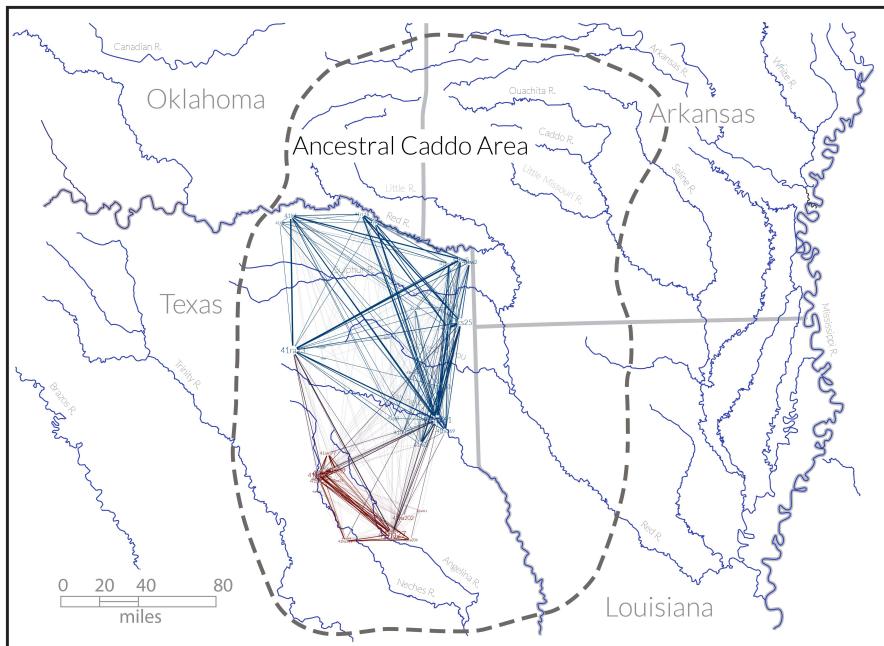
## 1 Introduction

Perdiz arrow points generally follow two distinct manufacturing trajectories; one that enlists flakes, and the other, blade flakes [1,2,3,4]. Lithic tool stone in the Caddo area of northeast Texas is relatively sparse, consists primarily of chert, quartzite, and silicified wood characteristic of the local geological formations, which may contribute to local variation in shape and size [4,5]. It has been demonstrated elsewhere that the morphology of Perdiz arrow points from northeast Texas vary significantly by time, raw material, and burial context [4]. 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 [6, 504].

A social network analysis of diagnostic artifacts from Historic Caddo (post-CE 1680) sites in northeast Texas demonstrated two spatially distinct *behavioral regions* [7] (Fig. 1). 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 significantly morphological variability following the same geographic extent [8,9,10,11], 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 [12], suggesting a second *shape boundary* between the ancestral Caddo area and central Texas.

The goal of this exploratory endeavor was to assess whether traditional metrics collected for Perdiz arrow points support the *shape boundary* posited in recent social network and geometric morphometric analyses, to determine whether linear metrics might be useful predictors of regional membership, and—if so—to identify those morphological features that articulate with each *behavioral region* using geometric morphometrics. It is assumed that complete



**Fig. 1** Historic Caddo network generated using ceramic and lithic types, which include Perdiz arrow points (DOI 10.17605/OSF.IO/WD2ZT), illustrating the two (north [blue] and south [red]) Caddo behavioral regions. The regions were identified using a modularity statistic to discern those nodes more densely connected to one another than to the rest of the network.

Perdiz arrow points included as offerings in Caddo burials represent the *design intent* of the maker. 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.

### 1.1 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* [13, 395].

General differences in Caddo ceramic forms have been noted elsewhere [14, 15]; 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 [10]. That preliminary observation was later confirmed using more robust samples of Hickory Engraved and Smithport Plain bottles [8,9], then expanded to include a greater variety of Caddo bottle types across a larger spatial and temporal extent [11].

The co-presence of diagnostic artifact and attribute types has been used to define Caddo phases and periods, which serve as a heuristic tool that aids archaeologists in explaining the local cultural landscape, as well as regional differences between local 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 the currently-defined categories [7]. This was achieved by enlisting a multi-scalar methodological approach [16,17], where northern and southern communities were parsed into constituent groups using the co-presence of diagnostic types paired with a modularity statistic [18,19]. Most of the constituent groups identified in the network analysis were found to articulate with known Caddo polities, while others were not [7].

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 [20]. The morphology of Gahagan bifaces from sites in central Texas was later found to differ significantly when compared with those recovered from the Caddo region [12]. That Gahagan bifaces were found to differ across two *spatial boundaries* was noteworthy, particularly since it has regularly been assumed that these large bifaces were manufactured in central Texas and arrived in the ancestral Caddo area as products of trade and/or exchange [12, 20]. 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 [11].

## 2 Methods and results

Sixty seven 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. Following collection, data were imported to R 4.1.1 [21] (supplementary materials), where boxplots were produced, along with a Principal Components Analysis (PCA) followed by analyses of variance (ANOVA) to test whether the morphology of Perdiz arrow points differs across the shape boundary (Fig.2).

Boxplots illustrate the distribution and mean for each of the five variables (Fig. 2a-e), and the PCA (Fig. 2f) illustrates over 92 percent of the variation in the sample among PC1 (84.65 percent) and PC2 (11.71 percent).

ANOVAs demonstrate significant differences in Perdiz arrow point morphology among four of the five variables (maximum length, width, stem length, and stem width) (supplementary materials). Maximum thickness does not differ significantly between the northern and southern communities, which led to the decision to conduct the subsequent geometric morphometric analysis as a two dimensional, rather than a three-dimensional, study (supplementary materials).

## 2.1 Predictive model

The utility of support vector machines to classify archaeological materials has increased with the rise of big data and digital repositories [22, 23, 24, 25]. For this effort, linear data were imported and modeled using the **scikit-learn** package in Python [26, 27] (supplementary materials). Data were 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

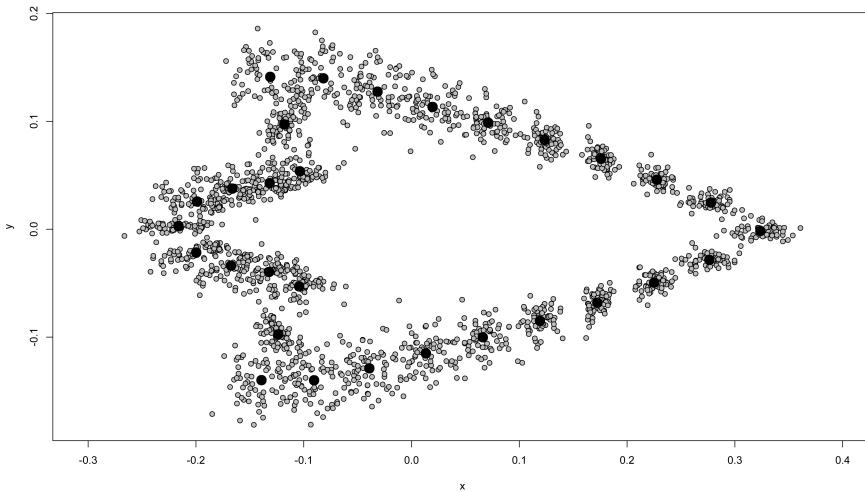
Each of the arrow points was imaged using a flatbed scanner (HP Scanjet G4050) at 600 dpi. The landmarking protocol developed for this study (supplementary materials) included six landmarks and 24 equidistant semilandmarks to characterize Perdiz arrow point shape, applied using the **StereoMorph** package in R [28]. The characteristic points and tangents used in the landmarking protocol were inspired by the work of Birkhoff [29].

Landmarks were aligned to a global coordinate system [30, 31, 32], achieved through generalized Procrustes superimposition [33] performed in R 4.1.1 [21] using the **geomorph** package v4.0.0 [34]. Procrustes superimposition translates, scales, and rotates the coordinate data allowing for comparisons among objects [35, 33]. 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 [36, 32] (Fig.3).

Principal components analysis [37] was used to visualize shape variation among the arrow points (Fig. 4). The shape changes described by each principal axis are commonly visualized using thin-plate spline warping of a reference image or 3D mesh [38, 39]. A residual randomization permutation procedure (RRPP; n = 10,000 permutations) was used for all Procrustes ANOVAs [40, 41], which has higher statistical power and a greater ability to identify patterns in the data should they be present [42]. To assess whether shape changes



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

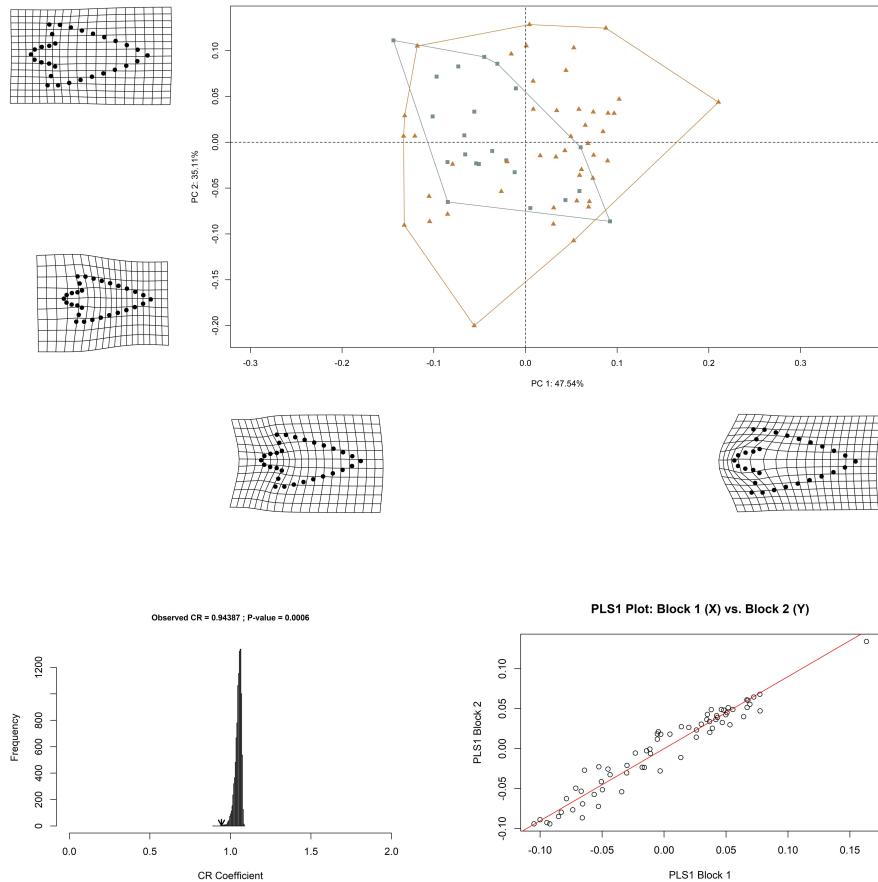


**Fig. 3** Results of generalized Procrustes analysis, illustrating mean shape (black) and all specimens in the sample (gray). Additional information related to the GPA, including those data and code needed to reproduce these results, can be found in the supplemental materials at <https://seldenlab.github.io/perdiz3/>.

with size (allometry), and differs by group (region), Procrustes ANOVAs [43] were also run that enlist effect-sizes (z-scores) computed as standard deviates of the generated sampling distributions [44]. Procrustes variance was used to discriminate between regions and compare the amount of shape variation (morphological disparity) [45], estimated as the Procrustes variance using residuals of linear model fit [46]. A pairwise comparison of morphological integration was used to test the strength of integration between blade and basal morphology using a z-score [47].

The analysis of modularity, which compares within-module covariation of landmarks against between-module covariation was significant (Fig. 4 and supplementary materials), demonstrated that Perdiz arrow point blades and bases are, in fact, modular. The test for morphological integration was also significant (Fig. 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 great utility in studies of Perdiz arrow point morphology that incorporate fragmentary specimens.

A Procrustes ANOVA was used to test whether a significant difference exists in Perdiz arrow point (centroid) size ( $RRPP = 10,000$ ;  $Rsq = 0.30681$ ;  $Pr(>F) = 1e-04$ ), followed by a second to test whether a significant difference exists in arrow point shape by region (northern vs. southern communities) ( $RRPP = 10,000$ ;  $Rsq = 0.0536$ ;  $Pr(>F) = 0.0161$ ). A comparison of mean consensus configurations was used to characterize intraspecific shape variation



**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 those data and code needed to reproduce these results, can be found in the supplemental materials at <https://seldenlab.github.io/perdiz3/>.

of Perdiz arrow points from the northern and southern *behavioral regions*. Diacritical morphology occurs primarily in basal shape, where the angle between the shoulder and base is more acute, and a base that is generally shorter and narrower in the southern *behavioral region* than it is in the north (supplementary materials).

### 3 Discussion

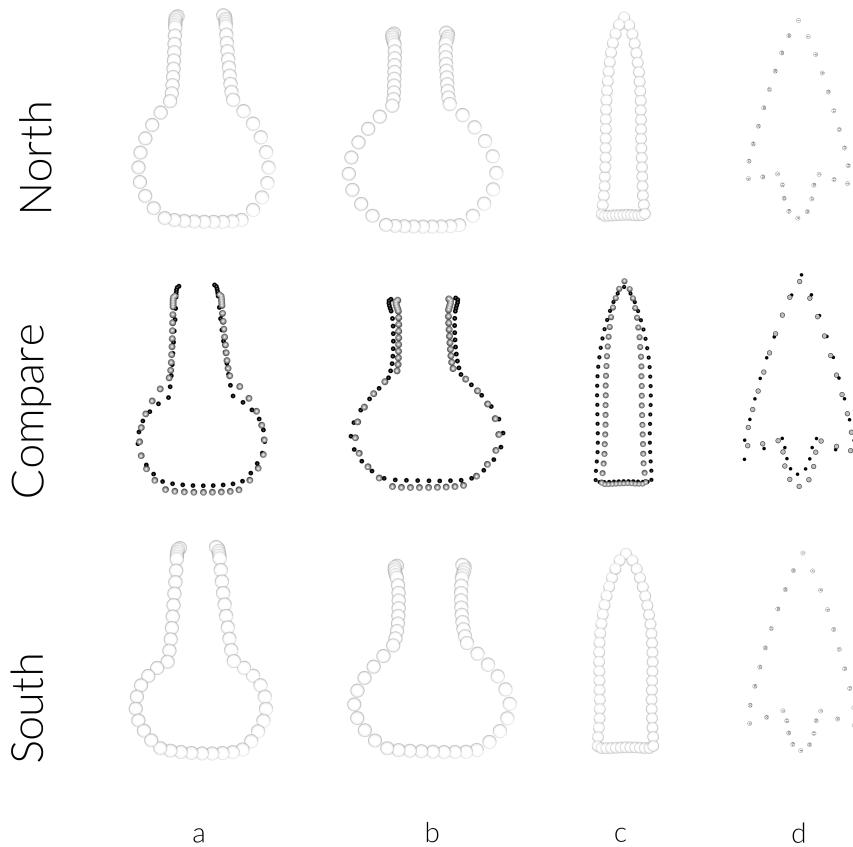
The *shape boundary* empirically delineates two discrete *behavioral regions* in the ancestral Caddo area. That the Perdiz arrow points recovered from Caddo burials north and south of the *shape boundary* were found to differ significantly, expands the scope of the *behavioral regions* to include three classes of artifacts (Caddo bottles, bifaces, and—now—arrow points) [8, 9, 10, 11, 12, 20]. For material culture offerings included in burial contexts, the Caddo were *selecting* for significant morphological differences in bottles and bifaces recovered from either side of the *shape boundary* (Fig. 5). Results clearly illustrate that those morphological differences among Perdiz arrow points found in the northern and southern *behavioral regions* (Fig. 5d) are predictable (supplementary materials), and can be disaggregated using the standard suite of linear metrics regularly collected in the context 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 Fig. 5). Allometry was also found to be significant, demonstrating that the shape of Perdiz arrow points differs with size. Those arrow points used in this study are considered to represent *design intent*, and are not thought to exhibit retouch or resharpening. This finding provides evidence in support of the argument that Perdiz arrow point morphology is labile [4].

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 base 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. Whether, and to what extent, it may be possible to identify specific groups of makers using unmodified arrow points from Caddo mortuary contexts remains unknown. Additional complexity is introduced when considering that Perdiz arrow points included in Caddo burials may have been manufactured elsewhere then transported to the ancestral Caddo territory, where they were potentially placed in burials by members of non-Caddo groups. This challenges the concept that all cultural material recovered from Caddo burials was manufactured by, and placed with the deceased, only by members of a specific Caddo family, group, or polity.

#### 3.1 Standardization and/or specialization

Morphological attributes are representative of intentional attributes related to morphological characteristics [48], and dimensional standardization has utility in identifying the range of variation and overlap of product morphology both in and between communities [49]. Further, relative dimensional standardiza-



**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.

tion may imply a smaller number of production units contrasted with larger production units [48].

While the Caddo bottles are representative of a complete system—or unit—the function of a biface (Perdiz arrow points and Gahagan bifaces in this context) is more limited, in that they represent only a single component of a much more dynamic system. Dimensional standardization in size has been identified for both the Caddo bottles and Gahagan bifaces. The similarities and differences in bottle shapes were found to transcend typological assignments, and bottles from the northern *behavioral region* were found to express a significantly greater diversity in size, yielding evidence for size standardization in the southern *behavioral region*. It is also the case that Gahagan bifaces from the Caddo area were found to express a significantly greater diversity in size compared to those from central Texas. These findings suggest that Caddo social tolerances, as they relate to burial traditions, may have been guided

by regionally-specific morphological traits that signaled group *membership* or *identity*.

### 3.2 Morphologically-distinct behavioral regions

In considering the role(s) of artifacts as aspects of *social identity*, it is important not to lose sight of the fact that people and artifacts are active agents in the production and maintenance of *social identity(ies)*. Both categories of artifacts (bottles and bifaces) contribute to local and regional *communities of identity* and *communities of practice* [50]. Generally, this concept may be more easily applied to bottles since they were manufactured and used by individuals sharing collective *Caddo identities*. Bifaces (Perdiz arrow points and Gahagan bifaces) 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 idea lends defensible credence to the concept 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 differ north and south of the *shape boundary*, indicate a haecceity of regionally-distinct perspectives related to production (bottles), and/or aesthetic choice/cultural interaction (bifaces). These differing perspectives incorporate group decisions that include shape, size, form, and decorative expression, which likely represent the culmination of generational perspectives [51]. Simply stated, such perspectives are representative of tradition. Eckert and colleagues [50] 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*. Perdiz arrow points and Gahagan bifaces recovered north and south of the *shape boundary* are morphologically distinct. 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, are not Caddo.

It is entirely possible that there are no *communities of practice* at all 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 the distinct retouch or resharpening approaches employed by Caddo knappers [4]. Similar interpretations can be applied to 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 non-local, or produced outside of the ancestral Caddo region, based on multiple factors that include raw material, workmanship, morphology, and context.

#### 4 Conclusion

This exploratory study demonstrated that linear metrics collected for Perdiz arrow points support the *shape boundary* posited in recent social network and geometric morphometric analyses, and determined that the same metrics can be used to predict regional membership. Those morphological features that discriminate between Perdiz arrow points recovered from each *behavioral region* were identified using geometric morphometrics, with the most substantial 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—more readily 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 [52]. Further work is warranted to expand the scope of this research program to include analyses of differential production within the two *behavioral regions* outlined in this study using a greater diversity of diagnostic Caddo artifact types.

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#### 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 at DOI: 10.17605/OSF.IO/UK9ZD.

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