Morphologically similar, but regionally distinct:   
Perdiz arrow points from Caddo burial contexts in the American Southeast

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Generally considered diagnostic of Late Prehistoric Toyah assemblages, Perdiz arrow points are characteristic of the transition from the Late Prehistoric to the Protohistoric. If larger Perdiz arrow points from Caddo burials are conceived of as products of trade and/or exchange with Toyah groups, then those with longer blade lengths provide inference to shifts in Caddo selective preference, while those with shorter blade lengths evince local approaches to resharpening and/or retouch that were uniquely Caddo. This study asks whether linear shape variables evince discrete regional resharpening strategies, whether morphological trajectories differ between the northern and southern behavioural regions, and whether morphological disparity differs between larger and smaller size classes, as defined by differences in blade length. Results demonstrate distinct regional resharpening strategies and morphological trajectories for Perdiz arrow points included as Caddo mortuary offerings in the northern and southern behavioural regions. Perdiz arrow point shapes were not found to differ in the large size class between the northern and southern behavioural regions, demonstrating consistency in Caddo preference, or—alternatively—Toyah manufacture. However, differences in the small size class suggest discrete local approaches to resharpening and/or retouch by Caddo knappers. Caddo groups that occupied the southern behavioural region may have also been less selective, preferring Perdiz arrow points with a greater range of diversity in shape and size, while their counterparts to the north preferred a more standardized product.

**Keywords**: computational archaeology, geometric morphometrics, phenotypic trajectory analysis, morphological disparity, museum studies, digital humanities, STEM, STEAM

Initially proposed by [Kelley (1947)](#_ENREF_34) and later revised by [Jelks (1962)](#_ENREF_30), the Toyah phase (CE 1250 – 1700) is among the most dynamic periods in Texas prehistory ([Collins 1995](#_ENREF_13)). It is representative of an effective and wide-spread bison hunting adaptation integrated with trade networks that linked the Mississippian villages of the American Southeast with the Pueblos of the American Southwest ([Spielmann 1991](#_ENREF_63)). Similarities in material culture assemblages thought to be associated with Toyah groups—which include Perdiz arrow points—have been documented across roughly 80% of Texas ([Johnson 1994](#_ENREF_31)). Caddo ceramics have been found in context with the Toyah toolkit outside of the ancestral Caddo region, and interpreted to be representative of trade and/or exchange with Caddo groups ([Arnn III 2012](#_ENREF_6); [Collins 1995](#_ENREF_13)). Decorative elements associated with Caddo ceramic wares adorn some of the bone-tempered ceramic vessels found in Toyah contexts, and geochemical data associated with ceramic artefacts supports links between the two groups ([Arnn III 2012](#_ENREF_6); [Ferguson et al. 2010](#_ENREF_22)). A more recent interpretation ([Carpenter 2017](#_ENREF_10)) suggests that the Caddo could have been active participants in seasonal long-range hunting efforts—in conjunction with several other groups across Texas—as the biogeographical range of bison expanded and contracted due to volatile paleoclimatic shifts in precipitation and aridity ([Lohse 2009](#_ENREF_39)).

Recent studies have demonstrated that Perdiz arrow points from Caddo burial contexts differ in morphology between the northern and southern Caddo behavioural regions ([Selden Jr. and Dockall 2022](#_ENREF_57)), and—when not limited to Caddo burial contexts—can also be said to differ through time, by raw material, and burial context ([Selden Jr et al. 2021](#_ENREF_51)). Perdiz arrow points are considered diagnostic of Toyah assemblages, and encompass a broad range of size and shape variation in comparison with other projectile points that occur in the region ([Suhm and Jelks 1962](#_ENREF_64); [Turner et al. 2011](#_ENREF_66)). Their presence in the ancestral Caddo region (Figure 1)—and in Caddo mortuary contexts—is also supportive of trade and/or exchange-based relationship/s between Toyah and Caddo groups. A recent social network analysis of Historic Caddo sites demonstrated two spatially distinct behavioural regions comprised of multiple subgroups ([Selden Jr. 2021a](#_ENREF_55)). The majority of those subgroups articulate with known cultural units in the larger ancestral Caddo region ([LaVere 1998](#_ENREF_38); [Newkumet and Meredith 1988](#_ENREF_42); [Perttula 1992](#_ENREF_46), [1993](#_ENREF_47)). 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 et al. 1954:504](#_ENREF_65)).

**Figure 1. Location of sites with Perdiz arrow points included in the study, extent of major drainage basins (Neches [brown], Sabine [maroon], and Red [navy] Rivers), and extent of the ancestral Caddo region (white). In the context of this effort, those sites from the Red River basin (navy) constitute the northern behavioural region, while those from the Sabine (maroon) and Neches (brown) River basins represent the southern behavioural region**.

Should Perdiz arrow points from Caddo burials be conceived of as products of trade and/or exchange with Toyah groups, then those with longer blade lengths may provide inference to shifts in Caddo selective preference, while those with shorter blade lengths may evince local approaches to resharpening and/or retouch that were uniquely Caddo (Figure 2). To evaluate change in Perdiz arrow point trajectories, two size classes were defined (large/small) for each behavioural region, conceptually representing the selective preference of Caddo traders (large), and local Caddo reduction and/or retouch practices (small). It was assumed at the outset that the smaller size class would exhibit a greater diversity of Perdiz arrow point shapes due to the range of responses by Caddo knappers necessary to address damage and breakage associated with use (Figure 2).

**Figure 2. Visualization of expectations 1) for Perdiz arrow point trajectories, where (a) morphological disparity in shape (dashed lines) is greater at a larger size (Caddo selective preference), and/or (b) morphological disparity in shape is greater at a smaller size (resharpening and/or retouch); where 2) morphological disparity in Perdiz arrow points is expected to be greater where blade length is shorter, due to episodic reduction or retouch; and 3) selected illustrations of Perdiz arrow points included with Caddo burials used in this study.**

**Methods**

In order to assess differences in Caddo selective preference, as well as resharpening and/or retouch trajectories between the northern and southern behavioural regions, the sample was divided into two *size classes* based on the mean maximum blade length of each region. Due to the potential preference in—and morphological variability associated with—raw material/s, the sample was subset by Caddo behavioural region prior to calculating the mean blade length, then assigned to large and small size classes based on whether the blade length of each Perdiz arrow point was larger or smaller than the mean. Following size class assignments, those data for the northern and southern Caddo behavioural regions were joined in advance of analysis.

The morphological form (shape + size) of the Perdiz arrow points was subsequently split into *shape* (representing proportions between dimensions in an object) and *size*. Size and shape were calculated using the method of log-shape ratios proposed by [Mosimann (1970)](#_ENREF_41), where the geometric mean is considered a proxy for size, and shape was calculated as the log of isometric size subtracted from the log of each linear/dimensional measure.

ANOVAs were used to identify differences between shape variables associated with Perdiz arrow point size classes from the northern and southern Caddo behavioural regions. Should a significant difference between behavioural regions be found, this would support the argument for differences in Caddo selective preference. Should a significant difference be found between the large and small size classes, that would convey proportional shape differences associated with local Caddo resharpening and/or retouch characteristics. Further information related to the analysis of linear shape variables, inclusive of all data and analysis code needed to reproduce the results, can be found in Chapter 2 of the supplementary materials.

*Geometric morphometrics*

Landmark data were aligned to a global coordinate system ([Kendall 1981](#_ENREF_35), [1984](#_ENREF_36); [Slice 2001](#_ENREF_62)), achieved through generalized Procrustes superimposition ([Rohlf and Slice 1990](#_ENREF_50)) performed in R 4.1.3 ([R Core Development Team 2022](#_ENREF_48)) using the geomorph ([Adams and Otárola-Castillo 2013](#_ENREF_4); [Baken et al. 2021](#_ENREF_9)) and RRPP libraries ([Adams and Collyer 2015](#_ENREF_3); [Collyer and Adams 2018](#_ENREF_16)). Procrustes superimposition translates, scales, and rotates the coordinate data to allow for comparisons among objects ([Gower 1975](#_ENREF_26); [Rohlf and Slice 1990](#_ENREF_50)). 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 ([Rohlf 1999](#_ENREF_49); [Slice 2001](#_ENREF_62)).

Principal components analysis ([Jolliffe 2002](#_ENREF_32)) was used to visualise shape variation among the Perdiz arrow points. The shape changes described by each principal axis are commonly visualized using thin-plate spline warping of a reference mesh ([Klingenberg 2013](#_ENREF_37); [Sherratt et al. 2014](#_ENREF_60)).

To assess whether shape changes with size (allometry) or differs by size class, Procrustes ANOVAs ([Goodall 1991](#_ENREF_25)) were run that enlist effect-sizes (zscores) computed as standard deviates of the generated sampling distributions ([Collyer et al. 2015](#_ENREF_18)). A residual randomization permutation procedure (RRPP; n = 10,000 permutations) was used for all Procrustes ANOVAs ([Adams and Collyer 2015](#_ENREF_3); [Collyer and Adams 2018](#_ENREF_16)), which has higher statistical power and a greater ability to identify patterns in the data should they be present ([Anderson and Ter Braak 2003](#_ENREF_5)).

A phenotypic trajectory analysis ([Adams and Collyer 2007](#_ENREF_1), [2009](#_ENREF_2); [Collyer and Adams 2007](#_ENREF_14), [2013](#_ENREF_15); [Collyer et al. 2015](#_ENREF_18)) was used to assess whether Caddo reduction or retouch trajectories differ between the northern and southern behavioural regions. The trajectory analysis was followed by an analysis of morphological disparity ([Collyer and Adams 2020](#_ENREF_17); [Foote 1993](#_ENREF_23); [Zelditch et al. 2004](#_ENREF_67)) to assess morphological diversity between size classes. Additional information related to the analysis of linear metrics, inclusive of all data and the analysis code needed to reproduce these results, can be found in Chapter 3 of the supplementary materials.

**Results**

Linear shape variables associated with Perdiz arrow point hafting elements (maximum stem length and stem width) were found to be morphologically stable in the northern and southern behavioural regions. However, attributes associated with blade morphology (maximum blade length, shoulder width, and width) were more dynamic. Blade length was found to differ significantly between the large and small size classes in both behavioural regions. While both shoulder width and width were stable between size classes in the northern behavioural region, they differed in the southern behavioural region (Figure 3). This suggests two distinct Caddo resharpening and/or retouch trajectories; one in the north where blade length was reduced but shoulder width remained stable, and another in the south where the entirety of the lateral edge was resharpened, resulting in a significant reduction in blade length and shoulder width.

**Figure 3. Conceptual rendering of differences found to occur between Perdiz arrow point resharpening trajectories in the a, northern; and b, southern behavioural regions. In both cases, attributes associated with hafting—maximum stem length and stem width—are morphologically stable. However, differential approaches to resharpening and/or retouch resulted in distinct shape differences in Perdiz arrow point blades. Resharpening and/or retouch efforts of Caddo knappers from the northern behavioural region was limited to maximum blade length, while those from the southern behavioural region were found to be more dynamic, including changes in maximum blade length, width, and shoulder width that occur between size classes.**

*Geometric morphometrics*

Principal components analysis (PCA) was conducted on scaled, translated, and rotated landmarks. PC1 accounts for 47.54% of the variation, and PC2 accounts for 35.11% of the variation, representing a combined 82.65% of shape variation in the sample. The plot visually illustrates shape changes primarily associated with Perdiz arrow point bases (PC1) and blade shapes (PC2) (Figure 4).

**Figure 4. PCA by size class, where PC1 is primarily associated with variability in base shape, and PC2 with blade shape.**

A Procrustes ANOVA was used to test for a difference in Perdiz arrow point shape and size by size class. Perdiz arrow point shape was found to differ between large and small size classes in the northern behavioural region, but not in the south. The shape of the large size class does not differ between behavioural regions; however, size does. The comparison of Perdiz arrow points in the small size class demonstrates that they differ in both shape and size. Allometry was found to be significant, and the homogeneity of slopes test indicates that slopes associated with large and small Perdiz arrow points from the northern and southern Caddo behavioural regions differ (Figure 5).

**Figure 5. The homogeneity of slopes test indicates that the slopes associated with large and small Perdiz arrow points from the northern and southern behavioural regions differ. This figure plots the first principal component of predicted values versus size as a stylized graphic of the allometric trend.**

Analyses of modularity and morphological integration returned significant results, and results of the trajectory analysis demonstrates a significant difference between shape trajectories for the northern and southern behavioural regions (Figure 6). The morphological disparity analysis by shape demonstrated that large Perdiz arrow points from the southern behavioural region occupy a significantly greater range of morphospace than the large and small Perdiz arrow points from the northern behavioural region. Additionally, the analysis of morphological disparity by size demonstrated that the large Perdiz arrow points from the southern behavioural region occupy a significantly greater range of morphospace than the large Perdiz arrow points from the northern behavioural region.

**Figure 6. Visualization of two shape trajectories for Perdiz arrow points (large/small) that occur in the northern and southern behavioural regions. Shape trajectories are projected onto the first two principal components of between-group shape variation (based on covariance matrix of group means). Trajectories are shown as lines, where the northern behavioural region is represented by squares, and the southern behavioural region by triangles. Transformations are added to facilitate an understanding of shape differences corresponding to large and small Perdiz arrow point shapes from each behavioural region.**

**Discussion**

If the production of certain craft items for a community is limited to a small number of individuals who devote some of their productive time to the manufacture of these craft products; then these specialists cannot participate in some or all of the basic community subsistence activities and must obtain part or all of their subsistence goods through exchange for their craft products ([Evans 1978:115](#_ENREF_21)).

Correlations between specialization and standardization have often, but not always, been supported by ethnographic and experimental data ([Clark 1986](#_ENREF_12); [Hardin 1979](#_ENREF_28); [Sinopoli 1988](#_ENREF_61)). In the case of material culture from Caddo burials in the northern and southern behavioural regions ([Selden Jr. 2018a](#_ENREF_52), [2018b](#_ENREF_53), [2019](#_ENREF_54), [2021b](#_ENREF_56); [Selden Jr. et al. 2020](#_ENREF_58); [Selden Jr. et al. 2018](#_ENREF_59)), bottle and biface morphologies communicate important information related to group affiliation through deliberate and differential production (bottles) as well as selective preference or aesthetic choice (bifaces) ([sensu Hodder and Renfrew 1982](#_ENREF_29)).

Morphological attributes are representative of intentional attributes related to morphological characteristics ([Costin 2005](#_ENREF_19)), and dimensional standardization has utility in identifying the range of variation and overlap of product morphology both in and between communities ([Arnold III 1991](#_ENREF_7)). Further, relative dimensional standardization may imply a smaller number of production units when contrasted with larger units ([Costin 2005](#_ENREF_19)). Standardization can also result from raw material selection and (for lithics) reduction practices ([Chase 1991](#_ENREF_11); [Dibble 1989](#_ENREF_20); [Monnier 2006](#_ENREF_40); [Nowell 2002](#_ENREF_43)), and has been conceptually linked to the notion of approximating a perceived ideal through the realization of a mental template ([Keller and Keller 1996](#_ENREF_33)).

The lens of this investigation is focused on Perdiz arrow points included as offerings in Caddo burials, and not on Toyah production. However, these projectiles may be reflective of Toyah craft specialization, in which—following [Evans (1978)](#_ENREF_21)—trade and/or exchange resulted in the distribution of *craft items* and the acquisition of raw materials. While the provenance of a mental template associated with the manufacture of Perdiz arrow points is relegated to Toyah producers, acquisition of Perdiz arrow points by the Caddo demonstrates strong selective preference for a particular shape that was common across both behavioural regions, and may have some bearing on Toyah production constraints. However, there were differences in size preference between behavioural regions, where the Caddo selected for smaller Perdiz arrow points in the north, and larger Perdiz arrow points in the south. Thus, while Caddo selective preference associated with Perdiz arrow point *shape* was dimensionally standardized between the Caddo behavioural regions, *size* was not.

It is possible that this pattern is indicative of differing behaviours related to acquisition. Whether that manifested as trade and/or exchange with different Toyah groups (production units?), or whether the Caddo in the northern behavioural region simply preferred smaller Perdiz arrow points is unknown. The difference may also have been expressed in economic terms, where one size may have held greater value, potentially expressed as social capital. Further, given the pattern/s associated with retouch, it may be that the Caddo were using Perdiz arrow points for different reasons; where one group used it as a projectile, while the other used it as a hafted cutting implement. Counts of larger Perdiz arrow points from Caddo burials in the southern behavioural region are higher than they are in the north, and include a greater diversity of sizes. This raises the question of whether commerce with Toyah groups was limited to Caddo traders from one behavioural region, where Caddo from the adjacent region were dependent on their peers, or another (Toyah?) intermediary, for access. Might that also account for consistency in Caddo selective preference related to *shape* for Perdiz arrow points in the large size class, and might that practice have resulted in Caddo burials from the southern behavioural region evincing a greater diversity in Perdiz arrow point *size*?

*On Caddo resharpening and/or retouch*

In contrast to the large size class considered to be products of Caddo commerce with Toyah groups, those Perdiz arrow points in the smaller size class were considered indicative of local approaches to resharpening and/or retouch that were uniquely Caddo. The analysis of linear shape variables demonstrated two discrete approaches to resharpening and/or retouch used by Caddo knappers in the northern and southern behavioural regions (see Figure 3). The trajectory analysis was used to assess patterns of shape change in Perdiz arrow points, and results demonstrate that resharpening and/or retouch trajectories in the northern and southern Caddo behavioural regions differ significantly (see Figure 6).

Comparisons of Perdiz arrow point morphology in each region demonstrated a significant difference in shape between the large and small size classes in the northern behavioural region, but not in the south. Thus, while resharpening practices in the north resulted in an appreciably different shape, it did not in the south. The comparison of size between the large and small size classes in each behavioural region did not yield a result that rose to the level of statistical significance. Between-region comparisons demonstrated that the Perdiz arrow points in the large size class were significantly larger in the southern behavioural region. Between-region comparisons of the small size class demonstrate significant differences in both shape and size, yielding additional support for two discrete Caddo resharpening trajectories. The initial expectation that Perdiz arrow points in the smaller size class would include a greater diversity of shapes due to differential resharpening and/or retouch practices required to address breakage associated with regular use was proven incorrect. While greater diversity was exhibited in the large size class between the northern and southern Caddo behavioural regions, comparisons of morphological disparity between large and small size classes in the northern and southern behavioural regions did not yield a significant result.

*Comparisons of Toyah-produced and Caddo-resharpened Perdiz arrow points*

These findings suggest a potential methodological avenue for comparing Perdiz arrow points found in the Toyah region with those found in and across peripheral/adjacent regions using the larger size class. Similarly, this approach may have utility in elucidating differential resharpening and/or retouch practices for other morphological types ([sensu O'Brien and Lyman 1999](#_ENREF_44)), where those attributes are expected to differ. Further work will be needed to clarify whether the approach yields similar results for general contexts outside of burials.

Given the broad range of morphology associated with Perdiz arrow points, and the diversity of fauna that they were used to hunt—including humans ([Aynesworth 1936](#_ENREF_8))—it would, perhaps, not be surprising to find that different groups expressed preferences associated with different morphological constraints. Should that be the case, it may be possible to leverage morphological traits to spatially delimit an area of the Toyah region where Perdiz arrow points were manufactured for trade and/or exchange with specific contemporary groups. Whether, and to what extent, Perdiz arrow points reflect Caddo selective preference is debatable; however, the fact that a specific shape—but not size—was preferred by the Caddo, or at minimum, preferred for Caddo burials, may yield those data needed to posit a potential locus of Toyah production. It is also possible that the morphological diversity found to occur in Perdiz arrow point shape and size may be reflective of differences in raw material size and preference.

**Conclusion**

This study asked whether linear shape variables evince discrete regional resharpening strategies, whether morphological trajectories differ between the northern and southern behavioural regions, and whether morphological disparity differs between larger and smaller size classes, as defined by differences in blade length. Results demonstrated differing regional resharpening strategies, and distinct morphological trajectories for Perdiz arrow points included as Caddo mortuary offerings in the northern and southern behavioural regions. Perdiz arrow point shapes were not found to differ in the large size class between the northern and southern behavioural regions, demonstrating consistency in Caddo preference, or—alternatively—Toyah manufacture. However, differences in the small size class suggest distinct local approaches to resharpening and/or retouch by Caddo knappers. Caddo groups that occupied the southern behavioural region may have been less selective, trading for Perdiz arrow points with a greater range of diversity in shape and size, while their counterparts to the north preferred a more standardized product.

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**Data management**

The data and analysis code associated with this project can be accessed through the supplementary materials (<https://seldenlab.github.io/perdiz.4/>) or the GitHub repository (<https://github.com/seldenlab/perdiz.4>), which is digitally curated on the Open Science Framework (<https://osf.io/85bu7/>). The replicable nature of this undertaking provides a means for others to critically assess and evaluate the various analytical components of this study (sensu [Gandrud 2014](#_ENREF_24); [Gray and Marwick 2019](#_ENREF_27); [Peng 2011](#_ENREF_45)), which is a necessary requirement for the production of reliable knowledge.

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