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

Robert Z. SELDEN, Jr.

DO NOT CITE IN ANY CONTEXT WITHOUT PERMISSION OF THE AUTHOR

**Robert Z. SELDEN, Jr.**, Heritage Research Center, Stephen F. Austin State University (US), Department of Biology, Stephen F. Austin State University (US), and Cultural Heritage Department, Jean Monnet University (FR) ([zselden@sfasu.edu](mailto:zselden@sfasu.edu))

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 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 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_64)). Similarities in material culture assemblages thought to be associated with Toyah groups include Perdiz arrow points, blade and scraper technology, and bone-tempered ceramics, which 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 also adorn some of the bone-tempered ceramic vessels, 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_40)).

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_58)), 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_52)). 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_65); [Turner, et al. 2011](#_ENREF_67)). 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_56)). The majority of those subgroups articulate with known cultural units in the larger ancestral Caddo region ([LaVere 1998](#_ENREF_39); [Newkumet and Meredith 1988](#_ENREF_43); [Perttula 1992](#_ENREF_47), [1993](#_ENREF_48)). 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_66)).

**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).**

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 selection or 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 selection 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 (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 for morphological differences associated with local raw material availability ([Selden Jr, et al. 2021:Figure 2](#_ENREF_52)), the sample was subset by Caddo behavioural region prior to calculating the mean blade length, then assigning 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 assignment, the datasets 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 then split into *shape* (representing proportions between dimensions in an object) and *size*, sensu [Klingenberg (2016)](#_ENREF_38). Size and shape were calculated using the method of log-shape ratios proposed by [Mosimann (1970)](#_ENREF_42), 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 the northern and southern 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 1 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_63)), achieved through generalized Procrustes superimposition ([Rohlf and Slice 1990](#_ENREF_51)) performed in R 4.1.3 ([R Core Development Team 2022](#_ENREF_49)) 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_51)). 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_50); [Slice 2001](#_ENREF_63)).

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_61)).

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_68)) 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 2 of the supplementary materials.

**Results**

Linear 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 the northern and southern 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 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 within the sample. The plot visually illustrates shape changes in Perdiz arrow point base (PC1) and blade shape (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_62)). In the case of material culture from Caddo burials in the northern and southern behavioural regions ([Selden Jr. 2018a](#_ENREF_53), [2018b](#_ENREF_54), [2019](#_ENREF_55), [2021b](#_ENREF_57); [Selden Jr., et al. 2020](#_ENREF_59); [Selden Jr., et al. 2018](#_ENREF_60)), 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_41); [Nowell 2002](#_ENREF_44)), 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 (differing 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. 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 northern and southern behavioural regions evincing a greater diversity of Perdiz arrow point *sizes*?

*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. The between-region comparison of the small size class demonstrates a significant difference in 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 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 projectiles from 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_45)), 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 those morphological traits to identify a general area in the broader Toyah region where those projectiles may have been manufactured. 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 may yield additional clues associated with the locus of Toyah production. It is also possible that the morphological diversity found to occur in Perdiz arrow point shape and size may reflect differences in raw material 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.

**Acknowledgments**

I extend my gratitude to the Caddo Nation of Oklahoma, the Caddo Nation Tribal Council, Tribal Chairman, and Tribal Historic Preservation Office for their guidance related to the development of the scanning protocols, for permission and access to NAGPRA and previously repatriated collections, and for frank discussions related to language surrounding burial contexts associated with Caddo children. Thanks also to the Anthropology and Archaeology Laboratory at Stephen F. Austin State University for the requisite permissions and access to the NAGPRA items from the Washington Square Mound site and Turner collection, and to Tom A. Middlebrook for brokering access to the Perdiz arrow points from Caddo burials at the Morse Mound site. Thanks also to John E. Dockall, Michael J. Shott, Lauren N. Butaric, David K. Thulman, Timothy K. Perttula, Jeffrey S. Girard, Hiram F. (Pete) Gregory, Thomas R. Hester, Harry J. Shafer, Bonnie L. Etter, Kersten Bergstrom, Christian S. Hoggard, Emma Sherratt, Dean C. Adams, and Michael L. Collyer for their constructive criticisms, comments, and suggestions throughout the development of this research program, and to the editors and anonymous reviewers for their comments and constructive criticisms, which further improved the manuscript.

**Funding**

Components of this analytical workflow were developed and funded by a Preservation Technology and Training grant (P14AP00138) to RZS from the National Center for Preservation Technology and Training, as well as grants to RZS from the Caddo Nation of Oklahoma, National Forests and Grasslands in Texas (15-PA-11081300-033) and the United States Forest Service (20-PA-11081300-074). Additional support for this project was provided by the Heritage Research Center at Stephen F. Austin State University.

**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_46)), which is a necessary requirement for the production of reliable knowledge.

**References Cited**

Adams, Dean C. and Michael L. Collyer

2007 Analysis of Character Divergence along Environmental Gradients and other Covariates. *Evolution* 61(3):510-515. DOI: 10.1111/j.1558-5646.2007.00063.x

2009 A General Framework for the Analysis of Phenotypic Trajectories in Evolutionary Studies. *Evolution* 63(5):1143-1154. DOI: 10.1111/j.1558-5646.2009.00649.x

2015 Permutation Tests for Phylogenetic Comparative Analyses of High-Dimensional Shape Data: What you Shuffle Matters. *Evolution* 69(3):823-829. DOI: 10.1111/evo.12596

Adams, Dean C. and Erik Otárola-Castillo

2013 geomorph: An R Package for the Collection and Analysis of Geometric Morphometric Shape Data. *Methods in Ecology and Evolution* 4(4):393-399. DOI: 10.1111/2041-210x.12035

Anderson, Marti J. and Cajo J. F. Ter Braak

2003 Permutation Tests for Multi-Factoral Analysis of Variance. *Journal of Statistical Computation and Simulation* 73(2):85-113. DOI: 10.1080=0094965021000015558

Arnn III, John Wesley

2012 *Land of the Tejas: Native American Identity and Interaction in Texas, A.D. 1300 - 1700*. The University of Texas Press, Austin.

Arnold III, Philip J.

1991 Dimensional Standardization and Production Scale in Mesoamerican Ceramics. *Latin American Antiquity* 2(4):363-370. DOI: 10.2307/971784

Aynesworth, K. H.

1936 Flint Arrowhead Wounds of Bones as Shown in Skeletons in Central Texas. *Central Texas Archeological Society* 2:74-79.

Baken, Erica K., Michael L. Collyer, Antigoni Kaliontzopoulou and Dean C. Adams

2021 geomorph v4.0 and gmShiny: Enhanced analytics and a new graphical interface for a comprehensive morphometric experience. *Methods in Ecology and Evolution* 10.1111/2041-210x.13723. DOI: 10.1111/2041-210x.13723

Carpenter, Stephen M.

2017 The Toyah Complex of South and Central Texas: Long-Range Mobility and the Emergence of Dual Economies. *Plains Anthropologist* 62(242):133-156. DOI: 10.1080/00320447.2016.1258858

Chase, Philip G

1991 Symbols and Paleolithic artifacts: Style, standardization, and the imposition of arbitrary form. *Journal of Anthropological Archaeology* 10(3):193-214.

Clark, John E

1986 From mountains to molehills: A critical review of Teotihuacan's obsidian industry. *Research in economic anthropology, supplement* 2(1986):23-74.

Collins, Michael B.

1995 Forty Years of Archaeology in Central Texas. *Bulletin of the Texas Archeological Society* 66:361-400.

Collyer, Michael L. and Dean C. Adams

2007 Analysis of Two-State Multivariate Phenotypic Change in Ecological Studies. *Ecology* 88(3):683-692. DOI: 10.1890/06-0727

2013 Phenotypic Trajectory Analysis: Comparison of Shape Change Patterns in Evolution and Ecology. *Hystrix* 24(1):75-83. DOI: doi:10.4404/hystrix-24.1-6298

2018 RRPP: An R Package for Fitting Linear Models to High-Dimensional Data using Residual Randomization. *Methods in Ecology and Evolution* 9(7):1772-1779. DOI: <https://doi.org/10.1111/2041-210X.13029>

2020 Phylogenetically aligned component analysis. *Methods in Ecology and Evolution* 12(2):359-372. DOI: 10.1111/2041-210x.13515

Collyer, Michael L., David J. Sekora and Dean C. Adams

2015 A Method for Analysis of Phenotypic Change for Phenotypes Described by High-Dimensional Data. *Heredity* 115(4):357-365. DOI: 10.1038/hdy.2014.75

Costin, Cathy L.

2005 Craft Production*.* In *Handbook of Archaeological Methods*, edited by Jerbert D. G. Maschner, pp. 1034-1107. AltaMira, Walnut Creek.

Dibble, Harold L

1989 The implications of stone tool types for the presence of language during the Lower and Middle Palaeolithic. *The human revolution: Behavioural and biological perspectives on the origins of modern humans* 1:415-431.

Evans, Robert K.

1978 Early Craft Specialization: An Example from the Balkan Chalcolithic*.* In *Social Archaeology: Beyond Subsistence and Dating*, edited by C. L. Redman, M. J. Berman, E. V. Curtin, W. T. Langhorne Jr., N. M. Versaggi and J. C. Wanser, pp. 113-129. Academic Press, New York.

Ferguson, Jeffrey R., Timothy K. Perttula and Michael D. Glascock

2010 Dividing Up the Caddo Cultural Landscape: Small-Scale Analysis of a Large Ceramic INAA Database*.* In *Studies on the Instrumental Neutron Activation Analysis of Woodland and Caddo Tradition Ceramics from Eastern Texas*, edited by Timothy K. Perttula. vol. Special Publication No. 17. Friends of Northeast Texas Archaeology, Austin and Pittsburg.

Foote, M.

1993 Contributions of Individual Taxa to Overall Morphological Disparity. *Paleobiology* 19(4):403-419.

Gandrud, Christopher

2014 *Reproducible Research with R and RStudio*. The R Series. CRC Press, London.

Goodall, Colin

1991 Procrustes Methods in the Statistical Analysis of Shape. *Journal of the Royal Statistical Society. Series B (Methodological)* 53(2):285-339.

Gower, J. C.

1975 Generalized Procrustes Analysis. *Psychometrika* 40(1):33-51. DOI: <https://doi.org/10.1007/BF02291478>

Gray, Charles T. and Ben Marwick

2019 Truth, Proof, and Reproducibility: There’s No Counter-Attack for the Codeless*.* In *Statistics and Data Science*, pp. 111-129. Communications in Computer and Information Science10.1007/978-981-15-1960-4\_8. DOI: 10.1007/978-981-15-1960-4\_8

Hardin, Margaret A

1979 The cognitive basis of productivity in a decorative art style: implications of an ethnographic study for archaeologists’ taxonomies. *Ethnoarchaeology: Implications of ethnography for archaeology*:75-101.

Hodder, Ian and Colin Renfrew

1982 *Symbols in action: ethnoarchaeological studies of material culture*. Cambridge University Press.

Jelks, Edward B.

1962 *The Kyle Site: A Stratified Central Texas Aspect Site in Hill Country, Texas*. The University of Texas, Department of Anthropology, Archaeology Series, No. 5.

Johnson, LeRoy

1994 *The Life and Times of Toyah-Culture Folk: The Buckhollow Encampment Site 41KM16, Kimble County, Texas*. Texas Department of Transportation and Office of the State Archeologist Report 38. Austin, Texas.

Jolliffe, Ian T.

2002 *Principal Component Analysis*. Springer, New York.

Keller, Charles M and Janet Dixon Keller

1996 *Cognition and tool use: The blacksmith at work*. Cambridge University Press.

Kelley, J. Charles

1947 The Cultural Affiliations and Chronological Position of the Clear Fork Focus. *American Antiquity* 13(2):97-109. DOI: 10.2307/275682

Kendall, David G.

1981 The Statistics of Shape*.* In *Interpreting Multivariate Data*, edited by Vic Barnett, pp. 75-80. Wiley, New York.

1984 Shape Manifolds, Procrustean Metrics, and Complex Projective Spaces. *Bulletin of the London Mathematical Society* 16(2):81-121. DOI: 10.1112/blms/16.2.81

Klingenberg, Christian Peter

2013 Visualizations in Geometric Morphometrics: How to Read and How to Make Graphs Showing Shape Changes. *Hystrix* 24:15-24.

2016 Size, shape, and form: concepts of allometry in geometric morphometrics. *Dev Genes Evol* 226(3):113-137. DOI: 10.1007/s00427-016-0539-2

LaVere, David

1998 *The Indians of Texas*. Texas A&M University Press, College Station.

Lohse, Jon C.

2009 *Archaeological investigations on the Herd Ranch in Western Menard County, Texas*. Texas State University.

Monnier, Gilliane

2006 Testing Retouched Flake Tool Standardization During the Middle Paleolithic: Patterns and Implications. *Transitions Before the Transition: Evolution and Stability in the Middle Stone Age*:57-83.

Mosimann, James E.

1970 Size Allometry: Size and Shape Variables with Characterizations of the Lognormal and Generalized Gamma Distributions. *Journal of the American Statistical Association* 65(330):930-945. DOI: 10.1080/01621459.1970.10481136

Newkumet, Vynola Beaver and Howard L. Meredith

1988 *Hasinai: A Traditional History of the Caddo Confederacy*. Texas A&M University Press, College Station.

Nowell, April

2002 Coincidental factors of handaxe morphology. *Behavioral and Brain Sciences* 25(3):413-414.

O'Brien, Michael J. and R. Lee Lyman

1999 *Seriation, Stratigraphy, and Index Fossils: The Backbone of Archaeological Dating*. Kluwer Academic/Plenum Publishers, New York.

Peng, Roger D.

2011 Reproducible Research in Computational Science. *Science* 334(6060):1226-1227. DOI: 10.1126/science.1213847

Perttula, Timothy K.

1992 *"The Caddo Nation": Archaeological and Ethnohistoric Perspectives*. University of Texas Press, Austin.

1993 Kee-Oh-Na-Wah'-Wah: The Effects of European Contact on the Caddoan Indians of Texas, Louisiana, Arkansas and Oklahoma*.* In *Ethnohistory and Archaeology: Approaches to Postcontact Change in the Americas*, edited by J. D. Rogers and S. M. Wilson, pp. pp. 89-109. Plenum Press, New York.

R Core Development Team

2022 *R: A Language and Environment for Statistical Computing. Electronic resource,*. R Foundation for Statistical Computing, Vienna, Austria.

Rohlf, F. James

1999 Shape Statistics: Procrustes Superimpositions and Tangent Spaces. *Journal of Classification* 16(2):197-223. DOI: 10.1007/s003579900054

Rohlf, F. James and Dennis E. Slice

1990 Extensions of the Procrustes Method for the Optimal Superimposition of Landmarks. *Systematic Zoology* 39(1):40-59. DOI: 10.2307/2992207

Selden Jr, Robert Z., John E. Dockall, C. Britt Bousman and Timothy K. Perttula

2021 Shape as a function of time + raw material + burial context? An exploratory analysis of Perdiz arrow points from the ancestral Caddo area of the American Southeast. *Journal of Archaeological Science: Reports* 37:102916. DOI: 10.1016/j.jasrep.2021.102916

Selden Jr., Robert Z.

2018a Ceramic Morphological Organisation in the Southern Caddo Area: Quiddity of Shape for Hickory Engraved Bottles. *Journal of Archaeological Science: Reports* 21:884-896. DOI: 10.1016/j.jasrep.2018.08.045

2018b A Preliminary Study of Smithport Plain Bottle Morphology in the Southern Caddo Area. *Bulletin of the Texas Archeological Society* 89:63-89.

2019 Ceramic Morphological Organisation in the Southern Caddo Area: The Clarence H. Webb Collections. *Journal of Cultural Heritage* 35:41-55. DOI: 10.1016/j.culher.2018.07.002

2021a An Exploratory Network Analysis of the Historic Caddo Period in Northeast Texas*.* In *Ancestral Caddo Ceramic Traditions*, edited by Duncan P. McKinnon, Timothy K. Perttula and Jeffrey S. Girard, pp. 240-257. LSU Press, Baton Rouge.

2021b Louisiana Limitrophe: An Iterative Morphological Exegesis of Caddo Bottle and Biface Production*.* In *Ancestral Caddo Ceramic Traditions*, edited by Duncan P. McKinnon, Jeffrey S. Girard and Timothy K. Perttula, pp. 258-276. LSU Press, Baton Rouge.

Selden Jr., Robert Z. and John E. Dockall

2022 Perdiz arrow points from Caddo burial contexts aid in defining discrete behavioral regions*.* In *Geometric Morphometrics in Archaeology*, edited by Robert Bishoff, Bonnie L. Etter and Robert Z. Selden Jr., pp. (in review). Springer|Nature, New York.

Selden Jr., Robert Z., John E. Dockall and Morgane Dubied

2020 A quantitative assessment of intraspecific morphological variation in Gahagan bifaces from the southern Caddo area and central Texas. *Southeastern Archaeology* 39(2):125-145. DOI: 10.1080/0734578x.2020.1744416

Selden Jr., Robert Z., John E. Dockall and Harry J. Shafer

2018 Lithic Morphological Organisation: Gahagan Bifaces from the Southern Caddo Area. *Digital Applications in Archaeology and Cultural Heritage* 10:e00080. DOI: 10.1016/j.daach.2018.e00080

Sherratt, Emma, David J. Gower, Christian P. Klingenberg and Mark Wilkinson

2014 Evolution of Cranial Shape in Caecilians (Amphibia: Gymnophiona). *Evolutionary Biology* 41:528-545. DOI: <https://doi.org/10.1007/s11692-014-9287-2>

Sinopoli, Carla M.

1988 The Organization of Craft Production at Vijayanagara, South India. *American Anthropologist* 90(3):580-597. DOI: <https://doi.org/10.1525/aa.1988.90.3.02a00040>

Slice, Dennis E.

2001 Landmark Coordinates Aligned by Procrustes Analysis Do Not Lie in Kendall's Shape Space. *Systematic Biology* 50(1):141-149. DOI: 10.1080/10635150119110

Spielmann, Katherine A.

1991 *Farmers, Hunters, and Colonists: Interaction Between the Southwest and the Southern Plains*. University of Arizona Press, Tucson.

Suhm, Dee Ann and Edward B. Jelks

1962 *Handbook of Texas Archeology: Type Descriptions*. Special Publication No. 1. Texas Archeological Society and Bulletin No. 4, Texas Memorial Museum, Austin.

Suhm, Dee Ann, Alex D. Krieger and Edward B. Jelks

1954 An Introductory Handbook of Texas Archeology. *Bulletin of the Texas Archeological Society* 25:1-562.

Turner, E. S., T. R. Hester and R. L McReynolds

2011 *Stone Artifacts of Texas Indians: Completely Revised Third Edition*. Taylor Trade Publishing, Lanham, Maryland.

Zelditch, Miriam Leah, Donald L. Swiderski, H. David Sheets and William L. Fink

2004 *Geometric Morphometrics for Biologists : A Primer*. Elsevier Science, Burlington.