

## 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 has yielded evidence for distinct *behavioral regions*, across which material culture from Caddo burials—Hickory Engraved and Smithport Plain bottles as well as Gahagan bifaces—have 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 communities of practice 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 and size, coupled with significant

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results for modularity and morphological integration. These findings bolster the argument for the establishment of at least two discrete *behavioral regions* in the ancestral Caddo area defined by 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 both morphology and size [4,5]. It has been demonstrated elsewhere that 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 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 different morphologies between the same two areas [8,9,10,11], extending the temporal range of the shape boundary. Gahagan bifaces from the ancestral Caddo area also differ significantly in shape, size, and form from those recovered at central Texas sites [12], suggestive of a second shape boundary between the Caddo region 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 Perdiz arrow points included as offerings in Caddo burials represent the design intent of the maker. Should the analysis yield significant results, it would



**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 identify those nodes more densely connected to one another than to the rest of the network .

bolster the argument for at least two discrete Caddo *behavioral regions*; 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, 16]; 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 extent [11].

The co-presence of diagnostic artifact and attribute types have been used to define the Caddo phases and periods that serve as a heuristic tool to aid archaeologists in explaining the local cultural landscape. The Historic Caddo network expounds upon those efforts, by building upon the previously defined phases and periods, and emphasizing the dynamic and manifold relational connections that transcend the currently-defined categories [7]. This was achieved by enlisting a multi-scalar methodological approach [17,18], where the northern and southern communities were parsed into constituent groups using diagnostic types paired with a modularity statistic [19,20]. A number of the constituent groups identified by the networks 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 [21]. 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 or exchange [12,21]. 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].

Perdiz arrow points were among the diagnostic artifact types included in the Historic Caddo network analysis [7], and it is expected that they will differ across the shape boundary; however, it remains unknown whether Caddo Perdiz arrow points might be said to differ by or through temporal periods in the northern and southern communities.

## 2 Methods and results

The sample of Perdiz arrow points used in this study consists of 67 intact specimens from Caddo burials in Camp, Nacogdoches, and Shelby counties (supplementary materials). A standard suite of linear metrics was collected for each specimen, including maximum length, width, thickness, stem length, and stem width. Following collection, data were imported to R (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 means for each of the five variables (Fig. 2a-e), and the PCA (Fig. 2f) illustrates over 92 percent of the varia-

tion in the sample among PC1 (84.65 percent) and PC2 (11.71 percent). The 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

For the support vector machine, linear data were imported to Python (supplementary materials), where they were 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

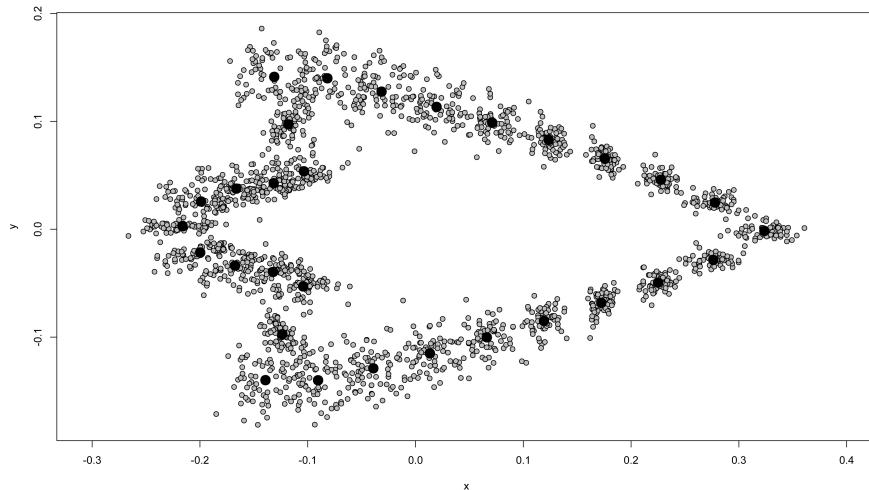
Each of the arrow points was imaged using a flatbed scanner (HP Scanjet G4050) at 600 dpi. The landmarking protocol developed for this study (supplementary materials) includes six landmarks and 24 equidistant semilandmarks to characterize Perdiz arrow point shape, and were applied using the **StereoMorph** package in R [22]. The characteristic points and tangents used in the landmarking protocol were inspired by the work of Birkhoff [23].

Landmark data were aligned to a global coordinate system [24, 25, 26], achieved through generalized Procrustes superimposition [27] performed in R 4.1.1 [28] using the **geomorph** package v4.0.0 [29]. Procrustes superimposition translates, scales, and rotates the coordinate data allowing for comparisons among objects [30, 27]. 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 [31, 26] (Fig.3).

Principal components analysis (Jolliffe 2002) 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 3D mesh (Klingenberg 2013; Sherratt, et al. 2014). A residual randomization permutation procedure (RRPP;  $n = 10,000$  permutations) was used for all Procrustes ANOVAs (Adams and Collyer 2015; Collyer and Adams 2018), which has higher statistical power and a greater ability to identify patterns in the data should they be present (Anderson and Ter Braak 2003).



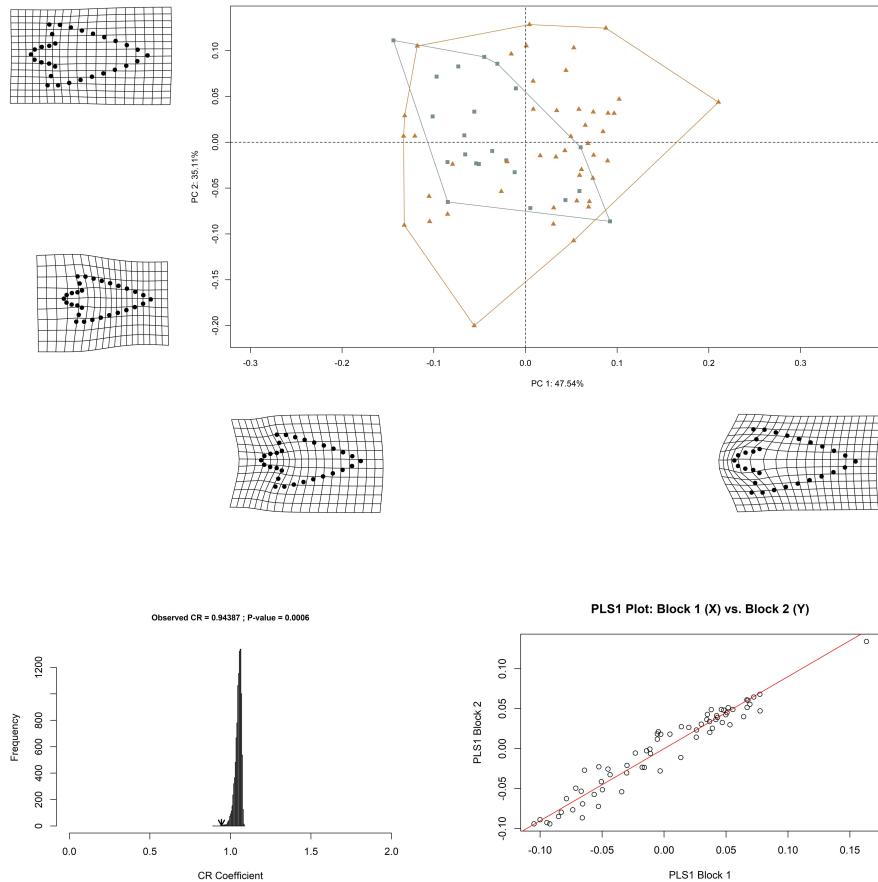
**Fig. 2** Boxplots for a, maximum length; b, maximum width; c, maximum thickness; d, stem length; e, stem width, and f, PCA for linear metrics associated with the Perdiz arrow points. Additional information related to the analysis, including data and code needed to reproduce these results, can be found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

To assess whether shape changes with size (allometry), and differs by group (region), Procrustes ANOVAs (Goodall 1991) were also run that enlist effect-sizes (z-scores) computed as standard deviates of the generated sampling distributions (Collyer, et al. 2015). Procrustes variance was used to discriminate between regions and compare the amount of shape variation (morphological disparity) (Zelditch, et al. 2004), estimated as the Procrustes variance using residuals of linear model fit (Adams, et al. 2018). A pairwise comparison of morphological integration was used to test the strength of integration between blade and basal morphology using a z-score (Adams and Collyer 2016).

A Procrustes ANOVA was used to test whether a significant difference exists in Perdiz arrow point (centroid) size, and results indicate a significant difference ( $RRPP = 10,000$ ;  $Rsq = 0.30681$ ;  $Pr(>F) = 1e-04$ ). A second Procrustes ANOVA was used to test whether a significant difference exists in arrow point shape by region (northern vs. southern communities), and results indicate a significant difference ( $RRPP = 10,000$ ;  $Rsq = 0.0536$ ;  $Pr(>F) = 0.0161$ ). A comparison of mean consensus configurations was used to characterize intraspecific shape variation of Perdiz arrow points from the northern and southern *behavioral regions*. Differential morphology occurs in the basal area, where the angle between the shoulder and base is more acute, with a base that is generally shorter and narrower in the southern *behavioral region* than it is to the north (Fig. 5).



**Fig. 4** Principal components analysis plot (PC1/PC2) for Perdiz arrow points by 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/>.

### 3 Discussion

The previously-defined communities of practice can now be extended to include Perdiz arrow points as a third category of Caddo material culture (bottles, bifaces, and arrow points) that differs significantly in morphology across the shape boundary. The shape boundary delineates—empirically—two discrete behavioral regions in the Caddo region.

Recent geometric morphometric studies have illustrated a clearly discernible shape boundary between the northern and southern Caddo behavioral regions



**Fig. 5** Mean shapes for Perdiz arrow points from the northern (a, left), and southern (b, center) behavioral region. In the comparison of the two (c, right), the northern behavioral region is represented by gray circles, and the southern, by black. Additional information related to the mean shapes, including those data and code needed to reproduce these results, can be found in the supplemental materials at <https://seldenlab.github.io/perdiz3/>.

that transcends three artifact categories from the Formative through Historic Caddo periods. This study clearly illustrates that those morphological differences among Perdiz arrow points found in the northern and southern behavioral regions are predictable, and can be identified using the standard suite of linear metrics regularly collected as part of cultural resource management endeavors.

That the Perdiz arrow points from Caddo burials in the northern and southern communities differ expands the scope to include a third class of artifacts that include Caddo bottles, bifaces, and—now—arrow points (Selden Jr., et al. 2021; Selden Jr. 2018a, 2018b, 2019, 2021b; Selden Jr., et al. 2020; Selden Jr., et al. 2018).

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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.

## References

1. J.E. Dockall, R.C. Fields, K.W. Kibler, C.J. Broehm, J. Budd, E.F. Gadus, K.M. Gardner, Testing and Data Recovery Excavations at the Jayroe Site (41HM51), Hamilton County, Texas (Waco District, CSJ No. 0909-29-030 (Part I)). Tech. rep., Reports of Investigations No. 187. Prewitt and Associates, Inc., Austin Texas. Archeological Studies Program, Report No. 184. Texas Department of Transportation, Environmental Affairs Division, Archeological Studies Branch, Austin Texas (2020)
2. L. Johnson, The Life and Times of Toyah-Culture Folk: The Buckhollow Encampment Site 41KM16, Kimble County, Texas. Report, Texas Department of Transportation and Office of the State Archeologist Report 38. Austin, Texas (1994)
3. R.A. Ricklis, *Toyah Components: Evidence for Occupation in the Project Area during the Latter Part of the Late Prehistoric Period* (Studies in Archeology 19. Vol. 1, Texas Archeological Research Laboratory, University of Texas, Austin, Texas, 1994), pp. 207–316
4. R.Z. Selden Jr., J.E. Dockall, C.B. Bousman, T.K. Perttula, 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** (2021). DOI 10.1016/j.jasrep.2021.102916
5. L.D. Banks, *From Mountain Peaks to Alligator Stomachs: A Review of Lithic Sources in the Trans-Mississippi South, The Southern Plains*. Memoir No. 4 (Oklahoma Anthropological Society, Norman, 1990)
6. D.A. Suhm, A.D. Krieger, E.B. Jelks, An Introductory Handbook of Texas Archeology, Bulletin of the Texas Archeological Society **25**, 1 (1954)
7. R.Z. Selden Jr., in *Ancestral Caddo Ceramic Traditions*, ed. by D.P. McKinnon, T.K. Perttula, J.S. Girard (LSU Press, Baton Rouge, 2021), pp. 240–257
8. R.Z. Selden Jr., A Preliminary Study of Smithport Plain Bottle Morphology in the Southern Caddo Area, Bulletin of the Texas Archeological Society **89**, 63 (2018). URL <https://scholarworks.sfasu.edu/crhr/283>
9. R.Z. Selden Jr., Ceramic Morphological Organisation in the Southern Caddo Area: Quiddity of Shape for Hickory Engraved Bottles, Journal of Archaeological Science: Reports **21**, 884 (2018). DOI 10.1016/j.jasrep.2018.08.045
10. R.Z. Selden Jr., Ceramic Morphological Organisation in the Southern Caddo Area: The Clarence H. Webb Collections, Journal of Cultural Heritage **35**, 41 (2019). DOI 10.1016/j.culher.2018.07.002. URL <https://www.sciencedirect.com/science/article/abs/pii/S1296207418301912?via%3Dihub>
11. R.Z. Selden Jr., in *Ancestral Caddo Ceramic Traditions*, ed. by D.P. McKinnon, J.S. Girard, T.K. Perttula (LSU Press, Baton Rouge, 2021), pp. 258–276
12. R.Z. Selden Jr., J.E. Dockall, M. Dubied, A quantitative assessment of intraspecific morphological variation in Gahagan bifaces from the southern Caddo area and central Texas, Southeastern Archaeology **39**(2), 125 (2020). DOI 10.1080/0734578x.2020.1744416
13. L. Cassaway. Indian-Pioneer History Project for Oklahoma: Sadie Bedoka (1937)
14. A.D. Krieger, *Culture Complexes and Chronology in Northern Texas, with Extensions of Puebloan Datings to the Mississippi Valley*, vol. Publication No. 4640 (The University of Texas, Austin, 1946)
15. T.K. Perttula, Diversity in Ancestral Caddo Vessel Forms in East Texas Archaeological Sites, Journal of Northeast Texas Archaeology **56**, 1 (2015)

16. R.Z. Selden Jr., T.K. Perttula, M.J. O'Brien, Advances in Documentation, Digital Curation, Virtual Exhibition, and a Test of 3D Geometric Morphometrics: A Case Study of the Vanderpool Vessels from the Ancestral Caddo Territory, *Advances in Archaeological Practice* **2**(2), 1 (2014). DOI 10.7183/2326-3768.2.2.64
17. C. Knappett, *An Archaeology of Interaction: Network Perspectives on Material Culture & Society* (Oxford University Press, Oxford, 2011)
18. B.J. Mills, M.A. Peebles, W.R. Haas Jr., L. Borck, J.J. Clark, J.M. Roberts Jr., Multiscalar Perspectives on Social Networks in the Late Prehispanic Southwest, *American Antiquity* **80**(1), 3 (2015). DOI 10.7183/0002-7316.79.4.3. URL <https://www.cambridge.org/core/journals/american-antiquity/article/multiscalar-perspectives-on-social-networks-in-the-late-prehispanic-southwest/B40CF133F9E61102185B25AD4DF0FE30>
19. V.D. Blondel, J.L. Guillaume, R. Lambiotte, E. Lefebvre, Fast Unfolding of Communities in Large Networks, *Journal of Statistical Mechanics: Theory and Experiment* **2008**(10), P10008 (2008). DOI 10.1088/1742-5468/2008/10/p10008. URL <<https://doi.org/10.1088/1742-5468/2008/10/P10008>>
20. R. Lambiotte, J.C. Delvenne, M. Barahona, Random Walks, Markov Processes and the Multiscale Modular Organization of Complex Networks, *IEEE Transactions on Network Science and Engineering* **1**(2), 76 (2014). DOI 10.1109/tnse.2015.2391998. URL <https://ieeexplore.ieee.org/document/7010026/>
21. R.Z. Selden Jr., J.E. Dockall, H.J. Shafer, Lithic Morphological Organisation: Gaha-gan Bifaces from the Southern Caddo Area, *Digital Applications in Archaeology and Cultural Heritage* **10**, e00080 (2018). DOI 10.1016/j.daach.2018.e00080
22. A.M. Olsen, M.W. Westneat, Stereomorph: An r package for the collection of 3d landmarks and curves using a stereo camera set-up, *Methods in Ecology and Evolution* **6**(3), 351 (2015). DOI 10.1111/2041-210x.12326
23. G.D. Birkhoff, *Aesthetic Measure* (Harvard University Press, Cambridge, 1933)
24. D.G. Kendall, *The Statistics of Shape* (Wiley, New York, 1981), pp. 75–80
25. D.G. Kendall, Shape manifolds, procrustean metrics, and complex projective spaces, *Bulletin of the London Mathematical Society* **16**(2), 81 (1984). DOI 10.1112/blms/16.2.81. URL <http://onlinelibrary.wiley.com/doi/10.1112/blms/16.2.81.abstract>
26. D.E. Slice, Landmark Coordinates Aligned by Procrustes Analysis Do Not Lie in Kendall's Shape Space, *Systematic Biology* **50**(1), 141 (2001). DOI 10.1080/10635150119110
27. F.J. Rohlf, D.E. Slice, Extensions of the Procrustes Method for the Optimal Superimposition of Landmarks, *Systematic Zoology* **39**(1), 40 (1990). DOI 10.2307/2992207. URL <https://academic.oup.com/sysbio/article-abstract/39/1/40/1629843?redirectedFrom=fulltext>
28. R.C.D. Team, *R: A Language and Environment for Statistical Computing. Electronic resource*, (R Foundation for Statistical Computing, Vienna, Austria, 2021). URL <http://www.R-project.org>
29. D.C. Adams, E. Otarola-Castillo, geomorph: An R Package for the Collection and Analysis of Geometric Morphometric Shape Data, *Methods in Ecology and Evolution* **4**(4), 393 (2013). DOI 10.1111/2041-210X.12035. URL <https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/2041-210X.12035>
30. J.C. Gower, Generalized Procrustes Analysis, *Psychometrika* **40**(1), 33 (1975). DOI <https://doi.org/10.1007/BF02291478>. URL <https://link.springer.com/article/10.1007%2FBF02291478>
31. F.J. Rohlf, Shape Statistics: Procrustes Superimpositions and Tangent Spaces, *Journal of Classification* **16**(2), 197 (1999). DOI 10.1007/s003579900054. URL <https://link.springer.com/article/10.1007%2Fs003579900054>