

Morphometric and meristic characterization of populations of the *Gila minacae* complex (Teleostei: Cyprinidae) from the Sierra Madre Occidental, Mexico

Carlos A. Ballesteros-Córdova*, Gorgonio Ruiz-Campos*,
Sergio Sánchez-González** and Alejandro Varela-Romero***

A morphological characterization is performed within the *Gila minacae* complex and congeneric species from the Sierra Madre Occidental, Mexico. A discriminant function analysis based on 33 morphometric and six meristic characters applied to 209 specimens revealed 15 body characters to be significantly different among the taxa compared. Southern populations inhabiting the Fuerte, Sinaloa and Culiacán River basins are morphologically distinct from *Gila minacae* populations from the Yaqui River basin and from remaining studied species. Southern populations have a deeper body and lower counts of gill rakers, dorsal-fin rays, and lateral line scales than *G. minacae* from the Yaqui River basin. Such differences suggest the presence of at least two species within the *Gila minacae* species complex.

Introduction

Fishes of the genus *Gila* comprise a morphologically diverse group inhabiting arid and semi-arid regions of the western United States (USA) and northwestern Mexico (Miller et al., 2005; Schönhuth et al., 2014). A recent phylogenetic analysis conducted on several Cyprinids from North America embracing all members of *Gila* suggest this genus as paraphyletic due the phylogenetic position of *G. coerulea* and *Ptychocheilus lucius*,

and the recovering of *G. robusta* specimens as a paraphyletic group (Schönhuth et al., 2014).

According to Schönhuth et al. (2014), the diversification of *Gila* species in Mexico occurred in both the Atlantic and Pacific slopes. The seven species inhabiting the Atlantic drainages make up a monophyletic lineage referred to as the Chihuahuan Desert group, while the four species of *Gila* inhabiting Pacific drainages (*G. ditaenia*, *G. purpurea*, *G. eremica*, and *G. minacae*) were also hypothesized as monophyletic. Although

* Colección Ictiológica, Facultad de Ciencias, Universidad Autónoma de Baja California, Carretera Transpeninsular Ensenada-Tijuana No. 3917, Col. Playitas, 22860 Ensenada, Baja California, México.
E-mails: caballesteros0411@gmail.com (CAB-C), gruiz@uabc.edu.mx (GR-C, corresponding author)

** Escuela de Biología, Universidad Autónoma de Sinaloa, Calzada de Las Américas y Universitarios s/n, Ciudad Universitaria, 80040 Culiacán, Sinaloa, México. E-mail: ssanchez@uas.edu.mx

*** Departamento de Investigaciones Científicas y Tecnológicas, Universidad de Sonora, Blvd. Luis Encinas y Rosales s/n, 83000 Hermosillo, Sonora, México. E-mail: alejandro.varela@unison.mx

Literature cited

- Ballesteros-Córdova, C. A., G. Ruiz-Campos, L. T. Findley, J. M. Grijalva-Chon, L. E. Gutiérrez-Millán & A. Varela-Romero. 2016. Morphometric and meristic characterization of the endemic desert chub *Gila eremica* (Cyprinidae, Teleostei), and its related congeners in Sonora, Mexico. Revista Mexicana de Biodiversidad, 87: 390–398.
- Ballesteros-Córdova, C. A., G. Ruiz-Campos, L. T. Findley, J. M. Grijalva-Chon, L. E. Gutiérrez-Millán & A. Varela-Romero. 2019. Mitochondrial evidence for a new evolutionary significant unit within the *Gila eremica* lineage (Teleostei, Cyprinidae) in Sonora, Northwest Mexico. Animal Biodiversity and Conservation, 42: 171–186.
- Bogart, M. T., N. Noriega-Felix, S. L. Vidal-Aguilar, L. T. Findley, D. A. Lytle, O. G. Gutiérrez-Rauch, J. A. Alvarado-Castro & A. Varela-Romero. 2014. Biogeography and conservation of aquatic fauna in spring-fed tropical canyons of the southern Sonoran Desert, Mexico. Biodiversity and Conservation, 23: 2705–2748.
- Bookstein, F. L., B. Chernoff, R. L. Elder, J. M. Humphries, G. R. Smith Jr. & R. E. Strauss. 1985. Morphometrics in evolutionary biology. Academy of Natural Sciences of Philadelphia, 15: 1–277.
- Brereton, R. G. 2015. The Mahalanobis distance and its relationship to principal component scores. Journal of Chemometrics, 29: 143–145.
- Castañeda-Rivera M., J. M. Grijalva-Chon, L. E. Gutiérrez-Millán, G. Ruiz-Campos & A. Varela-Romero. 2014. Analysis of the *Ictalurus pricei* complex (Teleostei: Ictaluridae) in northwest Mexico based on mitochondrial DNA. Southwestern Naturalist, 59: 434–438.
- Copus, J. M., W. L. Montgomery, Z. H. Forsman, B. W. Bowen & R. J. Toonen. 2018. Geopolitical species revisited: genomic and morphological data indicate that the roundtail chub *Gila robusta* species complex (Teleostei, Cyprinidae) is a single species. PeerJ 6:e5605.
- DeMarais, B. D. 1991. *Gila eremica*, a new cyprinid fish from northwestern Sonora, México. Copeia, 1991: 179–189.
- Elliott, N. G., K. Haskard & J. A. Koslow. 1995. Morphometric analysis of orange roughy (*Hoplostethus atlanticus*) off the continental slope of southern Australia. Journal of Fish Biology, 46: 202–220.
- Felger, R. S. & M. F. Wilson. 1995. Northern Sierra Madre Occidental and its Apachian outliers: a neglected center of biodiversity. Pp. 36–59 in: L. F. DeBano et al. (eds.), Biodiversity and management of the Madrean archipelago: the sky islands of southwestern United States and northwestern Mexico. United States Department of Agriculture Forest Service, Tucson.
- Ferrari, L., M. López-Martínez, G. Aguirre-Díaz & G. Carrasco-Núñez. 1999. Space-time patterns of Cenozoic arc volcanism in central Mexico: from the Sierra Madre Occidental to the Mexican Volcanic Belt. Geology, 27: 303–306.
- Ferrari, L., M. Valencia-Moreno & S. Bryan. 2005. Magmatismo y tectónica en la Sierra Madre Occidental y su relación con la evolución de la margen occidental de Norteamérica. Boletín de la Sociedad Geológica Mexicana. Volumen conmemorativo del centenario. Temas Selectos de la Geología Mexicana, 52: 343–378.
- González-Elizondo, S., M. González Elizondo, J. A. Tena-Flores, L. Ruacho-González & I. L. López-Enríquez, 2012. Vegetación de la Sierra Madre Occidental, México: una síntesis. Acta Botánica Mexicana, 100: 351–403, 2 pls.
- González-Elizondo, M. S., M. González-Elizondo, L. Ruacho-González, I. L. López-Enríquez, F. I. Retana Rentería & J. A. Tena-Flores. 2013. Ecosystems and diversity of the Sierra Madre Occidental. P. 67 in: G. J. Gottfried, et al. (eds.), Merging science and management in a rapidly changing world: biodiversity and management of the Madrean Archipelago III. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins.
- Hubbs, C. L. 1940. Speciation of fishes. American Naturalist, 74: 198–211.
- Hubbs, C. L. & K. F. Lagler 1958. Fishes of the Great Lakes region. Cranbrook Institute of Science Bulletin 26, Bloomfield Hills, 213 pp.
- Jolicoeur, P. 1963. The multivariate generalization of the allometry equation. Biometrics, 19: 497–499.
- Lammertink, J. M., J. A. Rojas-Tomé, F. M. Orona-Cillas & R. L. Otto. 1996. Status and conservation of old-growth forests and endemic birds in the pine-oak zone of the Sierra Madre Occidental, Mexico. Verslagen en Technische Gegevens, 69: 1–89.
- Mahalanobis, P. C. 1936. On the generalized distance in statistics. Proceedings of the National Institute of Sciences of India, 2: 49–55.
- Mayden, R. L., C. B. Dillman, H. Espinosa-Pérez, J. R. Tomelleri, B. R. Kuhajda, D. A. Hendrickson, G. Ruiz-Campos, A. B. De los Santos-Camarillo, F. G. De León, A. Varela-Romero, D. L. Propst, J. E. Brooks, L. T. Findley, A. L. George, D. A. Neely, I. de Los Angeles Barriga Sosa & K. E. Mayden. 2010. Evolution and diversity of trout species in México. Pp. 134–144 in: R. F. Carline & C. Lo Sapió, (eds.), Conserving wild trout. Proceedings of the Wild Trout X Symposium, Bozeman.
- Meek, S. E. 1902. A contribution to the ichthyology of Mexico. Field Columbian Museum, Zoological Series, 3: 63–128, pls 14–31.
- Miller, R. R. & M. L. Smith. 1986. Origin and geography of the fishes of Central Mexico. Pp. 487–519 in: C. H. Hocutt & E. O. Wiley (eds.), The zoogeography of North American freshwater fishes. Wiley-Interscience, New York.

- Miller, R. R., W. L. Minckley & S. M. Norris. 2005. Freshwater fishes of México. The University of Chicago Press, Chicago, 426 pp.
- Minckley, W. L. & P. C. Marsh. 2009. Inland fishes of the greater southwest: chronicle of a vanishing biota. University of Arizona Press, Tucson, 426 pp.
- Mittermeier, R. A., G. A. B. da Fonseca, M. Hoffman, J. Pilgrim, T. Brooks, P. Robles-Gil, C. G. Mittermeier & J. Lamoreux, 2004. Hotspots revisited: earth's biologically richest and most endangered terrestrial ecoregions. CEMEX/Agrupación Sierra Madre, México City, 392 pp.
- Norris, S. M., J. M. Fischer & W. L. Minckley. 2003. *Gila brevicauda* (Teleostei: Cyprinidae), a new species of fish from the Sierra Madre Occidental of México. Ichthyological Exploration of Freshwaters, 14: 19–30.
- Pires da Silva, A., S. Imhoff, N. F. B. Giarola & C. A. Tormena. 2001. Análisis multivariado y univariado en la discriminación de sistemas de uso de suelos del centro de Santa Fe. Edafología, 8: 21–34.
- Ruiz-Campos, G., S. Sánchez-González, R. L. Mayden & A. Varela-Romero. 2016. Meristic and morphometric comparison of an undescribed sucker of the Río Culiacán (*Catostomus* sp.) and Yaqui sucker (*Catostomus bernardini*) (Catostomidae, Teleostei) from the Sierra Madre Occidental, Mexico. Revista Mexicana Biodiversidad, 87: 380–389.
- Schönhuth, S., I. Doadrio & R. L. Mayden. 2006. A biogeographic perspective of the phylogeny of Mexican cyprinids (Actinopterygii, Cyprinidae). Pp. 102–124 in: M. L. Lozano-Vilano & A. J. Contreras-Balderas (eds.), Studies on the North American desert fishes in honor of E. P. (Phil) Pister, conservationist. Universidad Autónoma de Nuevo León, Monterrey.
- Schönhuth, S., M. J. Blum, L. Lozano-Vilano, D. A. Neely, A. Varela-Romero, H. Espinosa-Pérez, A. Perdices & R. L. Mayden. 2011. Interbasin exchange and repeated headwater capture across the Sierra Madre Occidental inferred from the phylogeography of Mexican stonerollers. Journal of Biogeography, 38: 1406–1421.
- Schönhuth, S., A. Perdices, L. Lozano-Villano, F. J. García-de-León, H. Espinoza-Pérez & R. L. Mayden. 2014. Phylogenetic relationships of North American western chubs of the genus *Gila* (Cyprinidae, Teleostei), with emphasis on southern species. Molecular Phylogenetics and Evolution, 70: 210–230.
- Schönhuth, S., L. Lozano-Vilano, A. Perdices, H. Espinosa-Pérez & R. L. Mayden. 2015. Phylogeny, genetic diversity and phylogeography of the genus *Codoma* (Teleostei, Cyprinidae). Zoological Scripta, 44: 11–28.
- Smith, G. R., T. E. Dowling, K. W. Gobalet, T. Lugaski, D. K. Shiozawa & R. P. Evans. 2002. Biogeography and timing of evolutionary events among Great Basin fishes. Pp. 175–234 in: R. Hershler & D. B. Currey (eds.), Great Basin aquatic systems history. Smithsonian Contributions to the Earth Sciences, Washington, DC.
- Varela-Romero, A. 2001. Newly documented localities for desert chub, *Gila eremica*, in tropical canyons, Río Mátape Basin, Sonora, Mexico. Proceedings of the Desert Fishes Council, 32: 33.
- Varela-Romero, A., D. A. Hendrickson, G. Yepiz-Plascencia, J. E. Brooks & D. A. Neely. 2011. Status of the Yaqui catfish (*Ictalurus pricei*) in the United States and Northwestern Mexico. The Southwestern Naturalist, 56: 277–285.

Received 12 July 2019
 Revised 22 August 2019
 Accepted 9 January 2020

The whole contribution can be purchased as PDF file.

Availability

Generally all our publications are available as PDF files; full publications as a general rule after the printed version is out of print. If you have questions concerning particular contributions please contact us by e-mail:
pdf@pfeil-verlag.de.

The PDF files are protected by copyright.

The PDF file may be printed for personal use. The reproduction and dissemination of the content or part of it is permitted. It is not allowed to transfer the digital personal certificate or the password to other persons.

Prices

Books: Prices are to be found in the catalog.

Articles in journals and single contributions or chapters in books:

10 EURO basic price per order (including the first 10 pages),
and

0,50 EURO per page, beginning with the 11th page.

Page numbers are found in the contents of the publications.

Orders

Use our order form for PDF files or send your order informal per e-mail (pdf@pfeil-verlag.de). The only accepted payment is by credit card. While using the order form for PDF files, your data will be transmitted by secure link (ssl). You also may send the informations informally by e-mail, fax, phone or mail.

Handling

As soon as possible, depending on our business hours and your order, you will receive your PDF file together with the certificate and password by e-mail.

Larger PDF files can be downloaded from our webspace, if necessary.

Your invoice will be sent out by e-mail after we charged your credit card.

To open the encrypted PDF files you have to install your personal certificate after your first order. All PDF files with the same certificate can be opened from that time on.

Dieser Beitrag kann als PDF-Datei erworben werden.

Verfügbarkeit von PDF-Dateien

Prinzipiell sind von allen unseren Publikationen PDF-Dateien erhältlich. Komplette Publikationen in der Regel erst nachdem die gedruckte Version vergriffen ist. Anfragen bezüglich bestimmter Beiträge richten Sie bitte per E-Mail an pdf@pfeil-verlag.de.

Die PDF-Dateien sind urheberrechtlich geschützt.

Ein Ausdruck der PDF-Dateien ist nur für den persönlichen Gebrauch erlaubt.

Die Vervielfältigung von Ausdrucken, erneutes Digitalisieren sowie die Weitergabe von Texten und Abbildungen sind nicht gestattet.

Das persönliche Zertifikat und das Passwort dürfen nicht an Dritte weitergegeben werden.

Preise

Bücher: Die Preise sind dem Katalog zu entnehmen. Zeitschriftenbeiträge und einzelne Kapitel aus Sammelbänden bzw. Büchern:

10 EURO Grundbetrag pro Bestellung (einschließlich der ersten 10 Seiten),
und

0,50 EURO pro Seite ab der 11. Seite.

Den Umfang der Beiträge entnehmen Sie bitte den Inhaltsverzeichnissen.

Bestellungen

Bestellungen sind mit dem PDF-Bestellformular oder formlos per E-Mail (pdf@pfeil-verlag.de) an uns zu richten. Die Bezahlung ist ausschließlich per Kreditkarte möglich. Bei Verwendung unseres Bestellformulars werden die Kreditkartendaten über eine gesicherte Verbindung (ssl) übermittelt. Sie können die Daten aber auch formlos per E-Mail, Fax, Post oder telefonisch übermitteln.

Abwicklung

So bald wie möglich, aber abhängig von unseren Bürozeiten und der gewünschten Bestellung, schicken wir Ihnen die PDF-Datei(en) zusammen mit Ihrem persönlichen Zertifikat und dem zugehörigem Passwort per E-Mail. Größere Dateien bieten wir Ihnen gegebenenfalls zum Herunterladen an.

Der fällige Betrag wird von Ihrer Kreditkarte abgebucht und Sie erhalten die Rechnung ebenfalls per E-Mail.

Um die verschlüsselten PDF-Dateien öffnen zu können, muss bei der ersten Bestellung das passwortgeschützte persönliches Zertifikat installiert werden, welches anschließend auf dem Rechner verbleibt. Alle mit diesem Zertifikat verschlüsselten Dateien können anschließend auf diesem Rechner geöffnet werden.