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Diversity of fish otoliths from the Gulf of Mexico and Caribbean Sea: report on the first digital collection of fish otoliths from the Atlantic region of Mexico

Xavier Chiappa Carrara, Maribel Badillo Alemán, Ariana Solís Gómez, Alfredo Gallardo Torres, Eduardo Pacheco Gongora

Diversity of fish otoliths from the Gulf of Mexico and Caribbean Sea: report on the first digital collection of fish otoliths from the Atlantic region of Mexico.

Maribel Badillo Alemán[1] <maribaam@ciencias.unam.mx>
Ariana Solís Gómez[2] <arianasolisgmz@gmail.com>
Alfredo Gallardo Torres[1] <gallalf@ciencias.unam.mx>
Eduardo Pacheco Gongora[1] <epacheco@ciencias.unam.mx>
Xavier Chiappa-Carrara[1,3,*] <xcc@ciencias.unam.mx>

[1] Laboratorio de Biología de la Conservación, Facultad de Ciencias, UNAM
[2] Posgrado en Ciencias del Mar y Limnología, UNAM
[3] Laboratorio Nacional de Biología del Cambio Climático, CONAHCYT
* Corresponding author

Abstract
The Otolith Collection of Fishes from the Gulf of Mexico and Caribbean Sea was created with the objective of conserving and illustrate the diversity of these structures from species living in the Gulf of Mexico, the Caribbean Sea, and the freshwater and brackish systems of the Yucatan Peninsula, incorporating morphological descriptions and morphometric data. Otoliths, non-skeletal calcareous structures that develop in the inner ear of fish, are essential for balance and hearing. They have become pivotal tools for age and growth determination, population analysis, and ecological, trophic, and archaeological studies due to their resistance to degradation and the extensive information they provide about the environment and physiology of fish. The collection now includes otoliths from 214 species from 67 families, obtained through sampling campaigns and collaborations with local fishermen. The otoliths are extracted using techniques that ensure the integrity of the structures for later preservation. High-resolution images are obtained using optical and scanning electron microscopy, and these images are stored in an online database. This database facilitates research and teaching by providing public access to digital specimens and associated data. In addition to fostering academic development, this collection represents a significant step towards the creation of a national platform for otolith data analysis, aligned with international efforts to digitize biological collections. Despite the financial and logistical challenges involved in building and maintaining biological collections, this collection demonstrates its value as an essential resource for taxonomic, systematic, and ecological studies, as well as for biodiversity education and awareness. The online availability of the collection not only facilitates access to data but also promotes innovation and international collaboration in the study of fishes and their habitats.

Keywords: Biological collection, digitization, fish, image analysis, online collection

Introduction
Throughout history, biological collections have played a fundamental role in documenting the biodiversity of our planet. They provide essential information for the knowledge, exploitation, and sustainable use of our biological capital, and they assist in the analysis of trends derived from environmental changes. Additionally, they contribute necessary

information for studies on environmental health, epidemiology, and national security, proving to be irreplaceable tools for investigating cases of biological terrorism (Suarez and Tsutsui 2004) and determining the effects of anthropogenic activities (Izzo et al. 2018). The information generated from the analysis of specimens kept in biological collections has motivated changes in public policies on the sustainable use of natural resources, significantly impacting social welfare (National Academies of Sciences, Engineering, and Medicine 2020).

Biological collections are not only essential repositories for taxonomic and systematic work on the biota but also contribute to the development of other scientific disciplines. They play a crucial role in education by raising awareness of the need to document and conserve biodiversity and by enabling the development of new skills in research and data analysis. Therefore, the role of biological collections transcends purely scientific objectives and should be considered necessary tools that benefit society (Kellner 2024).

At different regional levels, collections maintain and catalog specimens of local ecosystems, creating, preserving, and increasing information on species distribution, identifying endemic or invasive species, and evaluating changes in biodiversity over time (Meineke et al. 2018). Thus, biological collections are essential references in conservation efforts, including those focused on endangered species and their habitats.

As fishes have been a group of interest for centuries, they are part of several biological collections, notable for their diversity of forms and adaptations. Approximately 36893 fish species are recognized (Fricke et al. 2024), equivalent to more than half of all living vertebrates. Mexico, with its high diversity of fishes, boasts at least 2763 species (Espinosa-Pérez 2014), of which 1816 are found in the Gulf of Mexico and the Caribbean Sea (Robertson and Van Tassel, 2023). In this region, fishing activities by industrial and artisanal fleets, along with recreational activities such as diving and sport fishing, are depleting natural populations (De la Cruz et al. 2016). Given that many fish species present on the Atlantic coast of Mexico have economic, nutritional, cultural, ecological, or evolutionary importance, it is necessary to know the specific identity of organisms and study aspects of their biology, ecology, and biogeography, underscoring the relevance of scientific collections.

Although specimens deposited in ichthyological collections are useful for various research purposes, their importance in paleontological, archaeological, and trophic studies is particularly noteworthy. In trophic studies, for example, prey of piscivorous organisms are often identified by examining stomach contents, vomit, or feces (Baker et al. 2024). This methodology is limiting when the prey's degree of digestion is advanced. However, other structures such as otoliths (Baker et al. 2014), which may be present in the digestive tract of ichthyophagous organisms due to their resistance to degradation and retention of original characteristics in many situations (Rivaton and Bourret 1999; Tuset et al. 2008), can be recognized. In paleontology and archaeology, zooarchaeological remains, including otoliths, are valuable for reconstructing environmental conditions, such as the distribution and extent of water bodies, and recognizing the species used by ancient cultures (Lin et al. 2022).

Otoliths are non-skeletal calcareous concretions (Nolf 1985; Maisey 1987) that grow within the vestibular system of vertebrates, particularly in the membranous labyrinth of the inner ear. In bony fish, the inner ear consists of three semicircular canals and three otic chambers, each housing an otolith. Depending on the chamber in which they are located, otoliths are called sagitta (in the sacculum), lapillus (in the utricle), and asteriscus (in the lagena). These structures play a crucial role in balance, orientation, and sound detection (Platt and Popper 1981; Gauldie and Nelson 1988; Campana and Thorrold 2001). Otoliths are composed of calcium carbonate ($CaCO_3$) in the form of aragonite and other inorganic salts, with crystals embedded in an organic matrix composed of a fibrous protein called otolin, deposited concentrically around a nucleus (Martínez-Pérez et al. 2018). The presence of several elements is related to metabolically regulated processes and is influenced by both endogenous and exogenous factors. Therefore, otoliths can provide information on the physiological aspects of organisms and the environments in which they developed (Volpedo and Echeverría 2003). These characteristics have made otoliths key tools in research on age and growth (Francis and Campana 2004), population dynamics, trophic studies, archaeological analyses, and present and past environmental conditions.

Sagittae have a particular morphology that varies among species, making them useful as auxiliary structures in organism identification and for distinguishing between phylogenetically close species (Volpedo and Echeverría 2003). Analyzing the shape, size, and structural characteristics of otoliths not only allows for species identification but also helps investigate evolutionary relationships and reconstruct phylogenetic histories.

Rojo (2015) emphasized the importance of incorporating otoliths into fish collections, as they enable the extraction of biological information about species that is otherwise unattainable through the analysis of other structures such as spines, scales, or bones. Otoliths store unique data on the life history of organisms and the environmental conditions of their habitats. It is in this context that the Otolith Collection of Fishes from the Gulf of Mexico and Caribbean Sea was created and registered with the Mexican Ministry of Environment and Natural Resources (SEMARNAT, registration code DGVS-CC-305-18).

The main objective of this collection is to preserve otoliths of a wide variety of species, including those of economic and ecological importance, as well as endangered and endemic species from the Gulf of Mexico and Caribbean Sea, and freshwater and brackish systems of the Yucatan Peninsula. The addition of the Mexican Atlantic Fish Otolith Collection (Martínez-Pérez et al. 2011; Del Moral-Flores et al. 2016) and proper curation and maintenance have turned this collection into a national reference, contributing to research in disciplines such as biology, ecology, biogeography, archaeology, and fisheries, among others. To enhance this purpose and facilitate access to specimens and other resources such as databases or software for shape analysis, this collection is available online. Public access to information is thus guaranteed, scientific collaboration is encouraged, and educational and training opportunities are improved (Monfils et al. 2017), extending these benefits to a wide geographical extent.

Methods

Specimen collection

Since 2011, multiple campaigns have been conducted in various localities of the Gulf of Mexico and the Caribbean Sea to obtain bony fish specimens, which serve as the primary input of biological material. Specific sampling methods have been employed, involving different fishing gears operated under catch permits obtained from the competent authorities. Additionally, visits have been made to markets, fish markets, and ports, and agreements have been established with fishermen from different areas to direct sampling efforts towards certain species of interest. The Otolith Collection of Fishes from the Gulf of Mexico and Caribbean Sea has been enriched by the addition of the Mexican Atlantic Fish Otolith Collection (Martínez-Pérez et al., 2011; Del Moral-Flores et al., 2016).

It is important to note that otolith extraction requires that the specimens be fresh or frozen, as otoliths preserved in unneutralized formalin or alcohol degrade, reducing the chances of correct identification (Hecht, 1990) and limiting their usefulness as collection specimens.

After collection, each fish is identified to the species level using taxonomic keys and guides. Biometric data, such as total length (TL), standard length (SL), cephalic length (CL), body height, weight, and, when possible, sex, are recorded for each specimen. Capture data, including locality, date, and geographic coordinates, are also documented.

Otolith extraction

Two techniques are employed for otolith extraction. One method involves lifting the operculum, removing the gills, and breaking the bony capsules to expose and extract the otoliths with forceps. The other method involves separating the head from the body, removing the gill arches and surrounding tissue to locate the bony capsules. The blades of a pair of scissors are inserted into the center of the first vertebra, using them as a lever to lift the ventral bone of the capsule and expose the otoliths. These procedures are performed under a stereoscopic microscope.

Once extracted, the otoliths are cleaned of residual tissue, and detailed morphometric measurements, including perimeter, area, height, width, and acoustic sulcus dimensions, are obtained using Zen Pro software (Zeiss). These data allow for the calculation of different morphometric indices useful in species comparison.

The terminology used for the morphological descriptions of sagittae is derived from the works of Volpedo and Echeverría (2000), Mascareñas-Osorio et al. (2003), Tuset et al. (2008), and Martínez-Pérez et al. (2018).

Otoliths are stored in vials labeled with biometric and capture data, including a unique identification code for each specimen. The vials are placed in boxes, which are labeled and stored in the collection under controlled temperature and humidity conditions to ensure long-term preservation.

Digitization of the collection

The digitization of the Otolith Collection of Fishes from the Gulf of Mexico and Caribbean Sea is a key component in improving the accessibility and usefulness of the stored specimens. This collection includes a photographic archive of approximately 2600 otolith images obtained using optical and scanning electron microscopy techniques. These images are used not only for documentation and preservation but also to facilitate research and comparative analysis.

High-resolution images of the otoliths are obtained using an advanced Zeiss AxioZoom stereo microscope, which provides continuous magnification and excellent depth of field, crucial for capturing the morphological details of the structures. These images are used for both taxonomic identification and morphometric studies. Additionally, a scanning electron microscope (Jeol 7600F FESEM) is used to obtain high-resolution images with a large depth of field, allowing for the visualization of ultrastructural details of otoliths not perceptible with optical microscopy. This equipment is essential for studies requiring detailed analysis of the otolith surface and its microstructures.

Images are selected to highlight the distinctive characteristics of each otolith, with angles and focus optimized for this purpose. Each image is edited to standardize the black background, enhancing contrast and facilitating the visualization of morphological details. A watermark with the collection logo is added to each image to ensure provenance and maintain the collection's identity.

The digitized images are stored in a database management system that allows easy access and retrieval. Each image is associated with the biometric and capture data of the corresponding specimen, including the unique identification code.

Results

Physical specimens

The Otolith Collection of the Gulf of Mexico and Caribbean Sea comprises 3001 lots, representing 214 species from 67 families (Table 1). Sciaenidae is the most represented with 17 species, followed by Carangidae and Haemulidae, with 15 and 11 species, respectively.

The species with the highest number of specimens in the collection are *Menticirrhus americanus* (Linnaeus, 1758) with 191 lots, *Ariopsis felis* (Linnaeus, 1766) with 108 lots, *Bagre marinus* (Mitchill, 1815) with 106 lots, and *Haemulon plumierii* (Lacepède, 1801) with 102 lots. Each lot typically contains all three pairs of otoliths: sagitta, asteriscus, and lapillus.

The collection includes otoliths from specimens collected along the coasts of the states of Tamaulipas, Veracruz, Campeche, and Yucatan, which is the best-represented state with 1700 lots, followed by Campeche with 894 lots and Veracruz with 368 lots. Additionally, the collection contains 23 lots of otoliths from Cuba.

Fig. 1 illustrates the sagittal otoliths of most of the families included in the collection. These images on the collection's web page are accompanied by morphological descriptions and morphometric characteristics such as length, height, perimeter, and area of both the sagitta and the acoustic sulcus. These variables allow for the calculation of shape indices, including circularity, rectangularity, aspect ratio, and the proportion of the area occupied by the acoustic sulcus. The diversity of the shape of the saccular otoliths is notable, ranging from simple ellipsoids to complex patterns with species-specific projections and invaginations. The dorsal and ventral margins can be smooth, scalloped, lobed, serrated, or serrate. The anterior and posterior regions exhibit significant variability, being pointed, angulated, rounded, truncate, oblique, lanceolate, bilobed, double-pointed, or irregular. Many species have an indentation in the anterior region, the ostial fissure, which delineates the rostral and antirostral regions. The characteristics of the fissure, whether deep or shallow, angulated or rounded, affect the shape and size of these sections. The acoustic sulcus, a longitudinal depression along the medial face of the sagitta, consists of the ostium anteriorly and the cauda posteriorly. In some instances, thickening of the edges, known as cristae, and dorsal or ventral depressions are present along the acoustic sulcus.

Website

The online catalog of the Fish Otolith Collection of the Gulf of Mexico and Caribbean Sea aims to organize and present the information in a user-friendly yet comprehensive manner, available to academics, students, and anyone interested in fish biology and ecology.

The website features a detailed database with information on each otolith, including species, location, size and weight of the specimen, collector, and morphological parameters of the otolith. It also includes a gallery of images or scientific illustrations of the species and photographs of the otoliths obtained through optical and electron microscopy. Detailed morphological descriptions of the left sagitta of each species are accessible.

Before publication on the website, the quality of the digital data is verified to ensure high-value information that can positively impact research and education.

To facilitate consultation, the webpage offers search functions by taxon (family, genus, or species) and keywords related to otolith characteristics. Additionally, didactic resources such as videos on otolith extraction and description techniques, and the use of relevant equipment for their study are available. The otolith collection webpage can be accessed at https://otolitos.unam.mx.

Publications and analytical tools

Derived from the curatorial work of the collection and the information on each specimen, a catalog with descriptive cards of the sagittal otoliths of 155 fish species from the Gulf of Mexico was published (Martínez-Pérez et al., 2018). This catalog includes standardized descriptions of the shape, as well as some morphometric data of the structure, acoustic sulcus, and shape indices. Currently, a second edition of the catalog is being prepared, which will include information on species added in recent years.

Additionally, a software, Invariant Otolith Shape Analysis (IOSA), which can be downloaded here, https://sites.google.com/view/jorge-perez/community#h.hh1lv19s6hlj) has been developed to automatically obtain morphometric descriptors and shape invariants of otoliths from their images, based on the methodology proposed by Hevia-Montiel et al. (2021).

Recently, the collection has been used to corroborate the presence of fish remains in the Mayan archaeological record. This information will deepen our understanding of pre-Hispanic fishing practices and infer possible changes in some fish populations in the region.

Discussion

The Otolith Collection of the Gulf of Mexico and Caribbean Sea is a sample of the richness and ichthyological diversity of the region. It has a collection of 214 species belonging to 67 families, which represent a significant percentage (just over 11%) of the total number of species recorded for the Gulf of Mexico and the Caribbean Sea. (Robertson and Van Tassel, 2023). The families and species most represented in the collection reflect the specific composition of the local ichthyofauna, its ecological importance, and its relevance to the regional economy. This extensive taxonomic representation provides an invaluable database for biodiversity, taxonomy, and systematic studies of fishes in the region.

The otoliths in this collection come from specimens obtained in various geographic regions, enabling the study of species distribution and population variability in different localities of the Gulf of Mexico and the Caribbean. With 3001 lots in total, the collection provides a robust data set for statistical analyses, intraspecific variability studies, and temporal trend evaluations.

Otoliths are invaluable in paleontological, archaeological, and biological explorations, such as analyzing the stomach contents of piscivorous species. Reference collections have been established to assist in species identification from remains found in archaeological contexts, as documented by Disspain et al. (2016) and Lambrides et al. (2024). The catalogs by Mascareñas et al. (2003) and Martínez-Pérez et al. (2018), along with the website www.otolitos.unam.mx, support research efforts in Mexico.

The digitization of biological collections, including the Otolith Collection of the Gulf of Mexico and Caribbean Sea, is crucial for making scientific information universally accessible. Digitization transforms specimen information into digital formats, allowing for easy access and analysis by anyone with an internet connection. This approach modernizes the use of biological collections, eliminating the need for physical travel or loan requests, which risk loss or damage to the specimens.

Digitization also fosters new research topics and addresses global challenges related to climate change, food security, and conservation (Soltis, 2017). The online presence of the Otolith Collection makes it the first digital otolith collection in Mexico, facilitating international collaboration and knowledge dissemination. This effort aligns with global initiatives like the "Integrated Digitized Biocollections" (iDigBio), the "European Distributed System of Scientific Collections" (DiSSCo), and the "Innovation and Consolidation for Large Scale Digitization of Natural Heritage" (ICEDIG). These programs promote the networking of collections worldwide, contributing to the "global museum" concept (Bakker et al., 2020).

Despite the benefits of digitization, physical specimens remain the primary source of verifiable data. Digital information complements but does not replace physical specimens. Increased online accessibility often leads to more visits to collections and loan requests for physical specimens (Vollmar et al., 2010). Therefore, preserving physical specimens in optimal conditions is a primary task for the curatorial staff of the Otolith Collection.

Additionally, the webpage offers accessible image processing software that employs invariant descriptors, as detailed by Hevia-Montiel et al. (2021). These descriptors are independent of rotation, scale, or translation, thereby ensuring consistent results. This software provides additional information beyond traditional descriptors, such as otolith area or perimeter (Hevia-Montiel et al., 2021), which is particularly beneficial in taxonomic studies that rely on limited structures for species identification. By offering a user-friendly interface that allows the application of image processing through a webpage, the tool significantly broadens its user base. Enhancing collaboration is crucial, especially in studies involving these structures, where there is an increasing demand for web-based tools that enable researchers to browse and search images and data in conjunction with biological analyses.

The contributions of biological collections to knowledge, education, and innovation are immense but often unrecognized (National Academies of Sciences, Engineering, and Medicine, 2020; Kellner, 2024). Many scientific communities have highlighted the risks of inadequate funding for maintaining the infrastructure necessary for the proper functioning of these collections (Finkel, 2024; Kellner, 2024). Thus, the online presence of the Otolith Collection is a vital step toward creating a national platform that supports the analysis of bony fish otoliths in various contexts, including paleontological, archaeological, biological, and ecological studies (Begg et al., 2005; Disspain et al., 2016).

Conclusion

Otoliths serve multiple research purposes, including paleontological, archaeological, and biological explorations, and support species identification in archaeological contexts. The Otolith Collection of the Gulf of Mexico and Caribbean Sea represents the ichthyological diversity of the region, encompassing 214 species of 67 families, reflecting over 11% of the total species richness in the region. The collection's species composition mirrors the local ichthyofauna's ecological importance and its significance to the regional economy, making it a crucial resource for biodiversity studies.

With specimens collected from various regions, the collection provides valuable data for studying species distribution, population variability, and temporal trends in the Gulf of Mexico and the Caribbean. Furthermore, digitizing the Otolith Collection enhances global accessibility, facilitates international collaboration, and supports research on critical global challenges, such as climate change and conservation. The collection's website offers innovative image processing software that improves species identification and taxonomic studies, making these tools widely accessible to researchers. It is important to note that while digitization expands access to the collection, physical specimens remain the primary source of verifiable data, highlighting the need for their preservation. Therefore, we emphasize the importance of adequate funding for maintaining this and other biological collections, as they contribute significantly to knowledge, education, and innovation.

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Figure

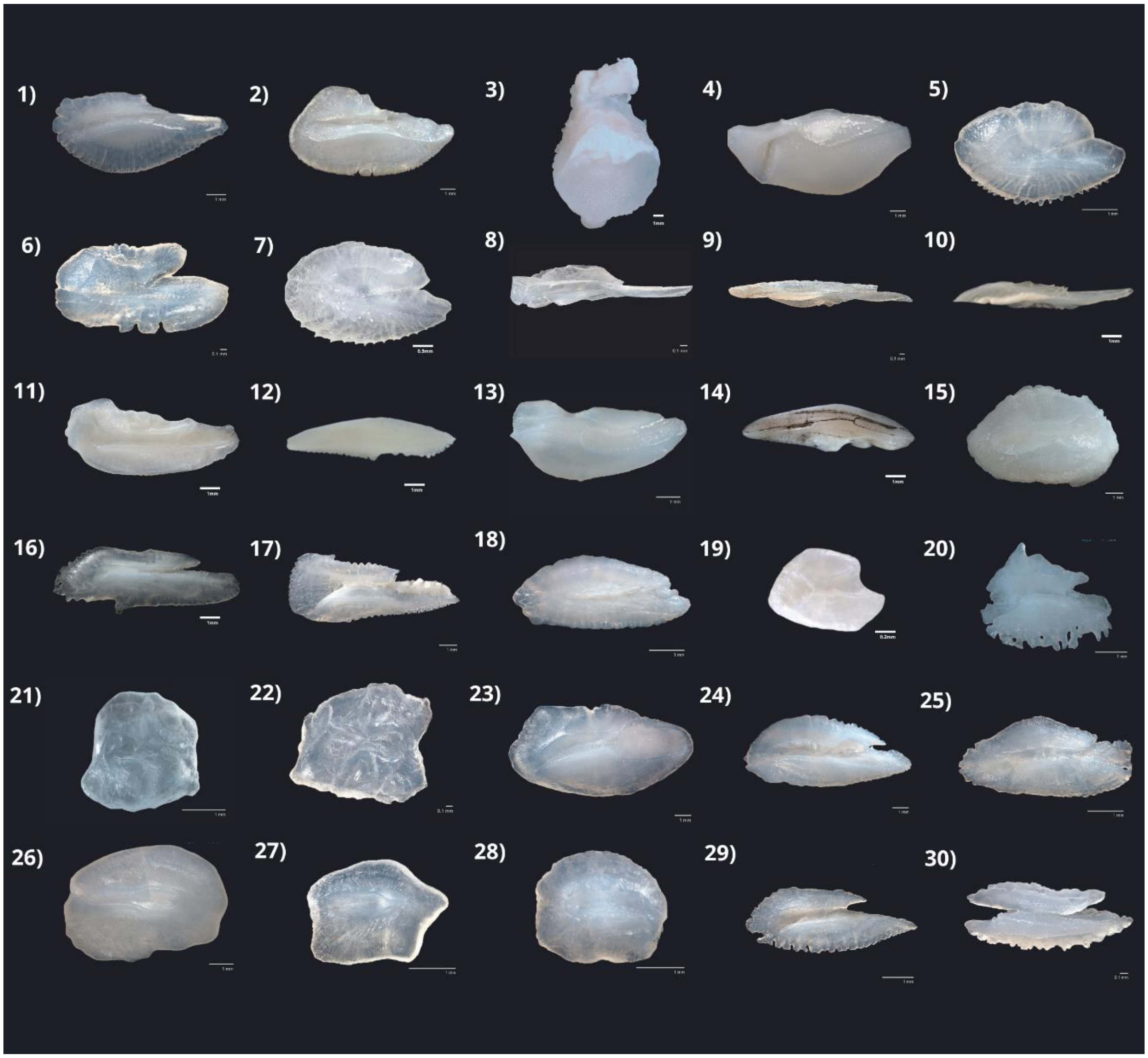

Figure 1. Diversity of sagittae otoliths from the Collection of Otoliths of Fishes from the Gulf of Mexico and the Caribbean Sea: 1) Family Elopidae, *Elops saurus* Linnaeus, 1766, 2) Family Megalopidae, *Megalops atlanticus* (Valenciennes, 1847) 3) Family Lepisosteidae, *Atractosteus tropicus* (Gill, 1863), 4) Family Albulidae, *Albula vulpes* (Linnaeus, 1758), 5) Family Engraulidae, *Anchoa cayorum* (Fowler, 1906), 6) Family Clupeidae, *Dorosoma petenense* (Günther, 1867), 7) Family Clupeidae, *Cetengraulis edentulus* (Cuvier, 1829), 8) Family Characidae, *Astyanax altior* Hubbs, 1936, 9) Family Heptapteridae, *Rhamdia guatemalensis* (Günther, 1864), 10) Family Ariidae, *Bagre marinus* (Mitchill, 1815), 11) Family Synodontidae, *Saurida brasiliensis* Norman, 1935, 12) Family Phycidae, *Urophycis floridana* (Bean & Dresel, 1884), 13) Family Holocentridae, *Holocentrus adscensionis* (Osbeck, 1765), 14) Family Ophidiidae, *Brotula barbata* (Bloch & Schneider, 1801), 15) Family Batrachoididae, *Sanopus reticulatus* Collette, 1983, 16) Family Pomatomidae, *Pomatomus saltatrix* (Linnaeus, 1766), 17) Family Scombridae, *Scomberomorus maculatus* (Mitchill, 1815) (Bloch, 1792), 22) Family Gobiidae, *Awaous banana* (Valenciennes, 1837), 23) Family

Centropomidae, *Centropomus parallelus* Poey, 1860, 24) Family Sphyraenidae, *Sphyraena barracuda* (Edwards, 1771), 25) Family Polynemidae, *Polydactylus octonemus* (Girard, 1858), 2 6) Family Cyclopsettidae, *Cyclopsetta chittendeni* Bean, 1895, 27) Family Paralichthyidae, *Citharichthys spilopterus* Gunther, 1862, 28) Family Achiridae, *Achirus lineatus* (Linnaeus, 1758), 29) Family Carangidae, *Hemicaranx amblyrhynchus* (Cuvier, 1833), 30) Family Echeneidae, *Echeneis neucratoides* (Zuiew, 1786).

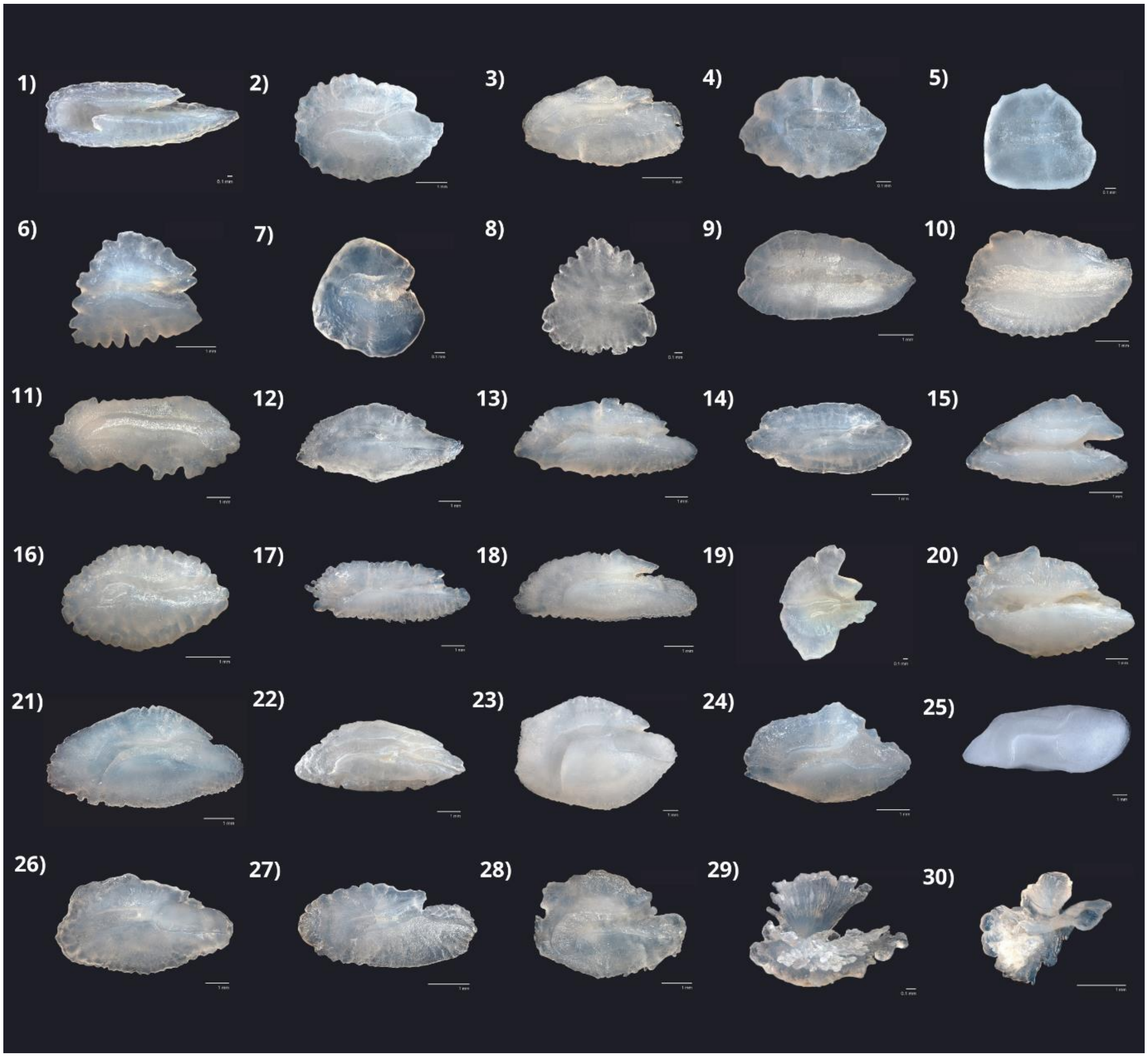

Figure 1. ...continuation 1) Family Rachycentridae, *Rachycentron canadum* (Linnaeus, 1766), 2) Family Cichlidae, *Mayaheros urophthalmus* (Gunther, 1862), 3) Family Pomacentridae, *Abudefduf saxatilis* (Linnaeus, 1758), 4) Family Atherinopsidae, *Menidia colei* Hubbs, 1936, 5) Family Rivulidae, *Cynodonichthys tenuis* (Meek, 1904), 6) Family Fundulidae, *Fundulus grandissimus* Hubbs, 1936), 7) Family Cyprinodontidae, *Cyprinodon artifrons* Hubbs, 1936, 8) Family Poeciliidae, *Belonesox belizanus* Kner, 1860, 9) Family Belonidae, *Strongylura timucu* (Walbaum, 1792), 10) Family Hemiramphidae, *Hemirramphus brasiliensis* (Linnaeus, 1758), 11) Family Mugilidae, *Mugil cephalus* Linnaeus, 1758, 12) Family Serranidae, *Diplectrum formosum* (Linnaeus, 1766), 13) Family Epinephelidae, *Epinephelus adscensionis* (Osbeck, 1765), 14) Family Grammistidae, *Rypticus maculatus* Holbrook, 1855, 15) Family Labridae, *Lachnolaimus maximus* Walbaum, 1792, 16) Family Triglidae, *Prionotus punctatus* (Bloch, 1793), 17) Family Scorpaenidae, *Scorpaena plumieri* Bloch, 1789, 18) Family Kyphosidae, *Kyphosus sectatrix* (Linnaeus, 1766), 19) Family Priacanthidae, *Priacanthus arenatus* Cuvier, 1829, 20) Family Malacanthidae, *Caulolatilus cyanops* Poey, 1866, 21) Family Lutjanidae, *Lutjanus griseus* (Linnaeus, 1758), 22) Family Gerreidae, *Gerres cinereus* (Walbaum, 1792), 23) Family Haemulidae, *Haemulon*

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plumierii (Lacepède, 1801), 24) Family Sparidae, *Lagodon rhomboides* (Linnaeus, 1766), 25) Family Sciaenidae, *Cynoscion nebulosus* (Cuvier, 1830), 26) Family Pomacanthidae, *Pomacanthus arcuatus* (Linnaeus, 1758), 27) Family Chaetodontidae, *Chaetodon ocellatus* Bloch, 1781, 28) Family Acanthuridae, *Achirus lineatus* (Linnaeus, 1758), *Acanthurus coeruleus* Bloch & Schneider, 1801, 29) Family Tetraodontidae, *Sphoeroides testudineus* (Linnaeus, 1758), 30) Family Balistidae, *Balistes capriscus* Gmelin, 1789.

Table

Table 1. List of species of the Otolith Collection of the Gulf of Mexico and the Caribbean Sea. Taxonomic classification according to Van der Laan et al. (2024). The size range of the specimens corresponds to the total length (TL), except in some cases where the standard length (SL) is used (*).

Family	Species	Number of specimens	Size range (mm)
Lepisosteidae	*Atractosteus tropicus* (Gill, 1863)	2	540-593
Elopidae	*Elops saurus* Linnaeus, 1766	38	87-613
Megalopidae	*Megalops atlanticus* (Valenciennes, 1847)	2	*385-426
Albulidae	*Albula vulpes* (Linnaeus, 1758)	6	351-292
Ophichthidae	*Ahlia egmontis* (Jordan, 1884)	1	365
Engraulidae	*Anchoa cayorum* (Fowler, 1906)	7	90
	Anchoa cubana (Poey, 1868)	2	*55
	Anchoa lamprotaenia (Hildebrand, 1943)	34	89-130
	Cetengraulis edentulus Cuvier, 1829	9	*94-140
Clupeidae	*Dorosoma petenense* (Günther, 1867)	6	*104-140
	Harengula clupeola (Cuvier, 1829)	10	51.47-130
	Harengula jaguana Poey, 1865	15	110-160
	Opisthonema oglinum (Lesuer, 1818)	24	33-250
	Sardinella aurita Valenciennes, 1847	3	*156-163
Cyprinidae	*Ctenopharyngodon idella* (Valenciennes, 1844)	1	261
Characidae	*Astyanax altior* Hubbs, 1936	23	55.7-79.1
Heptapteridae	*Rhamdia guatemalensis* (Günther, 1864)	4	91.5-1293
Ariidae	*Ariopsis felis* (Linnaeus, 1766)	108	56-402
	Bagre marinus (Mitchill, 1815)	106	267-540
Synodontidae	*Saurida brasiliensis* Norman, 1935	2	*184-203
	Synodus foetens (Linnaeus, 1766)	22	52.4-376
Phycidae	*Urophycis floridana* (Bean & Dresel, 1884)	5	256-327
Holocentridae	*Holocentrus adscensionis* (Osbeck, 1765)	5	92-280
	Holocentrus rufus (Walbaum, 1792)	2	110-115
	Myripristis jacobus Cuvier,1829	2	166-180

Ophidiidae	*Brotula barbata* (Bloch & Schneider, 1801)	3	372-550.8
	Ophidion holbrookii Putnam, 1874	3	77-141
Batrachoididae	*Opsanus beta* (Goode & Bean, 1880)	6	*98-205
	Opsanus dichrostomus Collette, 2001	2	105-130
	Sanopus reticulatus Collette, 1983	12	280-590
Pomatomidae	*Pomatomus saltatrix* (Linnaeus, 1766)	8	420-524
Scombridae	*Euthynnus alletteratus* (Rafinesque, 1810)	1	450
	Scomberomorus brasiliensis Collette, Russo & Zavala-Camin, 1978	5	*290-360
	Scomberomorus cavalla (Cuvier, 1829)	4	695-750
	Scomberomorus maculatus (Mitchill, 1815)	4	480-590
Trichiuridae	*Trichiurus lepturus* (Linnaeus, 1758)	8	*268-884
Dactylopteridae	*Dactylopterus volitans* (Linnaeus, 1758)	3	86-92
Mullidae	*Mulloidichthys martinicus* (Cuvier,1829)	2	250-268
	Pseudopenaeus maculatus (Bloch, 1793)	1	223
	Upeneus parvus Poey, 1852	3	*115-145
Callionymidae	*Chalinops pauciradiatus* (Gill, 1865)	6	27.2-36.9
Eleotridae	*Dormitator maculatus* (Bloch, 1792)	6	45-90
	Gobiomorus dormitor Lacepéde, 1800	6	*147-186
Gobiidae	*Awaous banana* (Valenciennes, 1837)	2	*51-62
	Gobionellus oceanicus (Pallas, 1770)	5	*93-159
	Gobiosoma robustum (Ginsburg, 1933)	6	28.2-36.3
Centropomidae	*Centropomus parallelus* Poey, 1860	3	*158-181
	Centropomus undecimalis (Bloch, 1792)	25	370-473
Sphyraenidae	*Sphyraena barracuda* (Edwards, 1771)	22	247-1015
	Sphyraena guachancho Cuvier, 1829	9	*148-583
Polynemidae	*Polydactylus octonemus* (Girard, 1858)	3	*78-195
Cyclopsettidae	*Cyclopsetta chittendeni* Bean, 1895	117	218-315
	Cyclopsetta fimbriata (Goode & Bean, 1885)	51	77-390
	Syacium papilosum (Linnaeus, 1758)	34	231-275
Paralichthyidae	*Citharichthys macrops* Dressel, 1885	1	153
	Citharichthys spilopterus Gunther, 1862	5	*56-138
	Paralichthys albigutta (Jordan & Gilbert, 1882)	2	139-530
Achiridae	*Achirus lineatus* (Linnaeus, 1758)	10	60-93.3
	Trinectes maculatus (Bloch & Schneider, 1801)	1	94.4
Carangidae	*Alectis ciliaris* (Bloch, 1787)	1	302
	Caranx crysos (Mitchill, 1815)	27	271-405
	Caranx hippos (Linnaeus, 1766)	17	233-370
	Caranx latus Agassiz, 1831	8	121-259
	Caranx ruber (Bloch, 1793)	4	246-305

	Chloroscombrus chrysurus (Linnaeus, 1766)	6	*17-182
	Hemicaranx amblyrhynchus (Cuvier, 1833)	1	*240
	Oligoplites saurus Bloch & Schneider, 1801	16	106-278
	Selar crumenophthalmus (Bloch, 1793)	6	*185-207
	Selene setapinnis (Mitchill, 1815)	5	*149-185
	Selene vomer (Linnaeus, 1758)	7	305-315
	Trachinotus carolinus (Linnaeus, 1766)	3	300-305
	Trachinotus falcatus (Linnaeus, 1758)	21	96-520
	Trachinotus goodei (Jordan & Evermann, 1896)	5	218-295
	Trachinotus meeki Brind, 1918	1	116.1
Echeneidae	*Echeneis neucratoides* (Zuiew, 1786)	10	320-523
Rachycentridae	*Rachycentron canadum* (Linnaeus, 1766)	3	219-690
Cichlidae	*Mayaheros urophthalmus* (Gunther, 1862)	11	123.9-235
	Oreochromis niloticus (Linnaeus, 1758)	1	245
	Parachromis friedrichsthalii (Heckel, 1840)	3	103-113
	Parachromis motaguensis (Günter, 1867)	4	230-269
	Petenia splendida (Günter, 1862)	5	238-265
	Rocio octofasciata Regan, 1903	10	48-74.5
	Thorichthys meeki Brind, 1918	3	54.1-96.7
Pomacentridae	*Abudefduf saxatilis* (Linnaeus, 1758)	5	75.4-156
	Neopomacentrus cyanomos (Bleeker, 1856)	10	32.1-85.8
	Stegastes leucostictus (Müller & Troschel, 1848)	2	106.5-109.5
	Stegastes xanthurus (Poey, 1860)	2	94.6-97.7
Atherinopsidae	*Atherinomorus stipes* (Muller & Troschel, 1848)	21	38.4-56.63
	Menidia colei Hubbs, 1936	9	11.5-33
	Menidia sp.	12	19.6-24.38
Rivulidae	*Cynodonichthys tenuis* (Meek, 1904)	1	41
	Kryptolebias marmoratus (Poey, 1880)	1	30
Fundulidae	*Fundulus grandissimus* Hubbs, 1936	41	90.6-160
	Fundulus persimilis Miller, 1955	19	78.6-122.2
	Lucania parva (Baird & Girard, 1855)	9	24-35.3
Cyprinodontidae	*Cyprinodon artifrons* Hubbs, 1936	57	16.4-45
	Floridichthys polyommus Hubbs, 1936	43	62-120
	Jordanella pulchra Hubbs, 1936	14	28-35.4
Poeciliidae	*Belonesox belizanus* Kner, 1860	12	55.9-91.5
	Gambusia yucatana Regan, 1914	14	19.8-36.5
	Poecilia mexicana (Steindachner, 1863)	3	74.1-88.8
	Poecilia velifera (Regan, 1914)	18	38-79

	Pseudoxiphophorus bimaculatus (Heckel 1848)	2	55-59.8
Belonidae	*Strongylura marina* (Walbaum, 1792)	10	260-332
	Strongylura notata (Poey, 1860)	42	195-433
	Strongylura timucu (Walbaum, 1792)	9	230
	Tylosurus crocodilus (Peron y Lesueur, 1821)	11	65-1020
Hemiramphidae	*Chriodorus atherinoides* Goode & Bean, 1882	28	109-190
	Hemirramphus brasiliensis (Linnaeus, 1758)	6	300
	Hyporhamphus unifasciatus (Ranzani, 1841)	43	140-326
Mugilidae	*Mugil cephalus* Linnaeus, 1758	14	127-232
	Mugil curema Valenciennes,1836	17	120-434
	Mugil trichodon Poey,1875	8	39.7-183
Serranidae	*Diplectrum formosum* (Linnaeus, 1766)	26	125-248
	Hypoplectrus ecosur Victor, 2012	7	58.1-115
	Serranus subligarius (Cope, 1870)	7	64.2-92
Epinephelidae	*Cephalopholis cruentata* (Lacepede, 1802)	6	270-305
	Cephalopholis fulva (Linnaeus, 1758)	1	235
	Epinephelus adscensionis (Osbeck, 1765)	12	*31-256
	Epinephelus morio (Valenciennes, 1828)	14	270-480
	Hyporthodus niveatus (Valenciennes, 1828)	3	350-367
	Mycteroperca bonaci (Poey, 1860)	3	345-625
Grammistidae	*Rypticus maculatus* Holbrook, 1855	3	140-142
Labridae	*Halichoeres radiatus* (Linnaeus, 1758)	1	*264
	Lachnolaimus maximus Walbaum, 1792	23	140-325
	Nicholsina usta (Valenciennes, 1840)	4	95-165
	Scarus coeruleus (Edwards, 1771)	1	130
	Sparisoma rubripinne (Valenciennes, 1840)	2	385
Triglidae	*Prionotus punctatus* (Bloch, 1793)	2	280-
	Prionotus scitulus Jordan & Gilbert, 1882	2	214-215
	Prionotus tribulus Cuvier, 1829	4	175-300
Scorpaenidae	*Pterois volitans* (Bloch, 1758)	1	*95.2
	Scorpaena brasiliensis Cuvier, 1829	5	155-215
	Scorpaena plumieri Bloch, 1789	14	105-240
Kyphosidae	*Kyphosus sectatrix* (Linnaeus, 1766)	4	140-427
Priacanthidae	*Priacanthus arenatus* Cuvier, 1829	3	310-325
	Pristigerys alta (Gill, 1862)	1	45
Malacanthidae	*Caulolatilus cyanops* Poey, 1866	1	*290
Lutjanidae	*Lutjanus analis* (Cuvier, 1828)	2	398
	Lutjanus apodus (Walbaum,1792)	1	206

	Lutjanus buccanella (Cuvier, 1828)	2	*180-191
	Lutjanus campechanus (Poey, 1860)	3	455-470
	Lutjanus cyanopterus (Cuvier,1828)	1	206
	Lutjanus griseus (Linnaeus, 1758)	20	69.2
	Lutjanus jocu (Bloch & Schneider, 1801)	1	348
	Lutjanus synagris (Linnaeus, 1758)	38	185-405
	Ocyurus chrysurus (Bloch, 1791)	24	68.9-321
	Rhomboplites aurorubens (Cuvier, 1829)	15	260-277
Gerreidae	*Diapterus auratus* Ranzani, 1842	6	*134-173
	Diapterus rhombeus (Cuvier, 1829)	5	*116-139
	Eucinostomus argenteus (Baird & Girard, 1855)	4	96.4-117.5
	Eucinostomus gula (Quoy & Gaimard, 1824)	42	66-113
	Eucinostomus harengulus Goode & Bean, 1880	5	*61-95
	Eucinostomus melanopterus (Bleeker, 1863)	2	*61-56
	Eugerres brasilianus (Cuvier, 1830)	7	180-280
	Eugerres plumieri (Cuvier, 1830)	45	96-317
	Gerres cinereus (Walbaum, 1792)	26	107.4-265
Haemulidae	*Anisotremus virginicus* (Linnaeus, 1758)	25	181-367
	Conodon nobilis (Linnaeus, 1758)	6	*57-185
	Haemulon aurolineatum Cuvier, 1830	24	162-249
	Haemulon bonariense Cuvier, 1830	8	150-342
	Haemulon carbonarium Poey, 1860	6	*147-265
	Haemulon flavolineatum (Desmarest, 1823)	6	*155-185
	Haemulon parra (Desmarest, 1823)	3	*215-259
	Haemulon plumierii (Lacepède, 1801)	102	160-315
	Haemulon sciurus (Shaw,1803)	4	186-253
	Orthopristis chrysoptera (Linnaeus, 1766)	26	127.1-244
	Rhonciscus crocro (Cuvier, 1830)	2	*192-211
Sparidae	*Archosargus probatocephalus* (Walbaum, 1792)	24	176-610
	Archosargus rhomboidalis (Linnaeus, 1758)	67	85.1-280
	Calamus bajonado (Bloch & Schneider, 1801)	15	215-540
	Calamus calamus (Valenciennes, 1830)	11	191-300
	Calamus campechanus Randall & Caldwell, 1966	18	185-249
	Calamus nodosus Randall & Caldwell, 1966	6	229-310
	Calamus pennatula Guichenot, 1868	3	282
	Calamus proridens Jordan & Gilbert, 1884	5	210-275

	Lagodon rhomboides (Linnaeus, 1766)	31	44.5-207
	Stenotomus chrysops (Linnaeus, 1766)	1	*210-521
Sciaenidae	*Bairdiella chrysoura* (Lacepéde, 1802)	5	82.2-165
	Bairdiella ronchus (Cuvier, 1830)	19	139-270
	Corvula batabana (Poey, 1860)	2	156.6-160
	Cynoscion arenarius Ginsburg, 1930	92	160-423
	Cynoscion jamaicensis (Vaillant & Bocourt, 1883)	2	*256-268
	Cynoscion nebulosus (Cuvier, 1830)	92	110-490
	Cynoscion nothus (Holbrook, 1848)	6	130-245
	Eques lanceolatus Linnaeus, 1758	32	80-335
	Menticirrhus americanus (Linnaeus, 1758)	191	204-400
	Menticirrhus littoralis (Holbrook, 1847)	11	91-365
	Menticirrhus saxatilis (Bloch &Schneider, 1801)	3	*226-236
	Micropogonias furnieri (Desmarest,1823)	59	74-412
	Micropogonias undulatus (Linnaeus, 1766)	39	86-425
	Pareques umbrosus Jordan & Eigenmann, 1889	7	55-210
	Pogonias cromis (Linnaeus, 1766)	1	84
	Stellifer lanceolatus (Holbrook, 1855)	6	*75-96
	Umbrina coroides Cuvier, 1830	7	*80-214
Lobotidae	Lobotes surinamensis (Bloch, 1790)	6	320-570
Pomacanthidae	Holacanthus bermudensis Goode, 1876	8	65-337
	Pomacanthus arcuatus (Linnaeus, 1758)	5	87-498
Chaetodontidae	Chaetodon ocellatus Bloch, 1781	34	40-124
Ephippidae	Chaetodipterus faber (Broussonet, 1782)	16	63.8-354
Acanthuridae	Acanthurus chirurgus (Bloch, 1787)	4	316
	Acanthurus coeruleus Bloch & Schneider, 1801	5	201-255
	Acanthurus tractus Poey, 1860	5	244-325
Ogcocephalidae	*Ogcocephalus cubifrons* (Richardson, 1836)	2	125-215
Diodontidae	*Chilomycterus schoepfii* (Walbaum, 1792)	13	96-285
	Diodon hystrix (Linnaeus, 1758)	1	490
Tetraodontidae	*Lagocephalus laevigatus* (Linnaeus, 1766)	5	330-554
	Sphoeroides nephelus (Goode & Bean, 1882)	6	124.6-280
	Sphoeroides spengleri (Bloch, 1785)	8	54-111.2
	Sphoeroides testudineus (Linnaeus, 1758)	7	157-235
Ostraciidae	*Acanthostracion quadricornis* (Linnaeus, 1758)	11	90-270
Monacanthidae	*Monacanthus ciliatus* (Mitchill, 1818)	4	81-136

	Stephanolepsis hispida (Linnaeus, 1766)	2	160
Balistidae	*Balistes capriscus* Gmelin, 1789	10	240-495

Author contribution

Maribel Badillo Alemán: Conceptualization, investigation, data curation, supervision, writing original draft.

Ariana Solís Gómez: Investigation, data curation.

Alfredo Gallardo Torres: Investigation, data curation, formal analysis, resources.

Eduardo Pacheco Gongora: Data curation, software development, visualization.

Xavier Chiappa-Carrara: Conceptualization, investigation, project administration, formal analysis, writing original draft, funding acquisition.