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ARTICLE

Scanning holotypes from the Vertebrate Paleontology Collection at the Museu Paraense Emilio Goeldi (Brazil): Tools for research and science outreach

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Abstract
The scanning of paleontological collections is increasingly important for morphological studies and science outreach. In addition to ensuring data sharing, digitization contributes to preserving morphological information in case of damage to the original specimens. In this communication, we aim to report digital versions of the holotypes from the Vertebrate Paleontology Collection at the Museu Paraense Emilio Goeldi, Brazil. For this purpose, eighteen holotypes of Early/Middle Miocene Teleostei from Pirabas Formation, northern Brazil, were scanned using microtomography, and cybertypes were proposed. The CT-Scan data were stored in a virtual repository, can be freely accessed, and are available for future studies on the morphology of these specimens. Furthermore, these specimens are tiny and fragile, and digital versions can be an alternative to safely handling them. Finally, the digitization of important specimens, at least of holotypes, needs to be a standard practice in museum collections over the next years.

KEYWORDS
cybertaxonomy, digital morphology, Miocene, museology, Pirabas formation, Teleostei

INTRODUCTION

The growing access to technologies for digitizing specimens from paleontological (and biological) collections has promoted advances in data sharing and replicability (see Davies et al., 2017). Regardless of the scanning method (CT-Scan, laser scan, or photogrammetry), these data can be freely distributed virtually and accessed by researchers worldwide (see Mallison, 2011; Mallison & Wings, 2014; Faulwetter et al., 2013; Akkari et al., 2015; Hocknull et al., 2021). 3D data are becoming the mainstream of data sharing by scientists when physical specimen access is impossible (Díez-Diaz et al., 2021). This statement is especially true since the COVID-19 pandemic (in 2020–2022) when access to scientific collections has been hampered for sanitary reasons (see Lobo et al., 2021). Besides, digitalized specimens are important during the peer review process because the interpretations can be checked, ensuring the reproducibility of results (Davies et al., 2017).

One of the most important advantages of digitalizing paleontological collections is that physical specimens can deteriorate, break, or disappear due to natural causes (Diéz Díaz et al., 2021) or during tragic events (see Benton, 2012; Martha, 2014; Brum et al., 2021; Rotti et al., 2021; Lobo et al., 2021). In these cases, at least digital information can be preserved. Digitalization of paleontological specimens from South America and the free distribution of data has been significantly increasing in recent years (e.g., Ruella et al., 2017; Batallés et al., 2018; Kerber et al., 2019; Pacheco et al., 2019; Pavanatto et al., 2019; Copetti et al., 2021; Ferreira et al., 2020; Grillo et al., 2020; Stefanello et al., 2020; Lobo et al., 2021).

The paleontological collection of the Museu Paraense Emilio Goeldi (Brazil) was founded in 1896 by Karl Friedrick Katzer. This collection has approximately 7583 specimens from the main geological units of the Amazon region, which include fossils from the Paleozoic of the Amazon Basin (Maecuru, Erere, Manacapuru, and Itaituba Formations), Mesozoic of the São Luís Basin (Alcântara and Codó Formations), Cenozoic of the Solimões Formation (Solimões and Acre basins) and Pirabas Formation (Bragantina Platform) (see Ramos et al., 2009 for a review). In this communication, we aim to report digital versions of the holotypes from the Vertebrate Paleontology Collection at the Museu Paraense Emilio Goeldi, and propose cybertypes for these specimens. The analyzed fossils are otoliths (tiny fossils of structures of calcium carbonate and other minerals that originated in the inner ear of teleost fishes) described by Aguilera et al. (2014).

Cybertypes

A new taxonomic concept has been discussed in recent years, complementing the conventional taxonomic workflow—the cybertype (see Godfray, 2007; Carvalho et al., 2007; Faulwetter et al., 2013; Akkari et al., 2015). The new term that supports research in systematics and taxonomy corresponds to a digital version of a type specimen (e.g., CT-Scan data, 3D models, genetic data). Faulwetter et al. (2013, pg. 4) conducted an extensive review of this and other cybertaxonomic concepts. In their review, they established three principles so that digitized versions can be considered cybertypes, as follows: "(a) A cybertype should provide morphological and anatomical information of the same accuracy and reliability as provided by the physical type material, independently of a specific research question in mind; (b) A cybertype should be linked to the original type material, which can be consulted if in doubt. This implies that any method used to create the cybertype should not affect the morphological, anatomical, and molecular identity of the original specimen (e.g., holotype, paratype, or neotype); (c) A cybertype has to be retrievable and freely accessible. This involves making the data available through a reliable (internet) source under an open-access license and providing adequate security measures, such as archiving, backups and ensuring data format compatibility in future, and allowing the annotation of the dataset with metadata in order to be retrievable and interpretable." Recently, Diéz Díaz et al. (2021) reviewed cybertaxonomic concepts in paleontology. They suggest that *cybertype* is a digital synonym of *holotype* and *digitype* as a digital synonym of *paratype*. Although cybertypes are not yet formally recognized by the International Code of Zoological Nomenclature, Akkari et al. (2018) emphasized that the virtual "type" transcends the restrictions and limitations in obtaining specimens of valuable, fragile, and restricted-access physical type. In addition, CT-Scan data provide details of the internal structures of specimens in a way that no other imaging method can.

MATERIAL AND METHODS

Collection and provenance

All the analyzed specimens are housed at the paleontological collection of the Museu Paraense Emilio Goeldi (MPEG), Belém, State of Pará, Brazil. The specimens are Teleostei otoliths described in Aguilera et al. (2014), and that paper needs to be consulted for further details on these specimens. The taxonomic framework follows the original description (Aguilera et al., 2014, 2016). The specimens were collected from carbonate exposures of the Pirabas Formation (Early-Middle Miocene) at Atalaia Beach (late Langhian to Serravallian, 14.2–12.7 Ma; Aguilera et al., 2020, 2022), Salinópolis, State of Pará (0°36′5″S, 47°18′48″W; Tavora et al., 2010). This sedimentary unit was deposited during the Early to Middle Miocene (Ramos et al., 2004; Martinez et al., 2017; Aguilera et al., 2020, 2022) in coastal marine environments with a tidal regime, marginal lagoons with mangrove forests, and tropical storms, before the origin of the Amazon delta (Aguilera et al., 2020, 2022). A diverse fossil record of marine organisms has been found in the outcrops of this formation (e.g., Ramos et al., 2004; Tavora et al., 2010; Nogueira et al., 2011, 2019; Aguilera & Páes, 2012; Aguilera et al., 2014, 2017; Martinez et al., 2017; Nogueira & Nogueira, 2017; Kerber & Moraes-Santos, 2021).

Scanning procedures

Eighteen specimens were scanned with a µCT scan Skyscan™ 1173 at the Laboratório de Sedimentologia e Petrologia of the Pontifícia Universidade Católica do Rio Grande do Sul (PUCRS), Porto Alegre (Brazil). Dragonfly software (Version 2020.2 [for Windows]. Object Research Systems (ORS) Inc, Montreal, Canada, 2020) was employed to render the 3D reconstructions of the figures. Reconstruction of each scan was made with the software *NRecon* (version 1.7.4.6; Bruker Micro-CT), and the parameters are included in the log file accompanying the slices. The reconstructed tomographic images were exported as 8-bit TIFF. The slices with no information were deleted to minimize the size of the files, but the original files of the scanning are kept by the senior author of the work and can be requested via email. The CT-Data and log data are housed in the virtual repository Morphosource (https://www.morphosource.org/projects/000422429?locale=en), where they can be freely accessed and used in any further morphological study.

Institutional abbreviations

MPEG–V, Vertebrate Paleontology Collection at the Museu Paraense Emilio Goeldi Belém Brazil.

SYSTEMATIC PALEONTOLOGY

Teleostei Müller, 1845

Congridae Kaup, 1856

Genus *Paraconger* Kanazawa, 1961

Paraconger paraensis Aguilera & Schwarzhans, 2014 (in Aguilera et al., 2014)

Figure 1a

Holotype: MPEG-1829-V, otolith.

Type locality: Atalaia Beach, Salinópolis Municipality, Pará State, Brazil (0°35′33.6″S, 47°18′55.6″W).

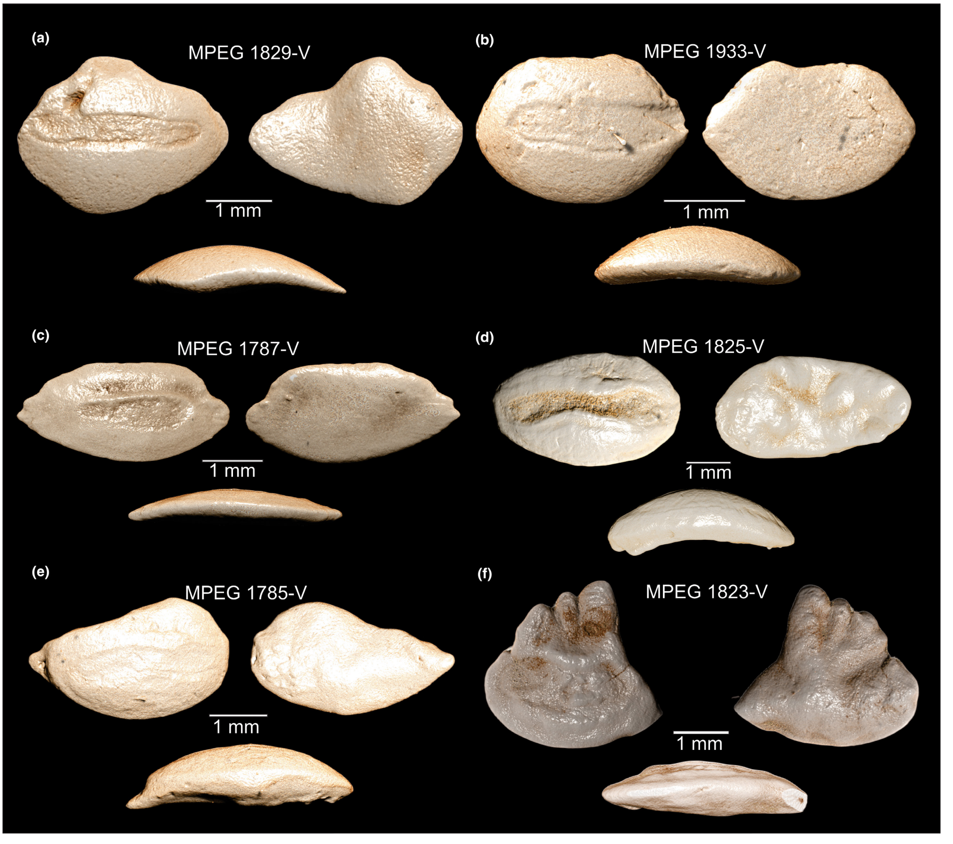

FIGURE 1 Digital renderings of otoliths of holotypes Teleostei fishes from Pirabas Formation, Pará State, Brazil. (a) MPEG-1829-V, *Paraconger paraensis*; (b) MPEG-1933-V, *Pythonichthys pirabasensis*; (c) MPEG- 1787-V, *Ogilbia brasiliensis*; (d) MPEG-1825-V, *Batrachoides confluentus*; (e) MPEG- 1785-V, *Batrachoides gracilentus*; (f) MPEG- 1823-V, *Porichthys atalaianus*. [Colour figure can be viewed at wileyonlinelibrary.com]

Description; Aguilera et al. (2014), page 427.
Cybertype: Micro-CT data with 507 slices, pixel size: 6.026644 µm, kV: 45, uA: 60.
Link: https://doi.org/10.17602/M2/M424766

Heterenchelyidae Regan, 1912
Genus *Pythonichthys* Poey, 1868
Pythonichthys pirabasensis Aguilera & Schwarzhans, 2014 (in Aguilera et al., 2014)
Figure 1b
Holotype: MPEG-1933-V, otolith.
Type locality: Atalaia Beach, Salinópolis Municipality, Pará State, Brazil (0°35′33.6″S, 47°18′55.6″W).
Description: Aguilera et al. (2014), page 427.
Cybertype: Micro-CT data with 387 slices, pixel size: 6.026644 µm, kV: 45, uA: 60.
Link: https://doi.org/10.17602/M2/M424304

Bythitidae Gill, 1861
Genus *Ogilbia* Jordan and Evermann, in Evermann and Kendell, 1898
Ogilbia brasiliensis Aguilera & Schwarzhans, 2014 (in Aguilera et al., 2014)
Figure 1c

Holotype: MPEG-1787-V, otolith.
Type locality: Atalaia Beach, Salinópolis Municipality, Pará State, Brazil (0°35′33.6″S, 47°18′55.6″W).
Description: Aguilera et al. (2014), page 429.
Cybertype: Micro-CT data with 556 slices, pixel size: 6.026644 μm, kV: 45, uA: 60.
Link: https://doi.org/10.17602/M2/M424757

Batrachoididae Jordan, 1896
Genus *Batrachoides* Lacepède, 1800
Batrachoides confluentus Aguilera & Schwarzhans, 2014 (in Aguilera et al., 2014)
Figure 1d
Holotype: MPEG-1825-V, holotype.
Type locality: Atalaia Beach, Salinópolis Municipality, Pará State, Brazil (0°35′33.6″S, 47°18′55.6″W).
Description: Aguilera et al. (2014), page 431.
Cybertype: Micro-CT data with 719 slices, pixel size: 6.026644 μm, kV: 45, uA: 60.
Link: https://doi.org/10.17602/M2/M427601

Batrachoides gracilentus Aguilera & Schwarzhans, 2014 (in Aguilera et al., 2014)
Figure 1e
Holotype: MPEG-1785-V, otolith.
Type locality: Atalaia Beach, Salinópolis Municipality, Pará State, Brazil (0°35′33.6″S, 47°18′55.6″W).
Description: Aguilera et al. (2014), page 431.
Cybertype: Micro-CT data with 576 slices, pixel size: 6.026644 μm, kV: 45, uA: 60.
Link: https://doi.org/10.17602/M2/M427616

Genus *Porichthys* Girard, 1855
Porichthys atalaianus Aguilera & Schwarzhans, 2014 (in Aguilera et al., 2014)
Figure 1f
Holotype: MPEG-1823-V, otolith.
Type locality: Atalaia Beach, Salinópolis Municipality, Pará State, Brazil (0°35′33.6″S, 47°18′55.6″W).
Description: Aguilera et al. (2014), page 431.
Cybertype: Micro-CT data with 194 slices, pixel size: 6.026644 μm, kV: 45, uA: 60.
Link: https://doi.org/10.17602/M2/M427622

Genus *Sanopus* Smith, 1952
Sanopus mendax Aguilera & Schwarzhans, 2014 (in Aguilera et al., 2014)
Figure 2a
Holotype: MPEG-1938-V, otolith.
Type locality: Atalaia Beach, Salinópolis Municipality, Pará State, Brazil (0°35′33.6″S, 47°18′55.6″W).
Description: Aguilera et al. (2014), page 431.
Cybertype: Micro-CT data with 449 slices, pixel size: 6.026644 μm, kV: 45, uA: 60.
Link: https://doi.org/10.17602/M2/M427636

Sanopus peregrinus Aguilera & Schwarzhans, 2014 (in Aguilera et al., 2014)
Figure 2b
Holotype: MPEG-1910-V, otolith.
Type locality: Atalaia Beach, Salinópolis Municipality, Pará State, Brazil (0°35′33.6″S, 47°18′55.6″W).

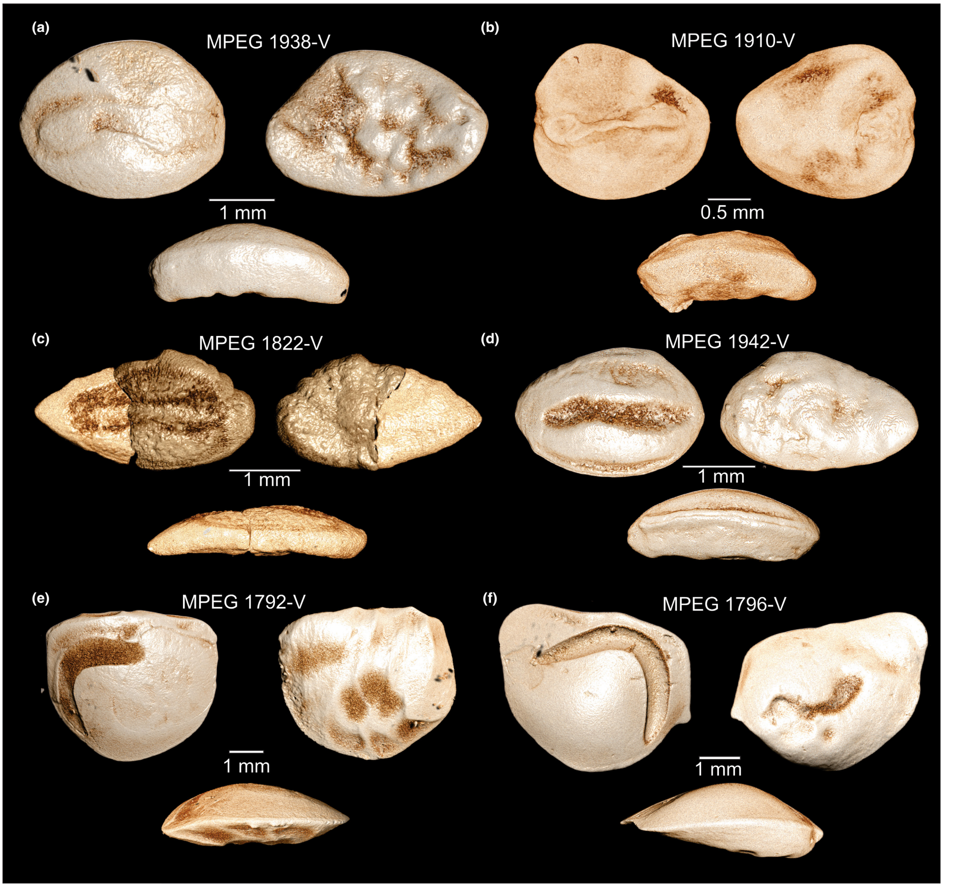

FIGURE 2 Digital renderings of otoliths of holotypes Teleostei fishes from Pirabas Formation, Pará State, Brazil. (a) MPEG-1938-V, *Sanopus mendax*; (b) MPEG-1910-V, *Sanopus peregrinus*; (c) MPEG-1822-V, *Thalassophryne aequaliter*; (d) MPEG-1942-V, *Thalassophryne pumilus* (mirrored); (e) MPEG-1792-V, *Aplodinotus santosi*; (f) MPEG-1796-V, *Equetulus amazonensis*. [Colour figure can be viewed at wileyonlinelibrary.com]

Description: Aguilera et al. (2014), page 431.
Cybertype: Micro-CT data with 149 slices, pixel size: 6.026644 μm, kV: 45, uA: 60.
Link: https://doi.org/10.17602/M2/M427652

Genus *Thalassophryne* Günther, 1861
Thalassophryne aequaliter Aguilera & Schwarzhans, 2014 (in Aguilera et al., 2014)
Figure 2c
Holotype: MPEG-1822-V, otolith.
Type locality: Atalaia Beach, Salinópolis Municipality, Pará State, Brazil (0°35′33.6″S, 47°18′55.6″W).
Description: Aguilera et al. (2014), page 433.
Cybertype: Micro-CT data with 129 slices, pixel size: 6.026644 μm, kV: 45, uA: 60.
Link: https://doi.org/10.17602/M2/M427668

Thalassophryne pumilus Aguilera & Schwarzhans, 2014 (in Aguilera et al., 2014)
Figure 2d
Holotype: MPEG-1942-V, otolith.

Type locality: Atalaia Beach, Salinópolis Municipality, Pará State, Brazil (0°35′33.6″S, 47°18′55.6″W).
Description: Aguilera et al. (2014), page 435.
Cybertype: Micro-CT data with 477 slices, pixel size: 6.026644 µm, kV: 45, uA: 60.
Link: https://doi.org/10.17602/M2/M427674

Sciaenidae Cuvier, 1829
Genus *Aplodinotus* Rafinesque, 1819
Aplodinotus santosi Aguilera & Schwarzhans, 2014 (in Aguilera et al., 2014)
Figure 2e
Holotype: MPEG-1792-V, otolith.
Type locality: Atalaia Beach, Salinópolis Municipality, Pará State, Brazil (0°35′33.6″S, 47°18′55.6″W).
Description: Aguilera et al. (2014), page 436; Aguilera et al. (2016), page 28.
Cybertype: Micro-CT data with 937 slices, pixel size: 6.026644 µm, kV: 45, uA: 60.
Link: https://doi.org/10.17602/M2/M427680

Genus *Equetulus* Aguilera & Schwarzhans, 2014 (in Aguilera et al., 2014)
Equetulus amazonensis Aguilera & Schwarzhans, 2014 (in Aguilera et al., 2014)
Figure 2f
Holotype: MPEG-1796-V, otolith.
Type locality: Atalaia Beach, Salinópolis Municipality, Pará State, Brazil (0°35′ 33.6″, S, 47° 18′ 55.6" W).
Description: Aguilera et al. (2014), page 436; Aguilera et al. (2016), page 36.
Cybertype: Micro-CT data with 898 slices, pixel size: 6.026644 µm, kV: 45, uA: 60.
Link: https://doi.org/10.17602/M2/M427957

Genus *Protolarimus* Aguilera & Schwarzhans, 2014 (in Aguilera et al., 2014)
Protolarimus? *mauryae* Aguilera & Schwarzhans, 2014 (in Aguilera et al., 2014)
Figure 3a
Holotype: MPEG-1805-V, otolith.
Type locality: Atalaia Beach, Salinópolis Municipality, Pará State, Brazil (0°35′ 33.6″, S, 47° 18′ 55.6" W).
Description: Aguilera et al. (2014), page 438; Aguilera et al. (2016), page 62.
Cybertype: Micro-CT data with 994 slices, pixel size: 6.026644 µm, kV: 45, uA: 60.
Link: https://doi.org/10.17602/M2/M427967

Genus *Plagioscion* Gill, 1862
Plagioscion travassosi Aguilera & Schwarzhans, 2014 (in Aguilera et al., 2014)
Figure 3b
Holotype: MPEG-1803-V, otolith.
Type locality: Atalaia Beach, Salinópolis Municipality, Pará State, Brazil (0°35′33.6″S, 47°18′55.6″W).
Description: Aguilera et al. (2014), page 439; Aguilera et al. (2016), page 56.
Cybertype: Micro-CT data with 1768 slices, pixel size: 14.888251 µm, kV: 100, uA: 80.
Link: https://doi.org/10.17602/M2/M427973

Genus *Protosciaena* Sasaki, 1989
Protosciaena brasiliensis Aguilera & Schwarzhans, 2014 (in Aguilera et al., 2014)
Figure 3c
Holotype: MPEG-1816-V, otolith.

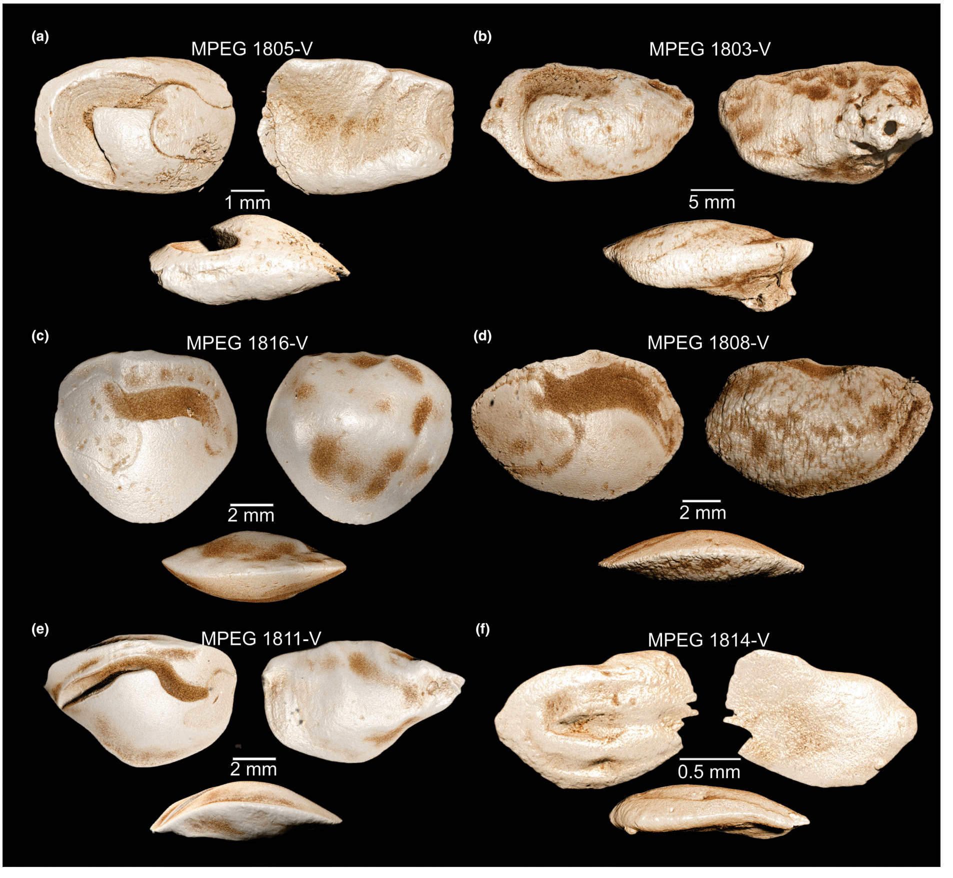

FIGURE 3 Digital renderings of otoliths of holotypes Teleostei fishes from Pirabas Formation, Pará State, Brazil. (a) MPEG-1805-V, *Protolarimus*? *mauryae*; (b) MPEG-1803-V, *Plagioscion travassosi*; (c) MPEG-1816-V, *Protosciaena brasiliensis*; (d) MPEG-1808-V, *Amazonasciaena rossettiae*; (e) MPEG-1811-V, *Xenotolithus retrolobatus*; (f) MPEG-1814-V, *Syacium predorsalis*. [Colour figure can be viewed at wileyonlinelibrary.com]

Type locality: Atalaia Beach, Salinópolis Municipality, Pará State, Brazil (0°35′33.6″S, 47°18′55.6″W).
Description: Aguilera et al. (2014), page 440; Aguilera et al. (2016), page 24.
Cybertype: Micro-CT data with 904 slices, pixel size: 6.026644 μm, kV: 45, uA: 60.
Link: https://doi.org/10.17602/M2/M427996

Genus *Amazonasciaena* Aguilera et al. (2016)
Amazonasciaena rossettiae (Aguilera & Schwarzhans, 2014) (in Aguilera et al., 2014)
Figure 3d
Holotype: MPEG-1808-V, otolith.
Type locality: Atalaia Beach, Salinópolis Municipality, Pará State, Brazil (0°35′33.6″S, 47°18′55.6″W).
Description: Aguilera et al. (2014), page 440; Aguilera et al. (2016), page 26.
Cybertype: Micro-CT data with 1516 slices, pixel size: 7.089968 μm, kV: 45, uA: 60.
Link: https://doi.org/10.17602/M2/M428122

Genus *Xenotolithus* Schwarzhans, 1993
Xenotolithus retrolobatus Aguilera & Schwarzhans, 2014 (in Aguilera et al., 2014)
Figure 3e
Holotype: MPEG-1811-V, otolith.
Type locality: Atalaia Beach, Salinópolis Municipality, Pará State, Brazil (0°35′33.6″S, 47°18′55.6″W).
Description: Aguilera et al. (2014), page 441; Aguilera et al. (2016), page 74.
Cybertype: Micro-CT data with 1461 slices, pixel size: 7.089968 µm, kV: 45, uA: 60.
Link: https://doi.org/10.17602/M2/M428182

Paralichthyidae Regan, 1910
Genus *Syacium* Ranzani, 1842
Syacium predorsalis Aguilera & Schwarzhans, 2014 (in Aguilera et al., 2014)
Figure 3f
Holotype: MPEG-1814-V, otolith.
Type locality: Atalaia Beach, Salinópolis Municipality, Pará State, Brazil (0°35′33.6″S, 47°18′55.6″W).
Description: Aguilera et al. (2014), page 443.
Cybertype: Micro-CT data with 432 slices, pixel size: 7.089968 µm, kV: 45, uA: 60.
Link: https://doi.org/10.17602/M2/M428216

FINAL REMARKS

The digitization of specimens characterizes a new approach to accessing scientific information from natural history collections and promotes access to morphological information (Lobo et al., 2021). Here, we reported digital versions of the holotypes of from the Vertebrate Paleontology Collection (fish Teleostean otoliths) at the MPEG (Aguilera et al., 2014) and proposed cybertypes, following the assumptions proposed by Faulwetter et al. (2013) and Diéz Díaz et al. (2021). This digital information is available for further morphological studies of these specimens and contributes to the outreach of scientific knowledge (Davies et al., 2017). As far as we know, this is one of the first Brazilian paleontological collections that digitalized the holotypes and included them in virtual repositories where they can be freely accessed (see discussion in Lobo et al., 2021). These tiny fossils of teleost fishes are fragile, and it is not uncommon to damage from physical handling during data collection or even during curatorial practices. In this sense, using digital versions can be an alternative to handling them safely.

As scanning techniques advance and become more accessible to researchers and museums, the virtual versions of holotypes—i.e., cybertypes—will probably become increasingly relevant due to the advantages associated with the concept (Akkari et al., 2015). Although cybertypes are no substitute for the original specimens, they also provide a backup of information in case of catastrophic loss of collections, or accidental damages to the original materials.

Scanning tools (CT-Scanners, laser scanners, etc.) are still not widely accessible to most Brazilian (and South American in general) researchers and curators, mainly due to the high cost of equipment and specific software for processing virtual data. Therefore, all digitalization projects and scanned specimens (see introduction) have added value. As such technologies become more widely accessible to researchers and curators, we expect that digitalizing important specimens, especially holotypes, will become standard museum practice soon.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in Morphosource at https://www.morphosource.org, reference number 000422429.

REFERENCES

Aguilera, O., & Páes, E. T. (2012). The Pirabas Formation (early Miocene from Brazil) and the tropical western central Atlantic subprovince. *Boletim do Museu Paraense Emílio Goeldi Ciências Naturais*, 7, 29–45.

Aguilera, O., Araujo, O. M. O., Hendy, A., Nogueira, A. A. E., Nogueira, A. C. R., Maurity, C. W., Kutter, V. T., Martines, M. V. A., Coletti, G., Dias, B. B., Silva–Caminha, S. A. F., Jaramillo, C., Bencomo, K., & Lopes, R. T. (2020). Palaeontological framework from Pirabas Formation (North Brazil) used as potential model for equatorial carbonate platform. *Marine Micropaleontology*, 154, 101813. https://doi.org/10.1016/j.marmicro.2019.101813

Aguilera, O., Luz, Z., Carrillo–Briceño, J., Kocsis, L., Vennemann, T. W., Toledo, P. M., Nogueira, A., Moraes–Santos, H., Polck, M. R., Ruivo, M. L., Linhares, A. P., & Monteriro, C. (2017). Neogene sharks and rays from the Brazilian "Blue Amazon". *PLoS One*, 12(8), e0182740. https://doi.org/10.1371/journal.pone.0182740

Aguilera, O., Martins, M. V. A., Linhares, A. P., Kutter, V. T., & Coleti, G. (2022). Palaeoenvironment of the Miocene Pirabas Formation mixed carbonate–siliciclastic deposits, Northern Brazil: Insights from skeletal assemblages. *Marine and Petroleum Geology*, 145, 05855. https://doi.org/10.1016/j.marpetgeo.2022.105855

Aguilera, O., Schwarzhans, W., & Béarez, P. (2016). Otoliths of the Sciaenidae from the Neogene of tropical America. *Palaeo Ichthyologica.*, 14, 1–124.

Aguilera, A. O., Schwarzhans, W., Moraes–Santos, H., & Nepomuceno, A. (2014). Before the flood: Miocene otoliths from eastern Amazon Pirabas Formation reveal a Caribbean–type fish fauna. *Journal of South American Earth Sciences*, 56, 422–446. https://doi.org/10.1016/j.jsames.2014.09.021

Akkari, N., Enghoff, H., & Metscher, B. D. (2015). A new dimension in documenting new species: high-detail imaging for myriapod taxonomy and first 3D cybertype of a new millipede species (Diplopoda, Julida, Julidae). *PLoS One*, 10(8), 0135243. https://doi.org/10.1371/journal.pone.0135243

Akkari, N., Ganske, A.-S., Komerički, A., & Metscher, B. (2018). New avatars for Myriapods: Complete 3D morphology of type specimens transcends conventional species description (Myriapoda, Chilopoda). *PLoS One*, 13(7), e0200158. https://doi.org/10.1371/journalpone.0200158

Batallés, M., Costoya, G., Tambusso, P. S., Varela, L., & Fariña, R. A. (2018). Megafauna 3D: fossil digitalization for education, outreach and research. A*bstracts of the 1º Paleontological Virtual Congress*, p. 43. https://doi.org/10.13140/RG.2.2.25394.66245

Benton, M. J. (2012). Naming the Bristol dinosaur, *Thecodontosaurus*: politics and science in the 1830s. *Proceedings of the Geologist's Association*, 123, 766–778. https://doi.org/10.1016/j.pgeola.2012.07.012

Brum, A. S., Pêgas, R. V., Bandeira, K. L. N., Souza, L. G., Campos, D., & Kellner, A. W. A. (2021). A new unenlagiine (Theropoda, Dromaeosauridae) from the Upper Cretaceous of Brazil. *Papers in Palaeontology*. online first. https://doi.org/10.1002/spp2.1375

Carvalho, M. R., Bockmann, F. A., Amorim, D. S., Brandão, C. R. F., Vivo, M., Figueiredo, J. L., Britski, H. A., Pinna, M. C. C., Menezes, N. A., Marques, F. P. L., Papavero, N., Cancello, E. M., Crisci, J. V., McEachran, J. D., Schelly, R. C., Lundberg, J. G., Gill, A. C., Britz, R., Wheeler, Q. D., … Nelson, G. J. (2007). Taxonomic impediment or impediment to taxonomy? A Commentary on Systematics and the Cybertaxonomic-Automation Paradigm. *Evolutionary Biology*, 34, 140–143. https://doi.org/10.1007/s11692-007-9011-6

Copetti, P., Parisi-Dutra, R., Da-Rosa, A. A. S., & Kerber, L. (2021). 3D model related to the publication: A new fossil of Tayassuidae (Mammalia: Cetartiodactyla) from the Pleistocene of northern Brazil. *MorphoMuseuM*, 7, e105. doi:10.18563/journal.m3.105

Davies, T. G., Rahman, I. A., Lautenschlager, S., Cunnigham, J. A., Asher, R. J., Barret, P. M., Bates, K. T., Bengtson, S., Benson, R. B. J., Boyer, D. M., Braga, J., Bright, J. A., Claessens, L. P. A. M., Cox, P. G., Dong, X.-P., Evans, A. R., Falkingham, P. L., Friedman, M., Garwood, R. J., … Donoghue, P. C. J. (2017). Open data and digital morphology. *Proceedings of Royal Society B: Biological Sciences*, 284, 20170194. https://doi.org/10.1098/rspb.2017.0194

Diéz Díaz, V., Mallison, H., Asbach, P., Schwarz, D., & Blanco, A. (2021). Comparing surface digitization techniques in palaeontology using visual perceptual metrics and distance computations between 3D meshes. *Palaeontology*, 64(2), 179–202. doi:10.1111/pala.12518

Dragonfly 2020.2. (2020). [Computer software]. Object Research Systems (ORS) Inc, Montreal, 706 Canada, 2020. Software available at http://www.theobjects.com/dragonfly

Faulwetter, S., Vasileiadou, A., Kouratoras, M., Dailianis, T., & Arvanitidis, C. (2013). Micro-computed tomography: Introducing new dimensions in taxonomy. *ZooKeys*, 263, 1–45. https://doi.org/10.3897/zookeys

Ferreira, J. D., Negri, F. R., Sánchez-Villagra, M., & Kerber, L. (2020). 3D model related to the publication: Small within the largest: Brain size and anatomy of the extinct *Neoepiblema acreensis*, a giant rodent from the Neotropics. *MorphoMuseuM*, 6, e107. doi:10.18563/journal.m3.107

Godfray, H. C. J. (2007). Linnaeus in the information age. *Nature.*, 446, 259–260. https://doi.org/10.1038/446259a

Grillo, O. N., Lobo, L. S., & Azevedo, S. (2020). LAPID: Using 3D to Recover Heritage Lost in a Fire. https://sketchfab.com/blogs/community/lapid-using-3d-to-recover-heritage-lost-in-a-fire. Access: 01/09/2022.

Hocknull, S. A., Wilkinson, M., Lawrence, R. A., Konstantinov, V., Mackenzie, S., & Mackenzie, R. (2021). A new giant sauropod, *Australotitan cooperensis* gen. et sp. nov., from the mid-Cretaceous of Australia. *PeerJ*, 9, e11317. https://doi.org/10.7717/peerj.11317

Kerber, L., & Moraes-Santos, H. (2021). Endocranial morphology of a middle Miocene south American dugongid and the neurosensorial evolution of Sirenians. *Journal of Mammalian Evolution*, 28, 661–678. https://doi.org/10.1007/s10914-021-09555-8

Kerber, L., Dias-da-Silva, D., & Negri, F. R. (2019). 3D models of fossils of Dinomyidae rodents (Rodentia: Caviomorpha) from the Miocene and Quaternary of Brazil. *MorphoMuseuM*, 5, e95. doi:10.18563/journal.m3.95

Lobo, L. S., Grillo, O. N., & Azevedo, S. A. K. (2021). Morphology, Pandemic, and 3D. *Arquivos de Zooologia*, 52, 33–40. doi:10.11606/2176-7793/2021.52.02

Pavanatto, A. E. B., Kerber, L., & Dias-da-Silva, S. (2019). 3D models related to the publication: Virtual reconstruction of cranial endocasts of traversodontid cynodonts (Eucynodontia: Gomphodontia) from the upper Triassic of Southern Brazil. *MorphoMuseuM*, 5, e97. doi:10.18563/journal.m3.97

Pacheco, C., Müller, R. T., Langer, M. C., Pretto, F., Kerber, L., & Dias-da-Silva, S. (2019). 3D models related to the publication: *Gnathovorax cabreirai*: a new early dinosaur and the origin and initial radiation of predatory dinosaurs. *MorphoMuseuM*, 5, e103. doi:10.18563/journal.m3.103

Mallison, H. (2011). Digitizing Methods for Paleontology: Applications, Benefits, and Limitations. In A. M. T. Elewa (Ed.), *Computational Paleontology* (pp. 7–43). Springer, Berlin.

Mallison, H., & Wings, O. (2014). Photogrammetry in paleontology – a practical guide. *Journal of Paleontological Techniques*, 12, 1–31.

Martinez, S., Ramos, M. I. F., McArthur, J. M., Del Río, C. J., & Thirlwall, M. F. (2017). Late Burdigalian (Miocene) age for Pectinids (Mollusca-Bivalvia) from the Pirabas Formation (northern Brazil), derived from Sr-isotope (87Sr-86Sr) data. *Neues Jahrbuch für Geologie und Paläontologie*, 283(3), 1–8.

Martha, S. O. (2014). Things we lost in the fire: the rediscovery of type material from Ehrhard Voigt's early publications (1923–1942) and the bryozoan collection of Hermann Brandes. *Annals of Bryozoology*, 4, 107–127.

Nogueira, A. A. E., & Nogueira, A. C. R. (2017). Ostracods biostratigraphy of the Oligo-Miocene carbonate platform in the northeastern Amazonia Coast and its correlation with the Caribbean region. *Journal of South American Earth Sciences*, 80, 389–403. https://doi.org/10.1016/j.jsames.2017.10.006

Nogueira, A. A. E., Ramos, M. I. F., & Puckett, M. (2011). The genera *Haplocytheridea* Stephenson, 1936 and *Cytheridea* Bosquet, 1852 (Subphylum Crustacea, Class Ostracoda) from the Early Miocene Pirabas Formation, Brazil. *Revue de Micropaléontologie*, 54(4), 215–235.

Nogueira, A. A. E., Ramos, M. I. F., & Hunt, G. (2019). Taxonomy of Ostracods from Pirabas Formation (Upper Oligocene- Lower Miocene), Eastern Amazonia (Pará state, Brazil). *Zootaxa*, 4573(1), 1–111. doi:10.11646/zootaxa.4573.1.1

Ramos, M. I. F., Távora, V. A., Pinheiro, M. P., & Baia, N. B. (2004). Microfósseis. In D. F. Rossetti & A. M. Góes (Eds.), *O Neógeno da Amazônia Oriental* (pp. 93–107). Belém.

Ramos, M. I. F., Moraes-Santos, H., Costa, S. A. R. F., & Toledo, P. M. (2009). *Catálogo de Fósseis do Museu Paraense Emílio Goeldi*. Editora do Museu Paraense Emílio Goeldi.

Rotti, A., Vezzosi, R., Mothé, D., & Avilla, L. S. (2021). Rising from the ashes: The biggest South American deers (Cetartiodactyla: Cervidae) once roamed Northeast Brazil. *J S Am Earth Sci.*, 108, 103154. https://doi.org/10.1016/j.jsames.2021.103154

Ruella, A., Acosta-Hospitaleche, C., Gelfo, J.N., Tonni, E.P., & Ametrano, S. (2017). Potencialidades del nuevo laboratorio de escaneo e impresión 3D de la División Paleontología de Vertebrados del Museo de La Plata. Abstracts of the 16th Jornadas de Educación, Sociedad de Ciencias Morfológicas de La Plata, La Plata, Argentina, p. 26–27.

Stefanello, M., Kerber, L., Martinelli, A. G., & Dias-da-Silva, S. (2020). 3D models related to the publication: A new prozostrodontian cynodont (Eucynodontia, Probainognathia) from the Upper Triassic of southern Brazil. *MorphoMuseuM*, 6, e120. https://doi.org/10.18563/journal.m3.120

Tavora, V., Dos Santos, A. A. R., & Araujo, R. N. (2010). Localidades fossilíferas da Formação Pirabas (Mioceno inferior). *Boletim do Museu Paraense Emilio Goeldi: Série Ciências Naturais*, 5(2), 207–224.

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