Victor Giovannetti

Tecidos mineralizados em Characiformes: estudo sistemático da variação morfológica da dentição oral e esqueletogênese

Mineralized tissues in Characiformes: systematic assessment of the morphological variation of the oral dentition and skeletogenesis

São Paulo

Outubro 2019

Victor Giovannetti

Tecidos mineralizados em Characiformes: estudo sistemático da variação morfológica da dentição oral e esqueletogênese

Mineralized tissues in Characiformes: systematic assessment of the morphological variation of the oral dentition and skeletogenesis

Tese apresentada ao Instituto de Biociências da Universidade de São Paulo, para a obtenção de Título de Doutor em Ciências, na Área de Zoologia.

Orientador(a) Dra. Mônica Toledo Piza Ragazzo

São Paulo

Outubro/2019

Ficha Catalográfica

Giovannetti, Victor Tecidos mineralizados em Characiformes: estudo sistemático da variação morfológica da dentição oral e esqueletogênese / Victor Giovannetti ; orientadora Mônica Toledo Piza Ragazzo. -- São Paulo, 2019. 369 f. Tese (Doutorado) - Instituto de Biociências da Universidade de São Paulo, Departamento de Zoologia. 1. Dentes. 2. Ontogenia. 3. Sequência de ossificação. I. Toledo Piza Ragazzo, Mônica, orient. II. Título.

Comissão Julgadora:

Prof(a). Dr(a).

Prof(a). Dr(a).

Prof(a). Dr(a).

Prof(a). Dr(a)

Prof(a). Dr(a).
Orientador(a)

Epígrafe

I've never learnt the names of a lot of fish. I always swot them up on the boat and forget them a week later. But watching the breathtaking variety of shape and movement keeps me entranced for hours, or would if the oxygen allowed. If I were not an atheist, I think I would have to be a Catholic because if it wasn't the forces of natural selection that designed fish, it must have been an Italian.

Douglas Adams, *The salmon of doubt*

Agradecimentos

Agradeço à Profª Dra. Mônica de Toledo Piza Ragazzo pela orientação, supervisão e amizade ao longo dos dez anos no Laboratório de Ictiologia. Por ser um modelo durante minha formação como cientista.

Ao Dr. Ralf Britz, por me receber no Museu de História Natural, por um período desafiador de seis meses de intenso aprendizado, e a Oliver Crimmen, pelo apoio curatorial. Nossas pausas para café quase diárias tornaram a minha estadia no museu tão agradável quanto produtiva.

Aos amigos e colegas que fiz durante minha estada no Laboratório de Ictiologia: Kleber Mathubara, João Pedro Fontenelle, Karla Soares, André Casas, George Mattox, Andrea Paixão, Carmen Paradeda, João Paulo Capretz, Caio Gomes, Mateus Soares, Maíra Ragno e Carolina Laurini. Um agradecimento especial a Karla Soares e Kleber Mathubara pela ajuda essencial durante a reta final da realização desse trabalho.

À Aline Stadnik, Suelen Mendes, Juliane Fagotti por me ajudarem a ter um pequeno pedaço de casa do outro lado do Atlântico.

À Lucila Barreiros por me ajudar a pensar em outras coisas além da tese nesses últimos cinco meses.

À minha família, Marlene Aparecida Giovannetti, Amanda Giovannetti e Marcio Roberto Giovannetti (in memorian) por todo o carinho e suporte ao longo desses anos.

Ao Dr. Aléssio Datovo, Dr. Oswaldo Oyakawa e Michel Donato Gianeti, do Museu de Zoologia da Universidade de São Paulo, pelos empréstimos materiais e apoio curatorial.

Aos técnicos do Departamento de Zoologia Enio Mattos e Philip Lenktaitis pelo apoio técnico prestado.

Ao Conselho Nacional de Desenvolvimento Científico e Tecnológico CNPq pela concessão 142195 / 2015-4. Este estudo foi financiado em parte pela Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Código Financeiro 88881.188036 / 2018-01.

Index

Introduction

The order Characiformes constitute a dominant group of fresh-water fishes with over 2200 species distributed in the Americas and Africa (Fricke *et al*. 2019). Most of its diversity is in the Neotropics, with approximately 2000 species present from the river basin on the south of the United stated until the central region of Chile and Argentina. Number and composition of the recognized families vary within the order (Reis, *et al*. 2003; Oliveira *et al*., 2011; Mirande, 2019), the variation mainly due to differences in relation to the limits of the family Characidae the most species rich family within the order with almost 1200 species. It is in this family that most taxonomical and phylogenetic issues still reside. The relatively small size, the high number of species, and the generalized morphology make it difficult to elucidate the taxonomical and phylogenetic questions within the family.

The current knowledge on the phylogenetic relations within the Characiformes derives mostly from studies based on morphological characters, mainly focused on the osteology. However, the utilization of alternative source of characters has become important in order to reevaluate previously proposed phylogenetic hypotheses as well as to further refine the knowledge on the relations of several taxa. Among the alternative source of characters, the use of molecular characters (Ortí & Meyer, 1997; Calcagnotto *et al*., 2005; Oliveira *et al*., 2011; Arcila *et al*. 2017; Betancur-R *et al*., 2019; Mirande 2019); reproductive biology characters (Weitzman *et al*., 2005); sperm ultrastructure (Gusmão-Pompiani *et al.*, 2009; Baicere-Silva *et al.*, 2011) along with cephalic miology (Datovo & Castro, 2012; Mattox & Toledo-Piza, 2012) and cephalic lateral-line system (Pastana *et al.*, 2019).

The most utilized source of characters for systematic studies of fishes is the skeleton, being the main source of information for most phylogenetic studies based on morphological characters (Mirande, 2010; Sidlauskas & Vari, 2008; Stiassny & Jensen, 1987; Tyler *et al*., 2003; Westneat, 1993; Wiley & Johnson, 2010; Winterbottom, 1974; Zanata & Vari, 2005). The dentition, a subset of the skeletal system, is notably variable in the Characiformes, among adult specimens several tooth morphologies are observed including conical, incisiviform, molariform, multicuspid (with variable number and arrangement of cusps) and mamilliform. This morphological diversity is associated to the several different trophic strategies adopted by different lineages within the order including piscivores, herbivores, detritivores and even lepidophagous taxa (Géry, 1977). Roberts (1967) stated that the trophic diversification had an important role on the diversification of the major lineages within the order. Roberts (1967) also stated that “in any broad studies of the biology, or systematics, or phylogeny, or evolutionary processes in the characoids, not only the morphology of the teeth in adults, but also tooth formation, tooth replacement and ontogenetic changes in dentition will have to be taken into account”.

Papers like those of Monod (1950) and Roberts (1967) surveyed several aspects such as the morphology of the functional teeth, morphology and arrangement of the developing replacement teeth, morphology of the bony cavities in which the replacement teeth are formed, histological aspects of the implantation of the functional teeth and of the developing replacement teeth along with the replacement patterns. Both authors had a relatively large representativeness of the diversity of the order. Little was produced on the characiform dentition with an ample sampling within the order since Roberts (1967). The most prevalent papers are those focusing in a single of few taxa investigating replacement patterns and ultrastructure (Berkovitz, 1975; 1980; Shellis & Berkovitz, 1976; Berkovitz & Shellis, 1978). Berkovitz & Shellis (2017) presented a review of the information in the literature on characiform dentition regarding tooth morphology and its relation to the diet of different lineages within the family and the different observed replacement patterns.

Information on the ontogenetic shifts in Characiformes dentition are also scarce, Azevedo and Vieira (1938) report ontogenetic modification on the dentition of *Prochilodus argenteus*, such modifications were later confirmed by Castro & Vari (2004). Azevedo *et al*. (1938) reported the presence of small conical teeth on the larvae of representatives of the Curimatidae and Tetragonopterinae. Trapani (2005) investigated the transition from unicuspid to multicuspid dentition in *Astyanax mexicanus* and concluded that the two dentitions are independent, since they present distinct origins (multicuspid teeth are formed intraosseously, whereas unicuspid teeth are formed extraosseously), diverging from what was proposed by Roberts (1967), that multicuspid teeth were the result of the fusion of several conical elements ate their base, presumably by some kind of bone tissue.

Information on teeth implantation mode for characiforms *Hepsetus odoe*, *Paracheirodon simulans* and *Rhoadsia altipinna* was presented by Fink (1981) in his survey on the ontogeny and phylogeny on tooth implantation mode across the

Actinopterygii. The position of developing replacement teeth was reported for representatives of the Alestidae, Anostomidae, Cynodontidae and Serrasalmidae by Trapani (2001) in his paper on the variation of intra- and extraosseous development of replacement teeth in Teleostei.

Papers that deal with the dentition in a broader taxonomical context are those that use tis anatomical complex as a source of characters (e.g. Malabarba, 1998; Zanata & Vari, 2005; Mirande, 2010; Ferreira *et al*., 2011; Mattox & Toledo-Piza, 2012), however not in great detail. The only recent paper on characiform dentition with detail encompassing the implantation mode, histological and ultrastructural aspects with satisfactory taxonomical sampling is the one from Scharcasky & Lucena (2008) with representatives of the families Anostomidae, Curimatidae, Prochilodontidae, Chilodontidae, Hemiodontidae and Parodontidae. Along with the descriptive approach the authors discussed the observed variations in the context of the knowledge of the phylogenetic relationships of these families. Despite the great detail the authors evaluated only part of the obtained data in the phylogenetic context.

In the past few years the interest in fish dentition appear to be going through a relative renaissance (Fraser *et al*. 2012; Conway, 2015; Bemis & Bemis, 2015; Bemis *et al*, 2019), and the Characiformes were not left out, Guisande *et al*. (2013) in their study on the ecological factors that could have driven the diversification among Neotropical Characiformes identified 14 different tooth morphologies and presented an ancestral character state reconstruction of six of those morphologies on the topology obtained by them based on mitochondrial and nuclear gene sequences. Thu authors stated that tooth morphology presented a strong phylogenetic signal, especially for the Anostomidae and Prochilodontidae. Atukorala & Franz-Odendaal (2014) explored spatial and temporal events in the tooth development of *Astyanax mexicanus* comparing cave-dwelling and surface forms. Kolmann *et al*. (2019) investigated the patterns of articulation among adjacent teeth the replacement pattern observed in the Serrasalmidae along with inferences on the evolution of this characters in the family.

As stated above, the skeleton of adult specimens is the major source of information for phylogenetic studies of the Characiformes, and to this date little is known about the development of the skeleton of representatives of the order. The study of ontogeny of the skeleton is not only a promising source of characters, but also a valuable resource utilized by comparative anatomists in order to understand in more detail the nature and homology of several morphological characters, and complements information based on the examination of adult specimens (Nelson, 1978; 1985; Britz & Johnson, 2002; 2005; Fraser et al., 2012). In addition, the study of ossification sequences is important in order to identify and understand heterochronic events that might be present in cases of miniaturization (Britz & Conway, 2009; Britz *et al*., 2009; Mattox *et al*. 2016).

Among the Ostariophysi studies on the skeletal development and ossification sequence were carried out for the Gonorhynchiformes (Taki *et al*., 1986; 1987; Kohno *et al*., 1996; Arratia & Bagarinao, 2010), non neotropical Siluriformes (Adriaens *et al*., 1997; Adriaens & Verraes, 1998) and Cypriniformes (Vandewalle *et al*., 1992; Cubbage & Mabee, 1996; Bird & Mabee, 2003; Engeman et al., 2009; Conway *et al*., 2017), the available information is scarce for Gymnotiformes and neotropical Siluriformes (Geerinckx et al., 2007) and Characiformes.

Studies on the ontogeny of the skeleton of the Characiformes are still scarce and most of them deal with only part of the skeleton. Bertmar (1959) published a monograph on the development of the neurocranium and visceral arches of *Hepsetus odoe* (Hepsetidae), the author focused on the development of chondral elements, rarely referring to ossified structures. Vandewalle *et al*. (2005) presented a study on the chondrogenesis and osteogenesis of the cranial skeleton of *Brycon moorei*. More recently, Walter (2013) presented a study on the chondrogenesis and osteogenesis of the cranium of the characid *Moenkhausia sanctaefilomenae* and Carvalho and Vari (2015) presented a study on the development of the mandibular, hyoid and branchial arches of *Prochilodus argenteus* (Prochilodontidae) with a discussion on the basal developmental patterns in Ostariophysi. Mattox *et al*. (2014) were the first to present a study on the development of the complete skeleton within the Characiformes, the authors proposed a sequence of ossification of the complete skeleton for *Salminus brasiliensis*.

The proposal of additional sequences of ossification for the complete skeleton constitutes an important source of information not only on the development of the selected taxa, but also enable the comparison among sequences of ossification of the complete skeleton of other representatives of the Characiformes and possibly identifying differences with phylogenetic significance.

The current study aims to document in detail the dentition including the aspects involved in the replacement for the Characiformes and to discuss this variation in a phylogenetic framework. Also, this study proposes complete sequences of ossifications of the characid *Astyanax lacustris* and the ctenoluciid *Ctenolucius hujeta*, along with a first attempt of a comparative analysis of complete sequences of ossification of representatives of Characiformes.

Chapter 1

Systematic assessment of the morphological variation of the oral dentition of Characiformes (Teleostei: Ostariophysi).

Abstract

The dentition is a character complex recognized for being highly informative for systematic studies for the order Characiformes, hence the dentition was widely explored in systematic studies of several lineages within the order. However, detailed systematic studies that discuss the observed variation in the context of the order as a whole are still scarce. We herein present a detailed study on the dentition of the Characiformes contemplating tooth morphology, tooth implantation mode and implantation position, arrangement of teeth on each bone, formation mode of replacement teeth and the chronological pattern of the replacement. Detailed descriptions are provided for 78 species of Characiformes. with representatives from all recognized families except for the recently described Tarumaniidae, representing 66 of the 278 recognized genera for the order. Fifty-nine characters are proposed including reinterpreted characters already proposed in the literature along with original characters. The variation and distribution of the proposed characters in Characiformes is discussed along with proposal of new interpretations of the identity and homology of tooth row in the premaxilla in representatives of the order. Descriptions of ontogenetic variations of dentition in selected characiform species are provided. Possible additional synapomorphies related to the dentition are proposed for the Anostomidae, Heterocharacinae and Serrasalminae. Two patterns of replacement within the Characoidei are identified and described in detail. Alternative interpretation for the identity and homology of the three tooth rows on the premaxilla present in *Brycon*, *Triportheus* and *Chalceus* is presented along with a proposal of homology of the single premaxillary tooth row present within the Characoidei and Citharinoidei.

Introduction

The order Characiformes constitute a dominant group of fresh-water fishes with over 2200 species distributed in the Americas and Africa (Fricke *et al*. 2019). Most of its diversity is in the Neotropics, with approximately 2000 species present from the river basin on the south of the United stated until the central region of Chile and Argentina. Number and composition of the recognized families vary within the order (Reis, *et al*. 2003; Oliveira *et al*., 2011; Mirande, 2019), the variation mainly due to differences in relation to the limits of the family Characidae the most species rich family within the order with almost 1200 species. It is in this family that most taxonomical and phylogenetic issues still reside. The relatively small size, the high number of species, and the generalized morphology make it difficult to elucidate the taxonomical and phylogenetic questions within the family.

The current knowledge on the phylogenetic relations within the Characiformes derives mostly from studies based on morphological characters, mainly focused on the osteology. However, the utilization of alternative source of characters has become important in order to reevaluate previously proposed phylogenetic hypotheses as well as to further refine the knowledge on the relations of several taxa. Among the alternative source of characters, the use of molecular characters (Ortí & Meyer, 1997; Calcagnotto *et al*., 2005; Oliveira *et al*., 2011; Arcila *et al*. 2017; Betancur-R *et al*., 2019; Mirande 2019); reproductive biology characters (Weitzman *et al*., 2005); sperm ultrastructure (Gusmão-Pompiani *et al.,* 2009; Baicere-Silva *et al.,* 2011) along with cephalic miology (Datovo & Castro, 2012; Mattox & Toledo-Piza, 2012) and cephalic lateral-line system (Pastana *et al*., 2019).

The most utilized source of characters for systematic studies of fishes in general and not only for the Characiformes is the skeleton, being the main source of information for most phylogenetic studies based on morphological characters (Mirande, 2010; Sidlauskas & Vari, 2008; Stiassny & Jensen, 1987; Tyler *et al*., 2003; Westneat, 1993; Wiley & Johnson, 2010; Winterbottom, 1974; Zanata & Vari, 2005). The dentition, a subset of the skeletal system, is notably variable in the Characiformes, among adult specimens several tooth morphologies are observed including conical, incisiviform, molariform, multicuspid (with variable number and arrangement of cusps) and mamilliform. This morphological diversity is associated to the several different trophic strategies adopted by different lineages within the order including piscivores, herbivores, detritivores and even lepidophagous taxa (Géry, 1977). Roberts (1967) stated that the trophic diversification had an important role on the diversification of the major lineages within the order. Roberts (1967) also stated that "in any broad studies of the biology, or systematics, or phylogeny, or evolutionary processes in the characoids, not only the morphology of the teeth in adults, but also tooth formation, tooth replacement and ontogenetic changes in dentition will have to be taken into account".

Monod (1950) conducted a comprehensive study of the dentition of several African Characiformes including representatives of all four African families (Hepsetidae, Alestidae, Citharinidae and Distichodontidae). The aspects of the dentition explored by the author included apart from the morphology of the functional teeth the morphology and arrangement of developing replacement teeth called by the author as "dents incluses", the bone cavities in which the replacement teeth are formed. The author also explored histological aspects of the developing replacement teeth, as well as of the implantation mode of the functional dentition.

Roberts (1967) presented a brief review on the published information on characiform dentition subsequent to Monod (1950) and presented several original observations on the morphology of the dentition on adults, tooth formation, morphological variation of the replacement tooth trenches, replacement patterns and ontogenetic changes in the dentition. Little was produced on the characiform dentition with an ample sampling within the order since Roberts (1967) paper. The most prevalent papers are those focusing in a single of few taxa investigating replacement patterns and ultrastructure (Berkovitz, 1975; 1980; Shellis & Berkovitz, 1976; Berkovitz & Shellis, 1978). Berkovitz & Shellis (2017) presented a review of the information in the literature on characiform dentition regarding tooth morphology and its relation to the diet of different lineages within the family and the different observed replacement patterns.

Papers on the ontogenetic shifts in Characiformes dentition are also scarce, Azevedo and Vieira (1938) reported the presence of small conical teeth in young *Prochilodus argenteus* arranged in two or three rows, these teeth are lost in juveniles and are later replaced by the several cylindrical teeth with convex tips observed in adults, the presence of small conical teeth in larval developmental stages of *Prochilodus* was later confirmed by Castro & Vari (2004). Azevedo *et al*. (1938) reported the presence of small conical teeth on the larvae of representatives of the Curimatidae and Tetragonopterinae. Trapani (2005) investigated the transition from unicuspid to multicuspid dentition in *Astyanax mexicanus* and concluded that the two dentitions are independent, since they present distinct origins (multicuspid teeth are formed intraosseously, whereas unicuspid teeth are formed extraosseously), diverging from what was proposed by Roberts (1967), that multicuspid teeth were the result of the fusion of several conical elements ate their base, presumably by some kind of bone tissue.

Information on teeth implantation mode for characiforms *Hepsetus odoe*, *Paracheirodon simulans* and *Rhoadsia altipinna* was presented by Fink (1981) in his survey on the ontogeny and phylogeny on tooth implantation mode across the Actinopterygii. The position of developing replacement teeth was reported for representatives of the Alestidae, Anostomidae, Cynodontidae and Serrasalmidae by Trapani (2001) in his paper on the variation of intra- and extraosseous development of replacement teeth in Teleostei.

Papers that deal with the dentition in a broader taxonomical context are those that use this anatomical complex as a source of characters (e.g. Malabarba, 1998; Zanata & Vari, 2005; Mirande, 2010; Ferreira *et al*., 2011; Mattox & Toledo-Piza, 2012), however not in great detail. The only recent paper on characiform dentition with detail encompassing the implantation mode, histological and ultrastructural aspects with satisfactory taxonomical sampling is the one from Scharcasky & Lucena (2008) with representatives of the families Anostomidae, Curimatidae, Prochilodontidae, Chilodontidae, Hemiodontidae and Parodontidae. Along with the descriptive approach the authors discussed the observed variations in the context of the knowledge of the phylogenetic relationships of these families. Despite the great detail the authors evaluated only part of the obtained data in the phylogenetic context.

In the past few years the interest in fish dentition appear to be going through a relative renaissance (Fraser *et al*. 2012; Conway, 2015; Bemis & Bemis, 2015; Bemis *et al*, 2019), and the Characiformes were not left out, Guisande *et al*. (2012) in their study on the ecological factors that could have driven the diversification among Neotropical Characiformes identified 14 different tooth morphologies and presented an ancestral character state reconstruction of six of those morphologies on the topology obtained by them based on mitochondrial and nuclear gene sequences. Thu authors stated that tooth morphology presented a strong phylogenetic signal, especially for the Anostomidae and Prochilodontidae. Atukorala & Franz-Odendaal (2014) explored spatial and temporal events in the tooth development of *Astyanax mexicanus* comparing cave-dwelling and surface forms. Kolmann *et al*. (2019) investigated the patterns of articulation among adjacent teeth the replacement pattern observed in the Serrasalmidae along with inferences on the evolution of this characters in the family.

We herein present detailed descriptions of the dentition of 78 species of Characiformes with representatives from all recognized families except for the recently described Tarumaniidae, representing 66 of the 278 recognized genera for the order. Fifty-nine characters are proposed including reinterpreted characters already proposed in the literature along with original characters. The variation and distribution of the proposed characters in Characiformes is discussed along with proposal of new interpretations of the identity and homology of tooth row in the premaxilla in representatives of the order. Descriptions of ontogenetic variations of dentition in selected characiform species are provided.

Material and Methods

The study of morphological aspects of the adult dentition of Characiformes was carried out through the examination of cleared and stained specimens prepared following the protocol of Taylor & Van Dyke (1985). The specimens had their jaws isolated form the rest of the skull, the dentition of the premaxilla, maxilla and dentary was described separately contemplating tooth morphology, tooth implantation mode and implantation position, arrangement of teeth on each bone, formation mode of replacement teeth and the chronological pattern of the replacement.

Seventy-eight species were included in this study, representing 66 of the 278 recognized genera in Characiformes (Fricke *et al*. 2019). Among the currently recognized characiform families only the Tarumaniidae was not included in the present study. Within the Characidae only representatives of the Spintherobolinae and the Tetragonopterinae were not examined. Table 1 lists the genera that had species examined and the number of examined genera relative to total number of genera within each family/subfamily. Selection of taxa selection was done aiming to encompass as much of the morphological variation of the dentition observed in Characiformes as possible and not the taxonomic diversity. Therefore, species-rich groups with conserved dentition among its representatives such as the Stethaprioninae had a relative restricted sampling.

More than one species of a given genus was examined whenever possible, in those cases the dentition was fully described for one species and the remaining species were described in a comparative manner. This was also applied for species of different closely related genera but with similar dentition. Exceptions were made whenever species within a genus had characteristic dentitions, mainly related to tooth arrangement on the jaws and aspects of tooth replacement. In such instances it was considered important to fully describe the dentition of a species, even with more congeners already fully described.

Within the premaxillary and dentary the relative position of the teeth is treated as having a medial-lateral distribution, so that teeth closer to the symphysis are referred as medialmost, while those further from the symphysis are referred as lateralmost. In the maxilla teeth are treated as having an antero-posterior distribution.

Cleared and stained specimens were cleared from attached tissue as much as possible in order to not alter the disposition of the replacement teeth formed in soft tissue and photographed with a Zeiss Axiocam camera attached to a Zeiss V20 stereomicroscope using the Z-stack option, the stacking of the obtained images was made with the Helicon Focus software. For organization purposes the images are presented and numbered following the order of the descriptions.

For organization purposes the descriptions are presented following the families and sub-families as presented in Mirande (2019), and in alphabetical order. Hepsetidae is considered herein as a valid family to facilitate the comparison with other groups with similar dentition.

Data analysis

A total of 59 characters is presented including number of teeth; tooth morphology; number, relative size and arrangement of tooth cusps; number of tooth rows; tooth implantation mode and implantation position; heterodonty; number of replacement teeth; and orientation of replacement teeth; replacement teeth formation mode; morphology of the bone cavities in which the replacement teeth are formed and the chronological patterning of the replacement. Quantitative characters are described first, followed by the qualitative characters, the latter organized into general (*i. e.* characters are not related to a specific bone), and those related to a specific bone (premaxilla, followed by maxilla and dentary)

The phylogenetic analysis carried out based on a character matrix (Table 2) of 59 characters of dentition in 78 characiform species. A character matrix was assembled using Microsoft Excel 2016. Qualitative and quantitative characters (counts) were coded separately and then concatenated into a combined matrix using a text editor (Microsoft notepad). Quantitative characters were treated as continuous and analyzed according to

Goloboff *et al*. (2006). Within the characters two are quantitative (characters 0 and 1) and the remaining characters are qualitative. Characters were numbered starting from 0 following the default option of TNT. Multistate characters were treated as unordered since there was no ontogenetic or clear morphoclinal evidence that could be used to treat them as ordered. A maximum parsimony analysis (Farris, 1983) was ran on TNT (Goloboff *et al*., 2008) to generate a hypothesis of phylogenetic relationships among the examined taxa. Searches for the most parsimonious trees employed the four algorithms of "the new technology search" (Goloboff *et al*., 2008), with the following parameters: 20 Ratchet total iterations, Tree-drift cycles adjusted to 20 and Tree-fusing rounds adjusted to 5. These parameters were used in a driven search adjusted to reach the minimum length 50 times, with random seed set to zero. Remaining parameters were kept in their defaults. Searches using character weighting were performed using Implied Weighting with k set to 1.0. This low value of k was chosen due to the expected high level of homoplasy within this character complex. Consistency and retention indexes or each character were calculated in TNT (Goloboff *et al*., 2008) (using the script wstats.run). The obtained trees were rooted in *Citharinus citharu* instead of in the distichodontid *Xenocharax spilurus*, which is widely considered as a basal taxon within the Characiformes (Vari, 1979; Arcila *et al*. 2017; Betancur-R *et al*., 2019), in order to test if a monophyletic Distichodontidae would be recovered based only in characters of dentition.

The option of running a formal phylogenetic analysis with the proposed characters was made despite the previous knowledge of the high level of homoplasy present in a character complex such as dentition and that the resulting topology would not express the relationship among the examined taxa in a precise manner. The execution of a formal phylogenetic analysis based on the proposed characters is an additional step towards the understanding of the variation and distribution of characters related to dentition in Characiformes and might help to identify possible informative character among those presented herein. Thus, it was deemed as a valuable exercise at this time.

Ontogenetic variation of dentition in selected characiform species

Information about ontogenetic changes in the morphology of the dentition of selected taxa is presented in a separate section. For most described taxa in this section the developmental series is not comprehensive, in most cases it is restricted to few specimens that do not present the dentition characteristic of adults. Examined taxa include: *Alestes macrophthalmus* (BMNH 1985.6.13.15-17 and BMNH 1955.12.20.670); *Alestes* *baremoze* (BMNH 1982.13.554-557); *Brycinus ferox* (BMNH 1981.2.17. 1506-1558 BMNH 1981.8.21.11-15); *Hydrocynus forskahlii* (BMNH 1981.2.17.760-764), and uncataloged specimens of *Leporinus* sp.; *Astyanax lacustris*; *Brycon orthotaenia*; *Ctenolucius hujeta*; *Prochilodus* sp. and *Colossoma macropomum*. Dentition of the premaxilla, maxilla and dentary was described separately contemplating tooth morphology, tooth implantation mode and implantation position, arrangement of teeth on each bone and formation mode of replacement teeth. Description is organized according to the size of the examined specimens, for pre-flexion specimens the notochord length (NL) is given, for pos-flexion specimens the standard length (SL) is given.

Results

The following section aims to introduce and define terms and definitions that will be used throughout the text. These definitions are related to tooth morphology; tooth implantation mode and position; presence of different tooth groups, the arrangement of teeth on the jaws; the replacement mechanism; the replacement teeth formation modes and the chronological patterning of tooth replacement.

Tooth morphology

Several tooth morphologies are present among examined taxa. The following definitions are used to aid in the process of description of the dentitions and the comparisons among different taxa.

<u>Conical teeth</u>: the term conical is restricted herein for unicuspid teeth with no lateral projections, regardless of the size of the tooth and its curvature. The terms canine/caniniform tooth or fang are not utilized. Given that this characterization appears to be only related to size, it is difficult to stablish a limit between what is called a conical tooth and what is called a canine, and have that limit to be applicable across the several taxa that have large conical teeth. *Agoniates halecinus* (Fig. 6), *Charax stenopterus*, *Acestrocephalus stigmatus* (Fig. 27) and *Lepidarchus adonis* are some examples of taxa with conical teeth.

<u>Unicuspid teeth:</u>

<u>- with lateral cutting-edge</u>: some taxa have unicuspid teeth with distinct lateral cutting-edges. *Acestrorhynchus microlepis* has conspicuous cutting-edges projecting laterally that result in an arrowhead profile (Fig. 1). *Hoplias malabaricus*, *Hepsetus odoe*

(Fig. 52) and *Cynodon gibbus* (Fig. 43) also have teeth with lateral-cutting edges, but in those taxa they do not project as much laterally as in *A. microlepis*, not changing the overall triangular profile of the tooth.

- with abruptly tapering cusp: unicuspid teeth with a constriction at the distal portion resulting in an abruptly tapering cusp (Figs. 4, 5) This abrupt taper towards the cusp tooth results in a distinct unicuspid tooth morphology differing from conical teeth (Figs. 6, 27).

- labiolingually flattened distally: some unicuspid teeth are flattened at their distal portion, *Leporinus bahiensis* (Figs. 21, 22) and *Abramites hypselonotus*, *Chilodus punctatus* and *Prochilodus lineatus* are examples of taxa with this tooth morphology.

Bicuspid teeth: a tooth with two cusps, the relative size of which can vary: cusps can be symmetrical due to the presence of a notch on its distal portion as in *Citharinus citharu* (Figs. 41, 42) and *Citharidium ansorgii*; cusps can be slightly asymmetric with cusps with different sizes (*Nannocharax multifasciatus*, Figs. 47, 48) or highly asymmetric (*Ichthyborus quadrilineatus*, Figs. 45, 46).

Multicuspid teeth:

- with conical base: these teeth have a base with circular or ellipsoid cross-section, a distinct more developed cusp in the midline with a variable number of lateral cusps smaller than the main cusp. The cusps are arranged in an arched line in dorsal view. The concavity of the arched line varies among taxa from barely curved in *Mimagoniates microlepis* (Fig. 35) to U shaped in *Triportheus albus* (Fig. 8). As a result of the arched arrangement of the cusps this tooth has one convex and one concave surface. Teeth with this morphology are observed in several characids (*Astyanax novae* Fig. 28, *Poptella compressa* Fig. 30), alestids (*Alestes baremoze* Fig. 10) which have the convex face turned labially in the dentary and lingually in the inner row of the premaxilla.

- with additional cusps on concave face: teeth with the morphology described above but with two additional cusps on their concave face are observed in the premaxillary inner row of some alestids (Fig. 10)

- labiolingually flattened distally: based circular in cross section, followed distally by a flattened region with several cusps, such as *Hemiodus microlepis* (Fig. 51). The tooth base can be long as in *Apareiodon ibitiensis* (Fig. 57) or short as in *Hemiodus microlepis* (Fig. 51). The alignment of the cusps also varies, they can diverge from each other as in *Hemiodus microlepis* (Fig. 51) or reach the same transversal line distally as in *Parodon pongoensis* (Fig. 58).

- with lateral cutting-edge: some taxa multicuspid teeth with distinct lateral cutting-edges on their cusps, this cutting edge is continuous along the cusps, this morphology is observed in *Serrasalmus elongatus* (Figs. 60, 61) and *Hydrocynus forskahlii* (Figs. 16, 17).

Mamilliform teeth: shape somewhat conical, but with the profile bell-shaped rather than triangular. This tooth morphology was observed in *Roeboides affinis* (Fig. 26), *Exodon paradoxus* and *Catoprion mento*

Pedicellate teeth: this term is used for the teeth with the diameter at the region of the cusps larger than at the tooth base, this was observed in unicuspid teeth (*Prochilodus lineatus* Fig. 59), bicuspid teeth (*Nannocharax multifasciatus*, Figs. 47, 48) and multicuspid teeth (*Parodon pongoensis*, Fig. 58).

Arrangement and development of cusps on multicuspid teeth: in some instances, the multicuspid teeth has a distinctly more developed cusp with smaller cusps on each side. In some taxa the main cusp lies in the midline of the tooth with the same number of cusps on each side, arranged symmetrically (Figs. 28, 29), whereas in other taxa the main cusp does not lie on the midline and there is a different number of lateral cusps on each side of the tooth, resulting in an asymmetric arrangement of the cusps (Figs. 7, 8 and 9). Multicuspid teeth without a distinct more developed cusp were also observed (Fig. 51).

Heterodonty: heterodonty is defined herein as the presence of teeth of different morphologies in the same bone. Differences in size alone or in number of cusps in multicuspid teeth (*i. e*. for taxa with multicuspid teeth with total number of cusps varying but not affecting the general tooth morphology such as *Hemiodus microlepis* with premaxillary teeth with nine to twelve cusps, Fig. 51) were not considered as heterodonty. Heterodonty is also observed between different bones in the same specimen.

Tooth implantation mode

In the most common observed condition the teeth are directly associated to the bone, firmly attached to it, with the limits between tooth and bone evident (Figs. 10, 11). This implantation mode is equivalent to type 2 of Fink (1981). Whenever the observed condition differed from the condition cited above it was fully described. Some taxa also have teeth directly associated to the underlying bone; however, the teeth are slightly mobile when manipulated. The last condition is teeth with no direct contact to the underlying bone, only embedded in soft tissue (Fig. 37) and in those cases the teeth are highly mobile.

Tooth implantation position

The most common observed condition is the teeth associate to the underlying bone in an acrodont manner (*i*. *e*. lying on the dorsal margin of the dentary, the ventral margin of the premaxilla and anteroventral margin of the maxilla, Figs. 28, 29). A pleurodont association was also observed in some taxa, in those instances the tooth base is implanted on the lingual margin of the bone (Figs. 21, 22).

Tooth groups identification

The arrangement of the teeth in the bone is variable, especially in the premaxilla and dentary. When more than one row was present the differentiation between them was made using differences in topology and tooth morphology. In cases that the identification of the presence of one or two rows was more complicated, (*i. e*. teeth are not arranged in two clear rows and have similar morphologies, Fig. *Mimagoniates microlepis*) differences in the mode of formation of the replacement teeth were considered.

Teeth arrangement on jaws

<u>Premaxilla</u>: the teeth on the premaxilla can be arranged in a single row, two or three rows. When two rows are present, the inner row always has the replacement teeth formed in soft tissue (Fig. 10), whereas the replacement teeth of the outer row are formed in bony cavities (Figs. 7, 8). When present, the middle row also has replacement teeth formed in bony cavities (Figs. 8, 23).

<u>Maxilla</u>: maxillary teeth, when present, are arranged in a single row of variable extension, from a single tooth at the anterior end up to the teeth present along the entire anteroventral margin of the bone (Figs. 4, 27).

<u>Dentary</u>: the main row of dentary teeth can be formed by a single group or divided in a medial group and in a lateral group. The lateral group generally is formed by small conical teeth. A row of small conical teeth is present is some taxa, lingual to the main row of dentary teeth (Fig. 27), the outer row of these taxa is considered as homologous to the main row of dentary teeth in taxa with a single row of teeth on the dentary. A parasymphyseal tooth is present in some taxa just lateral to the symphysis, in most taxa the parasymphyseal tooth is unicuspid and curved lingually (Fig. 8), in a few taxa this tooth is multicuspid (Fig. 20). An unpaired symphyseal tooth was only observed in

Ichthyborus quadrilineatus (Fig. 46). Heterodonty in the dentary teeth was observed for some taxa.

Replacement teeth

Number of preformed replacement teeth: in most cases in the examined taxa there is only one preformed replacement tooth for each functional tooth. The number of preformed replacement teeth was only reported when more than one preformed replacement tooth was observed for each functional tooth.

Morphology of replacement teeth: the developing replacement tooth is identical to its respective functional tooth in all taxa examined for this feature. Morphology of the developing replacement tooth was only described when it differed from the morphology of the functional tooth.

Formation of replacement teeth: developing replacement teeth occurs in a wide variety of conformations. In some instances, the replacement teeth are formed outside the bone in soft tissue, with no modification to the underlying bone (Fig. 10). Some taxa have replacement teeth are formed completely encased in a bony cavity (Fig. 62). Several different intermediate conditions are found, such as replacement teeth forming in soft tissue associated to shallow depressions on the underlying bone (Fig. 6); associated to a single depression on the underlying bone running along the entire base of the tooth row (Figs. 31, 32); associated to bony flaps or flanges (Figs. 21, 58). Replacement teeth can also be formed in a shallow cavity on the underlying bone with a single opening running along the entire cavity (Fig. 52) or in a deeper bony cavity associated to a single opening or several individual openings (Figs. 29, 32, 34).

Mechanism of tooth replacement

Teeth undergoing replacement were observed in several examined specimens. Those observations and information from the literature (Berkovitz, 1985; Berkovitz & Shelli, 1978; Trapani, 2001) suggest that teeth replacement in characiforms occurs as follows: the replacement teeth are formed in a distal-proximal orientation, cusps are calcified before the base of the tooth. Once the replacement tooth is developed the functional tooth falls due to reabsorption of bone tissue close to base of the tooth. Bone reabsorption and remodeling are evident in some of the examined specimens (Figs. 28, 29, 61, 62). The preformed replacement tooth then migrates to its functional position, this migration is variable among the examined taxa depending on the orientation of the developing replacement tooth. Once the functional position is reached, the final stages of calcification of the new functional tooth resumes until it meets the remodeling underlying bone. Before the process of calcification is complete, the new functional tooth has an uncalcified base, presumably constituted by connective tissue, thus this newly erupted tooth is very mobile when manipulated.

Patterns of tooth replacement

There is variation in the timing of tooth replacement among different bones and among different taxa. Different patterns of tooth formation were detected through comparison of developmental stages of the developing replacement teeth within a specific bone or tooth group, with its contralateral side and across different bones on the same side of the specimens or on specimens that were undergoing tooth replacement. Herein the pattern of tooth replacement was classified in two main categories, with the second one divided in two subcategories as follows:

Unilateral pattern: when replacement teeth are in similar developmental stages within a bone and coupled with other bone on the same side of the specimen (*e. g.* dentary and premaxilla on the right side with replacement teeth in similar developmental stages, different from the developmental stage of the replacement teeth on the left dentary and premaxilla). This similarity in the developmental stages in the same side of the specimen indicated that teeth on right and left side are replaced in different moments. When specimens undergoing replacement were available a further differentiation was possible:

i. Simultaneous unilateral pattern: In some specimens undergoing replacement one of the sides would be toothless with the replacement teeth migrating to their respective functional position (Figs. 28, 29, 62, 62). This pattern was observed mainly in the premaxillary teeth and the teeth of the medial group of the dentary.

ii. Sequential unilateral pattern: replacement of all teeth was not simultaneous but, following a mediolateral orientation. This pattern is evidenced by specimens with replacement teeth in similar developmental stages in one of the sides of the jaws, while the other side is undergoing replacement. The teeth closer to the symphysis on the side undergoing replacement are already on their respective functional position with no visible developing replacement teeth, the lateralmost tooth without a developing replacement tooth is not yet fully calcified, with connective tissue on its base. The replacement teeth of the remaining teeth are all visible and in late developmental stages (Fig. 25). This pattern was observed for the premaxilla and medial group of dentary teeth.

With no identified pattern: when replacement teeth are in several different developmental stages, with no correlation to the developmental stages of the replacement teeth in the same bone, nor with the replacement teeth on the contralateral side, nor the replacement teeth on the other toothed bones on the same side of the specimen (Fig. 27). This condition was also attributed for specimens that showed close to no difference in the developmental stages of the replacement teeth across contralateral bones.

Dentition descriptions

Acestrorhynchidae

Acestrorhynchinae

Acestrorhynchus microlepis **MZUSP 20591** 107.4 mm SL; **MZUSP 91854** 90.2 mm SL

Premaxilla: Teeth arranged in single row of 11 unicuspid teeth. Eight small conical teeth slightly curved lingually, followed laterally by large tooth with distinct lateral cutting edges. Medial and lateralmost teeth conical and of intermediate (Fig. 1a and 1b). **Replacement:** replacement teeth of small conical teeth formed in soft tissue just lingual to base of respective functional tooth, orientation similar to their respective functional tooth. Remaining replacement teeth of the medial and lateralmost functional teeth developing in individual bony cavities, cusp of replacement teeth visible through small opening on lingual side of wall that forms bony cavity. Openings slightly displaced laterally in relation to their respective functional tooth. Replacement tooth of medialmost tooth slanted about 90° in relation to its respective functional tooth, cusp pointing laterally. Replacement tooth of tooth with lateral cutting edges slanted approximately in 45° relative to its respective functional tooth, cusp pointing ventrolaterally. Replacement tooth of lateralmost tooth slightly slanted in relation to its respective functional tooth, cusp pointing medially (Fig. 1b).

Maxilla: teeth arranged in single row extending along entire anteroventral margin of ossification. Row divided in two groups, Anterior group with anteriormost tooth with conspicuous lateral cutting-edges, followed by two to four smaller teeth also with lateral cutting-edge, followed by the largest tooth on maxilla with conspicuous lateral cutting-edges, followed by posteriormost tooth on anterior group, intermediate size among anterior group teeth (Fig. 1c). Posterior group formed by a continuous row of 19-22 small unicuspid teeth also with lateral cutting-edge, posterior teeth slightly curved posteriorly at level of cusp (Fig. 1c). **Replacement:** replacement teeth of anterior group formed in bony cavities, cusps of replacement teeth visible through small openings on lingual side of bony wall that forms bony cavities, openings near their respective functional tooth base. Replacement tooth of anteriormost tooth and second anteriormost tooth slanted about 45° in relation to its respective functional tooth, cusp pointing anteriorly. Replacement teeth of two posteriormost teeth of anterior group also slanted about 45° in relation to their respective functional tooth, cusps pointing posteriorly. Replacement teeth of remaining functional teeth with similar orientation in relation to their respective functional teeth. Replacement teeth of posterior group formed in soft tissue, slanted 45° in relation to its respective functional tooth, cusp pointing posteriorly. Bony flap is visible on lingual surface of maxilla, partially covering developing replacement teeth. (Fig. 1d, 3).

Dentary: teeth arranged in two rows, main row divided in two groups. Medial group formed by seven or eight teeth, being four or five larger and more developed and three smaller teeth. Anteriormost, third and fourth medialmost teeth smaller than remaining teeth on medial group. Lateral group formed by continuous row of nine to eleven small unicuspid teeth also with lateral cutting-edge, laterally curved at level of cusp (Fig, 2a). Inner row with two small conical teeth curved lingually, medially displaced when compared to remaining dentary teeth. Inner row located lingual to four medialmost teeth of main row. (Fig. 2d). **Replacement:** replacement teeth of smaller teeth on medial group of main row formed in bony cavities. Medialmost replacement tooth formed in separate bony cavity, two lateralmost teeth formed in single bony cavity. Small dorsal openings of bony cavities slightly displaced laterally in relation to their respective functional tooth (Fig. 2d). Replacement teeth of four anteriormost functional teeth with similar orientation in relation to their respective functional teeth. Replacement tooth of medialmost large tooth formed in bony cavity associated to conspicuous dorsal opening, slightly displaced laterally in relation to its respective functional tooth, replacement tooth slanted about 45° in relation to its respective functional tooth, cusp pointing dorso-laterally. Replacement teeth of remaining large teeth also formed in bony cavities, slanted about 45° in relation to its functional tooth, cusp pointing dorso-laterally, almost always associated to small dorsal opening immediately lingual to their respective functional tooth (Fig. 1b). Replacement teeth of lateral group of main row formed in soft tissue slightly slanted laterally, associated to shallow continuous depression extending along lingual surface of the dentary (Fig. 1c). Replacement teeth of inner row formed in soft tissue, slightly slanted lingually in relation to its respective functional tooth, cusp pointing dorso-laterally.

<u>Replacement pattern</u>: with no identified pattern

***Acestrorhynchus pantaneiro* MZUSP 59717** 78.9 mm SL

<u>Premaxilla</u>: same condition described for *A. microlepis* except: seven small conical teeth (*vs*. eight small conical teeth in *A. microlepis*). **Replacement:** two replacement teeth preformed for largest tooth on premaxilla (*vs*. one replacement tooth for largest tooth on premaxilla in *A. microlepis*). Replacement tooth of lateralmost functional tooth slightly slanted with cusp pointing medially or replacement tooth with similar orientation in relation to its respective functional tooth (*vs.* slanted medially in *A. microlepis*). Replacement teeth of small conical teeth slanted approximately 90° in relation to their respective functional teeth, cusps pointing lingually (*vs*. replacement teeth with similar orientation in relation to their respective functional tooth in *A. microlepis*).

<u>Maxilla</u>: same condition described for *A. microlepis* except: 27-28 small unicuspid teeth (*vs*. 19-22 small unicuspid teeth in *A. microlepis*). **Replacement:** replacement teeth for unicuspid teeth between two largest teeth on anterior group formed in small and shallow cavities, more than half of length of each replacement teeth going through opening on lingual wall that forms bony cavity (*vs*. larger and deeper bony cavities, only tip of replacement teeth going through opening on medial bony wall in *A. microlepis*).

<u>Dentary</u>: same condition described for *A. microlepis* except: 15-16 teeth on lateral group (*vs*. 9-11 teeth in *A. microlepis*). **Replacement:** two developing replacement teeth for second lateralmost tooth on medial group (*vs.* only one replacement tooth visible for all functional teeth on medial group in *A. microlepis*).

<u>Replacement pattern</u>: same condition described for *A. microlepis*.

<u>General observations</u>: arrow-head tooth morphology not as conspicuous as in *A. microlepis*, but lateral cutting edges are evident.

Heterocharacinae

***Heterocharax virgulatus* MZUSP 29227** 34.9 and 36.0 mm SL

<u>Premaxilla</u>: teeth arranged in single row with nine unicuspid teeth, with no conspicuous curvature, three medialmost teeth larger than remaining teeth. Cusp with abrupt taper. **Replacement:** replacement teeth formed in soft tissue slanted approximately 90° in relation to their respective functional tooth, main cusp pointing

lingually. Replacement teeth of three medialmost functional teeth associated to shallow depressions on lingual surface of the premaxilla.

Maxilla: teeth arranged in a single row with 25-26 unicuspid teeth with no conspicuous curvature extending along almost entire anteroventral margin of maxilla. Cusp not tapering as abruptly as in premaxillary and dentary teeth. Fourth until seventh anteriormost teeth more robust, posteriormost teeth smaller, gradient between two described conditions is observed along the row. **Replacement:** replacement teeth formed in soft tissue, slightly slanted in relation to their respective functional tooth, cusps pointing ventroposteriorly. Replacement teeth of anteriormost functional teeth associated to shallow depressions on lingual surface of maxilla, just posterior to their respective functional tooth. Depression more evident on anterior region of maxilla.

Dentary: teeth arranged in single row divided in two groups. Medial group with five or six unicuspid teeth with no conspicuous curvature. Cusp with abrupt taper. Medial group restricted to the curved portion of the dentary. Lateral group with 30-34 unicuspid teeth with no conspicuous curvature. Cusp with abrupt taper. Lateral group extending posterior of third and fourth medialmost functional teeth on medial group until approximately half length of dorsal margin of dentary. Where two groups overlap, lateral group is lingual to medial group. **Replacement:** replacement teeth of medial group formed in single bony cavity with individual dorsal openings, just lingual to the base of their respective functional tooth, except for medialmost tooth formed in soft tissue associated to shallow depression on lingual surface of dentary. Replacement teeth of lateral group formed in soft tissue, slightly slanted laterally in relation to their respective functional tooth cusp pointing dorsolaterally.

Replacement pattern: with no identified pattern

***Lonchogenys ilisha* MZUSP 29253** 53.1 and 60.9 mm SL

Premaxilla: teeth arranged in single row with 13-14 unicuspid teeth, slightly curved lingually. Cusp with abrupt taper, teeth alternating in size, largest tooth roughly at middle of row. **Replacement:** replacement teeth formed in soft tissue with similar orientation in relation to their respective functional tooth.

Maxilla: teeth arranged in single row of 47-52 unicuspid teeth. Cusp with abrupt taper. Tooth row extending along entire anteroventral margin of maxilla (Fig. 3a). Anteriormost teeth large and robust and strongly curved lingually, posteriormost teeth smaller slenderer and not curved, gradient between two described conditions is observed along row (Fig. 3a). **Replacement:** replacement teeth formed in soft tissue with similar orientation in relation to their respective functional tooth (Fig. 3a)

Dentary: teeth arranged in two rows. Main row divided in two groups, medial group of main row with 10-13 unicuspid teeth slightly curved lingually. Cusp with abrupt taper. Teeth of main row larger than remaining dentary teeth (Fig. 3b). Part of teeth on medial group are labially displaced, not being attached to dorsal margin of dentary, condition more evident for 3rd until 8th medialmost teeth (Fig. 3b). Lateral group with 6-10 small conical teeth curved laterally. Cusps also tapering abruptly, condition less evident than in medial group. Teeth on the lateral group attached to dorsal margin of dentary (Fig. 3b). Inner row with 9-10 conical teeth curved lingually. Cusps also tapering abruptly, condition less evident than in the medial group. Functional teeth of inner row sitting on the lingual wall of bony cavity where anterior group is formed. Teeth on inner row smaller than remaining dentary teeth. Inner row extending from region between base of 3rd and 8th medialmost tooth on medial group of main row. Extension of inner row almost coincident with the extension of labially displaced teeth of medial group. **Replacement:** replacement teeth of medial group of main row formed in single bony cavity with single dorsal opening, replacement tooth of the medialmost tooth formed in soft tissue, not associated to bony cavity. Replacement teeth with similar orientation in relation to their respective functional tooth. Replacement teeth of lateral group formed in soft tissue slanted about 90° in relation to their respective functional tooth, cusps pointing laterally. Replacement teeth of inner row formed in soft tissue with similar orientation in relation to their respective functional tooth.

Replacement pattern: with no identified pattern.

Roestinae

***Roestes molossus* MZUSP 35556** 103.9 mm SL

Premaxilla: teeth arranged in single row with 9-10 unicuspid teeth, slightly curved lingually. Cusp with abrupt taper. Medialmost and second lateralmost teeth larger than remaining premaxillary teeth (Fig. 4a). **Replacement:** replacement tooth of medialmost functional tooth formed in bony cavity, slightly lingually slanted in relation to its respective functional tooth, lingual opening associated to developing replacement tooth, its cusp visible through opening (Fig. 4b). Replacement teeth of remaining premaxillary teeth formed in soft tissue associated to shallow depressions on lingual surface of the ossification, similar orientation in relation to their respective functional teeth (Fig. 4b).

Maxilla: teeth arranged in single row with 46-48 unicuspid teeth. Cusp with abrupt taper. Tooth row extending along entire anteroventral margin of maxilla. Anteriormost teeth larger, slightly curved posteriorly, posteriormost teeth smaller, almost straight, gradient between two described conditions observed along row. **Replacement:** replacement teeth formed in soft tissue with similar orientation in relation to their respective functional tooth. Bony flap from roughly 6th anteriormost tooth until posteriormost quarter of extension of maxilla, partially covering developing replacement teeth. Replacement teeth at middle portion of maxilla slightly slanted posteriorly (Fig. 4c).

Dentary: teeth arranged in two rows. Main row divided in two groups, medial group with 3 unicuspid teeth curved lingually. Cusp with abrupt taper. Teeth larger than remaining dentary teeth, labially displaced as in *Lonchogenys ilisha,* not attached to dorsal margin of dentary. Lateral group with 12 unicuspid teeth. Cusp with abrupt taper. Teeth slightly curved laterally (Fig. 4d, 5a). Inner row with two unicuspid teeth, broader and stouter than remaining dentary teeth, located close to symphysis (Fig 5b). **Replacement:** replacement teeth of medial group formed in single bony cavity, replacement teeth slightly displaced laterally and with similar orientation in relation to their respective functional tooth, large dorsal opening just lateral to third functional tooth. Replacement teeth of lateral group formed in soft tissue, medialmost replacement teeth associated to individual depressions on lingual surface of dentary. All replacement teeth slightly displaced laterally with similar orientation to their respective functional tooth. Replacement teeth of inner row formed in soft tissue, replacement teeth slanted about 90° in relation to their respective functional tooth, replacement tooth of medialmost functional tooth with cusp pointing lingually, replacement tooth of lateralmost functional tooth with cusp pointing laterally.

Replacement pattern: with no identified pattern.

Agoniatidae

***Lignobrycon myersi* not catalogued** 103.2 mm SL

Premaxilla: teeth arranged in two rows. Outer row with three or four tricuspid teeth, main cusps more developed than lateral ones, diameter at base larger than at level of cusps. Outer row extending from near symphysis until level of fourth medialmost tooth of inner row. Inner row with six or seven teeth with three or four cusps, main cusp more developed than lateral ones, cusps arranged in almost straight line in ventral view.

Diameter at region of base larger than at level of cusps. **Replacement:** replacement teeth of outer row formed in individual bony cavities, replacement teeth of two medialmost teeth on left premaxilla formed in single bony cavity. Small individual ventral openings slightly laterolingually displaced in relation to their respective functional tooth. Replacement teeth of inner row formed in soft tissue, slanted about 90° in relation to their respective functional tooth, main cusp pointing lingually, some replacement teeth with slight rotation on main axis of cusp.

Maxilla: teeth arranged in single row with 14-17 teeth along roughly entire anteroventral margin of maxilla. Four or five anteriormost teeth tricuspid, diameter at base of tooth larger than at level of cusps, morphologically similar to premaxillary teeth. Posteriormost teeth conical, slightly curved posteriorly at level of cusp. Gradient between two described conditions is observed along maxilla. **Replacement:** replacement teeth formed in soft tissue, replacement teeth of anteriormost teeth slanted about 90° in relation to their respective functional tooth, main cusp pointing lingually, posteriormost replacement teeth slightly posteriorly slanted, cusps pointing ventroposteriorly. Gradient between two described conditions is observed along maxilla.

Dentary: teeth arranged in single row divided in two groups. Medial group with four teeth with five to six cusps, main cusp markedly more developed than lateral ones, diameter at base of tooth larger than at level of cusps. Asymmetric teeth with six cusps with higher number of cusps lateral to main cusp. Lateral group with eight to nine tricuspid teeth, main cusp more developed than lateral ones, diameter at base of tooth larger than at level of cusps or conical teeth, slightly curved laterally at level of cusp. Unicuspid teeth, when present are medialmost on lateral group. **Replacement:** replacement teeth of medial group formed in single bone cavity, individual dorsal openings slightly laterolingually displaced in relation to their respective functional tooth. Replacement teeth slightly slanted laterally. Replacement teeth of lateral group formed in soft tissue slightly slanted and displaced laterally in relation to their respective functional tooth, cusps pointing laterally.

Replacement pattern: unilateral pattern on the premaxilla and medial group of the dentary, with no identified pattern on the maxilla and lateral group of the dentary.

General observations: on the left premaxilla the third tooth on the outer row is slightly lingually displaced, resulting in a non-linear arrangement of the teeth on both outer and inner rows. This tooth was considered as a inner row tooth because of its respective replacement tooth is formed in soft tissue.

Agoniatinae

***Agoniates halecinus* MZUSP 34327** 107.7 mm SL

Premaxilla: teeth arranged in two rows, outer row with four conical teeth with no conspicuous curvature, outer row extending along entire ventral margin of premaxilla. Inner row with four tricuspid teeth, main cusp markedly larger than lateral ones, diameter at base of tooth larger than at level of cusps. Premaxillary teeth not aligned in two distinct rows, arranged in zigzag pattern. **Replacement:** replacement teeth of outer row formed in single bony cavity with individual ventral openings, just lingual to their respective functional tooth. Replacement teeth with similar orientation to their respective functional tooth. Replacement teeth of inner row formed in soft tissue, each replacement tooth associated to deep depression on lingual surface of premaxilla, replacement teeth slanted about 90° in relation to their respective functional tooth, main cusp pointing lingually.

Maxilla: teeth arranged in single row of 28-30 conical teeth slightly curved lingually, tooth row extending along entire anteroventral margin of maxilla (Fig. 6a). **Replacement:** replacement teeth formed in soft tissue associated to individual well-defined depressions on lingual surface of maxilla. Replacement teeth slightly displaced posteriorly with similar orientation in relation to their respective functional tooth (Fig. 6a).

Dentary: parasymphyseal tooth conical, slightly displaced lingually, slightly curved lingually at level of cusp. Remaining teeth arranged in single row divided in two groups. Medial group with three tricuspid teeth, main cusp more developed than lateral ones, diameter at base of tooth larger than at level of cusps (Fig. 6b). Lateral group with seven conical teeth with no cutting edges and no conspicuous curvature. Medialmost tooth markedly larger than remaining teeth on lateral group. One small conical tooth just lateral to largest conical tooth. Two lateralmost teeth markedly smaller than remaining teeth on lateral group (Fig. 6b) **Replacement:** replacement tooth of parasymphyseal tooth formed in soft tissue associated to depression on lingual surface of dentary, lingual to its respective functional tooth, replacement tooth slanted about 90° in relation to its respective functional tooth, cusp pointing lingually. Replacement teeth of medial group formed in single bony cavity, individual dorsal openings slightly displaced lingually in relation to their respective functional tooth, replacement teeth slightly slanted, main cusps pointing lingually. Replacement tooth of largest conical tooth on lateral group formed in bony cavity with large dorsal opening just lateral to base its respective functional tooth, replacement tooth slanted laterally, cusp going through the dorsal opening (Fig. 6b). Replacement tooth of the of the small conical tooth just lateral to largest tooth formed in soft tissue associated to shallow depression on lingual surface of dentary, slanted about 90° in relation to its respective functional tooth, cusp pointing laterally (Fig. 6b). Replacement teeth of two lateralmost, small conical teeth formed in soft tissue associated to single depression on lingual surface of dentary, slanted about 45° in relation to their respective functional tooth. Replacement teeth of remaining conical teeth on lateral group formed in soft tissue associated to well-defined individual depressions of lingual surface of dentary, also slanted posteriorly, in more acute angle than angle of replacement tooth of largest conical tooth on lateral group (Fig. 6b).

Replacement pattern: unilateral pattern on the premaxilla, with no identified pattern on the maxilla and dentary.

Triportheinae

***Triportheus albus* MZUSP 117105** 103.9 mm SL

Premaxilla: teeth arranged in three rows. Outer row with four tricuspid teeth, all cusps of similar size, diameter at base of tooth and at level of cusps similar, lateralmost tooth on left premaxilla with four cusps (Fig. 7a). Middle row with two teeth with three or four cusps, morphologically similar to outer row teeth, cusps similar in size, diameter at base of tooth and at level of cusps similar. There is some spacing between outer row teeth at region of base of middle row teeth. Inner row with six teeth with five to seven cusps, main cusp more developed than lateral ones. Cusps of medialmost tooth arranged in U-shaped line in ventral view, cusps of lateralmost tooth arranged in smooth arch in ventral view, gradient between two described conditions is observed along inner row, concave face of the teeth pointing lingually (Fig. 8a). **Replacement:** replacement teeth of outer row formed in single bony cavity, with no ventral openings, replacement teeth slightly slanted in relation to their respective functional tooth, main cusp pointing lingually. Replacement teeth of middle row formed intraosseously, slanted about 90° in relation to their respective functional tooth, main cusp pointing lingually, lingual opening associated to replacement teeth of lateralmost tooth on middle row (Fig. 7b). Replacement teeth of inner row formed in soft tissue, slanted about 90° in relation to their respective functional tooth, main cusp pointing lingually.

Maxilla: one pentacuspid tooth, all cusps similar in size, diameter at base of tooth and at level of cusps similar. On left maxilla there is one conical tooth with no conspicuous curvature, just posterior to pentacuspid tooth (Fig. 8b). **Replacement:** replacement tooth of pentacuspid tooth formed in soft tissue, slanted about 90° degrees in relation to its respective functional tooth, main cusp pointing lingually. Replacement tooth on left maxilla with seven cusps, no visible replacement tooth for conical tooth.

Dentary: parasymphyseal tooth conical, slightly curved lingually at level of cusp, tooth large, as high as largest teeth on main row of dentary. Parasymphyseal tooth just lingual to medialmost tooth on main row (Fig. 8c). Remaining teeth arranged in single row divided in two groups. Medial group with five penta or hexacuspid teeth, main cusp more developed than lateral ones, Diameter at base of tooth larger than at level of cusps. Asymmetrical teeth with six cusps with higher number of cusps medial to main cusp, larger and more robust than the other teeth (Fig. 9a). Cusps of medialmost tooth arranged in arched line in dorsal view, cusps of lateralmost tooth arranged in almost straight line in dorsal view, gradient between two described conditions is observed along medial group, concave face of teeth pointing lingually (Fig. 9b). Lateral group with six teeth considerably smaller than those on anterior group, medialmost tooth tricuspid, main cusp markedly more developed than lateral ones, lateralmost tooth conical curved laterally at level of cusp, gradient between two described conditions is observed along lateral group. **Replacement:** replacement tooth of parasymphyseal tooth formed in soft tissue associated to depression on lingual surface of dentary, replacement tooth slanted 90° in relation to its respective functional tooth, cusp pointing laterally (Fig. 9b). Replacement teeth of medial group formed in single bone cavity, individual dorsal openings slightly laterolingually displaced in relation to their respective functional tooth, no dorsal opening associated to medialmost tooth. Replacement teeth slightly displaced laterally, replacement tooth of anteriormost tooth slanted laterally (Fig. 8c, 9b). Replacement teeth of lateral group formed in soft tissue, slightly displaced and slanted laterally in relation to respective functional tooth.

Replacement pattern: unilateral pattern on premaxilla, parasymphyseal and anterior group of main row of dentary, with no identified pattern on posterior group of dentary.

Triportheus angulatus **MZUSP 27314** 91.0 mm SL

Premaxilla: same pattern described for *T. albus* except: outer row with six or seven tricuspid teeth, lateralmost tooth on side with seven teeth conical (*vs*. four teeth with three or four cusps in *T. albus*). Middle row with three tricuspid teeth (*vs*. two teeth with three or four cusps in *T. albus*). Inner row teeth with three to six cusps (*vs*. inner row teeth with five to seven cusps in *T. albus*). **Replacement:** Ventral openings associated to replacement teeth of outer row (*vs*. ventral opening absent in *T. albus*)

Maxilla: same pattern described for *T. albus* except: two teeth on both maxillae, anteriormost with five or six cusps, posteriormost with three or four cusps (*vs*. two teeth only on the left side, anteriormost with five cusps, posteriormost conical in *T. albus*)

Dentary: same pattern described for *T. albus* except: medial group teeth with three to six cusps (*vs*. medial group teeth with five or six cusps in *T. albus*). Lateral group with eight or nine teeth (*vs*. lateral group with six teeth in *T. albus*). **Replacement:** dorsal opening associated to two posteriormost teeth on medial group coalesce together and stretch posteriorly beyond posterior margin of the posteriormost functional medial group teeth (*vs*. individual openings do not coalesce together in *T. albus*). Replacement teeth of medialmost teeth on lateral group formed in soft tissue, however, fairly close to posterior portion of enlarged dorsal openings related to lateralmost medial group teeth (*vs*. replacement teeth of lateral group teeth not associated to modifications on lingual surface of dentary in *T. albus*). Replacement tooth of lateralmost tooth on medial group with five evident cusps, its respective functional tooth has only three cusps.

Replacement pattern: same pattern described for *T. albus* except: the difference between the two sides regarding developmental stages of the replacement teeth is much more evident in *T. angulatus*.

Alestidae

***Alestes baremoze* BMNH 1982.13.554-557** 68.2 and 68.1 mm SL, 74.0 mm SL

Premaxilla: teeth arranged in two rows. Outer row with three tricuspid teeth, main cusp more developed than lateral ones. Diameter at base of tooth and at level of cusps similar. Outer row extending from near symphysis until level of space between second and third medialmost tooth on inner row second (Fig. 10a and 10c). Inner row with four teeth. Medialmost tooth asymmetrical (Fig. 10c), four to five cusps on convex face, the medialmost cusp being the largest, two additional cusps present at each side of concave face of tooth (Fig. 10c, black arrow). Second medialmost tooth with six to seven cusps on convex face, when with six cusps, two cusps medial to main, more developed cusp, remaining cusps lateral to latter. Two molariform cusps present, one in each lateral extremity of concave face of tooth. Third and fourth medialmost teeth with six to seven cusps. In larger specimens third medialmost tooth has two molariform cusps, similar to those of the two medialmost teeth, smaller specimens with only one molariform cusp on medial portion of concave face of tooth. Lateralmost tooth, of larger specimens with one molariform cusp on medial portion of concave face of tooth; smaller specimens lacking molariform cusps on lateralmost tooth. Medialmost tooth with cylindrical base, circular cross section, cusps arranged in arched line in ventral view. Lateralmost tooth labiolingually compressed with ellipsoid cross section, cusps arranged in almost straight line in ventral view, gradient between two described conditions is observed along inner row (Fig. 10c). **Replacement:** replacement teeth of outer row formed in single bone cavity for each tooth and without any openings. Replacement teeth slanted 90° and slightly laterally displaced in relation to their respective functional tooth, main cusp pointing lingually (Fig 10d). Replacement teeth of inner row formed in soft tissue, slanted about 90° in relation to their respective functional tooth, main cusps pointing lingually (Fig. 10b).

Maxilla: teeth absent (Fig. 10e).

Dentary: parasymphyseal tooth conical, slightly curved lingually (Fig.11b and c). Main row with four teeth. Medialmost tooth with six cusps, situated immediately anterior to parasymphyseal tooth. Second medialmost tooth with seven cusps, this tooth has a posteromedial projection on the lateral portion of its concave face, this projection accommodating itself on notch on lateral region of third medialmost tooth. Third medialmost tooth with six cusps. Three medialmost teeth with notch on their medial margin, between level of cusps and base of tooth (Fig. 11c, black arrows). Lateralmost tooth noticeably smaller than other dentary teeth and with three to four cusps (Fig. 11a). **Replacement:** replacement tooth of parasymphyseal tooth formed in soft tissue associated to shallow depression on anterior region of medial wall of bone cavity where replacement teeth of main row are formed (Fig. 11c). Replacement tooth slanted about 90° in relation to their respective functional tooth, cusp pointing posterolaterally. Replacement teeth of main row formed in single bone cavity with single dorsal opening that extends along base of functional teeth. Replacement teeth of three medialmost functional teeth laterally displaced in relation to their respective functional tooth. Replacement tooth of medialmost functional tooth laterally slanted in relation to its respective functional tooth (Fig. 11c). Replacement tooth of lateralmost functional tooth located more superficially in bone cavity and not as much laterally displaced as remaining replacement teeth, that results in almost overlap of replacement teeth of third medialmost and lateralmost functional teeth, the replacement tooth of lateralmost functional tooth in laterodorsal position in relation to replacement tooth of third medialmost functional tooth (Fig. 11b).

Replacement pattern: unilateral pattern.

Alestes macrophthalmus **BMNH 1985.6.13.15-17** 46.0 and 44.1 mm SL and **BMHN 1955.12.20.670** 73,3 mm SL* Specimen already dissected, standard length was estimated.

Premaxilla: same condition described for *Alestes baremoze* except: third medialmost tooth on outer row slightly displaced lingually, almost at same line of inner row (*vs*. all teeth on outer row aligned in same line). Inner row: medialmost tooth on inner row with three to five cusps (*vs*. medialmost tooth on inner row with four or five cusps in *A. baremoze*). Second and third medialmost and lateralmost teeth with six cusps (*vs.* second and third medialmost and lateralmost teeth with six or seven cusps in *A. baremoze*). **Replacement:** replacement teeth of two medialmost teeth on outer row formed in bony cavity, lateralmost tooth formed in depression on lingual surface of premaxilla. On one premaxillae of smallest specimen all three replacement teeth of outer row are formed in individual depression on lingual surface of premaxilla (*vs*. replacement teeth of outer row formed in bony cavities in *A*. baremoze).

Maxilla: same condition described for *Alestes baremoze*.

Dentary: same condition described for *Alestes baremoze* except: medialmost tooth with five cusps (*vs*. medialmost tooth with six cusps in *A. baremoze*); second medialmost tooth with six or seven cusps, when with six cusps, three of them medial to main, more developed cusp, the rest lateral to latter (*vs*. second medialmost tooth with seven cusps in *A. baremoze*); two medialmost teeth have notch on their medial margin, between level of cusps and base of tooth (*vs*. three medialmost teeth have notch on their medial margin, between level of cusps and base of tooth in *A. baremoze*); lateralmost tooth with three cusps (*vs.* lateralmost tooth with three or for cusps in *A. baremoze*).

Replacement pattern: unilateral pattern.

Brycinus sadleri **BMNH.1966.7.7.14** 75.7 mm SL and **BMNH.1965.10.8.47** 57,5 mm SL.

Premaxilla: teeth arranged in two rows. Outer row with four tricuspid teeth, main cusp more developed than lateral ones, diameter at base of tooth and at level of cusps similar. Outer row extending from near symphysis until lateral margin of third medialmost tooth on inner row (Fig. 12a). Inner row formed by four teeth. Medialmost tooth, fairly asymmetrical, five cusps on convex face, one cusp medial to main, more developed cusp, and three lateral, one molariform cusp on lateral region of concave face. Second medialmost tooth with seven cusps on convex face and two molariform cusps on concave face, one in each lateral extremity of concave face of tooth. Two medialmost teeth with constriction between base of tooth and level of cusps. Cusps on convex face of said teeth arranged in arched line in ventral view. Third medialmost and lateralmost teeth labiolingually compressed, ellipsoid cross section, both with seven to eight cusps arranged asymmetrically, two cusps lateral to main, more developed, cusp, remaining cusps medial to latter. Cusps on convex face arranged in almost straight line in ventral view (Fig. 12b). One small molariform cusp present on concave face of third medialmost tooth in just one side of one examined specimen. **Replacement:** replacement teeth of outer row formed in single bony cavity. Four small ventral openings, these being slightly laterally displaced in relation to their respective functional teeth (Fig. 12b). Replacement teeth slanted about 90° and slightly laterally displaced in relation to their respective functional tooth, main cusps pointing lingually. Replacement teeth of inner row formed in soft tissue, slanted about 90° in relation to their respective functional tooth, main cusp pointing lingually (Fig. 12a).

Maxilla: teeth absent (Fig. 12c).

Dentary: parasymphyseal tooth conical, slightly curved lingually (Fig 13b). Main row with four teeth. Medialmost tooth with six cusps just labial to parasymphyseal tooth. Second medialmost tooth also with six cusps, this tooth has posteromedial projection on lateral portion of its concave face without enamel layer equivalent to those on cusps. Third medialmost tooth with four or five cusps. Three medialmost teeth with notch on their lateral margin closest to symphysis between level of cusps and base of tooth. Lateralmost tooth with four cusps and noticeably smaller than other dentary teeth (Fig. 13a and b). **Replacement:** replacement tooth of parasymphyseal tooth formed in soft tissue associated to shallow depression on medial portion of the medial wall that forms bone cavity where replacement teeth of main row are formed (Fig. 13b). Replacement tooth slanted about 90° in relation to their respective functional tooth, cusp pointing posterolaterally. Replacement teeth of main row formed in single bone cavity with single dorsal opening extending along base of functional teeth. Replacement teeth of three medialmost functional teeth laterally displaced in relation to their respective functional tooth. Replacement tooth of medialmost functional tooth laterally slanted in relation to its respective functional tooth. Replacement tooth of lateralmost functional tooth located more superficially in bone cavity and not as much laterally displaced as remaining replacement teeth, that results in almost overlap of replacement teeth of third medialmost and lateralmost functional teeth, replacement tooth of fourth lateralmost functional tooth in laterodorsal position in relation to replacement tooth of third medialmost functional tooth (Fig. 13b). Bony cavities of replacement teeth of main row and replacement tooth of parasymphyseal tooth coalesce together.

Replacement pattern: unilateral pattern

Brycinus lateralis **BMNH 1965.3.12.375-376** 35.4 and 22.5* mm SL. * specimen already dissected, SL was estimated.

Premaxilla: same condition described for *Brycinus sadleri* except: outer row extending until third medialmost tooth of inner row (*vs*. outer row extending until lateral margin of third medialmost tooth on inner row in *B. sadleri*). Molariform cusp absent on concave face of third medialmost tooth on inner row (*vs*. small molariform cusps present on concave face of third medialmost tooth on inner row in *B. sadleri*). **Replacement:** small openings on medial surface of premaxilla, openings associated to two medialmost functional teeth on outer row (*vs*. such openings absent in *B. sadleri*).

Maxilla: same condition described for *Brycinus sadleri*.

Dentary: same condition described for *Brycinus sadleri* except: medialmost tooth on main row with five or six cusps (*vs*. medialmost tooth on main row with six cusps in *B. sadleri*); second medialmost tooth on main row with five or six cusps (*vs*. second medialmost tooth on main row with six cusps in *B. sadleri*); lateralmost tooth on main row with three cusps (*vs*. lateralmost tooth on main row with four cusps in *B. sadleri*).

Replacement pattern: same condition described for *Brycinus sadleri*

Brycinus imberi **BMNH 1969.9.25.61** 45.1 mm SL

Premaxilla: same condition described for *Brycinus sadleri* except: outer row extending from near symphysis until medial margin of third medialmost tooth on inner row (*vs*. outer row extending from near symphysis until lateral margin of third medialmost tooth on inner row in *B. sadleri*); Inner row: second medialmost tooth with six cusps on convex face (*vs*. second medialmost tooth with seven cusps on convex face in *B. sadleri*); third medialmost and lateralmost teeth with six cusps on convex face, asymmetrically arranged, two cusps lateral to main, more developed cusp, three cusps medial to latter (*vs*.

third medialmost and lateralmost teeth with seven to eight cusps arranged asymmetrically, two cusps lateral to main, more developed, cusp, remaining cusps medial to the latter in *B. sadleri*). One molariform cusp on medial margin of concave face of third medialmost tooth. (*vs*. molariform cusps on third medialmost tooth observed on only one side in *B. sadleri*).

Maxilla: same condition described for *Brycinus sadleri*.

Dentary: same condition described for *Brycinus sadleri*, except: main row: third medialmost tooth with six cusps (*vs*. third medialmost tooth with four or five cusps in *B. sadleri*); lateralmost tooth with three cusps (*vs*. lateralmost tooth with four cusps in *B. sadleri*). **Replacement:** Replacement tooth of lateralmost tooth not visible, probably accidentally removed during the dissection.

Replacement pattern: simultaneous unilateral pattern

Bryconalestes longipinnis **BMNH 1981.2.17.814** 36,1 mm SL

Premaxilla: teeth arranged in two rows. Outer row with three tricuspid teeth, main cusp more developed than lateral ones. Diameter at base of tooth and at level of cusps similar. Outer row extending from near symphysis until space between second and the third medialmost teeth on inner row (Fig. 14a). Inner row with four teeth. Medialmost tooth with five or six cusps, one or two cusps medial to main, more developed cusp, remaining cusps lateral to latter. One molariform cusp on lateral region of concave face, visible only on replacement tooth, that is noticeably larger than its respective functional tooth. Second medialmost tooth with seven cusps on convex face, two molariform cusps, one on each margin of concave face, only visible on replacement tooth that is noticeably larger than its respective functional tooth. Two medialmost teeth with cylindrical bases. Third medialmost tooth with seven cusps. Lateralmost tooth with six cusps, three cusps being medial to main cusp, more developed cusp, remaining lateral to latter. Medialmost tooth with cylindrical base, circular cross section, cusps arranged in arched line in ventral view. Lateralmost tooth labiolingually compressed with ellipsoid cross section, cusps arranged in almost straight line in ventral view, gradient between two described conditions is observed along inner row (Fig. 14b). **Replacement:** replacement teeth of outer row formed intraosseously (Fig. 14a) in single bony cavity. Small ventral openings slightly laterally displaced in relation to their respective functional tooth. Openings also present on lingual surface of premaxilla, one opening for each replacement tooth, in medio-lateral decreasing size gradient. Opening on lingual surface of premaxilla larger than ones on ventral surface of premaxilla. Replacement teeth slightly laterally displaced and slanted about 90° in relation to their respective functional tooth, main cusps pointing lingually. Replacement teeth of inner row formed in soft tissue, slanted about 90° in relation to their respective functional tooth, main cusp pointing lingually (Fig. 14b).

Maxilla: teeth absent.

Dentary: parasymphyseal tooth conical, slightly curved lingually (Fig. 15b). Main row with four teeth. Medialmost tooth with six or seven cusps just posterior to parasymphyseal tooth. Second medialmost tooth with seven cusps, this tooth with posteromedial projection on lateral portion of its concave face without enamel layer equivalent to those of cusps, this projection accommodating on notch on lateral region of third tooth. Third medialmost tooth with six cusps, also with notch in its medial margin and posteromedial projection on opposing margin without enamel layer equivalent to those of cusps. Second and third medialmost teeth have notch on their medial margin, between level of cusps and base of tooth. Lateralmost tooth noticeably smaller than remaining dentary teeth, with two or three cusps, slightly curved laterally (Fig. 15a and b). Teeth on right dentary noticeably larger than their contralateral counterparts. **Replacement:** replacement tooth of parasymphyseal tooth formed in soft tissue associated to depression on lingual surface of dentary, replacement teeth slated in 90° in relation to its respective functional tooth. Cusp pointing lingually and slightly laterally (Fig. 15a). Replacement teeth of main row formed in single bone cavity with single dorsal opening that extends along base of functional teeth. Replacement teeth of three medialmost functional teeth laterally displaced in relation to their respective functional tooth. Replacement tooth of medialmost functional tooth slightly laterally slanted in relation to its respective functional tooth (Fig. 15a). Replacement tooth of lateralmost functional tooth located more superficially in bone cavity and not as much laterally displaced as rest of replacement teeth, that results in almost overlap of replacement teeth of third medialmost and lateralmost functional teeth, replacement tooth of lateralmost functional tooth in dorsal position in relation to replacement tooth of third medialmost functional tooth. The bony cavities of replacement teeth of main row and replacement tooth of parasymphyseal tooth coalesce together.

Replacement pattern: unilateral pattern.

Hydrocynus forskahlii **BMNH 1981.2.17.760-764** 33.6; 44.1 and 50.9*mm SL. * Standard length estimated with the SL/lower-jaw length proportion.

Premaxilla: single row of five to seven teeth, smaller specimens with more teeth. Bases with circular cross section, morphology of distal portion varying from pentacuspid to almost unicuspid with vestigial lateral cusps (Fig. 16a and b). Higher number of multicuspid teeth in smaller specimens, whereas number of near unicuspid teeth is higher in larger specimens. Main cusp always more developed than lateral ones, even on pentacuspid teeth. Region of cusps labiolingually compressed forming clear cutting edge on margin of cusps. On the almost unicuspid, larger teeth, vestigial lateral cusps mark proximal limits of cutting edges of main cusp (Fig. 16 a and b), second medialmost tooth always is largest. Some specimens have small conical tooth on lateralmost position. **Replacement:** replacement teeth formed in soft tissue associated to large bone cavities on medial surface of premaxilla (Fig. 16b), replacement teeth slanted about 90° in relation to their respective functional tooth, main cusp pointing lingually.

Maxilla: teeth absent (Fig. 16c).

Dentary: single row of five or six teeth. Base of teeth always conical in shape, morphology of distal portion varying from tetracuspid to almost triangular profile (Fig. 17a and b). Higher number of multicuspid teeth in smaller specimens, whereas number of near unicuspid teeth is higher in larger specimens. Main cusp always more developed than lateral ones, even on tetracuspid teeth. Region of cusps labiolingually compressed forming clear cutting edge on margin of cusps. On almost unicuspid, larger teeth, vestigial lateral cusps mark proximal limits of cutting edges of main cusp (Fig. 17a and b). The medialmost tooth is always larger than others. **Replacement:** replacement teeth formed in bony cavities with ample dorsal openings. Two medialmost teeth formed in individual cavities, whereas the remaining teeth are formed in single bone cavity with single dorsal opening (Fig. 17b). Dorsal openings slightly posteriorly displaced in relation to their respective functional tooth. Replacement teeth slanted around 90° in relation to their respective functional tooth, main cusp pointing posteriorly.

Replacement pattern: with no identified pattern

Lepidarchus adonis **BMNH 1984.9.11.2** 18.5 mm SL and three uncatalogued specimens 23.9; 23.4 and 21,1 mm SL.

Premaxilla: single row of eight to ten small conical teeth slightly curved lingually, teeth present along entire ventral margin of premaxilla (Fig. 18a and d). **Replacement:** replacement teeth formed in soft tissue, slanted approximately 90° in relation to their respective functional tooth, cusps pointing lingually (Fig. 18b and c).

Maxilla: teeth absent (Fig. 19a).

Dentary: single row of twelve to fourteen small conical teeth slightly curved lingually. Six lateralmost teeth distinctly smaller than the others (Fig. 19a). **Replacement:** replacement teeth formed in soft tissue, slanted approximately 90°, cusps pointing lingually (Fig. 19b).

Replacement pattern: with no identified pattern.

Micralestes acutidens **MZUSP 62625** 35.5 and 51.9 mm SL

Premaxilla: teeth arranged in two rows. Outer row with three teeth, larger specimen with medialmost tooth tricuspid, second and third medialmost pentacuspid, smaller specimen with only tricuspid teeth. Teeth slightly pedicellate. Outer row extending from near symphysis until space between second and third medialmost teeth on inner row. Gap between second and third medialmost teeth larger than gap between medialmost and second medialmost tooth on outer row. Inner row with four teeth, medialmost tooth slightly asymmetrical with six cusps, two cusps medial to main cusp. Remaining teeth with nine cusps. Three medialmost teeth with main cusp noticeably more developed than lateral ones. Lateralmost tooth with all cusps similar in size. Medialmost tooth with circular cross section, cusps arranged in arched line in ventral view. Lateralmost tooth labiolingually compressed with an ellipsoid cross section, cusps arranged in almost straight line in ventral view, gradient between two described conditions observed along inner row. **Replacement:** replacement teeth of outer row formed intraosseously in single bony cavity, replacement teeth slanted about 90° in relation to their respective functional tooth, main cusp pointing lingually. Small ventral opening between second and third functional teeth. Replacement tooth of the third functional tooth visible through opening on lingual surface of premaxilla. Replacement teeth of inner row formed in soft tissue slanted slightly more than 90° in relation to their respective functional tooth cusps pointing dorsoposteriorly.

Maxilla: teeth absent.

Dentary: parasymphyseal tooth tricuspid and asymmetrical, medialmost cusp more developed (Fig. 20). Main row with four teeth, all with seven cusps and labiolingually compressed, with ellipsoid cross section. Three medialmost teeth with main cusps markedly more developed than lateral ones, difference in cusps size less evident on lateralmost tooth (Fig. 20). **Replacement:** replacement tooth of parasymphyseal tooth formed in soft tissue associated to depression on lingual surface of dentary. Replacement tooth slanted 90° in relation to its respective functional tooth, main cusp pointing lingually (Fig. 20). Replacement teeth of main row formed in single bone cavity with single dorsal opening that extends along base of functional teeth. Replacement teeth of three medialmost functional teeth laterally displaced in relation to their respective functional tooth. Replacement teeth of medialmost functional tooth slightly slanted laterally in relation to its respective functional tooth. Replacement tooth of lateralmost functional tooth not visible, possibly accidentally removed (Fig. 20). Bony cavities of replacement teeth of main row and replacement tooth of parasymphyseal tooth coalesce together (Fig. 20).

Replacement pattern: unilateral pattern.

***Phenacogrammus* cf. *interruptus* BMNH 1954.3.14.60-61** 37.9 and 38.7 mm SL

Premaxilla: teeth arranged in two rows. Outer row with two teeth with four or five cusps, diameter at base of tooth and at level of cusps similar. Outer row extending from near symphysis until space between second and third medialmost teeth of inner row. Inner row with four teeth. Medialmost tooth slightly asymmetrical with six cusps, two cusps medial to main cusp, more developed cusp and other three lateral to latter. Remaining teeth with seven cusps. Medialmost tooth with circular cross section, cusps arranged in arched line in ventral view. Lateralmost tooth labiolingually compressed with ellipsoid cross section, cusps arranged in almost straight line in ventral view, gradient between two described conditions observed along inner row. **Replacement:** replacement teeth of outer row formed intraosseously in individual bony cavities. Replacement teeth slanted 90° in relation to the respective functional tooth, main cusp pointing lingually. Replacement teeth of the inner row formed in soft tissue, slated in 90° in relation to their respective functional tooth, main cusp pointing lingually.

Maxilla: teeth absent.

Dentary: parasymphyseal teeth with two or three cusps, slightly curved lingually. Main row with four teeth. Medialmost tooth with six or seven cusps, just posterior to the parasymphyseal tooth. Second and third medialmost teeth with seven cusps. Lateralmost tooth with three or four cusps, noticeably smaller than remaining dentary teeth. Three anteriormost teeth with shallow notch between base and level of cusps on their medial margin. **Replacement:** replacement tooth of parasymphyseal tooth formed in soft tissue associated to depression on lingual surface of dentary. Replacement tooth slanted about 90° in relation to its respective functional tooth, main cusp pointing lingually and slightly laterally. Replacement teeth of main row formed in single bone cavity with single dorsal opening extending along base of functional teeth. Replacement teeth of three medialmost functional teeth posteriorly displaced in relation to their respective functional tooth. Replacement teeth of first and third medialmost functional teeth slightly laterally slanted in relation to its respective functional tooth. Replacement tooth of posteriormost functional tooth located more superficially in bony cavity and not as much posteriorly displaced as remaining replacement teeth, that results in almost overlap of replacement teeth of third medialmost and lateralmost functional teeth, replacement tooth of lateralmost functional tooth in dorsoposterior position in relation to replacement tooth of third medialmost functional tooth. The bony cavities of replacement teeth of main row and replacement tooth of parasymphyseal tooth coalesce together.

Replacement pattern: unilateral pattern.

Anostomidae

***Abramites hypselonotus* MZUSP 20929** 51.6 and 58.4 mm SL

Premaxilla: teeth arranged in single row of three teeth with no marked cusps, cross section at level of tooth base circular, distal region of teeth labiolingually compressed, medialmost tooth with shallow notch on its distal edge, slightly medial to its midline. Teeth base elongate, teeth slightly pedicellate. Teeth with pleurodont implantation, teeth slightly mobile when manipulated. **Replacement: Replacement:** replacement teeth formed in soft tissue, bony flange projecting laterally from symphysis, covering less than half width of lingual surface of medialmost replacement tooth. Replacement teeth with same orientation in relation to their respective functional tooth.

Maxilla: teeth absent.

Dentary: teeth arranged in single row with four teeth with no marked cusps, distal region of teeth labiolingually compressed, irregular distal margins, two medialmost teeth with clear notch on the lateral portion of their distal regions resulting in step-shape profile. Lateralmost tooth markedly smaller than remaining dentary teeth with acute cusp. Teeth with pleurodont implantation, teeth slightly mobile when manipulated. **Replacement:** replacement teeth formed in single bone cavity with ample dorsal opening as well as one ventral opening, which is slightly smaller than the dorsal one. Replacement teeth just ventral and with same orientation as their respective functional tooth.

Replacement pattern: with no identified pattern.

Laemolyta proxima **MZUSP 111373** 102.6 and 117.5 mm SL

Premaxilla: teeth arranged in single row with four teeth with four or five cusps. Region of cusps labiolingually compressed, cusps of medialmost tooth reaching the same height distally, cusps of remaining teeth arranged in fan-like aspect. Teeth slightly pedicellate. Teeth with pleurodont implantation, slightly mobile when manipulated. **Replacement:** replacement teeth formed in soft tissue, bony flange projecting laterally from symphysis, covering lingual surface of medialmost replacement tooth. Replacement teeth with same orientation in relation to their respective functional tooth.

Maxilla: teeth absent.

Dentary: teeth arranged in single row with four teeth with no marked cusps, distal region of teeth labiolingually compressed, two medialmost teeth with straight distal margin, the two posteriormost teeth with one to three notches on distal margin resulting in multicuspid aspect, all cusps reaching same transversal line distally. Base of teeth elongated, teeth slightly pedicellate. Teeth with pleurodont implantation, slightly mobile when manipulated. **Replacement:** replacement teeth formed in single bone cavity with ample dorsal opening as well as one ventral opening, which is slightly smaller than dorsal one. Replacement teeth just ventral and with same orientation their respective functional tooth. Replacement tooth of posteriormost tooth not visible in any of examined specimens, possibly removed accidentally during dissection.

Replacement pattern: with no identified pattern.

Leporinus bahiensis **MZUSP 112246** 87.5 mm SL

Premaxilla: teeth arranged in single row of three teeth with no marked cusps, distal region of teeth labiolingually compressed, irregular distal margins. Teeth with long base, teeth slightly pedicellate (Fig. 21 a and b). Teeth with pleurodont implantation, slightly mobile when manipulated, however, more firmly attached when compared to *L. proxima*. **Replacement:** replacement teeth formed in soft tissue, bony flange projecting laterally from symphysis, covering around half width of lingual surface of medialmost replacement tooth (Fig. 21 b). Replacement teeth with same orientation in relation to their respective functional tooth (Fig. 21b).

Maxilla: teeth absent.

Dentary: teeth arranged in single row with four teeth with no marked cusps, distal region of teeth labiolingually compressed, irregular distal margin. Base elongate, teeth slightly pedicellate (Fig. 22a and b), teeth more robust when compared to *L. proxima*.

Teeth with pleurodont implantation, slightly mobile when manipulated. **Replacement:** replacement teeth formed in single bone cavity with ample dorsal opening as well as one ventral opening, which is slightly smaller than the dorsal one (Fig. 22b). Replacement teeth just ventral and with same orientation as their respective functional tooth.

Replacement pattern: with no identified pattern.

Leporinus desmotes **MZUSP 88050** 77.1 mm SL

Premaxilla: same pattern described for *Leporinus bahiensis* except: teeth more firmly implanted on the bone than in *L. bahiensis*.

Maxilla: same pattern described for *L. bahiensis*.

Dentary: same pattern described for *L. bahiensis* except: single row with 3 teeth thinner and more firmly implanted on underlying bone than in *L. bahiensis*.

Replacement pattern: same patter descried for *L. bahiensis*.

Bryconidae

Brycon amazonicus **MZUSP 74668** 50.2, 51.4 and 57.4 mm SL and **MZUSP 82418** 78.5 mm SL

Premaxilla: teeth arranged in three rows. Outer row with 12-13 teeth, medialmost tricuspid, main cusp more developed than lateral ones, lateralmost conical, gradient between two described conditions observed along row. Diameter at base of tooth and at level of cusps similar (Fig. 23a). Middle row with three tricuspid teeth, larger than those of outer row. Teeth restricted to region near symphysis, extending laterally until fourth medialmost tooth on outer row. Diameter at base of tooth and at level of cusps similar. (Fig. 23a). Inner row with eight or nine teeth, diameter at region of base and level of cusps similar. Two medialmost teeth larger, medialmost slightly asymmetric with four cusps, second medialmost tooth is largest on premaxilla, with five cusps, concave face of both teeth pointing lingually. The medialmost teeth on remainder of inner row are tricuspid, while lateralmost are conical gradient between two described conditions is observed along row (Fig. 23b). **Replacement:** replacement teeth of outer row formed in single bony cavity, small ventral openings just lingual to their respective functional tooth. Replacement teeth with similar orientation in relation to their respective functional tooth (Fig. 23c). Replacement teeth of middle row formed in single bony cavity, with opening on the lingual surface of the premaxilla teeth slanted in relation to their respective functional tooth, main cusp pointing lingually (Fig. 23b). Replacement teeth of inner row formed in soft tissue, slanted about 90°in relation to their respective functional tooth, main cusp pointing lingually (Fig. 23b).

Maxilla: teeth arranged in single row with 25-26 conical teeth along roughly entire anteroventral margin od maxilla. Anteriormost tooth larger and with wider base than remaining maxillary teeth, anteriormost tooth on left maxilla with small lateral cusps (Fig. 24a). **Replacement:** replacement teeth formed in soft tissue associated to single shallow depression that extends along entire extension of tooth row (Fig. 24a). Replacement teeth of anteriormost functional teeth slanted about 90° in relation to their respective functional tooth, cusp pointing lingually, posteriormost teeth are slanted about 45° in relation to their respective functional tooth, cusp pointing ventroposteriorly, gradient between two conditions is observed along row (Fig. 24a).

Dentary: parasymphyseal tooth conical, smaller than medialmost tooth on main row, strongly curved lingually. Remining teeth arranged in two rows. Main row with 15-16 teeth. Three medialmost teeth larger and more robust than remaining teeth with three to five cusps (Fig. 24b), medialmost remaining teeth are tricuspid, lateralmost conical, gradient between two described conditions is observed along row (Fig. 24b). Inner row with 18-20 small conical teeth slightly curved lingually, placed on dorsal margin of lingual wall that forms bony cavity where replacement teeth of main row are formed (Fig. 24b). Medialmost tooth of inner row placed at region between fifth and sixth medialmost functional teeth of main row, inner row extends posteriorly beyond posteriormost functional tooth of main row (Fig. 24b). **Replacement:** replacement tooth of parasymphyseal tooth formed in soft tissue associated to shallow depression on lingual surface of dentary. Tooth slanted about 90° in relation to its respective functional tooth, cusp pointing lingually and slightly laterally (Fig. 24c). Replacement teeth of main row formed intraosseously in single bony cavity with single dorsal opening extending along base of main row. All replacement teeth posteriorly displaced, replacement tooth of medialmost tooth laterally slanted (Fig. 24c). Replacement teeth of inner row formed in soft tissue, slanted about 45° in relation to their respective functional tooth, cusps pointing laterally (Fig. 24c).

Replacement pattern: unilateral pattern.

***Brycon falcatus* MZUSP 38255** 112.3 mm SL

Premaxilla: same pattern described for *Brycon amazonicus* except: outer row with eight or nine tricuspid teeth, main cusp more developed than lateral ones (*vs*. outer row with 12-13 teeth, medialmost tricuspid, main cusp more developed than lateral ones, lateralmost conical in *B. amazonicus*). Middle row with four teeth, extending laterally until region between fourth and fifth medialmost functional teeth on outer row (*vs*. middle row with three teeth extending laterally until fourth medialmost tooth on outer row in *B. amazonicus*). Inner row with six teeth, four lateralmost teeth (*i. e*. inner row except two larger medialmost teeth) with three to five cusps (*vs*. inner row with eight or nine teeth, six or seven lateralmost teeth tricuspid to conical in *B. amazonicus*).

Maxilla: same pattern described for *B. amazonicus* except: single row with 25 teeth four anteriormost teeth tricuspid, main cusp more developed than lateral ones, diameter at base of tooth and at level of cusps similar, remining teeth conical (*vs*. anteriormost tooth larger than remaining maxillary teeth, tricuspid with main cusps markedly more developed than lateral ones in *B. amazonicus*).

Dentary: same pattern described for *B. amazonicus* except: main row with eight teeth (*vs*. main row with 15-16 teeth *B. amazonicus*), four medialmost teeth on main row are fairly larger and more robust than remaining dentary teeth, with four to five cusps (*vs*. three medialmost teeth larger and more robust than remaining teeth, with three to five cusps in *B. amazonicus*). Inner row with 16-18 teeth (*vs*. inner row with 18-20 teeth in *B. amazonicus*). Medialmost tooth of inner row placed at region of base of fifth medialmost functional tooth on main row, which is lateralmost tooth of group of larger teeth (*vs*. medialmost tooth of inner row placed at region between fifth and sixth medialmost functional teeth on main row in *B. amazonicus*). **Replacement:** it was not possible to examine replacement tooth of parasymphyseal tooth.

Replacement pattern: sequential unilateral pattern.

Brycon pesu **MZUSP 111757** 69.6 mm SL

Premaxilla: same pattern described for *Brycon amazonicus* except: outer row with nine or ten tricuspid teeth, lateral cusps well developed, teeth with slight constriction between region of base and level of cusps (*vs*. 12-13 teeth, medialmost tricuspid, main cusp more developed than lateral ones, lateralmost conical, gradient between two described conditions observed along row in *B. amazonicus*). Middle row with four teeth with three to five cusps, extending laterally until region of base of sixth medialmost functional tooth on outer row, no visible spacing between outer row teeth where middle row teeth are implanted (*vs*. middle row with three tricuspid teeth. Teeth restricted to region near symphysis, extending laterally until fourth medialmost functional tooth on outer row. In frontal view it is possible to identify some spacing between outer row teeth where middle row teeth are implanted in *B. amazonicus*). Inner row with six teeth, medialmost with five cusps, second medialmost with seven cusps, remaining teeth with five cusps (*vs*. Inner row with eight or nine teeth, the two medialmost larger, medialmost tooth slightly asymmetric with four cusps, the second medialmost tooth is largest on premaxilla, with five cusps. The medialmost teeth on rest of the inner row are tricuspid, while the lateralmost are conical, gradient between the two conditions is observed along the row in *B. amazonicus*). **Replacement:** replacement tooth of lateralmost tooth on middle row not clearly formed intraosseously, however, associated to well defined depression on lingual surface of premaxilla (*vs*. replacement teeth of the middle row formed intraosseously in *B. amazonicus*).

Maxilla: same patter described for *B. amazonicus* except: single row with 22 teeth, anteriormost tricuspid, lateral cusps evident, posteriormost conical, gradient between two described conditions observed along row (*vs*. teeth arranged in single row with 25-26 conical teeth. Anteriormost tooth larger and with wider base than the rest, tricuspid with main cusp markedly more developed than lateral ones in *B. amazonicus*). **Replacement:** replacement teeth of anteriormost functional teeth not lingually slanted, slightly posteriorly slanted, bony flap on lingual surface of maxilla, partially covering developing replacement teeth along roughly anterior half portion of maxilla (*vs*. replacement teeth formed in soft tissue associated to single shallow depression that extends along entire extension of tooth row. Replacement teeth of anteriormost functional teeth slanted about 90° in relation to its respective functional tooth, cusp pointing lingually, posteriormost teeth are slanted about 45° in relation to their respective functional tooth, cusp pointing ventroposteriorly, gradient between two conditions observed along row in *B. amazonicus*).

Dentary: same pattern described for *B. amazonicus* except: parasymphyseal tooth not as lingually curved, conspicuous, of similar size to medialmost teeth on main row (*vs*. parasymphyseal tooth conical smaller than medialmost tooth on main row, curved, cusp pointing lingually in *B. amazonicus*). Main row with 15 teeth, four medialmost with four or five cusps, more robust than remaining teeth on main row, medialmost tooth with four cusps, remaining medialmost teeth tricuspid, lateralmost teeth conical, gradient between two described conditions observed along row (*vs*. Main row with 15-16 teeth with three to five cusps. Three medialmost teeth larger and more robust than remaining teeth, medialmost remaining teeth are tricuspid, the lateralmost conical, gradient between two described conditions observed along row in *B. amazonicus*). Inner row with 22 markedly lingually curved conical teeth, medialmost tooth of inner row implanted at region of fifth medialmost functional tooth of the main row (*vs*. inner row with 18-20 small conical teeth slightly lingually curved medialmost tooth of inner row placed at region between fifth and sixth medialmost functional teeth on main row in *B. amazonicus*).

Replacement pattern: same pattern described for *B. amazonicus*.

Salminus brasiliensis **MZUSP 85578** 77.8 mm SL

Premaxilla: teeth arranged in two rows. Outer row with seven or eight unicuspid teeth, with distinct lateral cutting edges. Inner row with 10-12 teeth, medialmost teeth with lateral cutting edges present, but less developed than on teeth of outer row, lateralmost teeth lacking lateral cutting edges, gradient between two described conditions observed along row. Inner row somewhat disorganized. **Replacement:** replacement teeth of outer row formed intraosseously in single bony cavity, similar orientation to their respective functional tooth. Small ventral openings between bases of functional teeth. Replacement teeth of inner row formed in soft tissue, medialmost teeth slanted about 90° in relation to their respective functional tooth, cusps pointing lingually, the lateralmost teeth with similar orientation to their respective functional tooth, gradient between two described conditions observed along row.

Maxilla: teeth arranged in single row of 29-30 small teeth with lateral cutting edges, slightly curved posteriorly, extending along roughly entire anteroventral margin of maxilla. **Replacement:** replacement teeth formed in soft tissue, slightly slanted posteriorly. Bony flap on lingual surface of maxilla, partially covering developing replacement teeth along almost entire length of toothed portion of maxilla. Just six to eight posteriormost replacement teeth formed with no modifications on lingual surface of maxilla.

Dentary: teeth arranged in two rows. Main row with 21 unicuspid teeth with lateral cutting edges. Inner row composed of 40-50 small conical teeth fairly curved lingually. Teeth of inner row placed on dorsal margin of lingual wall that forms bony cavity where replacement teeth of main row are formed. Inner row extending from near symphysis to beyond lateralmost tooth of main row. Teeth placed close to each other, sometimes rendering it difficult to differentiate functional from replacement teeth. **Replacement:** replacement teeth of main row formed intraosseously in single bony cavity along base of functional teeth, some portions with individual dorsal openings, just laterolingual to their respective functional tooth, some portions with larger mediolaterally elongated openings, replacement teeth slightly slanted and displaced posteriorly. Replacement teeth of inner row formed in soft tissue slightly slanted and displaced laterally in relation to their respective functional tooth.

Replacement pattern: with no identified pattern.

Chalceidae

***Chalceus epakros* MZUSP 30754** 71.3 mm SL

Premaxilla: teeth arranged in three rows. Outer row with 10-12 tricuspid teeth with long bases, diameter at base of tooth and at level of cusps similar, slight constriction on middle portion of teeth. Medialmost teeth with three well developed cusps, lateralmost teeth with main cusp markedly more developed than lateral ones, gradient between two described conditions observed along row (Fig. 25a). Middle row with two pentacuspid teeth, their bases as long as ones on outer row teeth. The medialmost tooth just lingual to space between second and third medialmost functional teeth on outer row, lateralmost tooth on middle row just lingual to space between fourth and fifth medialmost functional teeth on outer row (Fig. 25a). Inner row with eight teeth with three to six cusps, medialmost tooth slightly asymmetrical, lateralmost teeth barely tricuspid. Cusps of four medialmost teeth arranged in curve in ventral view, concave face of teeth pointing labially (Fig. 25a). Outer and inner row extending through the entire ventral surface of premaxilla. **Replacement:** replacement teeth of outer row formed intraosseously in individual bone cavities, individual small ventral openings, just lingual to base of their respective functional tooth. Replacement teeth slanted about 90° in relation to their respective functional teeth, main cusps pointing lingually. Replacement teeth of middle row also formed intraosseously, slightly lingual to replacement teeth of the outer row. Replacement teeth slanted more than 90° in relation to their respective functional tooth, main cusps pointing dorsoposteriorly. Replacement teeth of inner row formed in soft tissue, slanted more than 90° in relation to their respective functional teeth, main cusps pointing dorsoposteriorly.

Maxilla: teeth arranged in single row of 13-15 sinuous teeth extending through roughly entire anteroventral margin of maxilla. Anteriormost teeth tricuspid, main cusp markedly more developed than lateral ones, posteriormost teeth conical, gradient between two described conditions observed along row (Fig. 25a). **Replacement:** replacement teeth formed in soft tissue associated to individual conspicuous depressions on lingual surface of maxilla.

Dentary: parasymphyseal tooth tricuspid, main cusp much more developed than lateral ones, tooth curved lingually, similar in size to medialmost tooth on main row (Fig. 25b). Remaining teeth arranged in two rows, main row with 12-14 teeth, three medialmost teeth pentacuspid, middle cusp noticeably more developed than lateral ones, medialmost remaining teeth tricuspid, lateralmost remaining teeth conical, gradient between two described conditions observed along row (Fig. 25b). Inner row with 18 small conical teeth slightly curved lingually, noticeably smaller than the conical teeth on main row. Medialmost tooth of the inner row at region of fourth medialmost tooth on main row, inner row extending laterally past lateralmost tooth on main row (Fig. 25b). Inner row teeth placed on dorsal margin of lingual bony wall that forms bony cavity in which replacement teeth of main row are formed (Fig. 25b). **Replacement:** replacement tooth of parasymphyseal tooth formed in soft tissue associated to depression on lingual surface of dentary, replacement tooth slanted 90° in relation to its respective functional tooth, main cusp pointing posterolaterally. Replacement tooth on left side with more developed lateral cusps than their respective functional tooth. Replacement teeth of the main row formed intraosseously in single bone cavity with single dorsal opening that extends along base of functional teeth. Replacement teeth slightly laterally displaced in relation to their respective functional tooth, replacement tooth of medialmost functional tooth laterally slanted in relation to its functional tooth. Replacement teeth of inner row formed in soft tissue slightly slanted and displaced laterally in relation to their respective functional tooth.

Replacement pattern: sequential unilateral pattern.

Characidae

Aphyocharacinae

***Aphyocharax* cf. *avary* MZUSP 115619** 36.1 mm SL

Premaxilla: teeth arranged in single row with seven tricuspid teeth, main cusp markedly more developed than lateral ones. Diameter at base of tooth and at level of cusps similar. **Replacement:** replacement teeth formed in soft tissue associated to individual depressions on lingual surface of premaxilla. Replacement teeth slanted about 90° in relation to their respective functional tooth, cusps pointing lingually and slightly dorsally.

Pulp cavity of functional teeth in contact with depressions where replacement teeth are formed.

Maxilla: teeth arranged in single row with 13-15 teeth extending along roughly three quarters of anteroventral margin of maxilla. Anteriormost teeth larger tricuspid, middle cusp markedly mores developed than lateral ones, posteriormost teeth conical and smaller, gradient between two described conditions observed along the row. **Replacement:** replacement teeth formed in soft tissue associated to individual depressions on lingual surface of maxilla. Depressions less evident on posterior portion of maxilla but still identifiable. Replacement teeth slanted about 90° in relation to their respective functional tooth, main cusps pointing lingually. Pulp cavity of the functional teeth in contact with the depressions in which the replacement teeth are formed.

Dentary: teeth arranged in single row divided in two groups. Medial group with eight or nine larger tricuspid teeth, diameter at base of tooth slightly larger than at level of cusps. Main cusp markedly more developed than lateral ones. Lateral group with eight or nine teeth, smaller than ones on medial group. Medialmost teeth tricuspid, lateral cusps even less developed than main cusps, lateralmost teeth conical, gradient between two described conditions observed along row. **Replacement:** replacement teeth of medial group formed in single bone cavity with individual dorsal openings just lingual to their respective functional tooth. Replacement teeth slanted about 45° in relation to their respective functional tooth, main cusp pointing dorsoposteriorly. Replacement teeth of lateral group formed in soft tissue associated to single depression on lingual surface of dentary, extending along base of lateral group base. Replacement teeth slanted in relation to their respective functional tooth, main cusps pointing laterally.

Replacement pattern: with no identified pattern

***Aphyocharax difficilis* MZUSP 27045** 59.4 mm SL

Premaxilla: same pattern described for *Aphyocharax*. cf. *avary* except: single row of nine teeth (*vs*. seven teeth in *A*. cf. *avary*).

Maxilla: same pattern described for *A*. cf. *avary* except: single row with 12-13 conical teeth (*vs*. 13-15 teeth, anteriormost tricuspid in *A*. cf. *avary*). Teeth row extending for half extension of anteroventral margin of maxilla (*vs*. three quarters of anteroventral margin of maxilla in *A*. cf. *avary*).

Dentary: same pattern described for *A*. cf. *avary* except: single row of 18-20 teeth (*vs*. 18 teeth in *A*. cf. *avary*). Medial group with 10-11 teeth (*vs*. eight or nine teeth in *A*.

cf. *avary*). Medial and lateral group divided by short edentulous region (*vs*. medial and lateral group continuous in *A*. cf. *avary*). Tricuspid teeth with main cusp more pronounced when compared to *A*. cf. *avary*.

Replacement pattern: same pattern described for *A*. cf. *avary*.

Characinae

***Charax stenopterus* MZUSP 9161** 67.8 mm SL photos, right side

Premaxilla: teeth arranged in two rows. Outer row with five conical teeth with almost no curvature, outer row not stretching along entire ventral margin of premaxilla. Inner row with nine conical teeth slightly smaller than teeth of outer row, also almost without curvature, inner row extending along entire ventral margin of premaxilla. **Replacement:** replacement teeth of outer row formed intraosseously with same orientation in relation to their respective functional tooth. Replacement teeth of inner row formed in soft tissue with similar orientation in relation to their respective functional tooth.

Maxilla: teeth arranged in single row with 40-44 small conical teeth along almost entire length of maxilla. Teeth slightly lingually curved at level of cusp, decreasing in size posteriorly. **Replacement:** replacement teeth formed in soft tissue, replacement teeth of anteriormost functional teeth slightly slanted posterolingually. The replacement teeth of posteriormost functional teeth slanted posteriorly. Gradient between two conditions observed along the row.

Dentary: teeth arranged in single row divided in two groups. Medial group with eight or nine conical teeth slightly curved lingually at level of cusp. Lateral group with 21-23 conical teeth also slightly curved lingually at level of cusp. Teeth gradually decreasing in size laterally. Teeth of lateral group slightly smaller than medial group teeth. **Replacement:** replacement teeth of medial group formed intraosseously in single bony cavity, individual dorsal openings for each developing replacement tooth, openings lingual and slightly displaced laterally in relation to their respective functional tooth. Replacement teeth with similar orientation in relation to their respective functional tooth. Replacement teeth of lateral group formed in soft tissue, slanted laterally in about 45° in relation to their respective functional tooth, cusp pointing laterally.

Replacement pattern: with no identified pattern.

***Roeboides affinis* MZUSP 34705** 63.3 mm SL

Premaxilla: teeth arranged in two groups. Four labially displaced (*i. e.* teeth displaced externally, implanted on labial surface of premaxilla) mamilliform teeth (Fig. 26a). Medialmost tooth largest, second and third medialmost teeth are similar to each other in size and smaller than remaining labial teeth, second medialmost tooth is most ventrally displaced labial tooth, third medialmost tooth is most dorsally displaced labial tooth, lateralmost labial tooth is intermediate in size between first and second and third labial teeth (Fig. 26a). Remaining premaxillary teeth also mamilliform, not arranged in straight continuous row. Eight teeth in total, all smaller than labial teeth. Medialmost tooth dorsally displaced, implanted on lingual surface of premaxilla. Second and third medialmost teeth implanted on ventral margin of premaxilla, there are no teeth on vertical through second medialmost labial tooth. Remaining teeth lateral to second medialmost labial tooth, also implanted on ventral surface of premaxilla (Fig. 26a). **Replacement:** replacement teeth of labial teeth formed intraosseously. Replacement teeth of medialmost functional tooth formed in individual bony cavity with small dorsal opening, replacement tooth of second medialmost functional teeth formed in individual bony cavity associated to conspicuous lingual opening, replacement tooth slanted about 45° in relation to its respective functional tooth, cusp pointing lingually. Replacement teeth of two lateralmost functional teeth formed in single bony cavity with small openings on its lingual wall. Replacement teeth slanted about 90° in relation to their respective functional tooth, cusp pointing laterally (Fig. 26a). Replacement teeth of smaller remaining teeth formed in soft tissue associated to shallow depressions on lingual surface of premaxilla, replacement teeth slanted about 90° in relation to their respective functional tooth, cusp pointing lingually (Fig. 26a)

Maxilla: teeth arranged in single row of nine mamilliform teeth along roughly entire anteroventral margin of maxilla (Fig. 26a). Third and fourth anteriormost teeth displaced laterally, implanted on labial surface of maxilla, both larger than remaining teeth, fourth tooth larger than third (Fig. 26a). **Replacement:** replacement teeth formed in soft tissue, associated to individual depressions on lingual surface of maxilla, size of depression is proportional to size of its respective functional tooth. Replacement teeth slanted posteroventrally in about 45° in relation to their respective functional tooth, replacement teeth not displaced, at same position as its respective functional tooth (Fig. 26a).

Dentary: teeth arranged in two groups. Two labial teeth (*i. e.* teeth displaced externally, implanted on labial surface of dentary), mamilliform and slightly larger than remaining dentary teeth. Medialmost labial tooth at region of base of second until fourth main row teeth, lateralmost labial tooth at region of base of fifth until seventh main row teeth (Fig. 26b). Main row with 13 or 14 mamilliform teeth, medialmost and seventh/eighth medialmost teeth larger than remaining main row teeth, lateralmost tooth of two larger teeth is largest on main row. Remaining teeth on main row smaller, but still mamilliform. **Replacement:** replacement teeth of labial teeth formed intraosseously, just lingual and slightly slanted lingually in relation to their respective functional tooth. Replacement teeth of two large teeth on main row formed intraosseously in individual bony cavities just ventrolingual to their respective functional tooth, small dorsal openings lingual to their respective functional tooth. Replacement teeth slanted about 45° in relation to their respective functional tooth, cusp pointing lingually. Replacement teeth of main row teeth between two larger teeth formed in soft tissue associated to bony cavities lingual to their respective functional teeth, replacement teeth slanted about 90° in relation to their respective functional tooth, cusp pointing lingually. Replacement teeth of teeth lateral to lateralmost main row large tooth formed in soft tissue associated to individual shallow depression on lingual surface of dentary, replacement teeth slanted about 90° in relation to their respective functional tooth cusp pointing laterally.

Replacement pattern: with no identified pattern.

Acestrocephalus stigmatus **MZUSP 94216** 85.0 mm SL

Premaxilla: teeth arranged in two rows. Outer row with eight or nine conical teeth, medialmost and lateralmost teeth larger than remaining teeth, all of which have similar size (Fig. 27a). Inner row with two conical teeth, similar in size and morphology to the two largest teeth on outer row, teeth pointing lingually (Fig. 27b). **Replacement:** replacement teeth of smaller teeth on outer row formed intraosseously in single bony cavity that extends through entire length of premaxilla, with no conspicuous openings, replacement teeth with similar orientation to their respective functional tooth (Fig 27b). Replacement tooth of medialmost tooth on outer row formed in soft tissue associated to large depression on lingual surface of premaxilla, slanted about 45° in relation to its respective functional tooth, cusp pointing lingually (Fig. 27b). Replacement tooth of lateralmost tooth on outer row formed in soft tissue, without any modification to underlying bone, slanted about 45° in relation to its respective functional tooth, cusp pointing laterally (Fig. 27b). Replacement teeth of inner row formed in soft tissue, slanted about 45° in relation to their respective functional tooth, cusps pointing lingually (Fig. 27b)

Maxilla: teeth arranged in single row with 42-45 small conical teeth curved posteriorly, extending along roughly the entire anteroventral margin of the maxilla (Fig 27c). **Replacement:** replacement teeth formed in soft tissue, slightly slanted posteriorly in relation to their respective functional tooth (Fig. 27c).

Dentary: teeth arranged in two rows. Main row divided in two groups, medial group with three large conical teeth. Medial- and lateralmost teeth similar in size, second medialmost smaller than remaining teeth and slightly labially displaced (Fig. 27d). Lateral group with 33-34 small conical teeth curved posteriorly. Medialmost tooth of lateral group just posterior to lateralmost tooth on medial group (Fig. 27d). Inner row with 11 small conical teeth curved lingually. Inner row extends from near symphysis until lateral margin of lateralmost tooth on medial group of main row (Fig. 27d). **Replacement:** replacement teeth of medial group of main row formed intraosseously in single bony cavity, replacement teeth slightly displaced laterally with similar orientation in relation to their respective functional tooth. Small dorsal openings just posterior to respective functional tooth present for medial- and lateralmost teeth (Fig. 27d). Replacement teeth of lateral group of main row formed in soft tissue, slightly slanted laterally (Fig. 27d). Replacement teeth of the inner row formed in soft tissue, slanted about 90° in relation to their respective functional teeth, cusp pointing lingually (Fig.27d).

Replacement pattern: with no identified pattern.

Cynopotamus xinguano **MZUSP 94196** 97.9 mm SL

Premaxilla: same pattern described for *Acestrocephalus stigmatus* except: **Replacement:** replacement teeth of larger functional teeth not observed.

Maxilla: same pattern described for *A. stigmatus* except: single row with 49-50 teeth (*vs*. single row with 42-45 teeth in *A. stigmatus*).

Dentary: same pattern described for *A. stigmatus* except: medial group of main row composed of five conical teeth, medialmost being smallest and fourth medialmost largest (*vs*. medial group of main row composed of three conical teeth in *A. stigmatus*). Lateral group of main row composed of 21-22 small conical teeth (*vs*. lateral group of main row composed of 33-34 small conical teeth in *A. stigmatus*). Inner row absent (*vs*. inner row present in *A. stigmatus*). **Replacement:** replacement tooth of fourth medialmost tooth on medial group of main row slightly slanted medially in relation to its respective functional tooth, replacement tooth of fifth medialmost tooth on medial group of main row slightly slanted laterally in relation to its respective functional tooth (*vs*. replacement teeth of medial group of main row with same orientation in relation to its respective functional tooth in *A. stigmatus*).

Replacement pattern: same pattern described for *A. stigmatus*.

Galeocharax gulo **MZUSP 27982** 103.8 mm SL

Premaxilla: same pattern described for *Acestrocephalus stigmatus* except: outer row with 11 teeth (*vs*. outer row with eight to nine teeth in *A. stigmatus*). **Replacement:** small ventral openings just lingual to small functional teeth, in some cases adjacent openings coalesce together (*vs*. small ventral openings associated to replacement teeth of small premaxillary teeth absent in *A. stigmatus*).

Maxilla: same pattern described for *A. stigmatus* except: single row of 44-45 teeth (*vs*. single row of 42-45 teeth in *A. stigmatus*).

Dentary: same pattern described for *A. stigmatus* except: medial group of main row with four large conical teeth, first to third medialmost equally spaced between each other, fourth medialmost more laterally displaced. Second medialmost tooth is smallest and slightly labially displaced, third medialmost tooth is largest, first and fourth medialmost teeth of similar size (*vs*. medial group of main row composed by three teeth in *A. stigmatus*). Lateral group of main row composed of 21-23 small conical teeth (*vs*. 33-34 teeth in *A. stigmatus*). Inner row with nine teeth, extending from near symphysis until medial margin of third medialmost tooth on medial group of main row (*vs*. inner row with 11 teeth extending from near symphysis until lateral margin of third medialmost tooth on medial group of main row in *A. stigmatus*). **Replacement:** dorsal openings associated to third and fourth medialmost functional teeth on medial group of main row (*vs*. dorsal opening associated to first and third medialmost teeth in *A. stigmatus*).

Replacement pattern: same pattern described for *A. stigmatus*.

Microschemobrycon callops **MZUSP 92953** 31.6 and 31.1 mm SL

Premaxilla: teeth arranged in single row with 11 or 12 tricuspid teeth, main cusp more developed than lateral ones, diameter at base of tooth and at level of cusps similar. Lateralmost teeth with lateral cusps less developed than lateral cusps of medialmost teeth. **Replacement:** replacement teeth formed in soft tissue, slanted about 90° in relation to their respective functional tooth, main cusp pointing lingually.

Maxilla: teeth arranged in single row of six to eight teeth restricted to anterior portion of anteroventral margin of maxilla. Anteriormost teeth tricuspid, main cusp more developed than lateral ones, diameter at base of tooth and at level of cusps similar. Posteriormost teeth conical, smaller than anteriormost teeth. Gradient between two described conditions is observed along row. **Replacement:** replacement teeth formed in soft tissue, slanted about 90° in relation to their respective functional tooth, main cusp pointing lingually.

Dentary: teeth arranged in single row divided in two groups. Medial group with ten or eleven tricuspid teeth, main cusp more developed than lateral ones, diameter at base of tooth and at level of cusps similar. Lateralmost teeth slightly smaller than medialmost teeth. Posterior group with four to six conical teeth, smaller than teeth on medial group. **Replacement:** replacement teeth of medial group formed in single bony cavity with single dorsal opening lingual to functional teeth, extending along entire row. Replacement teeth with similar orientation in relation to their respective functional tooth. Replacement teeth of lateral group formed in soft tissue, slightly slanted lingually.

Replacement pattern: with no identified pattern.

Phenacogaster tegatus **MZUSP 35889** 36.4 mm SL

Premaxilla: teeth arranged in two rows, outer row with seven teeth, three medialmost tricuspid, main cusp more developed than lateral ones. Diameter at base of tooth slightly larger than at level of cusps. Remaining teeth conical, smaller than medialmost, tricuspid teeth. Inner row with nine teeth, medialmost tooth tricuspid, main cusp more developed than lateral ones. Diameter at base of tooth slightly larger than at level of cusps, lateralmost tooth conical, smaller than medialmost teeth. Gradient between two described conditions is observed along inner row. In frontal view alternance between tricuspid teeth of outer and inner row teeth is visible. **Replacement:** replacement teeth of outer row formed intraosseously, replacement teeth slanted about 45° in relation to their respective functional tooth, cusps pointing lingually. Replacement teeth of inner row formed in soft tissue, just slightly slanted lingually.

Maxilla: teeth arranged in single row with 28-31 conical teeth along roughly 7/8 of anteroventral margin of maxilla. Teeth slightly curved lingually at level of cusp. Anteriormost teeth slightly larger than posteriormost teeth. **Replacement:** replacement teeth formed in soft tissue, replacement teeth of anteriormost functional teeth are slightly slanted posterolingually. The replacement teeth of posteriormost functional teeth slanted posteriorly. Gradient between two conditions is observed along maxilla.

Dentary: teeth arranged in single row divided in two groups. Medial group with seven tricuspid teeth, main cusp more developed than lateral ones. Diameter at base of tooth slightly larger than at level of cusps. Lateral group with eight or nine teeth, the medialmost tricuspid, morphologically similar to teeth on medial group, just smaller, remaining teeth conical, slightly curved lingually at level of cusp. Teeth decreasing in size laterally. **Replacement:** replacement teeth of medial group formed intraosseously in single bony cavity, individual dorsal openings for three medialmost teeth, openings lingual and slightly laterally displaced in relation to their respective functional tooth, single dorsal opening for four remaining replacement teeth on medial group. Replacement teeth slightly displaced laterally and slightly rotated clockwise on their main axis. Replacement teeth of lateral group formed in soft tissue associated to shallow depressions on lingual surface of dentary, replacement teeth slanted posteriorly in about 45° in relation to their respective functional tooth.

Replacement pattern: sequential unilateral pattern on maxilla and medial group of dentary. With no identified pattern on posterior group of dentary and maxilla.

General observations: teeth on premaxilla and dentary worn, cusps much less acute compared to the cusps of their respective functional teeth.

Cheirodontinae

***Odontostilbe* sp. MZUSP 4011** 37.4 and 40.9 mm SL

Premaxilla: teeth arranged in single row with five teeth labiolingually compressed at their distal portion with five to seven cusps, cusps not reaching same transversal line distally. Teeth pedicellate. **Replacement:** replacement teeth formed in soft tissue, two medialmost teeth slightly slanted in relation to their respective functional tooth, main cusp pointing lingually, remaining replacement teeth with similar orientation in relation to their respective functional tooth.

Maxilla: two teeth labiolingually compressed at their distal portion with five to seven cusps, cusps not reaching same transversal line distally teeth compressed labiolingually. Teeth pedicellate. Teeth slightly smaller than premaxillary teeth. **Replacement:** replacement teeth formed in soft tissue associated to shallow depressions on lingual surface of maxilla, slightly slanted in relation to their respective functional tooth, main cusp pointing lingually.

Dentary: teeth arranged in single row divided in tow groups. Medial group with eight teeth labiolingually compressed at their distal portion, teeth pedicellate. Teeth with four or five cusps, not reaching the same transversal line distally. Lateral group with two or three teeth with one to three cusps, diameter at base of tooth and at level of cusps similar. Teeth do not appear to be directly associated to underlying bone, area of base with tissue not stained with alizarin. **Replacement:** replacement teeth of medial group formed intraosseously in single bony cavity with individual dorsal openings, two lateralmost openings coalescing together. Replacement teeth slightly displaced laterally in relation to their respective functional tooth, Medialmost replacement teeth with similar orientation in relation to their respective functional tooth, remaining teeth slightly laterally slanted. Replacement teeth of lateral group formed in soft tissue associated to individual shallow depressions on lingual surface of dentary. One replacement tooth on right dentary on one specimen with one more cusp than its respective functional tooth, (6 cusps *vs*. 5 cusps respectively).

Replacement pattern: unilateral pattern including the maxillary teeth

Serrapinnus calliurus **MZUSP 105177** 29.7 and 29.2 mm SL

Premaxilla: teeth arranged in single row of five teeth labiolingually compressed at their distal portion with seven to nine cusps not reaching the same transversal line distally. Teeth pedicellate. Medialmost teeth with the main cusp markedly more developed than lateral ones, lateralmost teeth with cusps of similar size, gradient between two described conditions is observed along premaxilla. **Replacement:** replacement teeth formed in soft tissue, slated in about 90° in relation to their respective functional tooth, main cusp pointing lingually. Two medialmost replacement teeth slightly rotated on their main axis, labial surface slightly pointing medially.

Maxilla: two or three teeth labiolingually compressed at distal portion with six to eight cusps with similar size, cusps not reaching same transversal line distally. Teeth pedicellate. Teeth restricted to anterior portion of anteroventral margin of maxilla. **Replacement:** replacement teeth formed in soft tissue associated to single shallow depression on medial surface of maxilla. Replacement teeth slanted about 90° in relation to their respective functional tooth, main cusp pointing lingually.

Dentary: teeth arranged in single row divided in two groups. Medial group with seven or eight teeth labiolingually compressed at distal portion, teeth with five to seven cusps not reaching same transversal line distally. Teeth pedicellate. Lateral group with two teeth with one to three cusps, teeth smaller than remaining dentary teeth. **Replacement:** replacement teeth of medial group formed intraosseously in single bony cavity with single dorsal opening extending along entire base of medial group teeth. Replacement teeth slightly displaced laterally in relation to their respective functional tooth, Medialmost replacement teeth with similar orientation in relation to their respective functional tooth, remaining teeth slightly laterally slanted. Replacement teeth of lateral group formed in soft tissue with similar orientation in relation to their respective functional tooth.

<u>Replacement pattern</u>: unilateral replacement pattern.

<u>General observations</u>: on the left maxilla there is a conical tooth between the second and third anteriormost multicuspid teeth. On the same specimen, the replacement tooth of the third anteriormost tooth on the right dentary is not aligned with the remaining replacement teeth.

Exodontinae

***Exodon paradoxus* MZUSP 5165** 55.4 mm SL

<u>Premaxilla</u>: teeth divided in two groups. Three labial teeth (*i. e.* teeth displaced externally, implanted on labial surface of premaxilla), medialmost tooth mamilliform two remaining teeth conical slightly lingually curved. Remaining premaxillary teeth arranged in row of six conical teeth slightly smaller and more lingually curved than conical labial teeth, row extending along entire ventral margin of premaxilla. **Replacement:** replacement teeth of labial teeth formed intraosseously in individual bony cavities. Replacement tooth of mamilliform tooth associated to large dorsal opening, replacement tooth slanted about 45° in relation to its respective functional tooth, cusp pointing ventrally. Replacement teeth of conical labial teeth slanted about 45° in relation to their respective functional tooth, cusp pointing ventrally. Replacement teeth of remaining premaxillary teeth formed in soft tissue, slanted about 90° in relation to their respective functional tooth, cusp pointing lingually.

<u>Maxilla</u>: Teeth extending along roughly entire length of anteroventral margin of maxilla. Anteriormost tooth mamilliform, labially displaced, followed by conical tooth also labially displaced. Lingual to this conical tooth are three conical teeth curved lingually at level of cusp, these three teeth are the smallest on maxilla. Remainder of anteroventral toothed surface of maxilla with five conical teeth lingually curved at level of cusp, teeth fairly spaced between each other. **Replacement:** replacement tooth of mamilliform tooth formed in soft tissue associated to deep depression on lingual surface maxilla, replacement tooth with similar orientation in relation to its respective functional

tooth. Replacement tooth of conical functional teeth labially displaced tooth formed in soft tissue associated to deep depression on lingual surface of maxilla, opening associated to said depression on labial surface of maxilla, just posterior to its respective functional tooth, replacement tooth visible through said opening. Replacement tooth slightly slanted posteriorly in relation to its respective functional tooth. Replacement teeth of three lingually curved teeth formed in soft tissue with no clear modification to underlying bone, replacement teeth slanted about 45° in relation to their respective functional tooth, cusp pointing lingually. Replacement teeth of remaining maxillary teeth formed in soft tissue associated to depressions on lingual surface of maxilla. Small bony flap on anteroventral margin of depression partially covering developing replacement tooth forming shelf. Replacement teeth posteriorly displaced and slanted about 90°in relation to their respective functional tooth, cusp pointing ventroposteriorly. Small opening on anteroventral surface of maxilla associated to each developing replacement tooth, openings just posterior to their respective functional tooth.

Dentary: teeth arranged in two groups. Four mamilliform teeth slightly displaced labially. Medialmost mamilliform tooth near symphysis, remaining mamilliform teeth somewhat adjacent to each other, lateralmost at roughly half length of toothed portion of dentary. Second mamilliform tooth larger and more labially displaced than remaining mamilliform teeth which are of similar size among each other. Remaining dentary teeth arranged in row of 13-15 conical teeth curved lingually at level of cusp, teeth implanted on dorsal margin of dentary. **Replacement:** replacement teeth of mamilliform teeth formed in individual bony cavities with no conspicuous openings except replacement tooth of second medialmost mamilliform tooth which has dorsal opening just lateral to respective functional tooth. Replacement teeth slightly displaced laterally in relation to their respective functional tooth. Replacement tooth of medialmost and third medialmost mamilliform teeth with similar orientation in relation to their respective functional tooth, replacement tooth of second medialmost mamilliform tooth slanted about 45° in relation to its respective functional tooth, cusp pointing dorsally, replacement tooth of posteriormost mamilliform tooth slanted about 45° in relation to its respective functional tooth, cusp pointing laterally. Replacement teeth of remaining dentary teeth formed in soft tissue associated to depressions on lingual surface of dentary. Replacement teeth slightly displaced and slanted laterally in relation to their respective functional tooth.

Replacement pattern: with no identified pattern.

Stethaprioninae

***Astyanax multidens* MZUSP 117920** 39.8 mm SL

Premaxilla: teeth arranged in two rows, outer row with four tricuspid teeth, main cusp more developed than lateral ones, diameter at base of tooth and at level of cusps similar. Inner row with five teeth with four or five cusps arranged in slightly curved line in ventral view, diameter at base of tooth and at level of cusps similar, medialmost tooth asymmetrical with four cusps, only one cusp medial to main cusp. **Replacement:** replacement teeth of outer row formed intraosseously in single bony cavity, ventral openings just lingual to their respective functional tooth, replacement teeth with similar orientation in relation to their respective functional tooth. Replacement teeth of inner row formed in soft tissue, slanted about 90° in relation to their respective functional tooth, main cusp pointing lingually.

Maxilla: teeth arranged in single row of five to six teeth, five anteriormost teeth tricuspid, main cusps more developed than lateral ones, diameter at base of tooth and at level of cusps similar, posteriormost tooth conical with no clear curvature. Teeth restricted to anterior portion of anteroventral margin of maxilla. **Replacement:** replacement teeth formed in soft tissue with no conspicuous modifications to underlying bone, slanted about 90° in relation to their respective functional tooth, main cusp pointing lingually.

Dentary: teeth arranged in single row divided in two groups. Medial group with five pentacuspid teeth, main cusp more developed than lateral ones, diameter at base of tooth larger than at level of cusps. Lateralmost tooth markedly smaller than remaining teeth on row. Lateral group with seven or eight teeth, medialmost tooth tricuspid, main cusp more developed than lateral ones, diameter at base of tooth and at level of cusps similar, lateralmost tooth conical, laterally curved at level of cusp. Gradient between two described conditions observed along row. **Replacement:** replacement teeth of medial group formed intraosseously in single bony cavity, individual dorsal openings laterolingual to their respective functional tooth, two lateralmost dorsal openings coalesce together. Replacement teeth slightly displaced laterally and with similar orientation in relation to their respective functional tooth. Replacement teeth of lateral group formed in soft tissue, slightly slanted laterally, cusp pointing dorsoposteriorly.

Replacement pattern: sequential unilateral pattern on premaxilla and medial group on dentary undergoing replacement, with no identified pattern on maxilla and lateral group of dentary.

***Astyanax novae* MZUSP 97863** 52.1 mm SL

Premaxilla: same pattern described for *Astyanax multidens* except: inner row with five teeth with three to five cusps (*vs*. inner row with five teeth with four or five cusps in *A. multidens*). Cusps of inner row medialmost teeth arranged in semi-circle in ventral view (*vs*. cusps arranged in slightly curved line in ventral view in *A. multidens*). Inner row teeth with diameter at base of tooth larger than at level of cusps (*vs*. diameter at base of tooth and at level of cusps similar *A. multidens*) **Replacement:** Ventral openings associated to replacement teeth of outer row absent (*vs*. ventral openings just lingual to their respective functional tooth in *A. multidens*). Outer row replacement teeth slanted about 45° in relation to their respective functional tooth, main cusp pointing lingually (*vs*. outer row replacement teeth with similar orientation in relation to their respective functional tooth in *A. multidens*) (Fig. 28).

Maxilla: same pattern described for *A. multidens* except: single conical tooth, or single tricuspid tooth with main cusp markedly more developed than lateral ones (*vs*. teeth arranged in single row of five to six tricuspid teeth in *A. multidens*). **Replacement:** no replacement teeth were observed.

Dentary: same pattern described for *A. multidens* except: medial group with four teeth with four or five cusps. (*vs*. medial group with five pentacuspid teeth in *A. multidens*). Lateral group with four or five teeth (*vs*. lateral group with seven or eight teeth, medialmost tooth tricuspid, lateralmost tooth conical, gradient between two described conditions observed along row in *A. multidens*). **Replacement:** large foramen on lingual wall of bony cavity, ventral to developing replacement teeth (*vs*. no openings on bony lingual wall of cavity in *A. multidens*). Replacement teeth of lateral group slanted about 90° in relation to their respective functional tooth, cusp pointing laterally (*vs*. replacement teeth of lateral group slightly slanted laterally, cusp pointing dorsoposteriorly in *A. multidens*) (Fig. 29).

Replacement pattern: simultaneous unilateral pattern.

***Gymnocorymbus ternetzi* MZUSP 96717** 38.5 and 36.0 mm SL

Premaxilla: teeth arranged in two rows, outer row with four or five tricuspid teeth, main cusp more developed than lateral ones. Diameter at base of tooth and diameter at level of cusps similar. Inner row with five teeth with three to five cusps, main cusp more developed than lateral ones, cusps arranged in arched line in ventral view, concave face of teeth pointing labially. Diameter at base of tooth slightly larger than at level of cusps. Medialmost tooth asymmetrical with four cusps, only one cusp medial to main cusp. **Replacement:** replacement teeth of outer row formed intraosseously in single bony cavity, small ventral openings just lingual to their respective functional tooth present for some teeth, large openings on lingual surface of premaxilla for almost all of replacement teeth. Replacement teeth slightly slanted in relation to their respective functional tooth, main cusp pointing lingually. Replacement teeth of inner row formed in soft tissue, slightly slanted in relation to their respective functional tooth, main cusp pointing lingually.

Maxilla: one or two teeth. Anteriormost tricuspid, main cusp more developed than lateral ones, posteriormost conical slightly curved posteriorly at level of cusp, whenever there was single tooth it was tricuspid. **Replacement:** replacement teeth formed in soft tissue, slightly slanted in relation to their respective functional tooth, main cusp pointing lingually.

Dentary: teeth arranged in single row divided in two groups. Medial group with five teeth with three to five cusps, main cusp more developed than lateral ones. Diameter at base of tooth larger than diameter at level of cusps. Lateral group with eight or nine conical teeth curved laterolingually. Medialmost tooth of lateral group bicuspid in one examined specimen. **Replacement:** replacement teeth of medial group formed intraosseously in single bony cavity, replacement slightly displaced laterally, orientation similar to their respective functional tooth. Individual dorsal openings laterolingual to their respective functional tooth, two lateralmost openings coalesce together. Replacement teeth of lateral group formed in soft tissue slightly slanted laterally in relation to their respective functional tooth.

Replacement pattern: unilateral pattern on premaxilla and dentary medial group teeth, with no identified pattern on maxilla and lateral group of dentary.

***Poptella compressa* MZUSP 91879** 43.2 mm SL

Premaxilla: teeth arranged in two rows, outer row with four tricuspid teeth main cusp more developed than lateral ones, lateral cusps roughly parallel to main cusp. Diameter at base of tooth and at level of cusps similar (Fig. 30a). Inner row with five teeth with three to five cusps, medialmost teeth with main cusp markedly more developed than lateral ones. Cusps arranged in slight curve in ventral view, concave face of teeth pointing labially (Fig. 30a), medialmost tooth asymmetrical with four cusps, only one cusp medial to main cusp. **Replacement:** replacement teeth of outer row formed intraosseously, slanted about 45° in relation to their respective functional tooth, main cusp pointing lingually. Individual ventral openings just lingual to their respective functional tooth (Fig. 30b). Replacement teeth of inner row formed in soft tissue, slanted about 90° in relation to their respective functional tooth, main cusp tuned lingually (Fig 30b).

<u>Maxilla</u>: teeth arranged in single row of two teeth. Anterior tooth tricuspid, main cusp more developed than lateral ones, posterior tooth conical slightly curved posteriorly at level of cusp (Fig. 30c). **Replacement:** replacement teeth formed in soft tissue slanted about 90° in relation to their respective functional tooth, cusp pointing lingually (Fig. 30c).

<u>Dentary</u>: teeth arranged in single row divided in two groups. Medial group with four large and robust teeth with three to five cusps, main cusp markedly more developed than lateral ones, diameter at base of tooth larger than at level of cusps (Fig. 30d). Lateral group with eight to ten small conical teeth curved posteriorly at level of cusp (Fig. 30d). **Replacement:** replacement teeth of medial group formed intraosseously, single bony cavity with individual dorsal openings laterolingual to their respective functional tooth. Replacement teeth slightly displaced laterally, medialmost replacement tooth slightly slanted laterally (Fig. 30d). Replacement teeth of lateral group formed in soft tissue associated to individual shallow depressions on lingual surface of dentary, slightly slanted laterally (Fig. 30d).

<u>Replacement pattern</u>: sequential unilateral pattern on premaxilla and medial group on dentary medial group teeth, with no identified pattern on maxilla and lateral group of dentary.

Stevardiinae

Bryconamericus lethostigmus **MZUSP 41824** 40.6 and 51.2 mm SL

<u>Premaxilla</u>: teeth arranged in two rows. Outer row with three pentacuspid teeth, main cusp more developed than lateral ones, distal portion of tooth labiolingually compressed. Teeth pedicellate (Fig. 31c). Inner row with three or four teeth with five to seven cusps, main cusp more developed than lateral ones, distal portion of tooth labiolingually compressed. Teeth pedicellate (Fig. 31c). Inner and outer row teeth alternating along premaxilla. Outer and inner row are topologically indistinguishable, however functional teeth of on outer row tend to be slightly smaller and have fewer cusps when compared to functional teeth on inner row. The two rows are also distinguishable

by their replacement teeth formation mode. **Replacement:** replacement teeth of outer row formed in single bony cavity, individual openings on lingual surface of premaxilla associated to their respective functional tooth. Replacement teeth with similar orientation in relation to their respective functional tooth (Fig. 31a, b and d). Replacement teeth of inner row formed in soft tissue, slanted about 90° in relation to their respective functional tooth, main cusp pointing lingually (Fig. 31a, b and d)

Maxilla: teeth arranged in single row with six teeth with five cusps, main cusp more developed than lateral ones, distal portion of tooth labiolingually compressed. Teeth pedicellate, posteriormost teeth smaller than anteriormost teeth. Tooth row extending posteriorly past half length of maxilla (Fig. 31a, b and 32a). **Replacement:** replacement teeth formed in soft tissue associated to a single depression on lingual surface of maxilla, replacement teeth slanted about 90° in relation to their respective functional tooth (Fig. 31a ,b and 32a)

Dentary: teeth arranged in single row with 12 teeth with five or six cusps, main cusp more developed than lateral ones, distal portion of tooth labiolingually compressed. Teeth pedicellate, lateralmost tooth tricuspid, markedly smaller than remaining teeth and slightly slanted lingually. **Replacement:** replacement teeth formed in single bony cavity with individual dorsal openings, three lateralmost openings coalesce together. Replacement teeth with similar orientation in relation to their respective functional tooth, just slightly rotated anti-clockwise (Fig. 32b).

Replacement pattern: unilateral pattern including the maxillary teeth.

***Bryconamericus* sp. MZUSP 41824** 47.9 and 48.3 mm SL

Premaxilla: teeth arranged in two rows. Outer row with three or four tricuspid teeth, main cusp markedly more developed than lateral ones Teeth pedicellate, slight bulging between tooth base and level of cusps (Fig. 33a, b and c). Inner row with four tricuspid teeth, main cusp more developed than lateral ones. Teeth pedicellate, slight bulging between tooth base and level of cusps (Fig. 33a, b and c). **Replacement:** replacement teeth of outer row formed in single bony cavity with individual ventral openings associated to their respective functional tooth. Replacement teeth with similar orientation in relation to their respective functional tooth (Fig. 33a, b and c). replacement teeth of inner row formed in soft tissue, slanted about 90° in relation to their respective functional tooth.

Maxilla: single row of three or four tricuspid teeth. Main cusp more developed than lateral ones. Diameter at tooth base and at level of cusps similar. Tooth row not reaching half-length of maxilla (Fig. 34a). **Replacement:** Replacement teeth formed in soft tissue associated to single depression on lingual surface of maxilla. Replacement teeth slightly slanted posteriorly (Fig. 34a).

Dentary: teeth arranged in single row with seven or eight tricuspid teeth Diameter at base of tooth and at level of cusps similar, slight bulging between tooth base and level of cusps, more evident on two medialmost functional teeth. Lateralmost teeth smaller than remaining teeth (Fig. 34b, c and d). **Replacement:** replacement teeth formed in single bony cavity with individual dorsal openings for three medialmost functional teeth, dorsal openings lateral to these coalesce together. Replacement teeth with similar orientation in relation to their respective functional tooth (Fig. 34b, c and d).

Replacement pattern: unilateral pattern on premaxilla and dentary, with no identified pattern on maxilla.

***Mimagoniates microlepis* MZUSP 78942** 38.4 and 48.1 mm SL

Premaxilla: teeth arranged in two rows. Outer row with two or three tricuspid teeth, main cusp markedly more developed than lateral ones. Diameter at base of tooth and at level of cusps similar. Medialmost tooth on outer row between medialmost and second medialmost teeth on inner row, second medialmost tooth on outer row between second and third medialmost teeth on inner row, third medialmost tooth on outer row, when present, roughly at same position as third medialmost tooth on inner row, slightly displaced laterally (Fig. 35a and b). Inner row with six or seven tricuspid teeth, main cusps markedly more developed than lateral ones. Diameter at base of tooth and at level of cusps similar, inner row extending along entire ventral margin of premaxilla (Fig. 35a and b). **Replacement:** replacement teeth of outer row formed intraosseously in individual bony cavities, conspicuous openings on lingual wall of premaxilla, replacement teeth slightly slanted lingually in relation to their respective functional tooth (Fig. 35b). Replacement teeth of inner row formed in soft tissue associated to individual depressions on lingual surface of premaxilla, replacement teeth slanted about 90° in relation to their respective functional tooth, main cusp pointing lingually (Fig. 35b).

Maxilla: teeth arranged in single row of four or five tricuspid teeth, main cusp markedly more developed than lateral ones. Diameter at base of tooth and at level of cusps similar. Tooth row extends until roughly half-length of anteroventral margin of maxilla

(Fig. 35d). **Replacement:** replacement teeth formed in soft tissue associated to shallow depressions on lingual surface of maxilla, replacement teeth slanted about 45° in relation to their respective functional tooth, main cusp pointing posterolingually.

Dentary: teeth arranged in single row divided in two groups. Medial group with four or five tricuspid teeth, main cusp markedly more developed than lateral ones. Diameter at base of tooth larger than at level of cusps (Fig. 36a). Lateral group with seven to eleven teeth, medialmost teeth tricuspid, main cusp more developed than lateral ones, diameter at base of tooth and at level of cusps similar. Lateralmost teeth conical not curved (Fig. 36a). **Replacement:** replacement teeth of medial group formed intraosseously, single bony cavity with individual dorsal openings, laterolingually to their respective functional teeth. Replacement teeth slightly displaced and slanted laterally (Fig. 36b). Replacement teeth of lateral group formed intraosseously in single bony cavity with single dorsal opening, replacement teeth slightly slanted laterally (Fig. 36b).

Replacement pattern: sequential unilateral pattern, with no identified pattern on maxilla and lateral group on dentary.

General observations: teeth arrangement on the premaxilla can be interpreted as a single row of somewhat disorganized teeth. Taking the replacement mode into account the arrangement would be in two rows, the outer row just slightly labially displaced with two or three teeth with replacement teeth being formed intraosseously, in contrast with the inner row which replacement teeth are formed in soft tissue.

Incertae sedis

Trochilocharax ornatus 12.1 mm SL 15.3 mm SL, 15.8 mm SL female

Premaxilla: teeth arranged in single row of nine small unicuspid teeth slightly curved lingually at level of cusp. Tooth row follows outline of groove on ventral margin of premaxilla, teeth at said region are labially displaced. **Replacement:** replacement teeth formed in soft tissue with similar orientation in relation to their respective functional tooth.

Maxilla: teeth arranged in single row of ten small conical teeth slightly curved laterally at level of cusps. Row extends for roughly half-length of anteroventral margin of maxilla. **Replacement:** there are no visible replacement teeth on examined specimens.

Dentary: teeth arranged in single row divided in two groups. Medial group with nine small conical teeth slightly curved lingually at level of cusp. Conspicuous curvature on tooth row roughly at curve of dentary, teeth displaced labially, forming well defined semicircle. Lateral group with nine small conical teeth slightly curved lingually at level of cusp. Lateral group teeth implanted on dorsal margin of dentary, smaller than medial group teeth. **Replacement:** replacement teeth of medial group formed in soft tissue associated to conspicuous depression on lingual surface of dentary, replacement teeth with similar orientation in relation to their respective functional tooth (Fig.). Replacement teeth of lateral group formed in soft tissue with similar orientation in relation to their respective functional tooth.

Replacement pattern: with no identified pattern.

General observations: Mature males have more evident modifications on premaxilla and dentary teeth row outlines, resulting in more labially displaced teeth when compared to females and immature males.

Chilodontidae

***Chilodus punctaus* MZUSP 21359** 62.1 mm SL

Premaxilla: teeth arranged in single row of six unicuspid teeth, distal portion labiolingually compressed and spoon-shaped, elongated cylindrical base, diameter at base of tooth and at level of cusp similar. Teeth not directly attached to underlying bone (Fig. 37a) **Replacement:** replacement teeth formed in soft tissue with no modifications to underlying bone, replacement teeth dorsolingually displaced and with similar orientation in relation to their respective functional teeth (Fig. 37a).

Maxilla: teeth absent.

Dentary: teeth arranged in single row of six unicuspid teeth, distal portion labiolingually compressed and spoon-shaped, elongated cylindrical base, diameter at base of tooth and at level of cusp similar. Teeth not directly attached to underlying bone (Fig. 37b) **Replacement:** replacement teeth formed in soft tissue associated to a shallow groove on dorsal margin of medial region of dentary, replacement teeth ventrolingually displaced and with similar orientation in relation to their respective functional teeth (Fig.37b).

Replacement pattern: with no identified pattern.

Citharinidae

***Citharidium ansorgii* BMNH 1902.11.10.93** 58.8 mm SL

Premaxilla: teeth arranged in single row of 38 or 39 small teeth with thin elongated bases, teeth slightly sinuous, most of teeth unicuspid, some bicuspid (Fig. 38a and b).

There is no direct contact between teeth and underlying bone, (Fig. 38d and 39a). Teeth slightly mobile when manipulated. Teeth located in mediolaterally elongated bony cavity on ventral margin of premaxillae (Fig. 38c). **Replacement:** replacement teeth formed in soft tissue associated to bony cavity to which functional teeth are associated. Replacement teeth just dorsoposterior to their respective functional teeth (Fig. 38d).

Maxilla: teeth absent (Fig. 39b).

Dentary: teeth arranged in single row of 29-31 small teeth with thin elongated bases slightly sinuous, most of teeth unicuspid, some bicuspid (Fig 40a, b and c). There is no direct contact between teeth and underlying bone (Fig. 40d). Teeth slightly mobile when manipulated. Teeth located in mediolaterally elongated bony cavity on dorsoanterior margin of dentary (Fig. 40d). **Replacement:** replacement teeth formed in soft tissue associated to bony cavity to which functional teeth are associated. Replacement teeth just ventroposterior to their respective functional teeth.

Replacement pattern: with no identified pattern.

Citharinus citharu **BMNH 1904.10.25.38-43** 40.7 and 46.3 mm SL

Premaxilla: teeth arranged in single row of 31-34 labiolingually compressed bicuspid teeth, with elongated bases (Fig. 41a, b and c). There is no direct contact between teeth and underlying bone (Fig. 41b and c). Teeth slightly mobile when manipulated. Teeth located in mediolaterally elongated bony cavity that extends along entire ventral margin of premaxilla. Contralateral premaxillary cavities communicate at region of symphysis (Fig. 41a). **Replacement:** replacement teeth formed in soft tissue associated to bony cavity which the functional teeth are associated to. Replacement teeth just dorsoposterior to their respective functional teeth.

Maxilla: teeth absent (Fig. 41d).

Dentary: teeth arranged in single row of 34-37 labiolingually compressed bicuspid teeth with elongated bases. Two or three lateralmost teeth unicuspid, teeth slightly sinuous (Fig. 42a-e). There is no direct contact between teeth and underlying bone (Fig. 42e). Teeth slightly mobile when manipulated. Teeth located in mediolaterally elongated bony cavity on dorsoanterior margin of dentary. **Replacement:** replacement teeth formed in soft tissue associated to bony cavity which the functional teeth are associated to. Replacement teeth just ventroposterior to their respective functional teeth.

Replacement pattern: with no identified pattern.

Crenuchidae

Characidiinae

***Characidium* cf. *zebra* MZUSP 114369** 29.5 mm SL

Premaxilla: teeth arranged in single row of six teeth with elongated bases. Medialmost teeth tricuspid, main cusp markedly more developed than lateral ones, diameter at base of tooth slightly larger than at level of cusps, lateralmost teeth conical, slightly curved lingually at level of cusp. Gradient between two described conditions is observed along row. **Replacement:** replacement teeth formed in soft tissue with no conspicuous modifications to underlying bone, replacement teeth slightly slanted in relation to their respective functional tooth, main cusp pointing lingually.

Maxilla: teeth absent.

Dentary: teeth arranged in single row with nine or ten teeth with elongated bases. Medialmost teeth tricuspid, main cusp markedly more developed than lateral ones, diameter at base of tooth slightly larger than at level of cusps, lateralmost teeth conical, slightly curved lingually at level of cusps. Gradient between two described conditions is observed along row. Teeth gradually shorter laterally. **Replacement:** replacement teeth formed in single bony cavity with single dorsal opening extending along base of row, small ventral openings, replacement teeth with similar orientation to their respective functional tooth.

Replacement pattern: with no identified pattern.

Crenuchinae

***Crenuchus spilurus* MZUSP 69216** 33.2 mm SL

Premaxilla: teeth arranged in single row with 17 tricuspid teeth, main cusps more developed than lateral ones, diameter at base of tooth and at level of cusps similar. Two lateralmost teeth conical slightly curved lingually. **Replacement:** replacement teeth formed in soft tissue with no conspicuous modifications to underlying bone, replacement teeth slightly slanted in relation to their respective functional teeth, main cusp pointing lingually.

Maxilla: teeth absent.

Dentary: main row with 13 tricuspid teeth, main cusps slightly more developed than lateral ones, teeth slightly pedicellate. Inner row with nine conical teeth slightly curved lingually implanted on dorsal margin of lingual wall of cavity where replacement teeth of medial group are formed. Medialmost tooth on lateral group at region of second posteriormost tooth on medial row. **Replacement:** replacement teeth formed intraosseously in single bony cavity with single dorsal opening extending along base of row. Replacement teeth slightly displaced laterally with similar orientation to their respective functional tooth. Replacement teeth of inner row formed in soft tissue with no modification to underlying bone, replacement teeth with similar orientation to their respective functional tooth.

Replacement pattern: with no identified pattern.

Ctenoluciidae

***Boulengerella maculata* MZUSP 92845** 131.1 mm SL

Premaxilla: teeth arranged in single row of 114-116 small unicuspid teeth, labiolingually compressed, forming cutting edge at distal portion. Teeth strongly curved laterally, cusp overlapping with respective adjacent lateral tooth. Medialmost teeth less compressed, lateralmost teeth conspicuously smaller than remaining premaxillary teeth. **Replacement:** replacement teeth formed in soft tissue, slightly displaced laterally, replacement teeth slanted about 90° in relation to their respective functional tooth, cusp pointing laterally.

Maxilla: teeth arranged in single row of 12 or 13 unicuspid teeth extending along entire anteroventral margin of maxilla. Teeth smaller than premaxillary teeth, slightly curved posteroventrally. **Replacement:** replacement teeth formed in soft tissue associated to single shallow depression extending along the base of entire tooth row. Replacement teeth with similar orientation to their respective functional tooth.

Dentary: teeth arranged in single row of 118-120 small unicuspid teeth, labiolingually compressed, forming cutting edge at distal portion. Teeth strongly curved laterally, cusp overlapping with respective adjacent lateral tooth. Seven or eight lateralmost teeth conspicuously smaller and less curved than remaining dentary teeth. **Replacement:** replacement teeth formed in soft tissue, slightly displaced laterally, replacement teeth slanted about 90° in relation to their respective functional tooth, cusp pointing laterally.

Replacement pattern: with no identified pattern.

***Boulengerella lateristriga* MZUSP 32138** 145.4 mm SL

Premaxilla: same pattern described for *Boulengerella maculata* except: teeth arranged in single row of 130 small unicuspid teeth (*vs*. teeth arranged in single row of 114-116 small unicuspid teeth in *B. maculata*).

Maxilla: same pattern described for *B. maculata* except: teeth arranged in single row of 13-16 unicuspid teeth (*vs*. teeth arranged in single row of 12-13 unicuspid teeth in *B. maculata*).

Dentary: same pattern described for *B. maculata* except: teeth arranged in single row of 131 small unicuspid teeth (*vs*. teeth arranged in single row of 118-120 small unicuspid teeth in *B. maculata*).

Replacement pattern: same pattern described for *B. maculata*.

Curimatidae

***Steindachnerina insculpta* MZUSP 28825** 88.7 and 103.6 mm SL

Premaxilla: teeth absent.

Maxilla: teeth absent.

Dentary: teeth absent.

Cynodontidae

***Cynodon gibbus* MZUSP 89905** 103.8 mm SL

Premaxilla: teeth arranged in single row with 16-18 unicuspid teeth with no conspicuous curvature, medialmost and lateralmost teeth markedly larger than remaining teeth and with lateral cutting edges. Teeth alternating in size (Fig. 43a). **Replacement:** replacement teeth formed in soft tissue slanted about 90° in relation to their respective functional tooth, cusp pointing lingually (Fig. 43b). Replacement tooth of medialmost functional tooth more slanted than remaining teeth, cusp pointing dorsolingually.

Maxilla: teeth arranged in single row of 60 unicuspid teeth with no conspicuous curvature, teeth extending along entire anteroventral margin of maxilla. Teeth alternating in size. Larger teeth with lateral cutting edges (Fig. 43c). **Replacement:** replacement teeth formed in soft tissue. Larger teeth slanted about 90° in relation to their respective functional tooth cusp pointing ventroposteriorly, smaller teeth with similar orientation in relation to their respective functional tooth (Fig. 43c).

Dentary: teeth arranged in two rows, main row with 42-44 unicuspid teeth along roughly the entire dorsal margin of dentary. One slender unicuspid tooth on curve of dentary, markedly larger than remaining teeth, which alternate in size along entire row (fig. 43d). Larger teeth on main row slightly lingually curved and with lateral cutting edges (Fig. 44b). Inner row with two or three small unicuspid teeth strongly curved lingually. Inner row teeth implanted on dorsal margin of medial wall of bony cavity where replacement teeth of main row are formed. **Replacement:** replacement teeth of outer formed intraosseously in single shallow bone cavity with single dorsal opening extending along base of entire row, replacement teeth slanted about 90° in relation to their respective functional tooth, cusp pointing laterally. Replacement teeth of smaller functional teeth not as much slanted, closer to their respective functional tooth (Fig. 44a). Replacement teeth of inner row formed in soft tissue slanted lingually in relation to their respective functional tooth.

Replacement pattern: with no identified pattern.

***Hydrolycus tatauaia* MZUSP 99870** 118.3 mm SL

Premaxilla: same pattern described for *Cynodon gibbus* except: teeth arranged in single row with 16 unicuspid teeth (*vs*. teeth arranged in single row with 16-18 unicuspid teeth in *C. gibbus*) **Replacement:** two preformed replacement teeth for the lateralmost tooth on right premaxilla (*vs*. only one preformed replacement tooth in *C. gibbus*).

Maxilla: same pattern described for *C. gibbus* except: teeth arranged in single row of 55-59 unicuspid teeth (*vs*. teeth arranged in single row of 60 unicuspid teeth in *C. gibbus*). Teeth alternating in size only on anterior half of maxilla (*vs*. teeth alternating in size along entire anteroventral margin of maxilla).

Dentary: same pattern described for *C. gibbus* except: main row divided in two groups (*vs*. main row in single group in *C. gibbus*), medial group with 38 or 39 unicuspid teeth (*vs*. 42-44 unicuspid teeth in *C. gibbus*). Tooth on curve of dentary roughly three times the size of second largest dentary tooth (*vs*. slender unicuspid tooth on curve of dentary, markedly larger than remaining teeth, but not even two times the size of second largest dentary tooth in slender unicuspid tooth on curve of dentary, markedly larger than remaining teeth). Lateral group with 13 small conical teeth with no curvature, teeth not alternating in size (*vs* lateral group absent in *C. gibbus*). Inner row with one or two or small unicuspid teeth (*vs*. inner row with two or three small unicuspid teeth in *C. gibbus*). **Replacement:** replacement teeth of the lateral group of main row formed in soft tissue slightly slanted laterally in relation to their respective functional tooth (*vs* lateral group absent in *C. gibbus*).

Replacement pattern: same pattern described for *C. gibbus*.

***Rhaphiodon vulpinus* MZUSP 15219** 102.8 mm SL

Premaxilla: same pattern described for *Cynodon gibbus* except: teeth arranged in single row with 15-18 unicuspid teeth (*vs*. teeth arranged in single row with 16-18 unicuspid teeth in *C. gibbus*).

Maxilla: same pattern described for *C. gibbus* except: teeth arranged in single row of 48 or 49 unicuspid teeth (*vs*. teeth arranged in single row of 60 unicuspid teeth in *C. gibbus*). Teeth alternating in size only on anterior half of maxilla (*vs*. teeth alternating in size along entire anteroventral margin of maxilla).

Dentary: same pattern described for *C. gibbus* except: teeth arranged in single row (*vs*. teeth arranged in two rows in *C. gibbus*), main row divided in two groups (*vs*. main row in single group in *C. gibbus*), medial group with 24 or 25 unicuspid teeth (*vs*. 42-44 unicuspid teeth in *C. gibbus*). Tooth on curve roughly of dentary three times the size of second largest dentary tooth (*vs*. slender unicuspid tooth on curve of dentary, markedly larger than remaining teeth, but not even two times the size of second largest dentary tooth in slender unicuspid tooth on curve of dentary, markedly larger than remaining teeth). Lateral group with six or seven small conical teeth with no curvature, teeth not alternating in size (*vs* lateral group absent in *C. gibbus*). **Replacement:** replacement teeth of lateral group formed in soft tissue slightly slanted laterally in relation to their respective functional tooth (*vs* lateral group absent in *C. gibbus*).

Replacement pattern: same pattern described for *C. gibbus*.

Distichodontidae

***Ichthyborus quadrilineatus* BMNH 1912.4.1.55** 66.1* mm SL. * specimen already dissected, standard length estimated.

Premaxilla: teeth arranged in single row of 24 or 25 teeth. Medialmost tooth unicuspid larger than remaining premaxillary teeth, curved lingually (Fig. 45b). All other teeth bicuspid, medialmost teeth with the medial cusp curved ventroposteriorly, noticeably more developed than lateral cusp. Lateralmost teeth also with medial cusp more developed however not as much curved ventroposteriorly. Gradient between two conditions is observed along premaxilla. Lateral portion of premaxilla curved ventrally in a J shape (Fig. 45b). All teeth associated to underlying bone in pleurodont manner (*i. e.* teeth bases associated to lingual surface of labial bony wall forms bony cavity in which replacement teeth are formed). **Replacement:** replacement teeth formed in single bony cavity with single dorsal opening, both extending along entire ventral margin of premaxilla. Replacement teeth just dorsal to their respective functional tooth (45 a).

Maxilla: teeth absent (Fig. 45b).

Dentary: symphyseal tooth unicuspid, slightly curved lingually (Fig. 46a and b). Remaining teeth arranged in single row of 20 teeth. Medialmost tooth noticeably larger than remaining teeth, weakly bicuspid, posterior cusp as small projection on lateral margin of tooth. Other teeth bicuspid, medialmost teeth with cusp on medial margin laterally curved and noticeably larger than posterior cusp (Fig. 46b). Lateralmost teeth also bicuspid, cusp on medial margin slightly curved laterally. Gradient between two described conditions can be observed along dentary. All teeth associated to underlying bone in pleurodont manner (*i. e.* teeth bases associated to lingual surface of lateral bony wall that forms bony cavity in which replacement teeth are formed). **Replacement:** replacement teeth formed in single bony cavity with single dorsal opening, both extending along entire dorsal margin of dentary. Replacement teeth just ventral to their respective functional tooth (Fig. 46a).

Replacement pattern: with no identified pattern.

***Nannocharax* aff. *multifasciatus* BMNH 1976.3.18.2350-2352** 32.4 and 34.1 mm SL

Premaxilla: teeth arranged in single row with six teeth with cylindrical and elongated bases. Five medialmost teeth bicuspid, lateral cusp slightly larger than the medial cusp, difference in cusp size more evident on medialmost teeth (Fig. 47a). Lateralmost tooth unicuspid. Teeth gradually smaller laterally. All teeth associated to underlying bone in pleurodont manner (*i. e.* teeth bases associated to lingual surface of labial bony wall that forms bony cavity in which the replacement teeth are formed). **Replacement:** replacement teeth formed in bony cavity with single dorsal opening that extends along entire ventral margin of premaxilla, contralateral cavities communicate to each other at symphysis. Replacement teeth just dorsal to their respective functional tooth.

Maxilla: teeth absent (Fig. 47b).

Dentary: teeth arranged in single row with six teeth with cylindrical elongated bases. Five medialmost teeth bicuspid, lateral cusp slightly larger than medial cusp, difference in cusp size more evident on medialmost teeth (Fig. 48 a and b), less evident than cusp size difference observed for premaxillary teeth. Lateralmost tooth unicuspid. Teeth gradually smaller laterally. All teeth associated to underlying bone in pleurodont manner (*i. e.* teeth bases associated to lingual surface of labial bony wall that forms bony cavity in which replacement teeth are formed). **Replacement:** replacement teeth formed in a single bony cavity with single dorsal opening, both that extending along entire toothed portion of dentary, contralateral bony cavities communicate to each other at symphysis (Fig. 48 d). Replacement teeth just ventral to their respective functional tooth (Fig. 48d).

Replacement pattern: with no identified pattern.

Xenocharax spilurus **BMNH 1896.5.5.86** 66.0* mm SL. * specimen already dissected standard length estimated.

Premaxilla: teeth arranged in two rows. Outer row with 14-16 bicuspid teeth, all of similar size, cylindrical elongated base, cusps symmetrical. Inner row with 21 teeth, same morphology of outer row teeth, slightly smaller (Fig 49a, c and d). Teeth on inner row more lingually curved than outer row teeth. Inner row teeth implanted on ventral margin of lingual wall that forms bony cavity where replacement teeth of outer row are formed. Both inner and outer row extending along entire ventral margin of premaxilla. Teeth of inner and outer row not directly associated to underlying bone (Fig. 49c), slightly mobile when manipulated. **Replacement:** replacement teeth of outer row formed in single bony cavity with single ventral opening, both extending along entire ventral margin of premaxilla, ample dorsal openings present (Fig. 49b). Replacement teeth just dorsal to their respective functional tooth. Replacement teeth of inner row formed in soft tissue, just dorsal to their respective functional tooth.

Maxilla: teeth arranged in single row of seven bicuspid teeth with elongated cylindrical bases. Teeth restricted to anterior portion of anteroventral margin of maxilla (Fig. 50a). Teeth not directly associated to underlying bone, slightly mobile when manipulated. **Replacement:** replacement teeth formed in soft tissue, just dorsal to their respective functional tooth. Small bony flap is present on anterior portion of medial surface of maxilla, this bony flap covers with three anteriormost functional teeth and their respective replacement teeth (Fig. 50a).

Dentary: teeth arranged in three rows (Fig. 50c). Main row with 15 or 16 bicuspid teeth with cylindrical elongated bases. Middle row with 29 or 30 bicuspid teeth with similar morphology to main row teeth, but slightly smaller. Inner row with 27 to 30 teeth with similar size and morphology to middle row teeth. Main row extends laterally until roughly half-length of middle row (Fig. 50b). Inner row extends laterally slightly past lateral end of middle row. All teeth not directly associated to underlying bone, slightly mobile when manipulated. Teeth on inner row more lingually slanted than teeth on middle row, which are more lingually slanted than teeth on main row. Teeth on main row placed on labial bony wall of bony cavity in which replacement teeth of main row are formed. Teeth on middle row placed on labial wall that forms bony wall in which replacement teeth of middle row are formed. **Replacement:** replacement teeth of main row formed in single bony cavity with single dorsal opening, both extending posteriorly as much as functional teeth row, replacement teeth just ventral to their respective functional tooth (Fig. 50c). Replacement teeth of middle row formed in single bony cavity with single dorsal opening, both extending posteriorly as much as functional teeth row, replacement teeth just ventral to their respective functional tooth (Fig. 50c). Replacement teeth of inner row formed in soft tissue, just ventral to their respective functional tooth (Fig. 50c).

Replacement pattern: with no identified pattern.

Erythrinidae

Hoplias malabaricus **MZUSP 22111** 94.0 mm SL and **MZUSP 47718** 69.4 mm SL

Premaxilla: teeth arranged in single row with ten unicuspid teeth with no conspicuous curvature. Medialmost and third lateralmost teeth larger than remaining premaxillary teeth with clear lateral cutting-edges, remaining teeth alternating in size. **Replacement:** replacement teeth formed in soft tissue with similar orientation to their respective functional teeth, more than one preformed replacement teeth for larger premaxillary teeth.

Maxilla: teeth arranged in single row with 40-42 unicuspid teeth with no conspicuous curvature extending along roughly entire anteroventral margin of maxilla. Five anteriormost teeth alternating in size, fourth and fifth anteriormost teeth larger than remaining maxillary teeth, fifth anteriormost tooth slightly larger than fourth anteriormost tooth, both teeth with lateral cutting-edges. Remaining teeth posterior to five anteriormost teeth similar in size. **Replacement:** replacement teeth formed in soft tissue slightly displaced posteriorly and in similar orientation in relation to their respective functional tooth. Two preformed replacement teeth for fourth and fifth anteriormost teeth.

Dentary: teeth arranged in single row divided in two groups. Medial group with 16 or 17 unicuspid teeth with no conspicuous curvature alternating in size. Larger teeth with clear lateral cutting-edges, largest tooth roughly at curve of dentary. Lateral group with

15 or 16 unicuspid teeth slightly curved laterally at level of cusp. Teeth not implanted at dorsal edge of dentary, slightly displaced lingually. **Replacement:** replacement teeth of medial group formed in single bony cavity with single dorsal opening extending along entire base of medial group. Replacement teeth of medialmost functional teeth on medial group slanted medially, replacement teeth of lateralmost teeth functional teeth on medial group with similar orientation in relation to respective functional tooth. Two large ventral openings on cavity, more than one preformed replacement tooth for larger teeth on medial group. Replacement teeth of posterior group formed in soft tissue slightly displaced and slanted laterally in relation to their respective functional tooth.

Replacement pattern: with no identified pattern.

Gasteropelecidae

Carnegiella strigata **MZUSP 118760** 25.4 mm SL

Premaxilla: teeth arranged in single row with nine or ten teeth. Dimeter at base of tooth larger than at level of cusps. Five medialmost teeth tricuspid, main cusp markedly more developed than lateral ones. Remaining teeth conical with no conspicuous curvature. **Replacement:** replacement teeth formed in soft tissue slanted about 90° in relation to their respective functional tooth, cusp pointing lingually.

Maxilla: single conical tooth on anterior portion of anteroventral margin of maxilla tooth slightly curved posteriorly at level of cusp. **Replacement:** replacement tooth formed in soft tissue associated to shallow depression on lingual surface of maxilla. Replacement tooth slanted posteriorly in relation to its respective functional tooth.

Dentary: teeth arranged in single row divided in two groups. Medial group with six teeth. Dimeter at base of tooth larger than at level of cusps. Medialmost tooth conical or bicuspid, second through fourth medialmost teeth tricuspid, main cusp markedly more developed than lateral ones. Remaining teeth conical with no conspicuous curvature. Lateral group with six or seven conical teeth with no conspicuous curvature, teeth smaller than teeth on medial group. **Replacement:** replacement teeth of medial group formed in single bony cavity with individual dorsal openings slightly displaced laterally in relation to their respective functional teeth, two or three lateralmost openings coalescing together. Replacement teeth slanted about 45° in relation to their respective functional tooth, main cusp pointing lingually. Replacement teeth of lateral group formed in soft tissue, replacement teeth medialmost functional teeth associated to individual shallow depressions on lingual surface of dentary, replacement teeth of lateralmost teeth formed without any modification on underlying bone. Replacement teeth slightly slanted laterally in relation to their respective functional tooth.

Replacement pattern: unilateral pattern premaxilla and medial group of dentary, with no identified pattern on maxilla and lateral group on dentary.

Hemiodontidae

***Bivibranchia fowleri* MZUSP 97389** 77.3 mm and 44.0 mm SL

Premaxilla: One tricuspid tooth not directly associated to underlying bone, lateral cusps diverge from main cusp, all cusps reaching same transversal line distally. Diameter of tooth stem smaller than diameter at base of tooth, which is smaller than at level of cusps, cusps pointing lingually. **Replacement:** replacement teeth formed in soft tissue slanted about 45° in relation to their respective functional tooth, main cusp pointing posterodorsally.

Maxilla: teeth arranged in single row with seven tricuspid teeth not directly associated to the bone, lateral cusps diverge from main cusp, all cusps reaching same transversal line distally, diameter of tooth stem smaller than diameter at base of tooth, which is smaller than at level of cusps, cusps pointing lingually. **Replacement:** replacement teeth formed in soft tissue slanted about 45° in relation to their respective functional tooth, main cusp pointing posterodorsally.

Dentary: teeth absent.

Replacement pattern: with no identified pattern.

***Hemiodous microlepis* MZUSP 89300** 73.0 mm SL

Premaxilla: teeth arranged in single row with nine teeth with nine to twelve cusps, that do not reach the same height distally rendering fan like aspect to level of cusps (Fig. 51a). Base of teeth cylindrical, level of cusps labiolingually flattened, teeth pedicellate, slight constriction on distalmost portion of tooth base (Fig. 51a). Teeth slightly curved lingually at level of cusps resulting in spoon-like shape Teeth not directly associated to underlying bone (Fig. 51a), functional teeth mobile when manipulated. **Replacement:** replacement teeth formed in soft tissue, two or three developing replacement teeth for each functional tooth. Replacement teeth slanted about 90°, cusps pointing lingually, and slighted rotated anti-clockwise on their main axis in relation to their respective functional tooth (Fig. 51b).

Maxilla: teeth arranged in single row of nine teeth with three to nine cusps, extending along roughly entire anteroventral margin of maxilla. Anteriormost teeth morphologically identical to premaxillary teeth, cusps not reaching same transversal line distally, resulting in fan like aspect on level of cusps (Fig. 51a). Base of teeth cylindrical, level of cusps labiolingually flattened. Teeth pedicellate, slight constriction on distalmost portion of tooth base (Fig. 51a). Teeth slightly curved lingually resulting in spoon-like shape. Teeth gradually decreasing in size posteriorly, two posteriormost teeth with five and three cusps respectively, markedly smaller than remaining upper jaw teeth (Fig. 51a). Teeth not directly associated to underlying bone (Fig. 51a), functional teeth mobile when manipulated. **Replacement:** replacement teeth formed in soft tissue, one or two developing replacement teeth for each functional tooth. Replacement teeth slanted about 90°, cusps pointing lingually, and slighted rotated anti-clockwise on their main axis in relation to their respective functional tooth.

Dentary: teeth absent.

Replacement pattern: with no identified pattern.

Hepsetidae

***Hepsetus odoe* MZUSP 84869** 111.6 mm SL

Premaxilla: teeth divided in three groups. Medial group with 11 or 12 unicuspid teeth. Three medialmost and three lateralmost teeth larger than remaining premaxillary teeth, with conspicuous lateral cutting edges. Five or six smaller unicuspid teeth lingually curved at level of cusp, lateral cutting edges less evident than in larger premaxillary teeth (Fig. 52a). Lateral group with 17-19 unicuspid teeth posterolingually curved at level of cusps lateral cutting edges less evident than in larger premaxillary teeth. Teeth on posterior group slightly smaller than smaller teeth on medial group. Posterior group of teeth implanted on posterior projection of premaxilla. Inner group with 3 small conical teeth curved lingually, just lingual to medialmost tooth on medial group. **Replacement:** replacement teeth of four medialmost teeth on medial group formed in single bony cavity with individual ventral openings just lingual to their respective functional tooth, replacement teeth slanted about 90° in relation to their respective functional tooth, cusp pointing lingually. Two preformed replacement teeth for second, third and fourth medialmost teeth (Fig. 52c). Replacement teeth of remaining functional teeth on medial group formed in soft tissue, slanted about 90° in relation to their respective functional tooth. Three preformed replacement teeth for the third lateralmost functional tooth, two preformed replacement teeth for the two posteriormost functional teeth. Replacement teeth of posterior group formed in soft tissue, slanted about 90° in relation to their respective functional tooth, cusp pointing posterolingually. Replacement teeth of inner row formed in soft tissue, slanted about 90° in relation to their respective functional tooth, cusp pointing lingually.

Maxilla: teeth arranged in single row with 32-33 unicuspid teeth. Eight anteriormost teeth with lateral cutting edges and no conspicuous curvature, markedly larger than remaining maxillary teeth (Fig. 52a). Remaining teeth smaller, lateral cutting edges not as evident curved posterolabially (Fig. 52a). **Replacement:** Replacement teeth formed in soft tissue with no conspicuous modification to underlying bone. Replacement teeth of the eight larger, anteriormost teeth slanted about 90° in relation to their respective functional tooth, cusp pointing posteriorly two preformed replacement teeth for most functional teeth. Replacement teeth of remaining maxillary teeth slightly slanted posteriorly in relation to their respective functional tooth.

Dentary: teeth arranged in two rows. Main row with 28 or 29 unicuspid teeth alternating in size, larger teeth with lateral cutting edges and slightly curved lingually, remaining teeth with no conspicuous lateral cutting edges nor curvature (Fig. 52b). Inner row with 80-86 small conical teeth curved lingually, inner row extending slightly further laterally than main row. Inner row teeth implanted on dorsal margin of lingual wall of bony cavity where main row replacement teeth are formed (Fig. 52b). **Replacement:** replacement teeth of main row formed in single bony cavity with single dorsal opening extending along entire base of row (Fig 52d). Replacement teeth slanted about 90° in relation to their respective functional teeth, cusp pointing laterally. Two preformed replacement teeth for most functional teeth, specially the larger ones. Replacement teeth of inner row formed in soft tissue slightly curved posteriorly in relation to their respective functional tooth.

Replacement pattern: with no identified pattern.

Iguanodectidae

***Bryconops disruptus* MZUSP 109605** 59.3 mm SL

Premaxilla: teeth arranged in two rows, outer row with five tricuspid teeth, main cusp more developed than lateral ones, lateral cusps roughly parallel to main cusp, diameter at base of tooth and at level of cusps similar. Inner row with five teeth with five to seven cusps, main cusp more developed than lateral ones, diameter at base of tooth and at level of cusps similar. Cusps arranged in curved line in ventral view, concave face pointing labially. Medialmost tooth slightly asymmetric, cusps medial to main one smaller than ones lateral to it. **Replacement:** replacement teeth of outer row formed in single bony cavity, individual small ventral openings just ventral to their respective functional tooth, replacement teeth slanted about 45° in relation to their respective functional tooth, main cusp pointing lingually. Replacement teeth of inner row formed in soft tissue, slanted about 90° in relation to their respective functional tooth, main cusp pointing lingually.

Maxilla: teeth absent.

Dentary: teeth arranged in single row divided in two groups. Medial group with five teeth with three to seven cusps, main cusp more developed than lateral ones, diameter at base of tooth larger than diameter at level of cusps. Lateral group with five conical teeth laterolingually curved at level of cusp, teeth on lateral group markedly smaller than teeth on medial group. Medialmost tooth on lateral group bicuspid. **Replacement:** replacement teeth of medial group formed in single bony cavity with single dorsal opening extending along base of teeth of medial group, replacement teeth slightly slanted laterally. Replacement teeth of lateral group formed in soft tissue slightly slanted laterally in relation to their respective functional tooth. Replacement tooth of medialmost tooth tricuspid (*vs*. bicuspid functional tooth).

Replacement pattern: sequential unilateral pattern on premaxilla and medial group on dentary, with no identified pattern on lateral group on dentary.

***Iguanodectes geisleri* MZUSP 29616** 34.8 mm SL

Premaxilla: teeth arranged in two rows, outer row with two tricuspid teeth, main cusp more developed than lateral ones, lateral cusps roughly parallel to main cusp. Diameter at base of tooth and at level of cusps similar, medialmost tooth on outer row between medialmost and second medialmost teeth on inner row, lateralmost tooth on outer row between second and third medialmost teeth on inner row (Fig. 53a). Inner row with five teeth with seven to eight cusps main cusp more developed than lateral ones, distal portion labiolingually compressed, cusps arranged in straight line in ventral view, not reaching same transversal line distally. Diameter at level of cusps larger than at base of tooth, functional teeth slightly overlapping each other (Fig. 53a and b). **Replacement:** replacement teeth of outer row formed in single bony cavity individual ventral openings lingual to their respective functional teeth, replacement teeth slanted about 45° in relation to their respective functional tooth, main cusp pointing lingually (Fig. 53b). Replacement teeth of inner row formed in soft tissue, slanted about 90° in relation to their respective functional teeth, main cusps pointing lingually, some replacement teeth with main cusp pointing dorsoposteriorly (Fig. 53b).

Maxilla: teeth absent (Fig. 53b).

Dentary: teeth arranged in single row with five teeth with five to eight cusps, main cusps more developed than lateral ones, distal portion labiolingually compressed, cusps not reaching same transversal line distally. Teeth pedicellate (Fig. 53c). **Replacement:** replacement teeth formed in single bony cavity, single dorsal opening extending along entire region of tooth row. Replacement teeth slightly slanted and displaced laterally (Fig. 53c).

Replacement pattern: unilateral pattern.

Piabucus melanostoma **MZUSP 95080** 77.3 mm SL

Premaxilla: teeth arranged in single row with six teeth with thirteen to fifteen cusps, no clear main, more developed cusp. Distal portion of teeth labiolingually compressed, cusps arranged in straight line in ventral view, not reaching same transversal line distally. Teeth pedicellate, functional teeth slightly overlapping each other (Fig. 54a). **Replacement:** replacement teeth formed in soft tissue, slanted about 90° and slightly rotated on their main axis in relation to their respective functional tooth (Fig. 54b).

Maxilla: single row with two teeth with thirteen to fourteen cusps, no clear main, more developed cusp. Distal portion of teeth labiolingually compressed, cusps arranged in straight line in ventral view, not reaching same transversal line distally. Teeth pedicellate, functional teeth slightly overlapping each other (Fig. 54a). **Replacement:** replacement teeth formed in soft tissue, slanted about 90° and slightly rotated on their main axis in relation to their respective functional tooth (Fig. 54b).

Dentary: teeth arranged in single row with ten teeth with seven to twelve cusps, no clear main, more developed cusp. Distal portion of teeth labiolingually compressed, cusps arranged in straight line in ventral view, not reaching same transversal line distally. Teeth pedicellate, functional teeth slightly overlapping each other. Medialmost teeth with higher number of cusps, lateralmost tooth with five cusps, slanted medially (Fig. 54c). **Replacement:** replacement teeth formed in single bony cavity, single dorsal opening extending along entire region of tooth row. Replacement teeth slightly slanted and displaced laterally (Fig. 54c).

Replacement pattern: unilateral pattern including maxilla.

Lebiasinidae

Lebiasininae

***Lebiasina* sp. MZUSP 108870** 42.8 and 52.9 mm SL

Premaxilla: teeth arranged in single row of ten or eleven tricuspid teeth, main cusp more developed than lateral ones, diameter at tooth base and at level of cusps similar. Lateralmost tooth asymmetrical and bicuspid (Fig. 55a, b). **Replacement:** replacement teeth formed in soft tissue, slanted about 90° in relation to their respective functional tooth (Fig. 55c). Replacement tooth of the lateralmost tooth on left premaxilla is tricuspid

Maxilla: single row of seven teeth, anteriormost teeth tricuspid, main cusp more developed than lateral ones, diameter at tooth base and at level of cusps similar. Posteriormost teeth conical, with no clear curvature, gradient between two described conditions along maxilla. Tooth row not reaching half-length of maxilla (Fig. 55a). **Replacement:** replacement teeth formed in soft tissue with similar orientation in relation to their respective functional tooth.

Dentary: teeth arranged in two rows. Main row with 12 or 13 teeth, six or seven medialmost teeth tricuspid, main cusp more developed than lateral ones, teeth slightly pedicellate. Medialmost remaining teeth pentacuspid, main cusp more developed than lateral ones, teeth slightly pedicellate, two lateralmost teeth smaller than remaining teeth, tricuspid or conical (Fig 56a, b and c). Inner row with 28 or 29 small conical teeth curved lingually, teeth implanted on dorsal margin of lingual wall that forms bony wall in which main row replacement teeth are formed (Fig. 56c). **Replacement:** replacement teeth of main row formed in single bony cavity with single dorsal opening. Replacement teeth slightly slanted laterally in relation to their respective functional tooth (Fig. 56c). Replacement teeth of inner row formed in soft tissue slanted about 90° in relation to their respective functional tooth, cusp pointing lingually (Fig. 56c).

Replacement pattern: with no identified pattern.

Pyrrhulininae

***Nannostomus unifasciatus* MZUSP 97737** 34.1 mm SL

Premaxilla: teeth arranged in single row with six teeth with five to six cusps of similar size, not acute, Distal portion of tooth labiolingually compressed, cusps reaching same transversal line distally. Teeth pedicellate. **Replacement:** replacement teeth formed in soft tissue with similar orientation in relation to their respective functional tooth except for slight rotation in main axis.

Maxilla: one tooth with four cusps of similar size, not acute. Distal portion of tooth labiolingually compressed, cusps reaching same transversal line distally. Teeth pedicellate. **Replacement:** replacement tooth formed in soft tissue associated to shallow depression on lingual surface of maxilla, replacement tooth with similar orientation in relation to its respective functional tooth.

Dentary: teeth arranged in single row with six teeth with four to six cusps of similar size, not acute, Distal portion of tooth labiolingually compressed, cusps reaching same transversal line distally. Teeth pedicellate. **Replacement:** replacement teeth formed in single bony cavity, single dorsal opening along base of entire row, small ventral openings. Replacement teeth of two medialmost teeth slanted laterally, remaining replacement teeth with similar orientation in relation to their respective functional tooth.

Replacement pattern: with no identified pattern.

Parodontidae

Apareiodon ibitiensis **MZUSP 58429** 68.0 mm SL

Premaxilla: teeth arranged in single row of four teeth with eight to ten cusps similar in size, level of cusps labiolingually compressed, cusps not reaching same transversal line distally, cusps lingually curved resulting in spoon-shaped aspect. Bases elongated, teeth pedicellate (Fig. 57a and b). Teeth not directly associated to underlying bone, mobile when manipulated. **Replacement:** replacement teeth formed in soft tissue, four or five preformed replacement teeth for each functional tooth, rows of preformed replacement teeth separated by bony flaps. Replacement teeth slanted about 90°in relation to their respective functional tooth, main cusp pointing lingually. Replacement teeth of the two medialmost functional teeth rotated clockwise in about 90° in their main axis, replacement teeth of the two lateralmost functional teeth rotated anticlockwise in about 90° in their main axis (Fig. 57 b).

Maxilla: two teeth with six to nine cusps, similar in size, level of cusps labiolingually compressed, cusps not reaching same transversal line distally, cusps lingually curved resulting in spoon-shaped aspect. Bases elongated, teeth pedicellate. Teeth not directly associated to underlying bone, mobile when manipulated. Smaller but with similar morphology in relation to premaxillary teeth. **Replacement:** Replacement teeth formed in soft tissue associated to individual depressions on lingual surface of maxilla, replacement teeth slightly slanted lingually in relation to their respective functional tooth

Dentary: teeth absent (Fig. 57c).

Replacement pattern: with no identified pattern.

***Parodon* cf. *pongoensis* MZUSP 94916** 62.7 mm SL

Premaxilla: teeth arranged in single row of four teeth with eight to ten cusps similar in size, level of cusps labiolingually compressed, cusps reaching same transversal line distally. Bases elongated, teeth pedicellate (Fig. 58a). Teeth not directly associated to underlying bone, mobile when manipulated. **Replacement:** replacement teeth formed in soft tissue, four or five preformed replacement teeth for each functional tooth, rows of preformed replacement teeth separated by bony flaps. Replacement teeth slanted about 90°in relation to their respective functional tooth, main cusp pointing lingually. Replacement teeth of two medialmost functional teeth rotated clockwise in about 90° in their main axis, replacement teeth of two lateralmost functional teeth rotated anticlockwise in about 90° in their main axis.

Maxilla: two teeth with ten cusps, similar in size, level of cusps labiolingually compressed, cusps not reaching same transversal line distally. Bases elongated, teeth pedicellate. Teeth not directly associated to underlying bone, mobile when manipulated. Smaller but with similar morphology in relation to premaxillary teeth. **Replacement:** Replacement teeth formed in soft tissue associated to individual depressions on lingual surface of maxilla, replacement teeth slightly slanted lingually in relation to their respective functional tooth.

Dentary: two teeth displaced laterally. No marked cusps, tooth curved labially, diameter at base of tooth and at distal portion similar. Teeth not directly associated to the underlying bone, mobile when manipulated. **Replacement:** no replacement teeth were observed.

Replacement pattern: with no identified pattern.

Prochilodontidae

***Prochilodus lineatus* MZUSP 20809** 93.1 mm SL

Premaxilla: teeth arranged in two rows. Outer row with 87-94 unicuspid teeth labiolingually compressed distally, no evident cusp resulting in spoon-shape aspect, distal portion slanted medially, overlapping with adjacent teeth. Teeth pedicellate, tooth base long. Teeth embedded in soft tissue, not directly associated to underlying bone, teeth mobile when manipulated. Medialmost teeth with more evident distal portions than lateralmost teeth (Fig. 59 a). Inner row with 18 or 19 unicuspid teeth labiolingually compressed distally, no evident cusp resulting in spoon-shape aspect, teeth pedicellate, tooth base long. Teeth embedded in soft tissue, not directly associated to underlying bone, teeth mobile when manipulated. Medial portion of inner row lingually displaced, advancing labially, reaching outer row at region of 23rd medialmost tooth on outer row (Fig. 59a). **Replacement:** replacement teeth of both rows formed in soft tissue lingually displaced and with similar orientation in relation to their respective functional tooth, up to five preformed replacement teeth for each functional tooth, (four of which already identical to functional teeth), higher number of preformed replacement teeth on mid portion of outer row (Fig. 59b).

Maxilla: teeth absent.

Dentary: Main row with 77-82 unicuspid teeth labiolingually compressed distally, no evident cusp resulting in spoon-shape aspect, distal portion slanted medially, overlapping with adjacent teeth. Teeth pedicellate, tooth base long. Teeth embedded in soft tissue, not directly associated to underlying bone, teeth mobile when manipulated. Medialmost teeth with more evident distal portions than lateralmost teeth (Fig. 59a). Inner row with ten unicuspid teeth labiolingually compressed distally, no evident cusp resulting in spoon-shape aspect, teeth pedicellate, tooth base long. Teeth embedded in soft tissue, not directly associated to underlying bone, teeth mobile when manipulated. Medial portion of inner row lingually displaced, advancing labially, reaching main row at region of 12th medialmost tooth on main row (Fig. 59a). **Replacement:** replacement teeth of both rows formed in soft tissue lingually displaced and with similar orientation in relation to their respective functional tooth, up to five preformed replacement teeth for each functional tooth (four of which already identical to functional teeth), higher number of preformed replacement teeth on mid portion of main row (Fig. 59a).

Replacement pattern: with no identified pattern.

Serrasalmidae

***Catoprion mento* MZUSP 113306** 47.5 mm SL

Premaxilla: teeth arranged in single row of five unicuspid teeth with no curvature. Medialmost and third medialmost teeth conical in shape with abrupt tapering distally and acute cusp, similar to mamilliform teeth. Both teeth lingually displaced, smaller than remaining premaxillary teeth. Second, fourth and fifth medialmost teeth implanted on ventral margin of premaxilla, labiolingually compressed, with abrupt tapering distally, cusp fairly acute. Premaxillary teeth arranged in zigzag pattern (Fig. 60a). **Replacement:** replacement teeth formed in soft tissue associated to single depression along entire tooth row base, bony flap extending form lingual margin of depression partially covering developing replacement teeth from medialmost to fourth medialmost replacement teeth, forming shelf. Ventral openings on bony flap lingual to their respective functional tooth. Replacement tooth of lateralmost tooth formed in soft tissue associated to depression on lingual surface of premaxilla (Fig. 60b).

Maxilla: teeth absent.

Dentary: teeth arranged in single row of six teeth, two medialmost teeth with lateral cusps, remaining teeth unicuspid, all teeth labiolingually compressed, with abrupt tapering distally, cusp fairly acute. Teeth alternating in size, five medialmost teeth close to each other, lateralmost tooth laterally displaced (Fig. 60c and d). **Replacement:** replacement teeth formed in single bony cavity, entirely enclosed by bone with similar orientation in relation to their respective functional tooth (Fig. 60 d). Replacement tooth of lateralmost functional tooth formed in similar manner but in separate bony cavity (Fig. Fig. 60d).

Replacement pattern: with no identified pattern.

Myloplus arnoldi **MZUSP 111316** 63.5 and 73.9 mm SL

Premaxilla: teeth arranged in two rows, outer row with three unicuspid teeth labiolingually compressed distally resulting in evident cutting edges. Diameter at base of tooth and at level of cusp similar. Inner row with four distally labiolingually compressed teeth resulting in continuous cutting edge on distal margin of tooth, cutting edge U-shaped on medialmost teeth in ventral view, remaining inner row teeth with cutting edge less curved, concave face of all inner row teeth pointing labially. Second and third medialmost teeth on outer row and third and fourth medialmost teeth on inner row forming almost continuous cutting edge. **Replacement:** replacement teeth of outer row formed in soft tissue associated to depression on lingual surface of premaxilla, slightly curved lingually in relation to their respective functional teeth. Replacement teeth of inner row formed in soft tissue, slanted about 90° in relation to their respective functional tooth, cusp pointing lingually. Bony flap extending form lingual margin of depression partially covering developing replacement teeth

Maxilla: teeth absent.

Dentary: parasymphyseal tooth conical, slightly curved lingually at level of cusp and compressed mediolaterally. Remaining teeth arranged in single row divided in two groups. Medial group with three large and robust unicuspid teeth labiolingually compressed distally resulting in marked curved cutting edge, concave face of teeth pointing lingually. Lateral group with three unicuspid teeth, markedly smaller and less labiolingually compressed distally, cusp less acute, when compared to medial group teeth.

Replacement: replacement tooth of parasymphyseal tooth formed in soft tissue associated to depression on lingual surface of dentary. Replacement tooth slanted about 90° in relation to its functional tooth, cusp pointing lingually. Replacement teeth of medial group of main row formed intraosseously in single bony cavity, two small dorsal openings between each functional tooth, slightly displaced lingually and with similar orientation in relation to their respective functional tooth, and small opening on lingual surface of cavity wall. Replacement teeth slightly displaced and slanted laterally. Replacement teeth of lateral group formed in single bony cavity with single dorsal opening extending along lateral group base, replacement teeth slightly displaced and slanted laterally in relation to their respective functional tooth.

Replacement pattern: unilateral pattern.

General observation: dentaries that had gone through replacement more recently (*i. e*. replacement teeth less developed in relation to its contralateral) had higher number and more conspicuous dorsal openings associated to bony cavity where replacement teeth of medial group of dentary are formed. The dentary that had more developed replacement teeth had only one dorsal opening whereas the one that had gone through replacement more recently had two conspicuous dorsal openings. Said openings could be left from bone remodeling during the consolidation of the new dentition and not a constant conformation of the bone cavity.

***Serrasalmus elongatus* MZUSP 5613** 137.3 mm SL

Premaxilla: teeth arranged in single row with six distally labiolingually compressed teeth with clear cutting edge. Medialmost tooth with two cusps, one cusp lateral to main, more developed cusp, second and third medialmost teeth tricuspid, third medialmost tooth smallest on premaxilla. Three lateralmost teeth mediolaterally enlarged (more evident on lateralmost tooth), also tricuspid but with medial cusp less developed than other cusps, main cusp slanted laterally. All teeth close to each other interlocking visible on second, third and fourth medialmost teeth (Fig. 61a). **Replacement:** replacement teeth formed in soft tissue associated to depression on lingual surface of premaxilla. Bony flap extending from lingual margin of depression partially covering developing replacement teeth. Replacement teeth slightly slanted laterally in relation to their respective functional tooth (Fig. 61b)

Maxilla: teeth absent.

Dentary: teeth arranged in single row with seven distally labiolingually compressed teeth with clear cutting edge. Two medialmost teeth tricuspid, remaining teeth with two cusps, medial cusp more developed and laterally slanted, lateral cusp much smaller than medial cusp, its lateralmost portion fitting in socket on medial region of adjacent lateral tooth. Interlocking mechanism between all dentary teeth. Teeth gradually smaller laterally (Fig. 62a). **Replacement:** replacement teeth formed in single bony cavity, entirely enclosed by bone, replacement teeth with similar orientation and slightly displaced laterally in relation to their respective functional tooth (62b and c).

Replacement pattern: simultaneous unilateral pattern.

General patterns

Acestrorhynchidae

Acestrorhynchinae (*Acestrorhynchus microlepis* and *A. pantaneiro*)

Premaxilla: single row of small conical teeth and unicuspid teeth with lateral cutting edge and conspicuous constriction between tooth base and cusp, heterodont dentition. Replacement teeth of small conical teeth formed in soft tissue, replacement teeth of unicuspid teeth with lateral cutting edges formed in bony cavities.

Maxilla: single row of small unicuspid teeth divided in two groups. Small unicuspid teeth and unicuspid teeth with lateral cutting edges, heterodont dentition. Replacement teeth of small unicuspid teeth formed in soft tissue, replacement teeth of larger unicuspid teeth with lateral cutting edges formed in bony cavities. Toothed portion of the maxilla longer than edentulous portion.

Dentary: Inner row of small conical teeth. Main row divided in two groups, unicuspid teeth with lateral cutting edges, lateral group with small unicuspid teeth, heterodont dentition. Replacement teeth of medial group formed in bony cavities; replacement teeth of lateral group formed in soft tissue.

Replacement pattern: with no identified pattern.

Heterocharacinae (*Heterocharax virgulatus*, *Lonchogenys ilisha* and *Roestes molossus*)

Premaxilla: single row of unicuspid teeth with abruptly tapering cusps, homodont dentition. Replacement teeth formed in soft tissue except for medialmost premaxillary tooth on *Roestes molossus*.

Maxilla: single row of unicuspid teeth with abruptly tapering cusp, homodont dentition. Replacement teeth formed in soft tissue. Toothed portion of the maxilla longer than edentulous portion.

Dentary: inner row of small unicuspid teeth (absent in *H. virgulatus*). Main row divided in two groups, medial group with larger unicuspid teeth with abruptly tapering cusp, lateral group with small unicuspid teeth with abruptly tapering cusp, homodont dentition. Replacement teeth of medial group formed in bony cavity; replacement teeth of lateral group formed in soft tissue.

Replacement pattern: with no identified pattern.

Agoniatidae (*Agoniates halecinus*, *Lignobrycon myersi*, *Triportheus albus* and *Triportheus angulatus*).

Premaxilla: heterodont dentition (conical and tricuspid in *Agoniates*, tricuspid and multicuspid in *Lignobrycon* and *Triportheus*). Replacement teeth of outer (outer and middle row in *Triportheus*) row formed in bony cavity. Replacement teeth of inner row formed in soft tissue.

Dentary: heterodont dentition. Parasymphyseal tooth present in *Agoniates* and *Triportheus*.

Replacement pattern: unilateral pattern on premaxilla, parasymphyseal tooth and dentary medial group observed for *Triportheus*.

Alestidae (*Alestes baremoze*, *A. macrophthalmus*, *Brycinus sadleri*. *B. lateralis*, *B. imberi*, *Bryconalestes longipinnis*, *Hydrocynus forskahlii*, *Lepidarchus adonis*, *Micralestes acutidens*, *Phenacogrammus* cf. *interruptus*)

Premaxilla: Two rows of multicuspid teeth (single row of conical teeth in *Lepidarchus adonis* and unicuspid teeth with lateral cutting-edge in adults of *Hydrocynus forskahlii*). Outer row with tricuspid teeth (some specimens with pentacuspid teeth in *Micralestes acutidens*). Inner row teeth with molariform cusps in *Alestes*, *Brycinus* and *Bryconalestes*. Replacement teeth of outer row formed in single bony cavity (except in

Phenacogrammus). Replacement teeth of inner row formed in soft tissue. Heterodont dentition (except in *Hydrocynus* and *Lepidarchus*)

Maxilla: teeth absent

Dentary: conical parasymphyseal tooth (multicuspid in *Micralestes* and *Phenacogrammus*, absent in *Lepidarchus* and *Hydrocynus*). Single group of teeth. Replacement teeth of main row formed in single bony cavity with single dorsal opening (except in *Hydrocynus* and *Lepidarchus*). Bony cavities in which replacement tooth of main row and parasymphyseal tooth are formed coalesce together in *Brycinus*, *Bryconalestes*, *Micralestes* and *Phenacogrammus*. Heterodont dentition (except in *Lepidarchus* and *Hydrocynus*)

Replacement pattern: unilateral patter on *Alestes*, *Brycinus*, *Bryconalestes*, *Micralestes* and *Phenacogrammus*.

Anostomidae (*Abramites hypselonotus*, *Laemolyta proxima*, *Leporinus bahiensis* and *Leporinus desmotes*)

Premaxilla: Single group of distally labiolingually flattened teeth, pleurodont implantation, homodont dentition. Replacement teeth formed in soft tissue

Maxilla: teeth absent

Dentary: single group of distally labiolingually flattened teeth, pleurodont implantation, homodont dentition. Replacement teeth formed in bony cavity with single dorsal opening and ventral opening slightly smaller than dorsal one.

Replacement pattern: with no identified pattern.

Bryconidae (*Brycon amazonicus*, *Brycon falcatus*, *Brycon pesu* and *Salminus brasiliensis*).

Premaxilla: three tooth rows in *Brycon*, two in *Salminus*, heterodont dentition on both genera. Replacement teeth of outer and middle premaxillary row in *Brycon* formed in bony cavities, replacement teeth of inner row formed in soft tissue. In *Salminus* the replacement teeth of outer row are formed in bony cavities and the replacement teeth of inner row in soft tissue. *Salminus* only with unicuspid teeth, most teeth with lateral cutting edges.

Maxilla: single row of teeth, heterodont in *Brycon* and homodont in *Salminus*. Replacement teeth forms in soft tissue associated to slight modifications on underlying bone (depressions or bony flaps).

Dentary: heterodont dentition. Parasymphyseal tooth present in *Brycon* but not in *Salminus*. Two rows of teeth, inner row of small conical teeth implanted on the dorsal margin of the lingual wall that forms the bony cavity where the replacement teeth of the main row are formed. Replacement teeth of main row formed in a single bony cavity with single dorsal opening with some connections between labial and lingual walls, replacement teeth of the inner row formed in soft tissue.

Replacement pattern: with no identified pattern observed for *Salminus*. Unilateral pattern in the premaxilla and dentary of *Brycon*.

Chalceidae (*Chalceus epakros*)

Premaxilla: three tooth rows, heterodont dentition. Replacement teeth of outer and middle row formed in bony cavity.

Maxilla: heterodont dentition

Dentary: heterodont dentition. Parasymphyseal tooth tricuspid. Two rows of teeth, inner row of small conical teeth implanted on the dorsal margin of the lingual wall that forms the bony cavity where the replacement teeth of the main row are formed. Replacement teeth of main row formed in a single bony cavity with single dorsal opening, replacement teeth of the inner row formed in soft tissue.

Replacement pattern: sequential unilateral pattern.

Characidae

Aphyocharacinae (*Aphyocharax* cf. *avary* and *Aphyocharax difficilis*).

Premaxilla: Homodont dentition, single row of tricuspid teeth. Replacement teeth formed in soft tissue with some modification to underlying bone (individual depressions).

Maxilla: heterodont dentition, proportion between toothed and edentulous portions of maxilla varies. Replacement teeth formed in soft tissue with some modification to underlying bone (individual depressions).

Dentary: heterodont dentition, single row divided in two groups. Replacement teeth of medial group formed in single bony cavity with individual dorsal openings, replacement teeth of lateral group formed in soft tissue with some modification to underlying bone (single depression).

Replacement pattern: with no identified pattern.

Characinae (*Acestrocephalus stigmatus*, *Charax stenopterus*, *Cynopotamus xinguano*, *Galeocharax gulo*, *Phenacogaster tegatus*, *Microschemobrycon callops* and *Roeboides affinis*)

Premaxilla: homodont dentition (conical in *Charax*, *Acestrocephalus*, *Cynopotamus* and *Galeocharax*; mamilliform in *Roeboides* and tricuspid in *Microschemobrycon*). Two tooth rows except in *Microschemobrycon* and *Roeboides*. Replacement teeth of outer row formed in bony cavity; replacement teeth of inner row formed in soft tissue.

Maxilla: homodont dentition except in *Microschemobrycon*. Toothed portion of the maxilla longer than edentulous portion, except in *Microschemobrycon*. Replacement teeth formed in soft tissue, modification to the underlying bone only observed for *Roeboides* (individual depressions).

Dentary: great variation observed, see descriptions for details.

Replacement pattern: sequential unilateral pattern on premaxilla and dentary of *Phenacogaster,* with no identified pattern on remaining taxa.

Cheirodontinae (*Odontostilbe* sp. and *Serrapinnus calliurus*)

Premaxilla: homodont dentition, single row of multicuspid labiolingually compressed teeth, cusps not reaching the same transversal line distally, teeth pedicellate. Teeth slightly overlapping each other. Replacement teeth formed in soft tissue

Maxilla: homodont dentition, single row of multicuspid labiolingually compressed teeth, cusps not reaching the same transversal line distally, teeth pedicellate. Replacement teeth formed in soft tissue with slight modifications to underlying bone (depressions).

Dentary: heterodont dentition. Single row divided in two groups medial group with multicuspid labiolingually compressed teeth, cusps not reaching the same transversal line distally, teeth pedicellate. Lateral group with tricuspid and conical teeth. Replacement teeth of medial group formed in bony cavity with individual dorsal openings, replacement teeth of lateral group formed in soft tissue associated to slight modification to the underlying bone (depressions).

Replacement pattern: unilateral pattern.

Exodontinae (*Exodon paradoxus*)

Premaxilla: heterodont dentition (conical and mamilliform) divided in two groups, labially displaced teeth present, (see description for more details). Replacement teeth of the labially displaced teeth formed in individual bony cavities, replacement teeth of remaining premaxillary teeth formed in soft tissue.

Maxilla: heterodont dentition (conical and mamilliform), labially displaced teeth present. Replacement teeth formed in soft tissue associated to deep depression on the underlying bone

Dentary: heterodont dentition (conical and mamilliform) divided in two groups, labially displaced teeth present, (see description for more details). Replacement teeth of the labially displaced teeth formed in individual bony cavities, replacement teeth of remaining dentary teeth formed in soft tissue associated to depressions on underlying bone.

Replacement pattern: with no identified pattern.

Stethaprioninae (*Astyanax multidens*, *Astyanax novae*, *Gymnocorymbus ternetzi*, *Poptella compressa*)

Premaxilla: heterodont dentition, two rows of multicuspid teeth. Replacement teeth of outer row formed in single bony cavity, individual ventral opening associated to respective functional tooth, except in *Astyanax novae*; replacement teeth of inner row formed in soft tissue.

Maxilla: one or two teeth, except in *Astyanax multidens* (five or six teeth). Replacement teeth formed in soft tissue.

Dentary: heterodont dentition. Single row divided in two groups, medial group with multicuspid teeth, lateral group with conical teeth except in *Astyanax* (tricuspid and conical teeth). Replacement teeth of medial group formed in single bony cavity with individual dorsal opening, replacement teeth of lateral group formed in soft tissue, associated to depressions on lingual surface of dentary in *Poptella*.

Replacement pattern: unilateral pattern on premaxilla and medial group on dentary all examined taxa.

Stevardiinae (*Bryconamericus lethostigmus*, *Bryconops* sp. and *Mimagoniates* cf. *microlepis*)

Premaxilla: homodont dentition, two rows of tricuspid teeth, pentacuspid in *Bryconamericus lethostigmus*. Replacement teeth of outer row formed in individual bony cavities; replacement teeth of inner row formed in soft tissue.

Maxilla: homodont dentition, single row of tricuspid teeth, pentacuspid in *Bryconamericus lethostigmus* replacement teeth formed in soft tissue.

Dentary: Replacement teeth of medial group formed in a single bony cavity with individual dorsal openings.

Replacement pattern: unilateral pattern on premaxilla and medial group on dentary all examined taxa.

Incertae sedis (*Trochilocharax ornatus*)

Homodont conical dentition, labially displaced teeth on premaxilla and dentary see description for more details.

Chilodontidae (*Chilodus punctatus*)

Premaxilla: homodont dentition, single row of unicuspid teeth labiolingually flattened distally embedded in soft tissue not directly associated to the underlying bone.

Maxilla: teeth absent.

Dentary: homodont dentition, single row of unicuspid teeth embedded in soft tissue not directly associated to the underlying bone.

Replacement pattern: with no identified pattern.

Citharinidae (*Citharidium ansorgii* and *Citharinus citharu*)

Premaxilla: single row of bicuspid teeth (also unicuspid teeth in *Citharidium*) not directly associated to the underlying bone, associated to a bony cavity that runs along entire ventral margin of premaxilla. Replacement teeth formed in soft tissue associated to bony cavity.

Maxilla: teeth absent.

Dentary: single row of bicuspid teeth (also unicuspid teeth in *Citharidium ansorgii*) not directly associated to the underlying bone, associated to a bony cavity that runs along entire ventral margin of premaxilla. Replacement teeth formed in soft tissue associated to bony cavity.

Replacement pattern: with no identified pattern.

Crenuchidae (*Crenuchus spilurus* and *Characidium* cf. *zebra***)**

Premaxilla: heterodont dentition, single row of tricuspid and conical teeth. Replacement teeth formed in soft tissue.

Maxilla: teeth absent.

Dentary: heterodont dentition. Single row with tricuspid and conical teeth, inner row of small conical teeth in *Crenuchus*. Replacement teeth formed in single bony cavity with single dorsal opening, replacement teeth of inner row in *Crenuchus* formed in soft tissue.

Replacement pattern: with no identified pattern.

Ctenoluciidae (*Boulengerella lateristriga* and *Boulengerella maculata*)

Unicuspid teeth laterally curved, cusps overlapping adjacent lateral tooth. Replacement teeth formed in soft tissue, for details see description.

Replacement pattern: with no identified pattern.

Curimatidae (*Steindachnerina insculpta*)

Teeth absent in adults

Cynodontidae (*Cynodon gibbus*, *Hydrolycus tatauaia* and *Raphiodon vulpinus*)

Premaxilla: heterodont dentition, single row with conical and unicuspid with lateral cutting-edge teeth. Replacement teeth formed in soft tissue.

Maxilla: heterodont dentition, single row with conical and unicuspid with lateral cutting-edge teeth. Toothed portion of the maxilla longer than edentulous portion. Replacement teeth formed in soft tissue.

Dentary: heterodont dentition, single row with conical and unicuspid with lateral cutting-edge teeth, row divided in two groups in *Hydrolycus* and *Rhaphiodon* lateral group with small conical teeth. Inner row of small conical teeth in *Cynodon* and *Hydrolycus*. Replacement teeth of medial group formed in single bony cavity with single dorsal opening.

Replacement pattern: with no identified pattern.

Distichodontidae (*Nannocharax* cf. *multifasciatus*, *Ichthyborus quadrilineatus* and *Xenocharax spilurus*)

Bicuspid teeth, maxillary teeth present only in *Xenocharax spilurus*. No synchronization on the replacement was observed.

Erythrinidae (*Hoplias malabaricus*)

Premaxilla: heterodont dentition, single row of conical and unicuspid with lateral cutting-edges teeth. Replacement teeth formed in soft tissue, more than one preformed replacement tooth for some functional teeth.

Maxilla: heterodont dentition, single row of conical and unicuspid with lateral cutting-edges teeth. Replacement teeth formed in soft tissue, more than one preformed replacement tooth for some functional teeth.

Dentary: heterodont dentition. Single row with conical and unicuspid with lateral cutting-edge teeth divided in two groups. Replacement teeth of medial group formed in single bony cavity with a single dorsal opening, ample ventral openings on the cavity. Replacement teeth of lateral group formed in soft tissue.

Replacement pattern: with no identified pattern.

Gasteropelecidae (*Carnegiella strigata*)

Premaxilla: heterodont dentition. Single row with tricuspid and conical teeth. Replacement teeth formed in soft tissue.

Maxilla: single conical tooth, replacement tooth formed in soft tissue associated to shallow depression

Dentary: heterodont dentition, tricuspid and conical teeth. Unicuspid teeth medial to tricuspid teeth on medial group, lateral group with conical teeth. Replacement teeth of medial group formed in a single bony cavity with individual dorsal openings, replacement teeth of the lateral group formed in soft tissue associated to shallow depressions on the bone.

Replacement pattern: unilateral pattern on premaxilla and medial group of dentary.

Hemiodontidae (*Bivibranchia fowleri* and *Hemiodus microlepis*)

Premaxilla: homodont dentition, tricuspid in *Bivibranchia*, multicuspid in *Hemiodus*. Teeth not directly associated to underlying bone, embedded in soft tissue. Replacement teeth formed in soft tissue. Several preformed replacement teeth in *Hemiodus*.

Maxilla: homodont dentition, tricuspid in *Bivibranchia*, multicuspid in *Hemiodus*. Teeth not directly associated to underlying bone, embedded in soft tissue. Replacement teeth formed in soft tissue. Several preformed replacement teeth in *Hemiodus*.

Dentary: teeth absent.

Replacement pattern: with no identified pattern.

Hepsetidae (*Hepsetus odoe*)

Premaxilla: heterodont dentition, conical and unicuspid with lateral cutting-edges. Replacement teeth formed both in bony cavities and soft tissue, more than one preformed replacement teeth for some premaxillary teeth

Maxilla: heterodont dentition, conical and unicuspid with lateral cutting-edges. Replacement teeth formed in soft tissue

Dentary: heterodont dentition. Two tooth rows, main row with conical and unicuspid with lateral cutting-edges, inner row with small conical teeth implanted on the dorsal margin of the lingual wall that forms the bony cavity where the replacement teeth of the main row are formed. Replacement teeth of the main row formed in a single bony cavity with a single dorsal opening, two preformed replacement teeth for some main row teeth; replacement teeth of the inner row formed in soft tissue

Replacement pattern: with no identified pattern.

Iguanodectidae (*Bryconops disruptus*, *Iguanodectes geisleri* and *Piabucus melanostoma*)

Premaxilla: Outer row with tricuspid teeth in *Bryconops* and *Iguanodectes*, inner row with multicuspid teeth, slightly overlapping in *Iguanodectes* and *Piabucus*. Replacement teeth of outer row formed in a single bony cavity with ventral opening associated to their respective functional teeth, replacement teeth of the inner row formed in soft tissue.

Maxilla: teeth present only in *Piabucus*.

Dentary: replacement teeth formed in single bony cavity with a single dorsal opening.

Replacement pattern: unilateral pattern on premaxilla and medial group of dentary.

Lebiasinidae (*Lebiasina* sp., and *Nannostomus unifasciatus*)

Premaxilla: homodont dentition, single tooth row. Replacement teeth formed in soft tissue

Dentary: Replacement teeth of main row formed in a single bony cavity with a single dorsal opening.

Replacement pattern: with no identified pattern.

Parodontidae (*Apareiodon ibitiensis* and *Parodon* cf. *pongoensis*)

Premaxilla: homodont dentition, single row of multicuspid teeth with long bases, teeth pedicellate. Teeth not directly associated to underlying bone. Replacement teeth formed in soft tissue, up to five preformed replacement teeth

Maxilla: homodont dentition, teeth similar to premaxillary teeth. Replacement teeth formed in soft tissue associated to shallow depressions on the bone.

Dentary: teeth absent in *Apareiodon*, present on lateral portion of dentary in *Parodon*.

Replacement pattern: with no identified pattern.

Prochilodontidae (*Prochilodus lineatus*)

Premaxilla: homodont dentition, two rows of unicuspid teeth not directly associated to the underlying bone, embedded in soft tissue. Replacement teeth formed in soft tissue, up to five preformed replacement teeth.

Maxilla: teeth absent.

Dentary: homodont dentition, two rows of unicuspid teeth not directly associated to the underlying bone, embedded in soft tissue. Replacement teeth formed in soft tissue, up to five preformed replacement teeth.

Replacement pattern: with no identified pattern.

Serrasalmidae (*Serrasalmus elongatus*, *Myloplus arnoldi*, *Catoprion mento*)

Interaction among adjacent teeth observed in *Serrasalmus* and *Myloplus*.

Replacement pattern: unilateral pattern in *Serrasalmus* and *Myloplus*.

Characters

The characters listed herein are a combination of previously proposed characters previously proposed characters that were modified or reinterpreted in some way in order to be adequate to the variation observed in this study (32/59) and original characters (27/59). Characters encompass tooth morphology, number and arrangement on each bone; teeth implantation mode and position; replacement teeth formation mode, replacement and orientation; morphology of the bone cavitied in which the replacement teeth are formed and the chronological patter of the replacement. Characters are divided in quantitative and qualitative; the two quantitative characters are presented first and are counts of teeth on the outer row of the premaxilla and on the maxilla. Qualitative characters are divided under generalities (characters 2 - 12), premaxilla (characters 13 - 36), maxilla (characters 28 - 37) and dentary (characters 38 - 58). Most original characters proposed herein are related to aspects of the replacement, including the replacement teeth formation mode, morphology of the cavities in which the replacement teeth are formed and the chronological patterns of the replacement.

Quantitative characters

0. Number of teeth on outer row of premaxilla: (2-39). (Zanata & Vari, 2005: 34, character 59). (CI = 0,327; RI = 0.420)

The number of teeth on the outer row of the premaxilla on the examined taxa ranged from two to thirteen teeth. Zanata & Vari (2005: 34; character 59) also used the number of teeth on the outer row of the premaxilla as a character. The authors treated the number of teeth on the premaxillary outer row as a qualitative character with five states (0 six or more; 1 five; 2 four; 3 three; 4 two). As mentioned above the variation observed herein is higher, thus we opted to treat the number of teeth on the outer row of the premaxilla as a quantitative character. The number of teeth on premaxillary outer row varies from two teeth in *Iguanodectes geisleri* (Fig. 53a) and *Phenacogrammus interruptus* up to 39 in *Citharidium ansorgii* (Fig. 38a). This character was coded as inapplicable for taxa with only one premaxillary tooth row, since the single row of premaxillary teeth in those taxa was herein considered as homologous to the inner row in the premaxilla of taxa with two or three rows of premaxillary teeth within Characoidei.

1. Number of maxillary teeth: (1-60). (Mirande, 2010: 424, characters 1135 and 136). (CI = 0.181; RI = 0.607)

The examined taxa showed a wide variation on the total number of maxillary teeth, ranging from a single tooth up to 60 teeth. Mirande (2010: 424, characters 135 and 136) also used the number of maxillary teeth as a character, the author treated these characters as a qualitative, both with two states (0 only one or absent; two or more for character 135 and 0 up to three; 1 four or more for character 136). The author argued that any definition of discrete character states would have some level of subjectivity. However, the author justified his choice to threat the character as qualitative since: (i) the number of maxillary teeth was not normally distributed across his group of interest and few taxa had more than ten teeth; (ii) the intraspecific variation on the number of maxillary teeth is lower in species with low number of maxillary teeth when compared to species with high number of maxillary teeth; (iii) the option of analyzing the number of maxillary as a quantitative character would overestimate the phylogenetic information of the transformation in groups of higher and variable number of maxillary teeth. The observed variation herein was high (1-60) and the number of lineages with high number of maxillary teeth is higher in Characiformes than in Characidae, group of interest of Mirande (2010), we opted to treat the number of maxillary teeth as a quantitative character to understand the distribution of this character across the different lineages of the order. The number of teeth on premaxillary outer row varies from a single tooth in taxa such as *Astyanax novae*, *Carnegiella strigata* and *Nannostomus unifasciatus* up to 59 in *Hydrolycus tatauaia* and 60 in *Cynodon gibbus*. This character was coded as inapplicable for taxa lacking maxillary teeth, in taxa with intraspecific variation the highest value was used.

General characters

2. Morphology of premaxillary, maxillary and dentary teeth: (0) all teeth unicuspid; (1) one or more multicuspid teeth. (Zanata & Vari, 2005: 27, character 49; Mirande 2010: 419, character 118). (CI = 0.200, RI = 0.840)

The term unicuspid teeth of state 0 comprises the following morphologies: conical, unicuspid with lateral cutting-edges, unicuspid teeth with abruptly tapering cusp, unicuspid teeth labiolingually flattened distally and mamilliform. State 1 encompasses bicuspid teeth, multicuspid teeth with conical base, multicuspid teeth with additional cusps on concave face, multicuspid teeth labiolingually flattened distally and multicuspid teeth with lateral cutting-edge.

3. Number of cusps on multicuspid teeth: (0) two cusps, (1) three or more cusps. (CI = 1.000, RI = 1.000)

Within taxa with multicuspid teeth, two morphologies were observed. Bicuspid teeth (state 0) that result from the presence of a clear notch in the midline of the tooth, the cusps with similar size as in *Xenocharax spilurus* (Fig. 49 and 50) or asymmetric as in *Ichthyborus quadrilineatus* (Fig. 45 and 46). The alternative condition is a multicuspid tooth with at least three cusps (state 1) as in *Poptella compressa*, the number and relative size of the cusps is variable. Bicuspid teeth are restricted to the Citharinidae and Distichodontidae.

4. Relative size of cusps of multicuspid teeth with three or more cusps: (0) with one distinct cusp, larger than remaining cusps, (1) all cusps of similar size. (CI = 0.333, RI = 0.500)

Within examined taxa with multicuspid teeth two conditions regarding the relative size of the cusps were observed. In taxa such as *Alestes baremoze* the multicuspid teeth have a distinct cusp larger than the remaining cusps (state 0, Fig. 10 and 11). The alternative condition is a multicuspid tooth with all cusps of similar size as in *Parodon pongoensis* (state 1, Fig. 58) The only taxa with teeth with all cusps of similar size were *Laemolyta proxima*, *Parodon pongoensis*, *Hemiodus microlepis*, *Nannostomus unifasciatus* and *Piabucus melanostoma*.

5. Cusp arrangement on multicuspid teeth: (0) cusps not reaching same transversal line distally; (1) cusps reaching same transversal line distally. (CI = 0.333; RI = 0.600)

In the most common arrangement of the cusps of multicuspid teeth, the cusps have different sizes and diverge distally from each other (state 0 Figs. 28, 29). An alternative condition was observed in which cusps have roughly the same size and are somewhat parallel to each other, reaching the same line transversal to main axis of tooth distally (state 1 Fig. 58). Examined taxa that had at least one tooth as described for state 1 on the jaws are *Laemolyta proxima*, *Nannostomus unifasciatus* and *Parodon* cf. *pongoensis* (Fig. 58). Although in *Hemiodus microlepis*, there are not a distinctly developed cusp in the midline of the tooth, they arranged in a fan aspect, not reaching the same transversal line distally, therefore this character was coded as 0 for this species.

6. Constriction on distal region of unicuspid teeth resulting in an abrupt taper: (0) absent; (1) present. (CI = 1.000; RI = 1.000)

Unicuspid teeth with a constriction at the distal portion resulting in an abruptly tapering cusp (Figs. 4 and 5) were observed in some taxa. This abrupt taper towards the cusp of the tooth results in a distinct unicuspid tooth morphology different from conical teeth (Fig. 6). This characteristic tooth morphology is restricted to the members of the Heterocharacinae (sensu Mattox & Toledo-Piza, 2012).

7. Unicuspid teeth with lateral cutting edges: (0) absent; (1) present. (CI = 1.000; RI = 1.000)

Some taxa showed discrete flattening on the lateral surfaces of unicuspid teeth configuring lateral cutting edges. In *Acestrorhynchus* the cutting-edges project laterally in a conspicuous manner, altering the profile of the teeth, that is arrowhead shaped in this taxon (Fig 1.). In *Hoplias malabaricus, Hepsetus odoe* and *Cynodon gibbus* the cutting edges are not as much projected laterally, not altering the triangular profile of the tooth (Figs. 44, 52). In the taxa mentioned above the lateral cutting-edge runs along more than half of the length of the tooth, whereas in *Salminus brasiliensis* the lateral cutting-edge is restricted to the distal portion of the tooth, not extending beyond half-way of the length of the tooth.

8. Tooth attachment position: (0) acrodont; (1) pleurodont. (Vari: 1979: 277). (CI = 0.500; RI = 0.800)

Most characiforms have their teeth implanted in an acrodont manner on the underlying margin of the bone margin (state 0) (that is, on the ventral margin of the premaxilla, anteroventral margin of the maxilla and dorsal margin of the dentary, Figs. 10, 11). A less common condition is the pleurodont association of the teeth to the underlying bone, in which the base of the tooth is attached on the lingual surface of the premaxilla and dentary (state 1, Figs. 21, 22). Pleurodont implantation was reported for *Leporinus obtusidens* (Trapani, 2001) and for the Distichodontidae except *Xenocharax*, *Neolebias* and *Nannaethiops* (Vari, 1979). Among the examined taxa pleurodont implantation was observed in *Abramites hypselonotus*, *Laemolyta proxima*, *Leporinus bahiensis*, *Leporinus desmotes*, *Nannocharax multifasciatus* (Figs. 47, 48) and *Ichthyborus quadrilineatus* (Figs. 45, 46). The most common condition among the examined taxa is the acrodont dentition.

9. Arrangement of adjacent teeth within a tooth group: (0) without any overlap among adjacent teeth; (1) adjacent teeth overlapping without morphological alterations on the overlapping teeth; (2) overlapping teeth with morphological modifications resulting in an interlocking mechanism among them. (Zanata & Vari, 2005: 28, character 51; Mirande, 2010: 425, character 145). (CI = 0.250, RI = 0.647)

The most common condition for taxa with overlapping adjacent teeth is a mere overlapping of the distal portions of adjacent teeth without any morphological modifications to maintains that arrangement between them (state 0, Fig. 51). A more elaborated interaction between adjacent teeth allied to morphological variations that keep the strict contact among adjacent teeth (state 1, Fig. 62). Mirande (2010: 425, character 145) and Machado-Allison (1983) stated that in some members of the Serrasalmidae the dentary teeth articulate to each other. In the present study the interlocking among adjacent teeth is considered for premaxillary and dentary dentition. According to Kolmann *et al*. (2019) all serrasalmids interlock or buttress their teeth with some variation among them. Interlocking (state 1) was observed in *Serrasalmus elongatus* both on the dentary and on the premaxilla in a more evident manner in the dentary. The teeth interlock with a peg-and-socket system, in which the medialmost cusp of a tooth fits on a depression on the lateral margin of the medially adjacent tooth (Fig. 62). In *Myloplus arnoldi* the dentary teeth tightly overlap among each other, the medialmost margin of the tooth lingual to the lateralmost margin of the medially adjacent tooth, this interlocking mechanism was observed for *Myloplus shomburgkii* and defined as "buttress" by Kolmann *et al*. (2019). These two serrasalmid were coded as state 2. No interlocking nor overlapping among adjacent teeth was observed in *Catoprion mento*. Overlapping premaxillary teeth without any interlocking system (state 0) was observed for the multicuspid teeth of *Odontostilbe*, *Serrapinnus, Hemiodus* (Fig. 51), *Iguanodectes* (Fig. 53), *Nannostomus, Parodon* (Fig. 58) and *Apareiodon* (Fig. 57). In *Prochilodus* there is a great overlap at the distal portion of its unicuspid teeth due to the medial curvature on the distal portion of each tooth (Fig. 59). In *Ichthyborus quadrilineatus* the teeth slightly overlap, the medialmost portion of the tooth fits in the space between the two laterally curved cusp of the medially adjacent tooth (Figs. 45, 46). In *Boulengerella* the laterally curved cusp overlaps the laterally adjacent tooth both on premaxilla and dentary. This character was coded as inapplicable for taxa.

10. Ontogenetic shift from multicuspid to unicuspid teeth in premaxilla and dentary: (0) absent; (1) present. (Zanata & Vari, 2005: 28, character 50). (CI = 1.000; RI = 0)

Brewster (1986) and Zanata & Vari (2005, character 50) defined the character as a modification from tricuspid to unicuspid teeth in *Hydrocynus*. This shift was also observed in this study, however the specimens of *Hydrocynus forskahlii* examined had multicuspid teeth with up to five cusps, diverging from the tricuspid teeth observed by Brewster (1986) and Zanata & Vari (2005). No other examined taxa had such shift in tooth morphology. The mentioned authors restricted the examined area of interest to the anterior portion of the jaw, however, in the largest specimen of *Hydrocynus forskahlii* examined (50.9 mm SL) the shift from multicuspid to unicuspid teeth was observed on the premaxilla and dentary. The described condition is restricted to *Hydrocynus forskahlii* among the examined taxa.

11. Mamilliform teeth outside the mouth in adults: (0) absent; (1) present. (Mirande, 2010: 491, character 120; Mattox & Toledo-Piza, 2012: 847, character 69). (CI = 1.000; RI = 1.000)

Mamilliform teeth are a somewhat conical tooth but with the profile bell-shaped rather than triangular. This tooth morphology was observed in *Roeboides affinis* (Fig. 26), *Exodon paradoxus* and *Catoprion mento* (Fig. 60). The presence of mamilliform teeth on the premaxilla was used to diagnosed *Roeboides* since its establishment (Günther, 1864; Eigenmann, 1910; Lucena 1998) and the arrangement of these teeth on the lingual surface of the maxilla are informative within the genus (Lucena 1998). The presence of mamilliform teeth was used by Mirande (2010: 419, character 120) as a character. This author observed the presence of mamilliform teeth outside the mouth for *Exodon paradoxus*, *Roeboexodon geryi*, *Bryconoexodon juruenae* and *Probolodus heterosomus*. Mattox & Toledo-Piza (2012: 847, character 69), also used this characteristic as a character in their phylogenetic study of the Characinae, in the paper the authors observed the presence of mamilliform teeth outside the mouth in *Roeboides*, *Exodon*, *Bryconoexodon* and *Roeboexodon*. The authors state that the labially displaced mamilliform teeth was observed on the premaxilla, maxilla and dentary of the examined specimens of the cited taxa, in addition to these taxa the authors list three more characiforms that have such condition, the serrasalmin *Catoprion*, and the characids *Probolodus* (Lima *et al*., 2003) and *Serrabrycon* (Vari, 1986).

12. Pattern of tooth replacement: (0) with no clear synchronization within a tooth group; (1) unilateral pattern. (CI = 0.200; RI = 0.857)

Variation in the timing of tooth replacement was observed across examined taxa. Two main states of the timing of the replacement were identified. Taxa with no identified chronological pattern on the tooth replacement (state 0) are characterized by having replacement teeth in several different developmental stages, with no correlation to the developmental stages of the replacement teeth within the same bone, nor with the replacement teeth on the contralateral bone, nor the replacement teeth on the other toothed bones on the same side of the specimen. This condition was also attributed to specimens that showed close to no difference in the developmental stages of the replacement teeth across contralateral bones. Examples of taxa with this condition are *Boulengerella maculata*, *Acestrocephalus stigmatus*, *Salminus brasiliensis* and *Cynodon gibbus*. Alternatively, some taxa had replacement teeth in similar developmental stages within a bone and coupled with other bone on the same side of the specimen (*e. g.* dentary and premaxilla on the right side with replacement teeth in similar developmental stages, different from the developmental stage of the replacement teeth on the left dentary and premaxilla). This similarity in the developmental stages within a side of the specimen indicated that teeth on right and left side are replaced in different moments, for this condition was named as unilateral pattern, state 1 (Figs. 31, 32). When specimens undergoing replacement were available a further differentiation within the unilateral pattern was possible. For some specimens that were undergoing replacement one of the sides would be toothless with the replacement teeth migrating to their respective functional position (Figs. 28, 29, 61, 62) the term simultaneous unilateral pattern was used. Alternatively, for some specimens with the replacement in a unilateral pattern, the replacement of all teeth was not simultaneous but, following a mediolateral orientation. This pattern is evidenced by specimens with replacement teeth in similar developmental stages in one of the sides of the jaws, while the other side is undergoing replacement. The medialmost teeth on the side undergoing replacement are already on their respective functional position with no visible developing replacement teeth, the lateralmost tooth without a developing replacement tooth is not yet fully calcified, with connective tissue on its base. The replacement teeth of the remaining lateralmost teeth are all visible and in late developmental stages (Fig. 25). Roberts (1967) observed similar evidence of simultaneous replacement on one side of the jaws for *Bryconaethiops microstoma*, *Creagrudite maxillaris* (= *Creagrutus*), *Brycon atrocaudatus* and *Mylossoma* sp. which had replacement teeth midway to their functional positions and in *Phenacogrammus interruptus* that lacked developing replacement teeth on one side. Roberts (1967) reports a possible simultaneous replacement of all teeth in anostomids based on the examination of a series of *Schizodon fasciatus* including one specimen that lacked developing replacement teeth entirely. Within the anostomid examined herein two *Leporinus* (*L. bahiensis* and *L. desmotes*) had replacement teeth in similar developmental stages on both sides of the jaws, one of the two examined specimens of *Laemolyta proxima* lacked preformed replacement teeth entirely, on the right premaxilla the medialmost tooth seemed to be in the final stages of migration to the functional position, the mentioned anostomids had this character coded as 0. The replacement of all teeth is also reported for

Hydrocynus vittatus kept in captivity (Gagiano *et al*., 1996), the replacement of the entire dentition would take place in three to five days, such a short period of replacement would explain the reduced number of preserved specimens with replacement teeth. The examined *Hydrocynus forskahlii* did not show any signs of tooth replacement, therefore this character was also coded as 0 for this taxon.

Premaxilla

13. Teeth on premaxilla: (0) present; (1) absent. (Vari, 1983: 48). (CI = 1.000; RI = 0)

The absence of teeth on the premaxilla of adult specimens was only observed for the curimatid *Steindachnerina insculpta*. The absence of dentary and premaxillary teeth was proposed as a synapomorphy for the Curimatidae by Vari (1983). Premaxillary teeth are also lacking in the hemiodontid *Anodus* Cuvier 1829. This genus was previously included in the Curimatidae but Roberts (1974) and Vari (1989) further discussed that the similarities among *Anodus* and the curimatids apart from the lack of teeth were plesiomorphic.

14. Heterodonty on premaxillary teeth: (0) absent; (1) present. (CI = 0.100; RI = 0.757)

Heterodonty is defined herein as the presence of teeth of different morphologies on a specific bone. Differences in size alone or in number of cusps in multicuspid teeth (*i*. *e*. for taxa with multicuspid teeth with total number of cusps varying but not affecting the general tooth morphology such as *Serrapinnus calliurus* with premaxillary teeth with seven to nine cusps) were not considered as heterodonty. In *Acestrorhynchus microlepis* and *A*. *pantaneiro* it is observed heterodonty among unicuspid teeth, *i*. *e*. small conical teeth and unicuspid teeth with lateral cutting edges, whereas in *Agoniates halecinus* *Characidium* cf. *zebra* it is observed both unicuspid and multicuspid teeth. *Citharidium ansorgii*, *Ichthyborus quadrilineatus* and *Nannocharax multifasciatus* have unicuspid and bicuspid maxillary teeth. Heterodonty among multicuspid teeth is observed in *Alestes*, *Astyanax*, *Brycinus*, *Brycon*, *Bryconalestes*, *Bryconops*, *Carnegiella*, *Phenacogrammus*, *Poptella*, *Iguanodectes*, *Gymnocorymbus*, *Lignobrycon*, *Micralestes*. Mirande (2010: 423, character 131) used the presence of polymorphism in the inner row of the premaxilla as a character. The author referred the polymorphism to the presence of enlarged teeth on the medial region of the inner row on the premaxilla observed in taxa such as *Creagrutus*, *Piabina*, *Brycon* and *Triportheus*. The character of Mirande is not equivalent to the current character. A discussion on the definition of premaxillary teeth row and their homology across taxa is made in the section "Homology between premaxillary rows among taxa with one, two or three rows of functional teeth" in the discussion of this paper.

15. Multicuspid teeth with additional cusps on the concave face of the tooth in the inner row of premaxilla: (0) absent; (1) present. (Zanata & Vari: 35, character 64; Mirande, 2010: 422, character 126). (CI = 1.000; RI = 1.000)

Teeth with a conical base with circular or ellipsoid cross-section with additional cusps on the concave face of the tooth were observed on the inner row on the premaxilla of *Alestes baremoze* (Fig. 10), *Alestes macrophthalmus*, *Brycinus imberi*, *Brycinus lateralis*, *Brycinus sadleri* and *Bryconalestes longipinnis*. Multicuspid teeth with additional cusps on the concave face have been reported in the literature as early as Muller & Troschel (1844:88) who treated those teeth as molariform. Roberts (1967) stated that the "molariform teeth" present on the premaxilla of *Bryconaethiops* and *Alestes* evolved from a compound tooth with uniserial cusps, similar to the dentary teeth of *Alestes*, apparently in the ontogeny of these premaxillary teeth the outermost conical elements on both ends would have migrated around to the front of the compound element. Géry (1977) used the presence of such "molariform" teeth, among other characters, to define the Alestini that comprised *Bryconaethiops*, *Alestes* and *Brycinus*. Zanata & Vari (2005: 35, character 64) call these additional cusps "included cusps", the authors reported the presence of said cusps in *Alestes*, *Brycinus* and *Bryconaethiops*. Additionally, the authors questioned the homology of the "included cusps" of the three cited genera to the ones observed in *Bryconalestes*. No differences were detected between the additional cusps on the concave face of the teeth on the inner row of the premaxilla of *Alestes*, *Brycinus* and *Bryconalestes* species examined herein, the condition of these taxa was considered homologous among them. No representative of *Bryconaethiops* was included in the current study. There is evidence that the molariform cusps are added throughout ontogeny, in relative late stages in terms of teeth development. One examined specimen of *Alestes baremoze* had two multicuspid teeth with additional cusps on their concave face on the three medialmost teeth and one additional cusp on the lateralmost tooth, close to its medial margin, on the left premaxilla, whereas on the right side the third medialmost tooth had only one additional cusp on its concave face, close to its medial margin, and the lateralmost tooth had none. In addition, one examined specimen of *Bryconalestes* *longipinnis* had additional cusps on the concave face of teeth on the inner row of the premaxilla only on the replacement teeth. This ontogenetic addition of the molariform cusps would refute Roberts' (1967) hypothesis of cusp migration.

16. Number of rows of premaxillary teeth (0) one; (1) two; (2) three. (Zanata & Vari: 32, character 57; Mirande 2010: 420, character 122 and 123) (CI = 0.182; RI = 0.710)

The number of teeth rows is variable among Characiformes, in the present study taxa with a single row of teeth (state 0) such as *Abramites hypselonotus*, *Boulengerella maculata* and *Characidium zebra*. Two teeth rows (state 1) were observed in taxa such as *Astyanax novae* (Fig. 28), *Poptella compressa* (Fig. 30), *Alestes baremoze* (Fig. 10) and *Myloplus arnoldi*. Finally, three teeth rows (state 2) were observed in *Chalceus epakros* (Fig. 25), *Brycon amazonicus* (Fig. 23), *Brycon falcatus*, *Brycon pesu*, *Triportheus albus* (Fig. 8) and *Triportheus angulatus*. When a single row of premaxillary teeth was present, the replacement teeth of such row were formed exclusively in soft tissue. When two or three rows of premaxillary teeth were observed the replacement teeth of the inner row were formed exclusively in soft tissue, whereas the replacement teeth of the outer row and middle row (when present) were formed in bone cavities. This similarity in replacement teeth formation mode points to a possible homology between the inner row of teeth on the premaxilla of taxa with two or three rows of premaxillary teeth and the single row of teeth in taxa with a single row of premaxillary teeth. The number of tooth rows on the premaxilla has been used by several authors in phylogenetic studies of characiforms (Zanata & Vari, 2005: 32, character 57; Mirande, 2010: 420, characters 122 and 123). As stated by Mirande (2010) establishing the homology between premaxillary teeth rows on different taxa is not always a trivial task. The identification of different teeth rows was done herein combining tooth morphology, topological differences and development, the latter already used by Mirande (2010). The homology between premaxillary teeth rows across Characiformes is further discussed in the section "Homology between premaxillary rows among taxa with one, two or three rows of functional teeth" in the discussion. Taxa with labially displaced mamilliform teeth (*Roeboides affinis*, *Exodon paradoxus* and *Catoprion mento*) and taxa completely lacking premaxillary teeth were coded as inapplicable. The two rows of teeth in the premaxilla of *Prochilodus lineatus* are unique among the Characiformes given that the replacement teeth of both premaxillary teeth rows are formed in soft tissue. The several modifications on the dentition of *Prochilodus lineatus* made the proposal of homologies between the dentition observed in this taxon with other characiforms, for this reason this character was coded as inapplicable for this species.

17. Number of preformed replacement teeth for each respective functional tooth on the premaxilla: (0) one; (1) two; (2) three or more. (Vari, 1983: 49; Mirande, 2010: 423, character 132) (CI = 0.286; RI = 0.167)

The most common condition is to have only one preformed replacement tooth for each respective functional tooth on the premaxilla (state 0, Fig. 10). Some taxa have two preformed replacement teeth (state 1), such as *Acestrorhynchus pantaneiro*, *Hoplias malabaricus* and *Hepsetus odoe* (Fig. 52). Other taxa such as *Prochilodus lineatus*, *Hemiodus microlepis*, *Parodon pongoensis* and *Apareiodon ibitiensis* have at least one premaxillary tooth with at least three preformed replacement teeth (state 2). Parodontids (*Parodon* and *Apareiodon*) have up to five preformed replacement teeth on the premaxilla, the rows of replacement teeth of each functional teeth were separated by bony lamellae (Fig. 57). The replacement teeth of *Hemiodus* have similar orientation to those of the paraodontids but with no modifications on the underlying bone. *Prochilodus* also have several preformed replacement teeth on the premaxilla, four or five in most cases, however in *Prochilodus* the replacement teeth are not stacked as in the parodontids or in *Hemiodus*, but are lined up in such way that the base of the oldest replacement tooth (*i. e*. the one closest to functional position) was close to the cusp of the second oldest replacement tooth (Fig. 59). The number of preformed replacement teeth on the premaxilla was used as a character by Mirande (2010: 423, character 132) but the author treated used the number of replacement tooth rows, instead of dealing with the number of preformed replacement teeth for a single functional tooth. We opted to deal with a single functional tooth and its respective developing replacement teeth because variation on the number of preformed replacement teeth was observed in some taxa what made the identification of replacement teeth series across the entire premaxilla.

18. Replacement teeth of outer row on premaxilla formed in: (0) single bony cavity; (1) individual bony cavities. (CI = 0.333; RI = 0)

The premaxillary outer row, when present, has its replacement teeth formed inside bone cavities, however some variation was observed in the morphology of the bony cavities where they are formed. In some taxa all replacement teeth are formed sharing a single bony cavity (state 0), whereas in others each replacement teeth of the outer row are formed in its own bony cavity (state 1).

19. Openings on ventral surface of premaxilla associated to the cavity where replacement teeth are formed: (0) absent; (1) present. (CI = 0.250, RI = 0.400)

The replacement teeth of the outer row on the premaxilla are formed in bone cavities. In some taxa the developing replacement tooth is formed entirely enclosed in bone, with no openings on the ventral margin of the premaxilla (state 0, Fig. 23). Whereas some taxa have their developing replacement teeth of the outer row on the premaxilla associated to ventral openings on the ventral margin of the premaxilla (state 1). The most common condition is to have more conspicuous openings associated to the medialmost developing replacement teeth. However, in *Chalceus epakros* the ventral openings are clear on the lateralmost teeth on the outer row and in *Gymnocorymbus ternetzi* a single ventral opening was observed, associated to the lateralmost functional tooth, both were coded as state 1. In *Iguanodectes geisleri* the ventral openings are lingual to the inner row of premaxillary teeth, despite the apparent lingual displacement of the ventral opening this character was coded as state 1 for *Iguanodectes geisleri*.

20. Configuration of openings on ventral surface of the maxilla associated to the cavity where replacement teeth are formed: (0) at least one opening associated to one developing replacement tooth; (1) single ventral opening running along entire ventral margin of premaxilla. (CI = 1.000; RI = 1.000)

The most common condition on the examined taxa is the presence of individual ventral opening associated to the developing replacement teeth on the outer row of the premaxilla (state 0). In taxa such as *Xenocharax spilurus* the replacement teeth of the outer row of the premaxilla are formed in a single bone cavity associated to a single ventral opening that extends along the entire ventral surface of the premaxilla (state 1). The presence of a single ventral opening on the ventral surface of the premaxilla associated to the cavity in which the replacement teeth of the outer row are formed is restricted to the citharinids and distichodontids.

21. Arrangement of cusps on the medialmost multicuspid teeth on inner row of premaxilla: (0) semicircle in ventral view; (1) arched line in ventral view; (2) straight in

ventral view. (Zanata & Vari, 2005: 34, character 63; Mirande, 2010: 422, character 127) (CI = 0.400; RI = 0.800)

When in ventral view, it is possible to observe the alignment of the cusps of the medialmost multicuspid teeth on the inner row of the premaxilla. This character is applicable for taxa with a single row of teeth on the premaxilla, since this row is considered homologous to the inner row of taxa with two or three tooth rows on the premaxilla in this study. In some taxa such as *Triportheus albus* (Fig. 8) the cusps of the medialmost multicuspid tooth on the inner row of the premaxilla re arranged in a semicircle (state 0). Other taxa like *Micralestes acutidens* the cusps are arranged in an arched line in ventral view. Taxa with multicuspid teeth with several cusps like *Hemiodus microlepis* (Fig. 51) have the cusps aligned in an almost straight line in ventral view (state 2), this arrangement of the cusps was generally observed in taxa with multicuspid teeth labiolingually flattened distally. This variation on the arrangement of the cusps of premaxillary multicuspid teeth was used as a character by Zanata & Vari (2005: 34, character 63) and Mirande (2010, characters 127 and 128). In taxa with tricuspidate premaxillary inner row teeth as in *Agoniates halecinus*, *Aphyocharax* the condition was interpreted as arched line (state 1). Cusps arranged in a semicircle (state 0) were observed in *Astyanax novae*, *Myloplus arnoldi*, *Alestes macrophthalmus*, *Alestes baremoze*, *Brycinus sadleri*, *Brycinus lateralis*, *Brycinus imberi*, *Triportheus albus* and *Triportheus angulatus*.

22. Labially displaced teeth: (0) absent; (1) present. (CI = 1.000; RI = 1.000)

Some of the examined taxa had labially displaced mamilliform teeth on the premaxilla (see character 8), in addition to these taxa, *Trochilocharax ornatus* also showed labially displaced premaxillary teeth, but in this case the teeth were unicuspid slightly curved lingually.

23. Profile of medialmost multicuspid tooth on the inner row of the premaxilla: (0) diameter at base of tooth larger than or similar to diameter at level of cusps; (1) tooth pedicellate. (Mirande, 2010: 419, character 119). (CI = 0.250; RI = 0.850)

This character is applicable for taxa with a single row of teeth on the premaxilla, since this row is considered homologous to the inner row of taxa with two or three tooth rows on the premaxilla in this study. The more common conditions observed for the profile of the medialmost multicuspid tooth on the inner row on the premaxilla is a tooth with the diameter at base of tooth larger (Figs. 28, 29; state 0) or similar to the diameter at level of cusps (Fig. 35, 36; state 1). Some taxa have pedicellate teeth, teeth with the diameter at the level of the cusps larger than at the base of the tooth (Fig. 51; state 2). This character was treated as inapplicable for taxa with only unicuspid teeth on the premaxilla.

24. Premaxillary functional teeth implantation mode: (0) directly associated to underlying bone, well consolidated; (1) directly associated to underlying bone, slightly mobile when manipulated; (2) teeth embedded in soft tissue, tooth base not directly associated to underlying bone. (Langeani, 1998: 151, character 6; Castro & Vari, 2004: 20). (CI = 0.400; RI = 0.727)

Most characiforms have teeth firmly implanted on the underlying bone (state 0, Fig. Alestes), but not fully ankylosed, separated from the bone with a layer of unmineralized collagen fibers, the type 2 tooth attachment of Fink (1981). More uncommon conditions are found in anostomids, who have teeth associated to the underlying bone in a pleurodont manner and not as firmly implanted on the underlying bone slightly mobile when manipulated (state 1, Figs. 21, 22). Extreme conditions are observed in *Hemiodus microlepis*, *Bivibranchia fowleri*, *Prochilodus lineatus* and *Chilodus punctatus* (Fig. 37) in which the functional teeth are embedded in soft tissue, the base of the functional teeth is not in contact with the underlying bone (state 2).

25. Connection at symphysis between contralateral bony cavities where premaxillary replacement teeth are formed: (0) absent; (1) present. (Vari, 1979: 266). (CI = 1.000; RI = 1.000)

The most common condition when bony cavities for the development of premaxillary teeth are present is to have a clear separation between the contralateral premaxillary bony cavities at the symphysis (state 0, Fig. 10). Alternatively, in taxa such as *Ichthyborus quadrilineatus* (Figs. 45, 46) and *Nannocharax multifasciatus* (Figs. 47, 48) the shallow cavities in which the replacement teeth are formed connect at the region of the symphysis (state 1). Roberts (1967) reported that *Distichodus* have ample bony cavities on the premaxillae that connect between each other at the symphysis, similar condition is reposted for *Parastichodus*, *Distichodus*, *Nannocharax*, *Hemigrammocharax* and *Hemistichodus* by Vari (1979). The presence of a connection at the symphysis of the contralateral bony cavities where premaxillary replacement teeth are formed (state 1) is restricted to citharinids and distichocontinds.

26. Orientation of developing replacement teeth of the outer row on the premaxilla: (0) with similar orientation to its respective functional tooth; (1) oriented in different way from its respective functional tooth. (CI = 0.167; RI = 0.706)

Replacement teeth of the premaxillary outer row are commonly oriented in a similar way to their respective functional teeth (state 0). Alternatively, in some taxa such as *Poptella compressa* the replacement teeth of the outer premaxillary teeth are slanted labially (state 1). This character was coded as inapplicable for taxa within the Characoidei with a single tooth row on the premaxilla, since this tooth row is interpreted as homologous to the inner row of taxa with two or three tooth rows on the premaxilla. Taxa with labially displaced mamilliform teeth also had this character coded as inapplicable.

27. Orientation of developing replacement teeth of inner row on premaxilla: (0) with similar orientation to its respective functional tooth; (1) oriented in different way from its respective functional tooth. (CI = 0.200; RI = 0.667)

The most common condition observed is the replacement teeth slanted about 90° in relation to their respective functional teeth (state 1, Fig. 10). In taxa such as *Leporinus* the developing replacement tooth are oriented in a similar way in relation to its respective functional tooth (state 0, Figs. 21, 22). For taxa with only one premaxillary tooth row it was considered homologous to the inner row of taxa with two premaxillary teeth row due to same replacement teeth formation mode. Arrow-head teeth on *Acestrorhynchus* oriented differently, but the smaller teeth have replacement teeth with similar orientation in relation to their respective functional tooth. Replacement teeth of inner row of premaxilla with similar orientation to its respective functional tooth were observed in *Xenocharax spilurus*, all examined anosmids, *Prochilodus lineatus*, *Chilodus punctatus*, *Charax stenopterus*, *Roestes molossus*, *Lonchogenys ilisha*, *Hoplias malabaricus* and *Acestrorhynchus*.

Maxilla

28. Teeth on maxilla: (0) present; (1) absent. (Vari, 1983: 8; Castro & Vari, 2004: 20; Zanata & Vari, 2005: 41, character 79; Mirande 2010: 424 character: 134) (CI = 0.083; RI = 0.593)

Maxillary teeth are observed in several characiforms, the number of maxillary teeth varies widely, from few teeth in taxa such as *Triportheus albus* (Fig. 8) and *Gymnocorymbus ternetzi* to taxa with a high number of maxillary teeth such as *Cynodon gibbus* (Fig. 43) and *Acestrocephalus stigmatus* (Fig. 27). Alternatively, an edentulous maxilla (state 1) is observed in *Leporinus Alestes* (Fig. 10) *Citharinus* (Fig. 39) The presence or absence of maxillary teeth was also used as a character by Mirande (2010: 424, characters 134 and 135). A toothed maxilla is considered as plesiomorphic for Characiforms, the loss of maxillary teeth can be used to define groups within the order such as: “citharinids and distichodontids except *Xenocharax*, *Nannaethiops* and *Neolebias*” (Vari, 1979); “ the maxilla is edentulous across the Alestidae, other than in the basal genus *Chalceus*” (Zanata & Vari, 2005). The lack of maxillary teeth is also a synapomorphy for the group comprising the families Anostomidae, Chilodontidae, Curimatidae and Prochilodontidae (Vari, 1983; Castro & Vari, 2004: 20).

29. Heterodonty of maxillary teeth: (0) absent; (1) present. (CI = 0.167; RI = 0.667)

Heterodonty is defined herein as the presence of teeth of different morphologies on a specific bone. Differences in size alone or in number of cusps in multicuspid teeth (*i*. *e*. for taxa with multicuspid teeth with total number of cusps varying but not affecting the general tooth morphology such as *Serrapinnus calliurus* with premaxillary teeth with seven to nine cusps) were not considered as heterodonty. The most common condition observed was a homodont maxilla (state 0) as in *Acestrocephalus stigmatus* (Fig. 27) or *Piabucus melanostoma* (Fig 54). Alternatively, some taxa have teeth of varying morphology on the maxilla. Different morphology and different replacement teeth formation mode were used to determine heterodonty. Heterodont maxillae were observed in *Acestrorhynchus* which had an anterior group with arrowhead teeth and unicuspid teeth of intermediate size, both morphologies with replacement teeth formed intraosseously and a posterior group of small unicuspid teeth with replacement teeth formed extraosseously (see description for more detail). Small specimens *Astyanax novae* had one unicuspid tooth and larger specimens had one tricuspid tooth, but both morphologies were not found simultaneously on a single specimen. This was considered as ontogenetic variation and not as heterodonty. This character was coded as inapplicable for taxa with edentulous maxilla.

30. Number of preformed replacement teeth for each functional tooth on the maxilla: (0) one; (1) two; (2) three or more. (CI = 0.500; RI = 0.333)

The most common condition is to have only one preformed replacement tooth for each functional tooth on the maxilla (state 0). Some taxa showed as many as two preformed replacement teeth (state 1), such as *Acestrorhynchus pantaneiro*. Three or more preformed replacement teeth for a single functional tooth (state 2) was observed in *Hoplias malabaricus* and *Hepsetus odoe* This character was coded as inapplicable for taxa lacking maxillary teeth.

31. Proportion of toothed portion of anteroventral margin of maxilla: (0) toothed margin shorter than edentulous margin; (1) toothed margin longer than edentulous margin; (2) toothed and edentulous margin of similar length. (Mirande, 2010: 424, character 137; Mattox & Toledo-Piza, 2102: 849 character 74) (CI = 0.222; RI = 0.667)

Variation on the proportion of the toothed portion of the maxilla in relation to the edentulous portion was observed. Some taxa have teeth restricted to the anterior portion of the maxilla; therefore, the toothed margin is shorter than the edentulous margin (state 0, Fig. 30). Alternatively, some taxa such as *Galeocharax gulo* and *Acestrorhynchus microlepis* have the toothed portion of the maxilla longer than the edentulous one (state 1). Mirande (2010: 424, character 137) also used the proportion of the toothed margin in relation to the length of the edentulous margin on the maxilla as a binary character, "Extent of implantation of teeth along maxilla: (0) not reaching middle of maxillary lamella; (1) extending across almost entire maxillary lamella". Mattox & Toledo-Piza (2012: 849, character 74) dealt with the variation encompassing an intermediate state (2) observed in taxa such as *Aphyocharax* and *Trochilocharax*. In taxa with the toothed and edentulous margins of the premaxilla of similar length slight intraspecific variations could interfere in proportion between the length of toothed and edentulous margin of the maxilla, making it difficult to determine a character state for that taxa, resulting in an artificial polymorphism, the inclusion of a separate character state for such cases avoids that problem. The number and size range of examined specimens of each taxa in this paper were not sufficient to address if there are any ontogenetic changes in the proportion of toothed portion of the anteroventral margin of the maxilla. This character was coded as inapplicable for taxa without maxillary teeth.

32. Mamilliform teeth implanted on labial surface of maxilla: (0) absent; (1) present. (CI = 1.000; RI = 1.000)

Among the examined taxa only *Exodon paradoxus* and *Roeboides affinis* have mamilliform teeth on the labial surface of the maxilla (state 1, Fig. 26).

33. Formation of replacement teeth on maxilla: (0) in soft tissue with no modification on lingual surface of maxilla; (1) in soft tissue, associated to depressions on maxilla lingual surface of maxilla; (2) in some form of bony cavity. (CI = 0.143; RI = 0.500)

The mode of formation of replacement teeth on the maxilla varies among examined taxa. The most common condition observed is the replacement teeth being formed in soft tissue with no modification on the underlying bone (state 0) as in *Acestrocephalus stigmatus* (Fig. 27). Some taxa have the replacement teeth formed in soft tissue associated to depression of the lingual surface of the maxilla (state 1) as in *Bryconamericus lethostigmus* (Figs. 31, 32). *Acestrorhynchus microlepis* (Fig. 1) and *Exodon paradoxus* have some replacement teeth formed in cavities on lingual surface of the maxilla.

34. Profile of the multicuspid teeth on maxilla: (0) diameter at base of tooth larger than or similar to diameter at level of cusps; (1) tooth pedicellate. (Mirande, 2010: 419, character 119). (CI = 0.333; RI = 0.778)

The taxa with multicuspid teeth on the maxilla show variation on tooth morphology. In taxa such as *Lebiasina* sp. the diameter at the base of the tooth is similar to the diameter at the level of the cusps (state 0). Whereas taxa such as *Parodon pongoensis* (Fig. 58) and *Hemiodus microlepis* the teeth are pedicellate, with the diameter at the level of the cusps larger than the diameter at the base of the tooth (state 1). This character was coded as inapplicable for taxa with only unicuspid teeth on the maxilla.

35. Maxillary functional teeth implantation mode: (0) directly associated to underlying bone, well consolidated; (1) directly associated to underlying bone, slightly mobile when manipulated; (2) teeth embedded in soft tissue, tooth base not directly associated to underlying bone. (CI = 0.667; RI = 0.667)

Most characiforms have teeth firmly implanted on the underlying bone (state 0), (Fig 1) but not fully ankylosed, separated from the bone with a layer of unmineralized collagen fibers, the type 2 tooth attachment of Fink (1981). A more uncommon conditions is found in *Parodon pongoensis* (Fig. 58), this taxon has teeth directly associated to the bone, but slightly mobile when manipulated (state 1). Extreme conditions are observed in *Hemiodus microlepis* (Fig. 51), *Bivibranchia fowleri* in which the functional teeth are embedded in soft tissue, the base of the functional teeth is not in contact with the underlying bone (state 2). State 2 was only observed in the hemiodontids *Hemiodus microlepis* and *Bivibranchia fowleri*.

36. Orientation of developing maxillary replacement teeth: (0) with similar orientation to its respective functional tooth; (1) oriented in different way from its respective functional tooth. (CI = 0.167; RI = 0.167)

The most common condition observed is the replacement teeth with similar orientation in relation to their respective functional tooth (state 0). Some taxa such as *Piabucus melanostoma* (Fig. 54) have the replacement teeth slanted about 90º in relation to their respective functional tooth, with main cusp pointing lingually. Other taxa such as *Acestrocephalus stigmatus* have the maxillary replacement teeth slightly slanted posteriorly in relation to their respective functional tooth (Fig. 27). State 0 was only observed in *Boulengerella*, *Nannostomus unifasciatus*, *Lebiasina* sp. *Lonchogenys ilisha* and *Hoplias malabaricus*.

37. Alignment of distal margins of series of maxillary teeth: (0) approximately straight; (1) rounded due to gradual anteroposterior increase and decrease in size of teeth on anterior portion (Mattox & Toledo-Piza, 2012, character 73). (CI = 1.000; RI = 1.000)

This character was originally proposed by Mattox & Toledo-Piza (2012: 849, character 73). Among the examined taxa the most common condition is to have the maxillary teeth with similar length along the entire maxilla, this results in an approximately straight profile formed by the cusps of the maxillary teeth (Fig. 27). In some taxa such as *Acestrorhynchus microlepis* and *Cynodon gibbus* there is a size alternance, mainly in the anterior portion of the maxilla, resulting in a zigzag patter, these taxa was also coded as having the state 0 as in Mattox & Toledo-Piza (2012: 849, character 73). The state 1 was only observed in *Heterocharax*, *Hoplocharax*, *Gnathocharax*, and *Lonchogenys*, herein the state 1 is exclusive for *Heterocharax virgulatus* and *Lonchogenys ilisha* among the examined taxa. Neither *Gnathocharax* nor *Hoplocharax* were included in the current study.

Dentary

38. Teeth on dentary: (0) present; (1) absent. (Vari, 1983: 48; Langeani, 1998: 151, character 5; Sidlauskas & Vari: 106, character 36). (CI = 1.000; RI = 1.000)

Among the examined taxa, other than the edentulous *Steindachnerina insculpta*, only hemiodontids and *Apareiodon ibitiensis* lack dentary teeth.

39. Heterodonty on dentary teeth: (0) absent; (1) present. (CI = 0.091; RI = 0.600)

Heterodonty is defined herein as the presence of teeth of different morphologies on a specific bone. Differences in size alone or in number of cusps in multicuspid teeth (*i. e.* for taxa with multicuspid teeth with total number of cusps varying but not affecting the general tooth morphology such as *Serrapinnus calliurus* with premaxillary teeth with seven to nine cusps) were not considered as heterodonty. Homodont dentary dentition (state 0) is present in taxa with only unicuspid teeth on the dentary such as *Acestrocephalus stigmatus* (Fig. 27) and *Boulengerella maculata* and in taxa with multicuspid dentary teeth such as *Bryconamericus lethostigmus* (Fig. 32) and *Piabucus melanostoma* (Fig. 54). Heterodont dentition in the dentary (state 1) is present among unicuspid teeth in *Acestrorhynchus microlepis* (conical teeth and unicuspid teeth with lateral cutting-edges, Fig. 1). Taxa such as *Poptella compressa* have multicuspid on the medial portion of the dentary followed laterally by conical teeth on the dentary (Fig. 30), and *Alestes baremoze* which has multicuspid teeth and a conical parasymphyseal tooth (Fig. 11) were also coded as having heterodont dentary dentition.

40. Number of preformed dentary replacement teeth: (0) one; (1) two; (2) three or more. (Vari 1983: 49). (CI = 0.500; RI = 0)

The most common condition observed among the examined taxa is to have only one preformed replacement tooth for each functional tooth (state 0). Taxa such as *Acestrorhynchus pantaneiro* and *Hepsetus odoe* had at least one functional tooth with two preformed replacement teeth on the dentary (state 1). *Prochilodus lineatus* had an extreme condition in which each functional tooth had at least three preformed replacement teeth on the dentary. The highest number of preformed replacement teeth for a single replacement tooth observed was five, at the mid portion of the dentary main row (Fig. 59)

41. Parasymphyseal dentary tooth: (0) absent; (1) present. (Mirande, 2019, character 204). (CI = 1.000; RI = 1.000)

Parasymphyseal teeth are observed in some of the examined taxa. This tooth lies just lateral to the symphysis, lingual to the medialmost tooth in the main row of the dentary (Figs. 9, 11) We treat the parasymphyseal tooth as Mirande (2010: 425, character 144) did, not considering the parasymphyseal tooth homologous to the inner row of dentary teeth based on the different mode of replacement teeth formation. The inner row teeth are always formed in soft tissue with no modification to the underlying bone whereas the parasymphyseal tooth is formed in soft tissue either associated to a depression on the lingual of the dentary wall or in a bony cavity. The term parasymphyseal tooth is used because it is a paired structure and not to be confused with the unpaired, true symphyseal tooth of *Ichthyborus quadrilineatus* (see character 43 and description for detail). Parasymphyseal teeth were observed in *Myloplus arnoldi*, *Alestes*, *Bryconalestes longipinnis*, *Brycinus*, *Triportheus*, *Agoniates halecinus*, *Brycon*, *Chalceus epakros*, *Phenacogrammus interruptus* and *Micralestes acutidens*.

42. Parasymphyseal dentary tooth morphology: (0) conical, curved lingually; (1) multicuspid. (CI = 1.000; RI = 1.000)

The most common condition of parasymphyseal teeth observed is conical slightly curved lingually (state 0) as in *Triportheus, Alestes* (Fig. 11), *Myloplus*. In *Chalceus epakros* the parasymphyseal tooth is tricuspid (state 1) and symmetrical, the main cusp markedly more developed than the lateral ones and curved lingually. In *Micralestes acutidens* the parasymphyseal tooth is tricuspid and asymmetrical, the larger cusp is the medialmost, the tooth is slightly curved medially, this taxon was also coded as state 1. Multicuspid parasymphyseal tooth was only observed in *Chalceus epakros*, *Phenacogrammus interruptus* and *Micralestes acutidens* (Fig. 20).

43. Symphyseal tooth: (0) absent; (1) present. (Vari, 1979: 334). (CI = 1.000; RI = 0)

The term symphyseal tooth is restricted to the enlarged median dentary tooth of *Ichthyborus quadrilineatus* (Fig. 46). The presence of a symphyseal tooth was only observed in *Ichthyborus quadrilineatus* among the examined taxa.

44. Inner row of small conical teeth on dentary: (0) absent; (1) present. (Vari, 1979: 277; Zanata & Vari, 2005: 46, character 88; Mirande, 2019, character 203). (CI = 0.111; RI = 0.467)

An inner row of small lingually curved unicuspid teeth with replacement teeth developing in soft tissue is usually present in some characiforms, just lingual to the bony cavity where the replacement teeth of the main row are formed (state 1). *Acestrocephalus stigmatus* and *Galeocharax gulo* have the inner row restricted to the anterior region of the dentary (Fig. 27), whereas in *Salminus brasiliensis* and *Hepsetus odoe* the inner row of small conical teeth runs along the dentary almost as long as the main row of dentary teeth (Fig. 52), all of the mentioned taxa were coded as state 1 regardless of the differences in the length of the inner row. This character was coded as inapplicable for taxa that lack dentary teeth as adults. *Roestes* and *Lonchogenys* along with *Heterocharax* have peculiar conditions regarding inner row teeth. In *Roestes molossus* the inner row of teeth is composed of only two conical teeth, implanted near the symphysis. In *Lonchogenys ilisha* the inner row is longer, extending laterally from near the symphysis almost until the medialmost tooth of the posterior group on the dentary. *Heterocharax virgulatus* was coded as not having an inner row of teeth on the dentary since the small unicuspid teeth located labial to the medial group are considered as a medial projection of the medial group rather than an separate inner row. This option is justified by the continuity on the row of adjacent small unicuspid teeth (*vs*. a clear topological distinction between posterior group and inner row on *Lonchogenys ilisha*) and the distance between the so called inner row and the symphysis, the inner row of dentary teeth observed in all other taxa was always implanted close to the symphysis.

45. Labially displaced teeth on dentary: (0) absent; (1) present. (CI = 0.333; RI = 0.500)

Some taxa such as *Trochilocharax ornatus* and the *Roeboides affinis* and *Exodon paradoxus* had labially displaced teeth in the anterior portion of the dentary. Acestrocephalus and other cynopotamini *sensu* Mattos & Toledo-Piza (2012) have one denary tooth on the medial group slightly displaced labially, however not as much as in the taxa mentioned above, with said tooth clearly implanted on the dorsal margin of the dentary, therefore were coded as lacking labially displaced teeth. In *Roestes molossus* and *Lonchogenys ilisha* (Fig. 3) the teeth on the medial group of the dentary are not implanted on the dorsal margin of the dentary, in these taxa these teeth are dislocated labially.

46. Arrangement of teeth on main row of dentary: (0) a single group of teeth; (1) divided in two groups. (CI = 0.091; RI = 0.667)

The main row of teeth on the dentary can be formed by a single group of teeth as in *Alestes baremoze* (state 0, Fig. 11), or in two groups, a medial and a lateral group (state 1). The definition of the tooth groups is made based on tooth morphology and replacement teeth formation mode. In *Acestrocephalus stigmatus* and *Galeocharax gulo* there are two tooth groups, both groups formed by conical, however the medial group have replacement teeth formed in bone cavities whereas the replacement teeth of the lateral group formed in soft tissue (Fig. 27). In *Poptella compressa* the medial group is formed by multicuspid teeth with replacement teeth formed in bone cavities, the posterior group is formed by small conical teeth with the replacement teeth formed in soft tissue (Fig. 30).

47. Transition between medial and lateral group of teeth on main row of dentary: Outer row composition: (0) gradual; (1) abrupt. (Zanata & Vari: 45, character 85; Mirande 2010: 426 character 148). (CI = 1.000; RI = 1.000)

In taxa with the main row of dentary teeth divided into a medial and a lateral group such as *Aphyocharax avary*, there is a gradual decrease in size between the tricuspid teeth on the medial group and the conical teeth on the lateral group (state 0). Alternatively, in taxa such as *Poptella compressa* the transition between the two groups of dentary teeth is abrupt due to the different size and morphology of the teeth in each group (state 1, Fig. 30). *Acestrocephalus stigmatus* (Fig. 27) and *Galeocharax gulo* have teeth with the same morphology both on the medial and lateral groups, however, there is a conspicuous size difference between the teeth on the two groups, these taxa were interpreted as having the state 1. The relative difference in size among the dentary teeth was used as a character by Mirande (2010: 426, character 148), however the author did not make any distinction between a gradual decrease in size within a single tooth group and the difference in size between the teeth of separate tooth groups.

48. Profile of the medialmost multicuspid tooth on the main row of teeth on the dentary: (0) diameter at base of tooth larger than or similar to diameter at level of cusps; (1) tooth pedicellate. (Mirande, 2010: 419, character 119). (CI = 0.167; RI = 0.737)

Variation was observed on the profile of the medialmost tooth on the dentary of the examined taxa. The medialmost tooth on the main row of the dentary of *Lignobrycon myersi* and *Gymnocorymbus ternetzi* have the diameter at the base of the tooth larger than at the level of the cusps (state 0). In *Chalceus epakros* the diameter at the base of the tooth and at the level of the cusps is similar (state 1, Fig. 25). Whereas the medialmost tooth on the dentary of *Bryconamericus lethostigmus* is pedicellate, the diameter at the base of the tooth is smaller than at the level of the cusps (state 2, Figs. 32, 33).

49. Dentary functional teeth implantation mode: (0) directly associated to underlying bone, well consolidated; (1) directly associated to underlying bone, slightly mobile when manipulated; (2) teeth embedded in soft tissue, tooth base not directly associated to underlying bone. (CI = 0.667; RI = 0.875)

Most characiforms have teeth firmly implanted on the underlying bone (state 0, Fig. 11), but not fully ankylosed, separated from the bone with a layer of unmineralized collagen fibers, the type 2 tooth attachment of Fink (1981). More uncommon conditions are found in anostomids, who have teeth associated to the underlying bone in a pleurodont manner and not as firmly implanted on the underlying bone, slightly mobile when manipulated (state 1, Fig.). Extreme conditions are observed in *Prochilodus lineatus* (Fig. 59) and *Chilodus punctatus* (Fig. 37) in which the functional teeth are embedded in soft tissue, the base of the functional teeth is not in contact with the underlying bone (state 2).

50. Mode of replacement tooth formation on the dentary: (0) all teeth formed in soft tissue; (1) at least a group of teeth formed inside bone cavity. (Zanata & Vari, 2005: 47, character 90). (CI = 0.250, RI = 0.400)

The most common condition for the examined taxa is at least a group of dentary teeth with replacement teeth formed in some kind of bone cavity (state 1, Fig. 33). Some taxa had the replacement teeth on the dentary formed exclusively in soft tissue, without any modifications to the underlying bone (state 0, Fig. 37). Replacement teeth on the dentary formed exclusively in soft tissue were only observed in *Prochilodus lineatus*, *Chilodus punctatus*, *Trochilocharax ornatus*, *Lepidarchus adonis* and *Boulengerella*.

51. Morphology of the bone cavity in which the replacement teeth are formed on the dentary: (0) shallow trench, replacement teeth slanted 90° in relation to the respective functional tooth; (1) bone cavity not as in state 0. (Toledo-Piza, 2000: 34, character 37; Zanata & Vari, 2005: 47 character 91). (CI = 1.000, RI = 1.000)

Some taxa have the replacement teeth of the main row on the dentary formed in a shallow trench, all replacement teeth slanted 90° in relation to their respective functional tooth (state 0, Fig. 52). Most of the examined taxa had the replacement teeth of the dentary formed in a bony cavity with different configuration (state 1), in a bone cavity deep enough to have the developing replacement teeth just slightly slanted laterally. (Fig. 11). State 0 is restricted to the examined cynodontids and *Hepsetus odoe*.

52. Arrangement of dorsal openings associated to the bone cavity in which the replacement teeth are formed on the dentary: (0) single dorsal opening extending along the whole length of the cavity; (1) single bony cavity with individual dorsal openings for each developing replacement tooth, lateralmost openings coalescing together or not. (CI = 0.125, RI = 0.720)

The dorsal opening associated to the bone cavities in which the developing replacement teeth of the dentary are formed were arranged in two conditions. Some taxa had small individual openings associated to each developing replacement teeth (state 1, Figs. 29, 32, 34), whereas some taxa had a single dorsal opening extending along the entire length of the bone cavity (state 0, Figs. 20, 52).

53. Replacement teeth on the dentary formed in single cavity without any openings: (0) absent; (1) present. (CI = 0.500, RI = 0)

The lack of any openings associated to the bone cavity in which the replacement teeth of the dentary are formed (state 1, Fig. 62) was observed in *Serrasalmus elongatus* and *Catoprion mento*.

54. Replacement teeth on the dentary formed in single cavity with ample ventral opening: (0) absent; (1) present. (Vari, 1983: 50; Sidlauskas & Vari, 2008: 122, character 60). (CI = 1.000, RI = 1.000)

An ample ventral opening associated to the bone cavity in which the replacement teeth of the dentary are formed (state 1, Fig. 22). This condition was considered as a synapomorphy for the Anostomidae by Vari (1983) and Sidlauskas & Vari (2008). Among the examined taxa state 1 was only present in the examined anostomids.

55. At least one replacement tooth formed in individual bone cavity on the dentary: (0) absent; (1) present. (CI = 0.250, RI = 0.500)

Some taxa had at least one replacement tooth formed in an individual bone cavity in the dentary (state 1), this condition was observed in *Hydrocynus forskahlii* (Fig. 17), *Catoprion mento* (Fig. 60), *Exodon paradoxus*, *Acestrorhynchus microlepis* and *A. pantaneiro* and *Agoniates halecinus*.

56. Connection at symphysis between contralateral bony cavities where dentary replacement teeth are formed: (0) absent; (1) present. (CI = 1.000; RI = 1.000)

Some taxa such as the citharinids and distichodontids have replacement teeth on the dentary being formed in a single bony cavity with a single dorsal opening extending along the entire tooth row. The cavities of the contralateral dentaries are connected at the symphysis in these taxa (state 1, Fig. 46), this condition was observed in *Distichodus* by Roberts (1967). The most common condition observed is the complete separation between bony cavities on the dentary at the symphysis. State 1 was observed in all examined distichodontids.

57. Connection between depression on bone where replacement tooth of the parasymphyseal tooth is formed and bony cavity where remaining dentary teeth are formed: (0) absent; (1) present. (CI = 0.500; RI = 0.800)

The replacement tooth of the parasymphyseal tooth is formed in soft tissue associated to a depression on the lingual wall of the dentary. In Brycon and Triportheus this depression on the bone where the replacement tooth of the parasymphyseal tooth is formed and the bone cavity in which the replacement teeth of the main row are formed are clearly separated (state 0). In taxa such as *Brycinus, Micralestes acutidens*, *Phenacogrammus interruptus* and *Bryconalestes longipinnis* the depression is connected to the bony cavity where the replacement teeth of the other dentary teeth are formed (state 1, Fig. 20). This character was coded as inapplicable for taxa that lack a parasymphyseal tooth.

58. Orientation of developing replacement teeth on the medial group of the main tooth row on dentary: (0) with similar orientation to its respective functional tooth; (1) oriented in different way from its respective functional tooth. (Zanata & Vari, 2005: 47, character 91). (CI = 0.063; RI = 0.559)

The most common condition observed was the replacement teeth slightly displaced laterally and with similar orientation in relation to their respective functional teeth (state 0, Figs. 8, 9). Some taxa with enlarged unicuspid teeth such as cynodontids and *Agoniates halecinus* (Fig. 6) have replacement teeth on the dentary slanted in relation to their respective functional tooth, with cusp pointing laterally (state 1). Taxa with multicuspid teeth such as *Bryconamericus lethostigmus* also have the replacement teeth oriented in a different way in relation to their respective functional tooth (Fig. 33) Taxa with a single dentary teeth row had this row considered as homologous to the outer row of taxa with two rows.

Not utilized characters

NU 1. Arrangement of external tooth row of premaxilla: (0) continuous; (1) separated in medial and lateral series with gap.

This character was proposed by Mattox and Toledo-Piza (2012: 847, character 70), who stated that the most common condition among the taxa that have more than one premaxillary tooth row is to have the outer row teeth evenly spaced (state 0). Among the taxa that those authors coded as having a clear spacing dividing the outer row in a medial and a lateral series only *Exodon* was coded differently in the present study. This character was coded as inapplicable for *Exodon paradoxus* since we were not able to stablish the homology of the labially displaced mamilliform teeth with the outer row teeth of other taxa. Taxa with only one premaxillary teeth row were also coded as inapplicable. A condition as described by the authors was observed only in *Phenacogaster tegatus*, *Bryconops interruptus* and *Iguanodectes geisleri* were interpreted as having the state 0 and not 1 as interpreted by Mattox & Toledo-Piza, therefore this character was not used in the analysis and considered as an autapomorphy for *Phenacogaster tegatus*.

Phylogenetic analysis

The analysis resulted in a total of nine equally most parsimonious trees of length 29.02036. The strict consensus of all nine equally parsimonious trees is presented (Fig.). The nine equally most parsimonious trees obtained differ in the relations within clade 120 (comprising *Steindachnerina insculpta*, *Hemiodus microlepis*, *Bivibranchia fowleri* and *Apareiodon ibitiensis*) and within clade 116 for *Poptella compressa*, *Bryconops disruptus*, *Gymnocorymbus ternetzi* and *Astyanax multidens*. These four taxa did not form monophyletic groups among them, only successive sister groups within clade 116.

Lists of common synapomorphies and character modifications are presented in the appendix

Variation and distribution of characters related to dentition in Characiformes

In this section a discussion is presented about the evolution of the characters related to dentition among the suprageneric groups recognized within characiforms based on the variation observed in the taxa examined in the present study.

General characters

An exclusively unicuspid dentition (character 2) was the least common condition among examined taxa, present mainly in taxa with predatory behavior such as the Heterocharacinae, Cynodontidae, Cynopotamini, *Hepsetus odoe*, *Acestrorhynchus*, *Salminus brasiliensis*, *Hoplias malabaricus* and *Boulengerella*. Unicuspid teeth with lateral cutting-edges (character 7) are typical of predatorial taxa, in a similar way to the exclusively unicuspid dentition. Among examined taxa this condition was observed in representatives of Ctenoluciidae (*Boulengerella*), Bryconidae (*Salminus brasiliensis*), Erythrinidae (*Hoplias malabaricus*), Acestrorhynchidae (*Acestrorhynchus microlepis* and *A. pantaneiro*), Hepsetidae (*Hepsetus odoe*) and Cynodontidae (*Cynodon gibbus*, *Rhaphiodon vulpinus* and *Hydrolycus tatauaia*). In the current analysis this condition was optimized as a synapomorphy for a clade comprising the cited taxa. Unicuspid teeth with a constriction on the distal portion resulting in an abrupt taper (Character 6) were only observed in the examined representatives of the Heterocharacinae (*Heterocharax virgulatus*, *Lonchogenys ilisha* and *Roestes molossus*). This character possibly represents an additional synapomorphy for the Heterocharacinae *sensu* Mattox & Toledo-Piza (2012) and may be confirmed after the examination of the remaining genera in the subfamily (*Gilbertolus*, *Gnathocharax* and *Hoplocharax*). Exclusively unicuspid dentition is also present in some anostomids (*Abramites hypselonotus*, *Leporinus bahiensis* and *L. desmotes*), *Chilodus punctatus* and *Prochilodus lineatus* within the Anostomoidea. This condition is also present in the miniaturized taxa examined herein (*Trochilocharax ornatus* and *Lepidarchus adonis*). Mamilliform teeth outside the mouth (character 11) are present in *Roeboides affinis*, *Exodon paradoxus* and *Catoprion mento*. However, mamilliform teeth implanted on the labial surface of the maxilla (character 32) were only present in *Roeboides affinis* and *Exodon paradoxus*.

Bicuspid teeth (character 3) are only present in the Citharinidae and Distichodontidae. Multicuspid teeth with three or more cusps are restricted to the Characoidei, this condition was optimized as a synapomorphy for a clade comprising all the examined representatives of the Characoidei. Different types of multicuspid teeth occur among examined taxa with this tooth morphology. Multicuspid teeth with a distinct larger cusp (character 4) being the most common condition. Multicuspid teeth with all cusps of similar size are present in representatives of the Anostomidae (*Laemolyta proxima*), Parodontidae (*Parodon pongoensis*), Hemiodontidae (*Hemiodus microlepis*) and Lebiasinidae (*Nannostomus unifasciatus*). The arrangement of the cusps on multicuspid teeth generally results in the cusps diverging from each other, multicuspid teeth with cusps reaching the same transversal line distally (character 5) are present in all examined Citharinidae, in *Xenocharax spilurus*, *Laemolyta proxima*, *Parodon pongoensis* and *Nannostomus unifasciatus*.

Pleurodont tooth attachment (character 8) is only present in the examined representatives of the Anostomidae and Distichodontidae, except *Xenocharax spilurus*. This condition was previously reported for the Distichodontidae except *Xenocharax*, *Neolebias* and *Nannaethiops* by Vari (1979) but was not was not treated as a character in the phylogenetic studies of the Anostomidae (Vari, 1983 and Sidlauskas & Vari, 2008) further investigation is needed in order to test if the pleurodont implantation of teeth is an additional synapomorphy for the Anostomidae.

Interlocking mechanisms among adjacent teeth (character 9) was only observed in representatives of the Serrasalmidae (*Serrasalmus elongatus* and *Myloplus arnoldi*) in the present study. This condition was observed for some of the representatives of the Serrasalmidae by Machado-Allison (1983) and studied in detail by Kolmann *et al*. (2019). The presence of overlap between adjacent teeth but with no morphological modification such as those present in the Serrasalmidae, occurs in representatives of the Distichodontidae (*Ichthyborus quadrilineatus*), all examined representatives of the Anostomidae, *Prochilodus lineatus*, Hemiodontidae (*Hemiodus microlepis*), all examined Parodontidae, Lebiasinidae (*Nannostomus unifasciatus*), all examined Ctenoluciidae, Iguanodectidae (*Iguanodectes geisleri* and *Piabucus melanostoma*), all examined Cheirodontinae and the stevardiin *Bryconamericus lethostigmus*.

The ontogenetic shift from multicuspid to unicuspid teeth on both jaws (character 10) is restricted to *Hydrocynus forskahlii*. This condition was already reported for the genus by Brewster (1986) and recovered as a synapomorphy of the genus by Zanata & Vari (2005).

A synchronized unilateral pattern of tooth replacement occurs only in taxa with multicuspid dentition, e.g. in representatives of the Characidae, Serrasalmidae, Gasteropelecidae, Agoniatidae, Bryconidae, Chalceidae and Alestidae. A clear synchronized unilateral pattern of tooth replacement could not be clearly observed in

Lignobrycon myersi and *Serrapinnus calliurus*, possibly because of the few specimens available for the current study. Examination of additional material might result in the identification of the unilateral pattern in these taxa. Among examined taxa with the synchronized unilateral pattern. *Brycon falcatus* and *Chalceus epakros* have a sequential replacement mode, whereas *Astyanax novae* and *Serrasalmus elongatus* have a simultaneous replacement mode. A simultaneous pattern of replacement on both jaws is reported in the literature for anostomids (Roberts, 1967) and *Hydrocynus* (Gragiano *et al*., 1996), Examined anostomids had the developing replacement teeth in similar developmental stages in both right and left premaxilla and dentary, not contradicting what was reported by Roberts, however, further investigation, ideally as a horizontal study similar to the one conducted by Berkovitz (1975) is needed in order to confirm a synchronic replacement in Anostomidae. The lack of a clear temporal pattern of replacement was observed in taxa with simple unicuspid teeth. A wave pattern for the replacement of teeth on the premaxilla and dentary was proposed for *Oncorhynchus mykiss* (Berkovitz & Moore, 1974; 1975) and *Salmo salar* (Huysseune & Witten, 2006), both taxa have simple unicuspid teeth on both jaws. Further investigation is needed in order to test if this wave pattern of replacement is present in characiforms. The lack of a clear temporal pattern of replacement was also observed in taxa with several preformed replacement teeth like *Parodon pongoensis*, *Hemiodus microlepis* and *Prochilodus lineatus*. The high number of preformed replacement teeth might indicate frequent replacement events, but whether the replacement follows any temporal pattern is yet to be tested.

Heterodonty was observed in the three tooth bearing bones among the examined taxa. Heterodont premaxillary dentition (character 14) is present in all representatives of the Agoniatidae, Chalceidae, Cynodontidae and in *Hoplias malabaricus*, *Hepsetus odoe*, and *Acestrorhynchus*. Homodont premaxillary dentition is present in all examined representatives of the Anostomidae, Hemiodontidae, Parodontidae, and Ctenoluciidae. Within the Characidae the most common condition was the heterodont dentition except in *Charax stenopterus*, Cynopotamini, Aphyocharacinae and Stevardiinae. Most examined taxa had homodont maxillary dentition. Heterodont maxillary dentition (character 29) is present in *Microschemobrycon callops*, *Lebiasina* sp., *Lignobrycon myersi*, *Astyanax multidens*, *Chalceus epakros* and all examined *Brycon*, in these taxa the maxillary dentition is composed by multicuspid and conical teeth. *Exodon paradoxus* also has heterodont maxillary dentition comprised of mamilliform and conical teeth. In

Hoplias malabaricus, Hepsetus odoe and all examined *Acestrorhynchus* and cynodontids the heterodont dentition comprises unicuspid teeth with lateral cutting-edges and conical teeth. Alternatively, heterodont dentary dentition was the condition present in most examined taxa. Homodont dentition on the dentary (character 39) is present in predatory taxa with simple conical teeth such as the Cynopotamini, in *Boulengerella* the homodont dentition is composed of small unicuspid teeth with lateral-cutting edges curved laterally. Taxa with multicuspid teeth labiolingually compressed distally such as *Piabucus melanostoma*, *Nannostomus unifasciatus* and *Bryconamericus lethostigmus* also have homodont dentition on the dentary. Unicuspid teeth labiolingually compressed distally form the homodont dentition in the anostomids *Leporinus* and *Abramites hypselonotus*, *Prochilodus lineatus* and *Chilodus punctatus*.

The most common condition in the examined taxa is to have a single preformed replacement tooth for each functional tooth in the premaxilla (character 17), maxilla (character 30) and dentary (character 40). Two preformed replacement teeth for a given premaxillary functional tooth are present in *Hoplias malabaricus*, *Acestrorhynchus pantaneiro* and *Hydrolycus tatauaia*. Three or more preformed replacement teeth were observed in *Hepsetus odoe, Prochilodus lineatus, Hemiodus microlepis* and all examined Parodontidae. In *Hoplias*, *Acestrorhynchus, Hydrolycus* and *Hepsetus* the supranumerary replacement teeth were always observed for the larger teeth on the premaxilla. All examined parodontids and *Hemiodus microlepis* have two preformed replacement teeth for each functional maxillary tooth *Hoplias malabaricus* and *Hepsetus odoe* have three preformed replacement teeth for the largest maxillary tooth, similar to what was observed in the premaxilla. Two preformed replacement teeth for a single functional tooth on the dentary were observed in *Acestrorhynchus pantaneiro* and *Hepsetus odoe*. In *Prochilodus lineatus* and *Hoplias malabaricus* at least three preformed teeth were observed for a given functional tooth on the dentary. For *Hepsetus odoe, Hoplias malabaricus* and *Acestrorhynchus pantaneiro* the observed supranumerary preformed replacement teeth were observed for the largest functional teeth, similarly for what was observed for the premaxilla and maxilla. In *Prochilodus* however, all functional teeth on the dentary had at least three preformed replacement teeth.

Premaxilla

Among examined representatives of the Characoidei with two premaxillary tooth rows the replacement teeth of the outer row are formed in bony cavities whereas the replacement teeth of the inner row are formed in soft tissue. Taxa with a single premaxillary tooth row always had the replacement teeth formed in soft tissue. Therefore, the single premaxillary tooth row was considered as homologous to the inner row on the premaxilla of taxa with two or three premaxillary tooth rows. Alternatively, within examined representatives of the Citharinoidei only *Xenocharax spilurus* had two rows of teeth on the premaxilla, and in this species the replacement teeth of the outer row are formed in a bone cavity whereas the replacement teeth of the inner row are formed in soft tissue. All remaining examined Citharinoidei (*Citharinus citharu*, *Citharidium ansorgii*, *Ichthyborus quadrilineatus* and *Nannocharax multifasciatus*) have a single row of premaxillary teeth on the premaxilla, with replacement teeth formed in a bone cavity. Thus, the single row of premaxillary teeth of *Citharinus citharu*, *Citharidium ansorgii*, *Ichthyborus quadrilineatus* and *Nannocharax multifasciatus* is tentatively considered as homologous to the outer row of taxa with two premaxillary tooth rows.

Premaxillary teeth arranged in three rows (character 16) was observed in *Triportheus*, *Brycon* and *Chalceus* among examined taxa. The identity and homology of the tree rows of premaxillary teeth is discussed below in the section "Homology between premaxillary rows among taxa with one, two or three rows of functional teeth".

An edentulous premaxilla (character 13) was only observed in the single curimatid examined (*Steindachnerina insculpta*). The absence of dentary and premaxillary teeth was proposed as a synapomorphy for the Curimatidae by Vari (1983). Premaxillary teeth are also lacking in the hemiodontid *Anodus* Cuvier 1829. This genus was traditionally included in the Curimatidae, but Roberts (1974) and Vari (1989) further discussed that the similarities among *Anodus* and the curimatids apart from the lack of teeth were plesiomorphic.

The presence of additional cusps on the concave face of the multicuspid teeth on the inner row of the premaxilla (character 15) was only present in the Alestidae for the genera *Alestes*, *Bryconalestes* and *Brycinus*. This condition was also used as a character by Zanata & Vari (2005), the authors reported that this condition is also present in *Bryconaethiops*. Zanata & Vari (2005) questioned the homology between the additional cusps observed in *Bryconalestes* with the additional cusps observed in Alestes, *Bryconaethiops* and *Brycinus*. No morphological differences between the additional cusps present in the examined *Alestes* and *Brycinus* and those present in the examined *Bryconalestes*. Therefore, the condition present in these three genera was considered homologous herein.

Regarding the number of teeth on the outer row on the premaxilla (character 0), citharinids were the taxa with the highest counts (39 in *Citharidium ansorgii* and 34 in *Citharinus citharu*). Among distichodontids a trend towards a higher number was also observed (26 in *Ichthyborus quadrilineatus* and 16 in *Xenocharax spilurus*), *Nannocharax multifasciatus* is the exception with only six teeth on the outer row. Within the Characoidei taxa with the highest number of teeth on the outer row on the premaxilla are representatives of the Bryconidae (8-13 in *Salminus brasiliensis* and *Brycon amazonicus* respectively), Chalceidae (13 in *Chalceus epakros*) and Cynopotamini (9 in *Acestrocephalus stigmatus* and *Cynopotamus xinguano* and 11 in *Galeocharax gulo*). Low numbers of teeth on the outer row of the premaxilla is present in the Alestidae (3 in *Alestes*, *Bryconalestes* and *Micralestes* and 4 in *Brycinus*); Iguanodectidae (2 in *Iguanodectes geisleri* and 5 in *Bryconops disruptus*); Serrasalmidae (3 in *Myloplus arnoldi*); Stethaprioninae (4 in *Astyanax* and 5 in *Poptella compressa*) and Stevardiinae (3 in *Mimagoniates microlepis* and *Bryconamericus lethostigmus*).

The most common condition observed for the bony cavities in which the replacement teeth of the outer row of the premaxilla are formed (character 18) is the presence of a single cavity for all developing replacement teeth. Replacement teeth of the outer row of the premaxilla formed in individual bone cavities is present in *Mimagoniates microlepis*, *Agoniates halecinus* and *Phenacogrammus interruptus* and probably represent highly specialized conditions. The connection at the symphysis of the contralateral bone cavities in which the replacement teeth of the outer row of the premaxilla are formed (character 25) was only observed in the examined Citharinoidei. Most examined taxa had some kind of opening on the ventral surface of the premaxilla associated to the bone cavity in which the replacement teeth of the outer row are formed (character 20), either a single ventral opening along the entire cavity (Citharinoidei), individual bony cavities were observed in all remaining examined representatives of the Characoidei. The lack of opening on the bone cavity where the replacement teeth of the outer row of the premaxilla are formed (Character 19) was only observed in *Astyanax novae*, *Myloplus arnoldi*, *Alestes baremoze*, *Alestes macrophthalmus* and *Micralestes acutidens*.

Cusps arranged in a semicircle on the medialmost multicuspid tooth of the inner row of the premaxilla (character 21) was observed in *Astyanax novae*, *Myloplus arnoldi*, *Alestes baremoze*, *Alestes macrophthalmus*, *Brycinus sadleri*, *Brycinus lateralis*, *Brycinus imberi*, *Triportheus angulatus* and *Triportheus albus*. Zanata & Vari (2005: 34, character 63) semicircular arrangement of the cusps of the teeth on the inner row of the premaxilla for *Alestes*, *Brycinus*, *Bryconaethiops* and *Bryconalestes* and a similar condition in *Triportheus*. The authors considered the condition observed in the Alestidae as nonhomologous to that present in *Triportheus*. Similarly, we agree that the condition present in Alestidae, *Triportheus*, *Astyanax novae* and *Myloplus arnoldi* probably have evolved independently. Cusp arranged in a straight line was observed in taxa with multicuspid teeth labiolingually flattened distally such as *Hemiodus microlepis*, *Laemolyta proxima*, *Nannostomus unifasciatus*, *Piabucus melanostoma*, *Iguanodectes geisleri* and all examined Cheirodontinae. The remaining taxa had the cusps of this tooth arranged in an arched line. Mirande (2010: 422, character 127) reported an intermediate state between the semicircular arrangement and the cusps arranged in a shallow arch in *Bryconops affinis* which was coded as polymorphic by the author. The condition present in the examined species of *Bryconops* (*B. disruptus*) was cusps arranged in arched line.

Apart from taxa with mamilliform teeth on the labial surface of the premaxilla (*Exodon paradoxus*, *Roeboides affinis* and *Catoprion mento*), *Trochilocharax ornatus* also had labially displaced premaxillary teeth implanted on the labial surface of the premaxilla (character 22). This condition was optimized as a synapomorphy of a clade formed by the four cited taxa.

Pedicellate teeth on the inner row of the premaxilla (character 23) is present in all examined Alestidae except *Hydrocynus forskahlii* and *Lepidarchus adonis*. This condition was also observed in all examined hemiodontids, parodontids, cheirodontins, in *Iguanodectes geisleri*, *Piabucus melanostoma*, *Nannostomus unifasciatus*, *Laemolyta proxima*, *Serrasalmus elongatus* and *Bryconamericus lethostigmus*. *Bryconamericus* sp. was also coded as having pedicellate teeth, however, the condition in this taxon might not be homologous to that observed in the other cited taxa. In *Bryconamericus* sp. the teeth have a circular cross section along almost the entire length of the tooth and are “bulbous” distally whereas in the remaining taxa the teeth are somewhat labiolingually flattened distally.

Premaxillary teeth embedded in soft tissue (character 24) was observed in *Prochilodus lineatus*, *Chilodus punctatus* and all examined hemiodontids. The examined citharinids, parodontids and anostomids are similar in having premaxillary teeth directly associated to the bone but slightly mobile when manipulated. The remaining examined taxa have premaxillary teeth firmly implanted on the underlying bone. The condition present in the examined representatives of the Anostomidae deserves further investigation of the histological aspects of this implantation mode. Scharcasky & Lucena (2008) conducted a study of the histological characters of the teeth of anostomids among other taxa, however, the implantation mode of *Leporinus* was undetermined, but considered different from that of Prochilodontidae and Chilodontidae and that observed by the authors in Characidae, Acestrorhynchidae and Parodontidae.

Regarding the orientation of replacement teeth on the premaxilla the plesiomorphic condition for the outer row of the premaxilla is to have the developing replacement teeth oriented in a similar way to its respective functional tooth, as observed in all examined Citarinoidei. These replacement teeth are oriented differently in the examined Alestidae except *Hydrocynus forskahlii* and *Lepidarchus adonis*, all examined Stethaprioninae except *Astyanax multidens* in *Chalceus epakros*, *Iguanodectes geisleri*, *Mimagoniates microlepis*, *Lignobrycon myersi*, *Triportheus angulatus* and *Triportheus albus*. The replacement teeth of the inner row of the premaxillary are generally slanted, cusps pointing lingually. In all examined anostomids, *Prochilodus lineatus*, *Chilodus punctatus*, *Xenocharax spilurus*, *Charax stenopterus*, *Roestes molossus*, *Lonchogenys ilisha*, *Hoplias malabaricus* and *Acestrorhynchus*. Almost all of the taxa with the replacement teeth with similar orientation have simple unicuspid teeth in the inner row, except *Laemolyta proxima* and *Xenocharax spilurus*.

Maxilla

An edentulous maxilla (character 28) in present in the Anostomidae, Chilodontidae, Curimatidae and Prochilodontidae, a condition was considered synapomorphic for a group comprising these four families (Vari, 1983; Castro & Vari, 2004). All examined Alestidae, Crenuchidae and Serrasalmidae also lack maxillary teeth. Among the examined Citahrinoidei only *Xenocharax spilurus* have maxillary teeth. All examined Iguanodectidae lack maxillary teeth except *Piabucus melanostoma*.

Regarding the number of maxillary teeth (character 1) the highest counts were observed in the examined Cynodontidae (60 in *Cynodon gibbus*, 59 in *Hydrolycus tatauaia* and 49 in *Rhaphiodon vulpinus*) this high number of maxillary teeth was optimized as a synapomorphy for the group of these taxa in the current analysis. High number of maxillary teeth was also observed in the Bryconidae (22-20 in *Brycon pesu* and *Salminus brasiliensis* respectively); Heterocharacinae (26-52 in *Heterocharax virgulatus* and *Lonchogenys ilisha* respectively); *Agoniates halecinus* (30); *Hepsetus odoe* (33); *Hoplias malabaricus* (42); *Acestrorhynchus* (29 in *A. microlepis* and 35 in *A.*

pantaneiro) Characinae (30-50 in *Phenacogaster tegatus* and *Cynopotamus xinguano* respectively). A long maxilla with high number of teeth is probably associated to the trophic strategy of the cited taxa and possibly have evolved independently several times in Characiformes.

Among examined taxa, only *Aphyocharax difficilis*, *Trochilocharax ornatus* and *Boulengerella* have the toothed and edentulous portions of the maxilla of similar length (character 31). Taxa that have the toothed portion longer than the edentulous portion were generally taxa with high number of maxillary teeth except for *Bryconamericus lethostigmus* and *Hemiodus microlepis* that have wide maxillary tooth and a relatively short maxilla.

Maxillary replacement teeth formed in some kind of bone cavity (character 33) was only observed for the larger lateral cutting-edge bearing teeth of *Acestrorhynchus* and the mamilliform maxillary tooth of *Exodon paradoxus*. Otherwise this character was not very informative. Developing replacement teeth oriented in a similar way to their respective functional teeth in the maxilla (character 36) were only observed in all examined Lebiasinidae and Ctenoluciidae and in *Xenocharax spilurus*, *Hoplias malabaricus* and *Lonchogenys ilisha*. All other examined taxa had the maxillary replacement teeth oriented in a different way in relation to their respective functional tooth.

Pedicellate maxillary teeth were observed in all examined Parodontidae, Hemiodontidae and Cheirodontinae, this condition was also observed in Lebiasinidae (*Nannostomus unifasciatus*), Iguanodectidae (*Piabucus melanostoma*) and n *Bryconamericus lethostigmus* and *Triportheus angulatus*.

Maxillary teeth embedded in soft tissue (character 35) is present only in the examined Hemiodontidae. Maxillary teeth of the Parodontidae and *Xenocharax spilurus* are directly associated to the underlying bone but slightly mobile when manipulated. The implantation of maxillary teeth was not covered by Scharcansky & Lucena (2008), further investigation is necessary on the implantation mode of the maxillary dentition in Parodontidae.

The rounded alignment of the distal margins of the maxillary teeth due to gradual anteroposterior increase and decrease in size of teeth on anterior portion was corroborated as restricted to the Heterocharacini as proposed by Mattox & Toledo-Piza (2012), the representatives of the Heterocharacini examined herein represented by *Heterocharax virgulatus* and *Lonchogenys ilisha*.

Dentary

Lack of dentary teeth (character 38) is only present in the curimatid *Steindachnerina insculpta*, in all examined hemiodontids and in the parodontid *Apareiodon ibitiensis*. *Parodon pongoensis*, the other examined parodontid have only two labially cuspid teeth on the dentary, embedded in soft tissue.

A parasymphyseal tooth on the dentary (character 41) was observed for representatives of the Agoniatidae (*Triportheus albus*, *Triportheus angulatus* and *Agoniates halecinus*), Alestidae (*Alestes baremoze*, *Alestes macrophthalmus*, *Brycinus sadleri*, *Brycinus lateralis*, *Brycinus imberi*, *Bryconalestes longipinnis*, *Micralestes acutidens* and *Phenacogrammus interruptus*), Bryconidae (*Brycon amazonicus*, *Brycon falcatus* and *Brycon pesu*), Chalceidae (*Chalceus epakros*) and Serrasalmidae (*Myloplus arnoldi*). Among the cited taxa the most common condition was a conical parasymphyseal tooth (character 42), In *Chalceus epakros*, *Micralestes acutidens* and *Phenacogrammus interruptus* the parasymphyseal tooth was multicuspid. A single symphyseal tooth (character 43) was only observed in the distichodontid *Ichthyborus quadrilineatus*.

An inner row of small conical teeth on the dentary (character 44) was observed in representatives of the Bryconidae, Lebiasinidae, Crenuchidae, Hepsetidae and Chalceidae, in these taxa the inner row of conical teeth is relatively long and associated to the dorsal margin of the labial wall that forms the bone cavity in which the replacement teeth of the outer row are formed. Whereas in *Acestrocephalus stigmatus*, *Galeocharax gulo*, *Acestrorhynchus*, *Cynodon gibbus* and *Hydrolycus tatauaia* the inner row of conical teeth is shorter, restricted to the anterior portion of the dentary not associated to the bony cavity where the replacement teeth of the outer row are formed. Within the Heterocharacinae (*sensu* Mattox & Toledo-Piza, 2012) only *Heterocharax virgulatus* lacks an inner row of dentary teeth.

The labially displaced dentary teeth (character 45) of *Exodon paradoxus* and *Roeboides affinis* are mamilliform, whereas in *Trochilocharax* these teeth are conical. Labially displaced teeth were also observed in *Roestes molossus* and *Lonchogenys ilisha*, in these taxa the teeth are the characteristic distally constricted teeth of the examined Heterocharacinae (sensu Mattox & Toledo-Piza, 2012).

The main tooth row on the dentary not divided in two groups (character 46) was optimized as the plesiomorphic condition in Characiformes. The main row of teeth on the dentary is divided in two groups in several different families and subfamilies: in all examined Heterocharacinae, Cheirodontinae, Aphyocharacinae, Stethaprioninae and

Agoniatidae, in *Hoplias malabaricus*, *Acestrorhynchus*, *Rhaphiodon vulpinus*, *Hydrolycus tatauaia* and *Myloplus arnoldi*. Within the taxa with the main row separated in two groups the separation is abrupt (character 47) in the Heterocharacinae, Cynopotamini, Stethaprioninae, Agoniatidae, *Hoplias malabaricus*, *Acestrorhynchus*, *Rhaphiodon vulpinus*, *Hydrolycus tatauaia*, *Myloplus arnoldi* and *Aphyocharax difficilis*.

Pedicellate teeth on the dentary (character 48) were observed in all examined Lebiasinidae, Cheirodontinae, Serrasalmidae (except *Catoprion mento*) Distichodontidae (*Nannocharax multifasciatus*), Iguanodectidae, (except *Bryconops disruptus*), Alestidae (except *Lepidarchus adonis*) and *Bryconamericus lethostigmus*.

Dentary teeth embedded in soft tissue, not directly associated to the underlying bone (character 49) were observed in representative of the Prochilodontidae, Chilodontidae and the parodontid *Parodon pongoensis*. All examined anostomids, citharinids and *Xenocharax spilurus* had teeth directly associated to the underlying bone, but slightly mobile when manipulated. All other examined taxa had dentary teeth firmly attached to the underlying bone.

Dentary replacement teeth formed exclusively in soft tissue (character 50) were observed in the Chilodontidae and Prochilodontidae, both families have derived dentitions embedded in soft tissue with no direct contact to the underlying bone. *Trochilocharax ornatus*, *Lepidarchus adonis* also have the replacement teeth on the dentary formed in soft tissue, both taxa are small sized when adults, considered as miniaturized based on the definition of Weitzman & Vari (1988). The conical dentition of these two species, similar to that observed in larval Characiformes might be a reductive character. Dentary replacement teeth formed in the dentary were also observed in *Boulengerella*, another taxon with simple unicuspid dentition.

Most of the examined taxa have replacement teeth formed in some kind of bony cavity for at least a group of teeth in the dentary. The connection at the symphysis of the contralateral bone cavities in which the replacement teeth are formed in the dentary (character 56) was only observed in the examined Distichodontidae. Variation on the morphology of the bony cavity, orientation of the developing replacement teeth and the conformation of the openings associated to the bony cavities was observed. A shallow trench in which the replacement teeth of the main row of the dentary are formed slanted 90° in relation to their respective functional tooth (character 51) was only observed in the Cynodontidae and *Hepsetus odoe*. This condition was considered as a synapomorphy for the Cynodontidae by Toledo-Piza (2000: 54, character 37).

Individual dorsal openings on the bony cavity in which the replacement teeth of the medial group of the dentary are formed (character 52) were observed in most examined Characidae (except *Serrapinnus calliurus* and *Microschemobrycon callops*) and in the Agoniatidae and *Acestrorhynchus*. A single dorsal opening was observed in the Citharinoidei, Anostomidae, Lebiasinidae, Crenuchidae, Bryconidae and Alestidae. An ample ventral opening on the bone cavity in which the replacement teeth of the dentary are formed (character 54) was only observed on the examined representatives of the Anostomidae. This condition was considered as a synapomorphy of Anostomidae by Vari (1983) and confirmed as such by Sidlauskas & Vari (2008). The replacement teeth on the dentary formed in bony cavities without any openings (character 53) was only observed in the examined Serrasalminae (*Serrasalmus elongatus* and *Catoprion mento*), the examination of additional representatives of this subfamily is needed in order to test if this condition is an additional synapomorphy for this clade.

At least one replacement tooth formed in an individual bony cavity in the dentary (character 55) was observed in *Agoniates halecinus*, *Acestrorhynchus pantaneiro* and *Acestrorhynchus microlepis*, in these taxa the replacement tooth of the largest dentary tooth is formed in an individual bone cavity on the anterior portion of the dentary. In *Hydrocynus forskahlii* the replacement teeth of the two anteriormost functional teeth are formed in individual bony cavities. In *Catoprion mento* the replacement tooth of the posteriormost functional tooth is the one formed in an individual bony cavity. Whereas in *Roeboides affinis* and *Exodon paradoxus* the mamilliform teeth are the ones formed in single bony cavities.

The replacement teeth of the parasymphyseal tooth and of the remaining dentary teeth being formed in a single bone cavity (character 57) was only observed in the examined Alestidae except *Hydrocynus forskahlii* and *Lepidarchus adonis*.

The orientation of the developing replacement teeth on the dentary (character 58) was not very informative. The replacement teeth oriented in a similar way in relation to the respective functional tooth was optimized as the plesiomorphic condition and was observed in all examined Citharinoidei, Anostomidae, Serrasalmidae, Crenuchidae, Bryconidae, Cynopotamini, Triportheus, *Hoplias malabaricus*, *Roestes molossus*, *Lonchogenys ilisha*, *Gymnocorymbus ternetzi*, *Astyanax*, *Charax stenopterus*, *Microschemobrycon callops* and *Bryconamericus* sp., the remaining taxa all had the developing replacement teeth on the dentary oriented differently from their respective functional tooth.

Anostomidae

Two characters resulted in synapomorphies for the four anostomid species representing three of the 14 genera included in the family: character 8: (0>1) pleurodont tooth attachment, this condition is also present in the examined Distichodontidae. Character 54: (0>1) replacement teeth on the dentary formed in single bony cavity with ample ventral opening, this condition was recovered as an exclusive synapomorphy for the group. The pleurodont tooth attachment in anostomid was mentioned by Sidlauskas & Vari (2008), but the authors did not treat it as a character "the anterior wall of the trench serves as the area of attachment on the jaw for the pleurodont functional teeth (e.g. *Leporinus obtusidens*, Trapani, 2001: fig. 6)." (Sidlauskas & Vari, 2008: 122). Replacement teeth on the dentary formed in single bony cavity with ample ventral opening was already regarded as derived for the Anostomidae by Vari (1983). This condition was hypothesized as a synapomorphy for the Anostomidae but not recovered by the authors as such (Sidlauskas & Vari, 2008: 112. Further investigation is needed on anostomid tooth implantation mode in order to test if it is a synapomorphy for the family. Among the synapomorphies proposed by Vari (1983) and Sidlauskas & Vari (2008) for the Anostomidae three are related to dentition: four teeth on the premaxilla (character 31); dentary teeth spade or chisel-shaped, tapering to pointed or blunt distal margin with or without additional cusping (character 37) and dentary teeth with large, well-developed posterior lamina (character 38).

Characoidei

All representatives of the Characoidei included in the current study, representing 61 of the 254 recognized genera, were recovered as a monophyletic group (clade 81) with two synapomorphies: 3: (0>1) the presence of multicuspid teeth with three or more cusps, this condition was optimized as an exclusive synapomorphy for the group. Character 9: (0>1) the overlap among adjacent teeth without morphological modifications, this condition was also observed in the distichodontid *Ichthyborus quadrilineatus*.

Cynopotamini

Four characters are proposed as synapomorphies for the three examined genera of the Cynopotamini (clade 84). Character 0: (0.162>0.189) nine teeth on the outer row of the premaxilla, the Cynopotamini are among the examined Characoidei with the higher number of teeth on the outer row of the premaxilla along with the examined Bryconidae. Character 16 (0>1) two rows of premaxillary teeth, this condition was highly homoplastic in the current analysis, being present in several other taxa. Character 33 (1>0) replacement teeth of the premaxilla formed in soft tissue without any modification to the underlying bone. Character 58 (1>0) and the replacement teeth of the dentary oriented in a similar way to their respective functional tooth. The relationship between these three genera has been recovered within the characinae (Mattox & Toledo-Piza, 2012; Mirande 2010; 2019) but none of the synapomorphies listed by the authors are related to dentition.

Acestrorhynchus

Three characters were herein proposed as synapomorphic for the two species of *Acestrorhynchus* included in the current study (*A. pantaneiro* and *A. microlepis*). Character 33: (0>2) replacement teeth on the maxilla formed in some kind of bony cavity, this condition was also observed in *Exodon paradoxus*. Character 52 (0>1) replacement teeth on the dentary formed in bony cavity with individual dorsal openings. Character 55: (0>1) at least on replacement tooth on the dentary formed in and individual bony cavity, condition also observed in *Hydrocynus forskahlii*, *Roeboides affinis*, *Exodon paradoxus* and *Catoprion mento*. Among the 28 unambiguous synapomorphies proposed for the genus by Toledo-Piza (2007) four are related to dentition. The proposed characters herein might be additional synapomorphies for the genus.

Boulengerella

Three characters are proposed herein as synapomorphic for the two species of Boulengerella included in the current study (*B. maculata* and *B. lateristriga*). Character 9 (0>1) overlap among adjacent teeth without morphological modifications. Character 31 (1>2) toothed and edentulous margins of the maxilla with similar length, this condition is also present in *Trochilocharax ornatus* and *Aphyocharax difficilis*. Character 36: (1>0) replacement teeth on the maxilla with similar orientation to their respective functional tooth. A similar condition to the overlap among adjacent teeth without morphological modification (character 9 of the current study) was reported as a synapomorphy for Ctenoluciidae by Vari (1995: 39) “the posteriorly recurved crowns on the numerous teeth on each jaw” the posterior curvature reported by the author result in the overlap among adjacent teeth. Vari (1995) recovered Boulengerella as a monophyletic group based on 17 synapomorphies one of which is dentition-related: “The acute angle at which the rows of teeth of the contralateral premaxilla meet anteriorly”, such characteristic was not included in the current analysis.

Brycinus

Four teeth on the outer row of the premaxilla was herein recovered as a synapomorphy for all three examined species of *Brycinus* (*B. sadleri*, *B. lateralis* and *B. imberi*) character 0: (0.027>0.054). This condition was also recovered as a synapomorphy for the genus by Zanata & Vari (2005).

Cynodontidae

All examined representatives of the Cynodontidae (*Cynodon gibbus*, *Rhaphiodon vulpinus*, *Hydrolycus tatauaia*) were recovered as a monophyletic group (clade 138) based on an ambiguous synapomorphy: character 1: 0.542-0.576>0.814-0.983. The examined cynodontids were among the taxa with the higher number of maxillary teeth (60 in *Cynodon gibbus*, 59 in *Hydrolycus tatauaia* and 49 in *Rhaphiodon vulpinus*), *Lonchogenys ilisha*, with 52 and *Cynopotamus xinguano* with 50 maxillary teeth was the only examined taxa outside the Cynodontidae with such high number of maxillary teeth. Among the 24 synapomorphies proposed by Toledo-Piza for the Cynodontidae two are related to dentition. The high number of maxillary teeth is a possible additional synapomorphy for the family.

Heterocharacinae

A distinct morphology of the unicuspid teeth present in all representatives of the Heterocharacinae examined herein (*Roestes molossus*, *Lonchogenys ilisha* and *Heterocharax virgulatus*), character 6: (0>1) unicuspid teeth with distal portion tapering abruptly is herein proposed as synapomorphy for these a clade composed by these three taxa (clade 141). This condition is not present in any other examined taxa. A monophyletic group containing the three cited genera along with *Gilbertolus*, *Gnathocharax Hoplocharax* was recovered by Mattox & Toledo-Piza (2012), no dentition related character was listed by the seven proposed synapomorphies that support their assemblage. The derived tooth morphology described herein could be a new morphological character supporting the Heterocharacinae.

Distichodontidae

All examined representatives of the Distichodontidae (*Xenocharax spilurus*, *Nannocharax multifasciatus* and *Ichthyborus quadrilineatus*) were recovered as a monophyletic group based on a single exclusive synapomorphy: connection at symphysis between contralateral bony cavities where dentary replacement teeth are formed (character 56: 0>1). According to Vari (1979: 266) *Xenocharax* along with *Nannaethiops* and *Neolebias* have the plesiomorphic condition of shallow premaxillary replacement tooth trenches, opposed to the expanded, bulbous cavities broadly open to their partners across the symphysis. The bone cavities in the dentary of *Xenocharax spilurus* are indeed less developed than those of *Nannocharax multifasciatus* and *Ichthyborus quadrilineatus* but all three taxa share the derived condition of the connection of the contralateral bone cavities at the symphysis.

Ontogenetic variation of dentition in selected characiform species

Alestidae

Alestes macrophthalmus BMNH 1985.6.13.15-17 (2 C&S 44.1 mm SL and 46.0 mm SL) and BMNH 1955.12.20.670 (73.3 mm SL) and ***Alestes baremoze*** BMNH 1982.13.554-557 (3 C&S 68.1 – 74.0 mm SL)

There is ontogenetic variation in the presence of additional cusps on the concave face of the premaxillary teeth. Smaller specimens (44.1 and 61.2 mm SL) had only one additional cusp in the second medialmost tooth, on the margin closest to the symphysis. Specimens larger than 70.0 mm SL have two additional cusps on that tooth, one on each lateral margin of the concave face. In a similar manner, smaller specimens lack the additional cusps on the concave face of the third medialmost tooth (vs. present on the specimen larger than 70 mm SL).

Brycinus ferox BMNH 1981.2.17. 1506-1558 (42.0 mm SL); BMNH 1981.8.21.11-15 (6 C&S 13.6 – 29.1 mm SL)

Specimens smaller than 16.1 mm SL have only conical teeth. In the 16.1 mm SL specimen, there is a tricuspid tooth being formed in the premaxilla, as a replacement tooth of a functional tooth on the inner row

In one examined specimen (16.1 mm SL) the right dentary has only unicuspid teeth whereas in the left dentary the teeth are undergoing replacement and three tricuspid teeth are visible migrating to their functional positions (Fig. 64)

A larger specimen (29.1 mm SL) has multicuspid teeth on the dentary and premaxilla, the functional teeth are already arranged in two rows in the premaxilla.

Hydrocynus forskahlii BMNH 1981.2.17.760-764 (3 C&S 33.6 - 50.9 mm SL)

The smallest examine specimen (33.6 mm SL) had teeth with up to five cusps on the premaxilla and up to four on the dentary. In a slightly larger specimen (44.1 mm SL) the medialmost teeth have a lower number of cusps. In the largest examined specimen (50.9 mm SL), the medialmost teeth is almost unicuspid, with rudimentary lateral cusps. The lateralmost teeth both on the premaxilla and dentary are still tricuspid.

Anostomidae

***Leporinus* sp**. (uncatalogued 5 C&S 8.7mm NL – 25.3 mm SL)

Premaxilla: At 8.7 mm NL there are ten conical teeth; and in in a 9.7 mm NL specimen the teeth are conspicuously curved lingually. By 11.1 mm NL 19 small conical teeth are present resulting in a comb-like aspect. At 25.3 mm SL the dentition is similar to the condition observed in adults with four teeth of similar size except for the fourth medialmost tooth which is conical.

Maxilla: teeth absent.

Dentary: At 8.7 mm NL eight conical teeth are present. At 9.7 mm NL there are three to four posteriormost teeth larger than those on the premaxilla. By 11.0 mm NL there are 14 long conical teeth curved lingually. At 25.3 mm SL the dentition is similar to the condition observed in the adults with five teeth with irregular distal margins, the medialmost tooth is larger and the two lateralmost teeth are rod-like and smaller than the rest.

Bryconidae

Brycon orthotaenia (uncatalogued, 6 C&S 14.7 mm NL – 35.9 mm SL)

Premaxilla: At 14.7 mm NL around 20 conical teeth are present along the entire ventral margin of the bone, which is posteriorly elongated, forming the entire dorsal margin of the mouth gape. By 29.5 mm SL there are about 30 conical teeth barely organized in two rows, with some of the teeth closest to the symphysis larger than the others. Several teeth with bases not stained with alizarin, probably at the final stages of replacement. At 35.9 mm SL there are about 20 teeth on the premaxilla arranged in two rows, which are more organized than at 29.5 mm SL. Some teeth closer to the symphysis with distinct morphology, they are also unicuspid but with a wider base.

Maxilla: At 14.7 mm NL teeth are absent. By 29.5 mm SL there is a single row of five to ten small conical teeth along the ventral margin of the posterior half of the bone. Several teeth with bases not stained with alizarin, probably at final stages of replacement. At 35.9 mm SL there is a single row of about 15 thin conical teeth posteriorly curved extending along the ventral margin of the posterior half of the bone.

Dentary: At 14.7 mm NL there is a single row of 17 elongated conical teeth along almost the entire dorsal margin of the bone. By 29.5 mm SL there are about 30 teeth barely organized in two rows. Several teeth with bases not stained with alizarin, probably at the final stages of replacement. At 35.9 mm SL there is a total of 25-28 teeth, clearly organized in two rows on the anterior portion, where the teeth are posteriorly curved and slightly larger. Between the two rows on the anterior portion there is a developing replacement tooth with distinct morphology, conical, not curved and with a wide base. Posteriormost teeth smaller than the rest, thin and slightly curved.

General observation: the several teeth with the base not stained by alizarin in 29.5 mm SL might suggest frequent replacement cycles.

Characidae

Astyanax lacustris (95 C&S 2.9 mm NL – 20.7 mm SL)

Premaxilla: By 5.1 mm NL the premaxilla has two small conical teeth. At 11.0 mm SL the premaxilla has around 11 teeth slightly smaller than the ones on the outer row of the dentary, tooth row somewhat disorganized. At 14.0 mm SL the premaxillary replacement teeth are tricuspid and formed in soft tissue slanted in relation to the respective functional tooth, cusp pointing lingually, as they are in adults. At 19.7 there is evidence of simultaneous unilateral pattern of replacement (Fig. 65). By 20.7 mm SL, there are two distinct rows of multicuspid teeth, similar to the condition observed in adults.

Maxilla: Teeth absent.

Dentary: At 5.1 mm NL the dentary already has three small conical teeth. By 5.8 mm NL there are six or seven small conical teeth restricted to the anterior portion of the dentary. At 11.0 mm SL There are two rows of teeth separated by a bony cavity where replacement teeth of the outer row are formed. The outer row is formed by three larger, stouter conical teeth with wide base and the inner row by more numerous small teeth. By

14.0 mm SL the dentary teeth are larger and some already have additional lateral cusps, the replacement teeth are already formed intraosseously. Small conical teeth are restricted to the portion of the dentary that is laterally overlapped by the maxilla when the mouth is closed. At 19.7 there is evidence of simultaneous unilateral pattern of replacement (Fig. 66). By 20.7 mm SL the dentition is similar to the one observed in adults.

Ctenoluciidae

Ctenolucius hujeta (94 C&S 3.8 mm SL – 29.4 mm SL)

Premaxilla: At 4.7 mm NL there is a single conical tooth on the medial region of the premaxilla. By 7.0 mm SL there are five teeth on each premaxilla. At 9.3 mm SL there are 10 conical teeth, the contralateral rows not yet reaching each other medially. By 29.4 mm SL the teeth on the posterior portion of the premaxilla are curved posteriorly with cutting edge anteriorly, medialmost teeth more conical in shape, with no cutting edges but also curved posteriorly. At 30.0 mm SL the largest tooth on the "inner row" of the premaxilla as observed in the adults is present.

Maxilla: At 9.3 mm SL the maxilla bears four conical teeth. By 29.4 mm SL the maxilla has the same aspect and association to the premaxilla as the adult. At this size there are ten conical teeth with no cutting edges, slightly smaller than the ones on the premaxilla and dentary.

Dentary: At 3.8 mm NL the dentary already has one conical tooth. By 4.7 mm NL there are five conical teeth posteriorly curved. At 7.0 mm SL there are six teeth more spaced between each other when compared to the premaxillary teeth. By 9.3 mm SL there are 14 teeth, there is already evidence of replacement, teeth with base not stained with alizarin. At 10.9 mm SL the teeth arranged in two rows, overlapping at around the mid-point of the dorsal margin of the dentary. By 19.9 mm SL there are clearly two rows of teeth, inner row starting at half the length of the dentary, with smaller teeth. Outer row with larger teeth, replacement teeth formed in bone cavities, slanted, cusps pointing posteriorly, while the replacement teeth of the inner row are formed in soft tissue, not as much posteriorly rotated. At 29.4 mm SL the teeth of outer row resemble the ones of the adult, curved posteriorly, with a cutting edge anteriorly. Inner row formed by conical teeth smaller than the ones of the outer row.

Prochilodontidae

***Prochilodus* sp.** (uncatalogued, 6 C&S 12.1 mm NL – 32.2 mm SL)

Premaxilla: At 12.1 mm NL there are six conical teeth. By 32.2 mm SL the observed dentition is already similar to that observed in adults, with teeth not directly associated to the underlying bone.

Maxilla: teeth absent

Dentary: At 12.1 mm NL there are six conical teeth slightly larger than the premaxillary teeth. By 32.2 mm SL the observed dentition is already similar to that observed in adults, with teeth not directly associated to the underlying bone.

Serrasalmidae

Colossoma macropomum (uncatalogued, 9 C&S 5.4 mm NL – 19.3 mm SL)

Premaxilla: At 12.0 mm NL there is a single conical tooth on the left premaxilla, slightly smaller than the dentary teeth, right premaxilla edentulous. By 15.0 mm SL seven conical teeth are visible. At 19.3 mm SL there are six to seven conical teeth alternating in size, replacement teeth already visible, slanted lingually.

Maxilla: teeth absent

Dentary: At 12.0 mm NL there are three small conical teeth located near the symphysis. By 15.0 mm SL there are seven to eight conical teeth, the anteriormost being labially displaced. At 19.3 mm SL the teeth are arranged in two rows, the outer row composed of three L-shaped teeth, base of tooth associated to the labial surface of the dentary, the inner row composed by seven to eight conical teeth smaller than the ones on the outer row.

Ectopterygoid: at 19.3 mm SL: two conical teeth on the left ectopterygoid and one on the right ectopterygoid. Replacement teeth visible, slanted anteriorly.

Cleared and stained specimens larger than 19.3 mm SL (smallest examined 12.0 mm SL) do not have teeth on the ectopterygoid. On these specimens it is possible to observe the increase in tooth size throughout the successive replacement cycles, one side with clearly larger teeth than the other, condition more evident on the dentary.

Discussion

Homology between premaxillary rows among taxa with one, two or three rows of functional teeth.

Within examined taxa, premaxillary teeth can be arranged in one up to three rows of teeth, except for the edentulous curimatids. Within the Citharinoidei, *Xenocharax* *spilurus* has two rows of premaxillary teeth. The replacement teeth of the outer row are formed in a bony cavity whereas the replacement teeth of the inner row are formed in soft tissue, the remaining Cithrinoidei examined herein (*Citharinus citharu*, *Citharidium ansorgii*, *Nannocharax multifasciatus* and *Ichthyborus quadrilineatus*) had a single row of premaxillary teeth with replacement teeth formed inside a bony cavity. This might indicate that the outer row observed in *Xenocharax spilurus* is homologous to the single row of premaxillary teeth of the remaining Citharinoidei.

Within the Characoidei the most common condition among the Characidae and most Alestidae is the presence of two rows of functional teeth on the premaxilla, an outer row with replacement teeth formed in bony cavity and an inner row with replacement teeth formed in soft tissue. Among other taxa such as the Anostomidae, Aphyocharacinae, Cheirodontinae, Chilodontidae, Citharinidae, Crenuchidae, Cynodontidae, Erythrinidae, Gasteropelecidae, Hemiodontidae, Lebiasinidae and Parodontidae the premaxillary teeth are arranged in a single row, in all of the representative of the mentioned taxa the replacement teeth of the single row of premaxillary teeth are formed in soft tissue. This could point to a possible homology between the inner row of premaxillary teeth of taxa with two rows of premaxillary teeth (Characidae, Alestidae) and the single row of teeth on the premaxilla of the Anostomidae, Aphyocharacinae, Cheirodontinae, Chilodontidae, Citharinidae, Crenuchidae, Cynodontidae, Erythrinidae, Gasteropelecidae, Hemiodontidae, Lebiasinidae and Parodontidae.

Taxa such as *Triportheus*, *Chalceus* and *Brycon* have three rows of premaxillary teeth. Given the mode of formation of replacement teeth of the teeth on the middle row it is more likely that they are related to the outer row teeth. According to Roberts (1967) the explanation of the origin of a third row of functional premaxillary teeth involving preformed replacement teeth is worth considering "Ordinarily the replacement teeth do not come into functional position unless some of the functional teeth are lost or shed, but in the phylogeny of *Brycon* an entire row of replacement teeth may have been added to the functional dentition" (Roberts, 1967: 241). In this manner the middle row of premaxillary teeth in these three genera would be a duplication of the outer row, since both outer and middle row have replacement teeth formed in bony cavities. The use of the replacement teeth formation mode results in alternative interpretations of the identity of teeth rows in some taxa. ***Brycon*:** Lima (2017) in the revision of the cis-andean species of the genus follows an interpretation fist advanced by Bölke (1958: 68) and adopted by Howes (1982: 2) "to consider the outer series formed by small teeth as the first series, the pair of enlarged teeth near the symphysis of the premaxillary as the third series, and the middle-sized teeth situated at the inner (lingual), lateral border of the premaxillary and between the first, outer series and the inner, third series in the middle portion of the premaxillary as being the second series" (Lima, 2017: 8, Figs. 1 and 2). Given this interpretation the middle row would have a composite of replacement teeth formation modes, the medialmost teeth with replacement teeth formed in bony cavity and the lateralmost with replacement teeth formed in soft tissue. Additionally, the outer row would have replacement teeth formed in a bony cavity and the inner row, composed of two enlarged teeth near the symphysis, would have replacement teeth formed in soft tissue, it seems that the tooth morphology and the relative position are important for this interpretation. Changes in tooth morphology and arrangement along the ontogeny are related to successive replacement cycles (Trapani, 2005), hence the replacement teeth formation mode are taken into account in the interpretation of the identity of teeth rows herein. In our interpretation the premaxillary dentition of *Brycon* is arranged in an outer row of tricuspid teeth with replacement teeth formed in bony cavity, a middle row of tricuspid teeth, slightly larger than those on outer row and with replacement teeth formed in bony cavities as well, and an inner row of teeth with different morphologies among them but all with replacement teeth formed in soft tissue. This new interpretation concurs with the definition of the premaxillary teeth rows in *Chalceus* presented by Zanata & Toledo-Piza (2004) and points to a great similarity between the three examined genera bearing three rows of premaxillary teeth (*Brycon*, *Chalceus* and *Triportheus*). ***Mimagoniates*:** Menezes & Weitzman (2009) stated that the premaxillary teeth of *Mimagoniates* are arranged in one irregular row, forming a single unit. The premaxillary teeth of *Mimagoniates microlepis* specimens examined herein (see description) are similar in morphology and irregularly arranged. However, when we take the replacement teeth formation mode into account it is possible to discriminate the premaxillary teeth in two separate rows, an outer row with two or three teeth with replacement teeth formed in a bony cavity and an inner row with six or seven teeth with replacement teeth formed in soft tissue. ***Bryconamericus lethostigmus*:** Hirschmann *et al*. (2017) reallocated *Odontostoechus lethostigmus* Gomes 1947 to *Bryconamericus* the authors justify their decision based on previous studies that showed that this species would be more closely related to species of *Bryconamericus sensu stricto* (Mirande, 2010; Javonillo *et al*., 2010; Oliveira *et al*., 2011; Thomaz *et al*. 2015) rather than closely related to *Bryconacidnus*, *Ceratobranchia*, *Monotocheirodon*, *Othonocheirodus*, *Rhinopetitia*, and *Rhinobrycon*

(Böhlke, 1954; Menezes et al., 2013; Netto-Ferreira et al., 2014), according to the authors the second hypothesis were based on direct observations of mouth shape and had not been subjected to congruence tests of homology. Hirschmann *et al*. (2017) stated that the apparently single row of premaxillary teeth of *Bryconamericus lethostigmus* that served as evidence to assign this species to the Cheirodontinae (Malabarba, 1998), is the merging of two separate teeth rows. Indeed, the two examined *B. lethostigmus* examined herein show a seemingly single row of premaxillary teeth, however when the replacement teeth formation mode is taken into account it is possible two distinguish two teeth groups one with replacement teeth formed in soft tissue and another one with replacement teeth formed in soft tissue (Fig. 31). The single tooth row is also interpreted herein as the result of the merging of two rows. Hirschmann *et al*. (2017) state this merge occurs along the ontogeny, However, the smallest *B. lethostigmus* examined herein (40.6 mm SL) already had the premaxillary teeth with same morphology and clearly arranged in a single row topologically diverging from what is recorded by Hirschmann *et al*. (2017, Figs. 4 and 5), that stated that specimen up to 40 mm SL "with well-defined double or single series, or in most cases with teeth of inner and outer rows partially merged in single series". Unfortunately, the authors did not mention differences in replacement teeth formation modes, and we did not have access to specimens smaller than 40 mm SL.

The use of information on the formation of replacement teeth also allows the identification of two distinct groups of teeth on the main row on the dentary. Taxa such as *Acestrocephalus stigmatus* have only conical teeth on the dentary, however it is possible to divide the dentary teeth in a medial group of larger conical teeth with replacement teeth formed inside bone cavities and a lateral group of smaller conical teeth with replacement teeth formed in soft tissue (Fig. 27) In other taxa the separation between medial and lateral groups is easier due to heterodonty, the medial group is composed of multicuspid teeth with replacement teeth formed in bony cavities whereas the lateral group is formed by small conical teeth with replacement teeth formed in soft tissue (*Poptella compressa*, Fig. 30). The difference observed on the formation of the replacement teeth of these tooth groups are a consequence of ontogenetic modifications on the dentary dentition. Roberts (1967) stated that the lateral group of small unicuspid dentary teeth in taxa with modified dentition *e. g*. members of the "Ichthyboridae", entire subfamily "Nannostominae", *Chalcinus* (= *Triportheus*) would be a retention of the primitive condition present on the young specimens. This was corroborated herein, the retention of small conical teeth on the lateral portion of the dentary was observed in the ontogeny of *Astyanax lacustris*, specimens smaller than 11.0 mm SL have a somewhat disorganized row of conical teeth on the dentary, with several replacement teeth being formed, from 11.0 mm SL forward the teeth on the dentary are separated by a bone cavity where larger teeth start to be formed. At 14.0 mm SL multicuspid teeth are formed inside that bone cavity on the medial portion of the dentary, along the development the medialmost portion of the dentary no longer has unicuspid teeth only multicuspid teeth whereas the lateralmost portion of the dentary still has the same conical teeth, that will be retained even in the adult specimens. This probably is the case for *Poptella compressa*, information on the ontogeny of the dentition within the Characinae is lacking, investigation is needed in order to corroborate that the lateral group of small conical teeth on the dentary of *Acestrocephalus stigmatus* is a retention of the dentition observed in larval stages.

Intra- and extraosseous development of replacement teeth

Trapani (2001) conducted a survey of the position of developing replacement teeth among teleosts, based upon a literature review and the examination of skeletal material. In that paper the author distinguishes two conditions "Replacement teeth may develop in the soft tissue outside the bone ("extraosseous" development; *e. g.* cyprinids) or inside bony crypts, in a fashion sometimes superficially resembling replacement in mammals ("intraosseous" development; *e. g.* cichlids)". The author also suggested that the intraosseous development evolved in three separate lineages of teleosts, in the branchial and palatal dentitions of *Albula*, in the oral and/or pharyngeal dentitions of some acanthopterygians, and in the oral dentition of some Characiformes. Among Characiformes the author examined the following taxa: *Leporinus obtusidens*, *Schizodon fasciatus* (Anostomidae); *Alestes lateralis* (Alestidae); *Hydrolycus scomberoides* (Cynodontidae); *Salminus maxillosus* (Characidae); *Hoplias malabaricus* (Erythrinidae) and *Hepsetus odoe* (Hepsetidae) and gathered information from the literature for the following taxa: *Serrasalmus/Pygocentrus* (Serrasalmidae); *Ctenolucius* sp. (Ctenoluciidae) and *Saccodon* spp. (Parodontidae).

Even in a small sampling, considering the taxonomical and morphological diversity among the Characiformes, the author described some intermediate conditions between intra- and extraosseous replacement teeth development along the examined taxa and stated that: "the distinction between intra- and extraosseous becomes somewhat arbitrary in a few cases within the group. I have opted to be conservative and use the term intraosseous only when developing teeth are completely encased by bone". Thus, the only taxa that are reported by Trapani (2001) as having replacement teeth developing intraosseosly were *Serrasalmus*/*Pygocentrus*.

As shown in the results section, an extensive diversity of replacement teeth development is present in Characiformes, from exclusively extraosseous with no modification of the bone tissue of the jaws present in taxa with less modified dentition, such as *Boulengerella* as well as in taxa with extremely derived dentition such as *Prochilodus* to development teeth developing intraosseously sensu Trapani (2001) completely encased by bone as observed in *Serrasalmus elongatus* and *Catoprion mento*. Intermediate conditions are present in several taxa, such as the replacement tooth of parasymphyseal tooth of *Brycon*, *Triportheus* and *Myloplus* that is formed in soft tissue, but associated to a depression on the lingual surface of the dentary, The replacement teeth on the maxilla of *Bryconamericus lethostigmus* are formed in soft tissue associated to a depression that runs along the base of the maxillary tooth row. The replacement teeth of the dentary in cynodontids and *Hepsetus* are formed in a shallow trench. The replacement teeth of the medial group on the main row of the dentary of the *Carnegiella strigata* and *Mimagoniates microlepis* are formed in a single bony cavity with individual dorsal opening associated to each developing replacement tooth.

The formation of replacement teeth in Characiformes is extremely diverse, blurring the simple division between extra- and intraosseous development, this dichotomy does not reflect the diversity observed herein.

Spatial and temporal replacement patterns

According to Roberts (1967) in characiforms with numerous unicuspid teeth such as *Hepsetus*, *Hoplias*, *Salminus* and *Ctenolucius* the production and replacement of teeth appears haphazard and may actually occur randomly. The author also suggested that a polymodal replacement progressing simultaneously down the length of the jaws is widespread in lower vertebrates and might be present in *Rhaphiodon vulpinus*. Berkovitz & Moore (1974, 1975) in a longitudinal study on the salmoniform *Salmo gairdnerii* (= *Oncorhynchus mykiss*) trying to establish what are the replacement patterns in the lower and upper jaw teeth of that species, stated that the dentary teeth are replaced in waves passing through alternate tooth positions passing steeply from back to front of the dentary, a pattern similar to that observed in the premaxilla and maxilla but with less steep replacement waves. Huysseune & Witten (2006) recorded that in another salmoniform, *Salmo salar*, teeth in every third position are in the same developmental stage in most examined specimens, even though some specimens showed some variation. Longitudinal studies such as these are yet to be carried out with characiforms with simple unicuspid dentition. A clear synchronization or wave patterns of replacement within a tooth group was not identified in *Hepsetus*, *Hoplias*, *Salminus* and *Rhaphiodon* nor in the ctenoluciid *Boulengerella* in the current study, in these taxa the replacement teeth were observed in not sequential positions and in different developmental stages. Alternatively, some taxa show a clear synchronization in the replacement within a tooth group, this synchronization can be identified clearly when the examined specimen has one of the sides of the jaws undergoing replacement as was the case of *Serrasalmus elongatus*, *Phenacogaster tegatus*, *Astyanax multidens* and *Brycinus imberi* or by the difference between the developmental stages of the developing replacement teeth on both sides as was observed in *Bryconalestes longipinnis Carnegiella strigata* or even in the lack of developing replacement teeth on one side as observed in *Micralestes acutidens*, in these cases, presumably, the side that lacks developing replacement teeth had just undergone replacement. Roberts (1967) observed similar evidence of simultaneous replacement on one side of the jaws for *Bryconaethiops microstoma*, *Creagrudite maxillaris* (= *Creagrutus*), *Brycon atrocaudatus* and *Mylossoma* sp. which had replacement teeth midway to their functional positions and in *Phenacogrammus interruptus* that lacked developing replacement teeth on one side. Kolmann *et al*. (2019) state that unilateral replacement (defined by the authors as when "one side of the replacement dentition is more developed than the opposite side") is a synapomorphy for the Serrasalmidae in relation to their putative immediate out group, the Hemiodontidae (Arcila *et al* 2017; Betancur-R *et al*. 2019), as was discussed herein this condition is widespread in characiforms and a more careful evaluation of the evolution of this character along the Characiformes is needed. Within the latter group, some taxa such as *Chalceus epakros* and *Brycon amazonicus* have the replacement mediolaterally oriented (see description for more detail). The replacement would take place in one of the sides with the medialmost teeth being replaced before the lateralmost. The difference in timing between the replacement of the medialmost teeth in relation to the lateralmost teeth is also reported for *Serrasalmus* (Berkovitz, 1975; Berkovitz & Shellis, 1978), in this taxon the apparent synchronic replacement of the entire dentition in one of the sides of a given jaw actually has slight medio-lateral gradient on both initiation and eruption, this may occur due to the interlocking mechanisms between each tooth. Roberts (1967) reports a possible simultaneous replacement of all teeth in anostomids based on the examination of a series of *Schizodon fasciatus* including one specimen that lacked developing replacement teeth entirely. Within the anostomid examined herein two *Leporinus* (*L. bahiensis* and *L. desmotes*) had replacement teeth in similar developmental stages on both sides of the jaws, one of the two examined specimens of *Laemolyta proxima* lacked preformed replacement teeth entirely, on the right premaxilla the medialmost tooth seemed to be in the final stages of migration to the functional position. The replacement of all teeth is also reported for *Hydrocynus vittatus* kept in captivity (Gagiano *et al*., 1996), the replacement of the entire dentition would take place in three to five days, such a short period of replacement would explain how hard it is to observe the replacement in preserved specimens.

Trapani *et al*. (2005) did a revision on the data on periodicity and number of replacement events on the literature, the functional life of the teeth in Oncorhynchus mykiss is from eight to 16 weeks (Berkovitz & Moore, 1974), whereas in *Hydrocynus* it can vary from two to three months (Gagiano *et al*., 1996). Berkovitz and Shellis (1978) estimated that there would be approximately 27 replacement events over the life cycle in piranhas, Trapani *et al*. estimated around 40 replacement events over the life cycle of *Astyanax mexicanus*

Replacement mechanism

Roberts (1967) speculated about the migration that the replacement tooth would have to do in order to assume the functional position while describing the morphology of the bony cavities in which the dentary replacement teeth are formed in *Hydrocynus*, which, according to the author, are completely roofed over, however the roof is pierced by a foramen through which the tip of the developing replacement tooth projects into the mouth cavity. “Before it can move into functional position, a replacement tooth presumably must first withdraw from the mouth cavity until it is entirely within the replacement trench” (Roberts, 1967). Given the observed drastic bone reabsorption and remodeling for some taxa such as *Astyanax novae* and *Serrasalmus elongatus* (Figs.) it is unlikely that the replacement tooth would undergo such movement, instead it is likely that the bone would undergo drastic reabsorption, clearing the way for a simple 90° migration from the bony cavity to the functional position. Similar orientation of replacement teeth is observed in all three toothed bones of *Acestrorhynchus* and the dentary of *Agoniates halecinus*, unfortunately replacement of such teeth was not observed.

The formation of the replacement teeth takes place from the tooth cusp towards its base, perhaps this orientation was what led Roberts (1967) to state that the multicuspid teeth of all characiforms are the result of the combination of several unicuspid teeth held together at their bases by probably bony tissue. Another observation made by this author is that the base of the newly erupted teeth is translucent in cleared and stained specimens *i. e.* not yet calcified, the author observed thin condition in *Hepsetus* and *Hoplias*, the same condition was observed for several taxa herein (*Phenacogaster tegatus*, *Astyanax novae*, *Astyanax multidens*, *Brycinus imberi*, *Lebiasina* sp., *etc*.), the replacement tooth assumed its functional position before it is fully formed, once in the functional position the tooth continues to be formed towards the underlying bone which is going through the final stages of remodeling.

Kolmann *et al*. (2019) argued that serrasalmids would be the first documented example of the pairing of intraosseous tooth replacement with polyphyodonty (continuous replacement) and large tooth size, the latter already pointed out by Bemis & Bemis (2015). Polyphyodonty is extremely common in characiforms with several unicuspid teeth *e. g. Acestrorhynchus*, *Hepsetus*, *Galeocharax* all of which have replacement teeth formed extraosseously, specially the smaller functional teeth. Moreover, the large multicuspid teeth on the premaxillary inner row of alestids and characids are all formed extraosseously.

Primitive condition of the characiform dentition

Roberts (1967) hypothesized that the primitive condition of the characiform dentition would consist in unicuspid dentition, a single row of teeth on the premaxilla and maxilla, in which the row would extend beyond the mouth gape, and two rows separated by a shallow replacement “trench” on the dentary. Since the author believed to have demonstrated that the multicuspid teeth would be derived from several unicuspid teeth joined by their bases, all characiforms with multicuspid teeth would have derived from forms with the primitive dentition.

According to Roberts (1967) the constant number of functional teeth in taxa with complex dentition , especially the Characidae, is regarded as derived, whereas the variable number of functional teeth of taxa with mainly unicuspid teeth such as *Salminus*, *Hepsetus*, *Hoplias* and *Ctenolucius* is regarded as primitive, consequently the simultaneous replacement observed in taxa with more complex dentition is regarded as derived while the somewhat random replacement of taxa with simple unicuspid dentition is regarded as primitive. Herein the synchronization of the replacement in unilateral pattern was only observed for taxa with multicuspid teeth within the Characoidei. The proposal of an ancestral condition of the dentition for the entire order is problematic, given that the two lineages recognized as less derived within Characiformes (Distichodontidae and Citharinidae) have very specialized dentition adapted to specific trophic strategies.

Conclusions

Detailed examination of an already vastly explored character complex resulted in the refinement of characters related to dentition as well as the proposal of possible additional synapomorphies for the Heterocharacinae (unicuspid teeth with abruptly tapering cusp), Serrasalminae (replacement teeth of the dentary formed in completely enclosed bony cavities) and Anostomidae (pleurodont implantation on premaxilla and maxilla).

Unilateral replacement patterns were observed in several taxa with multicuspid dentition including representatives of the Characidae, Chalceidae, Alestidae, Serrasalmidae, Iguanodectidae, Bryconidae and Agoniatidae. Furthermore, two distinct patterns within the unilateral pattern were identified the simultaneous unilateral replacement pattern observed in *Serrasalmus* and *Astyanax* and the sequential unilateral pattern observed in *Brycon* and *Chalceus*.

Using information related to the different mode of replacement tooth formation allowed: (i) a proposition of an alternative interpretation of the identity and homology of the three premaxillary tooth rows observed in *Brycon*, *Triportheus* and *Chalceus*; (ii) the identification of two tooth rows for taxa in which this differentiation is problematic such as *Mimagoniates* and *Bryconamericus lethostigmus*; (iii) a proposition of homology between the single row of teeth present in taxa within the Characoidei and the inner row of taxa with two or three tooth rows on the premaxilla; (iv) the proposition of homology of the single row of teeth present in taxa within the Citharinoidei with the outer row of *Xenocharax spilurus*.

Future perspectives

The optimal course of action would be to evaluate the evolution of the characters proposed herein would be in a larger character matrix and see how the dentition characters would interact with the remaining characters and then use their optimization to discuss their modifications along the Characiformes tree. Another approach would be to use the most current phylogenetic trees for Characiformes (*e. g.* Arcila *et al.* 2017, Mirande, 2019, Betancur-R *et al.* 2019), evaluate the character state of as many of their terminal taxa as possible and then apply Bayesian stochastic character mapping and/or maximum-likelihood-based means of ancestral state reconstruction to map changes in character states across the tree, similar to what Fontenelle *et al.* (2017) did to estimate the evolution of the number of angular cartilages in Potamotrygoninae and Kolman *et al.* (2019) did to estimate the evolution of heterodonty and tooth replacement in Serrasalmidae.

The limited exploration of histological aspects of the characiform dentition, along with the information already available in the literature (Monod, 1950; Fink, 1981, Scharcansky & Lucena, 2008, Kolmann *et al.* 2019) indicate that the ultrastructure would be a rich source of morphological variation. The investigation of types of mineralized tissues that are present, and their potential variation could help to elucidate eve more the evolution of the characiform dentition.

Taxa with several preformed replacement teeth such as the Hemiodontidae, Prochilodontidae and Parodontidae are promising model organisms to study the mechanisms involved in tooth replacement as well as their genetic control, due to the several and continuous replacement events that these organisms undergo and the relative ease to get live specimens from aquaculture and the pet trade. This bypasses a common constrain in developmental studies in Otophysans that are limited to species such as *Astyanax mexicanus* and *Danio rerio*.

Interpretation of the identity and homology of teeth rows combining tooth morphology, topology and the replacement teeth formation mode could help to better understand the evolution and trace the homology of the dentition among taxa with peculiar premaxillary teeth arrangement such as *Creagrutus*, *Triportheus*, *Chalceus*, *Brycon* and “*Odontostoechus*”.

References

Arcila, D., Ortí, G., Vari, R. P., Armbruster, J. W., Stiassny, M. L. J., Ko, K. D., Sabaj, M. H., Lundberg, J. Revell, L. J., Betancur-R, R. 2017. Genome-wide interrogation advances resolution of recalcitrant groups in the tree of life. *Nature Ecology & Evolution*. 1: 0020.

Atukorala, A. D. S. & Franz-Odendaal, T. A. 2014. Spatial and temporal events in tooth development of *Astyanax mexicanus*. *Mechanisms of Development*. 134: 42-54.

Azevedo, P., Dias, M. V. & Vieira B. B. 1938. Biologia do saguirú (Characidae, Curimatinae) *Memórias do Instituto Oswaldo Cruz*. 33(4): 481-554.

Azevedo, P., & Vieira B. B. 1938. Contribuição para o catálogo biológico dos peixes fluviais do nordeste do Brasil. Ispetoria Federal de Obras contra as Secas, Rio de Janeiro. 13 pp.

Baicere-Silva, C. M., Ferreira, K. M., Malabarba, L. R. Benine, R. C. & Quagio-Grassiotto, I. 2011. Spermatic characteristics and sperm evolution on the subfamily Stevardiinae (Ostariophysi: Characiformes: Characidae). *Neotropical Ichthyology*. 9 (2). 377-392.

Bemis, K. E. & Bemis, W. E. 2015. Functional and developmental morphology of tooth replacement in the Atlantic wolffish *Anarchias lupus* (Teleostei: Zoarcoidei: Anarhichadidae). *Copeia* 103(4): 886-901.

Bemis, K. E., Burke, S. M., St. John, C. A. & Hilton, E. J. Tooth development and replacement in the Atlantic cutlassfish, *Trichiurus lepturus*, with comparisons to other Scombroidei. *Journal of Morphology*. 280: 78-94.

Berkovitz, B. K. B. & Moore, M. H. 1974. A longitudinal study of replacement patterns of teeth on the lower jaw and tongue in the rainbow trout *Salmo gairdneri*. *Archives of Oral Biology*. 19: 1111-1119.

Berkovitz, B. K. B. & Moore, M. H. 1975. Tooth replacement in the upper jaw of the rainbow trout (*Salmo gairdneri*). *Journal of Experimental Zoology*. 193: 221-234.

Brewster, B. 1986. A review of the genus Hydrocynus Cuvier 1819 (Teleostei: Characiformes). *Bulletin of the British Museum (Natural History), Zoology* 50 (3): 163-206.

Berkovitz, B. K. B. & Shellis, R. P. 1978. A longitudinal study of tooth succession in piranhas (Pisces: Characidae), with an analysis of the tooth replacement cycle. *Journal of Zoology, London*. 184: 545-561.

Berkovitz, B. K. B, & Shellis, R. P. 2017. The teeth of non-mammalian vertebrates. Amsterdam, the Netherlands: Elsevier.

Berkovitz, B. K. B. 1975. Observations on tooth replacement in piranhas (Characidae). *Archives of Oral Biology*. 20: 53-56.

Berkovitz, B. K. B. 1980. The effect of age on tooth replacement patterns in piranhas (Pisces: Characidae). *Archives of Oral Biology*. 833-835.

Betancur-R, R., Arcila, D., Vari, R. P., Hughes, L. C., Oliveira, C., Sabaj, M. H., Ortí, G. 2019. Phylogenomic incongruence, hypothesis testing, and taxonomic sampling: The monophyly of characiform fishes. *Evolution*. 73(2): 329-345.

Böhlke, J. E. 1954. Studies on fishes of the fish family Characidae, No. 7: a new genus and species of glandulocaudinae characids from central Brazil. *Stanford Ichthyological Bulletin*. 4(4): 265-74.

Böhlke, J. 1958. Studies on fishes of the family Characidae n° 14. A report on several extensive collections from Ecuador. *Proceedings of the Academy of Natural Sciences of Philadelphia*, 110, 1–121.

Brewster, B. 1986. A review of the genus *Hydrocynus* Cuvier 1819 (Teleostei: Characiformes). *Bulletin of the British Museum (Natural History), Zoology* 50 (3)**:** 163-06.

Calcagnotto, D., Schaefer, S. A. & DeSalle, R. 2005. Relationships among characiform fishes inferred from analysis of nuclear and mitochondrial gene sequences. *Molecular Phylogenetics and Evolution*. 36. 135-153.

Castro, R. M. C., Vari, R. P. 2004. Detritivores of the South American fish family Prochilodontidae (Teleostei: Ostariophysi: Characiformes): a phylogenetic and revisionary study. *Smithsonian Contributions to Zoology* 622: 1–190.

Conway, K. W., Bertrand, N. G., Browning, Z, Lancon T. W. & Clubb, F. J. 2015. Heterodonty in the new world: an SEM investigation of oral dentition in the clingfishes of the subfamily Gobiesocinae (Teleostei: Gobiesocidae). *Copeia*. 103(4): 973-998.

Datovo, A & Castro, R. M. C. 2012. Anatomy and evolution of the mandibular, hyopalatine, and opercular muscles in characiform fishes (Teleostei: Ostariophysi). *Zoology*. 115 (2), 84-116.

Eigenmann, C. H. 1910. Catalogue of the fresh-water fishes of tropical and south temperate America. In: *Reports of the Princeton University expeditions to Patagonia 1896–1899. Zoology 3* (pt 4): 375–511.

Farris, J. S. 1983. The logical basis of phylogenetic analysis. In: Platnick, N. & Funk, V. A. eds. Advances in cladistics. Proceedings of the second meeting of the Willi Hennig Society. New York. Columbia University Press. 7-36.

Ferreira, K.M., Menezes, N.A., Quagio-Grassiotto, I., 2011. A new genus and two new species of Stevardiinae (Characiformes: Characidae) with a hypothesis on their relationships based on morphological and histological data. *Neotropical Ichthyology*. 9, 281–298.

Fink, W. L. 1981. Ontogeny and phylogeny of tooth attachment modes in actinopterygian fishes. *Journal of Morphology*, 167, 167–184.

Fontenelle, J. P, Loboda, T. S., Kolmann, M & de Carvalho, M. R. 2017. Angular cartilage structure and variation in Neotropical freshwater stingrays (Chondrichthyes: Myliobatiformes: Potamotrygonidae), with comments on their function and evolution. *Zoological Journal of the Linnean Society*. 183(1): 121-142.

Fraser, G. J., Britz, R., Hall, A. Johanson, Z. & Smith, M. M. 2012. Replacing the first-generation dentition in pufferfishe with a unique beak. *Proceedings of the National Academy of Sciences*, *USA*. 109. 8179-8184.

Fricke, R., Eschmeyer, W. N. & Van der Laan, R. (eds) 2019. Eschmeyer's Catalog of Fishes: Genera, Species, References. (http://researcharchive.calacademy.org/research/ichthyology/catalog/fishcatmain.asp). Electronic version accessed 10 10 2019.

Gagiano, C. L., Steyn, G. J. & Du Preez, H. H. 1996. Tooth replacement of tigerfish *Hydrocynus vittatus* from the Kruger National Park. *Koedoe*. 39(1): 117-122.

Géry, J. 1977. Characoids of the world. THF Publications, Neptune City, 672 pp.

Goloboff, P. A., Farris, J. S. & Nixon, K. C. 2008. TNT, a free program for phylogenetic analysis. *Cladistics*. 13: 225-245.

Goloboff, P. A., Mattoni, C. I. & Quinteros, A. S. 2006 Continuous characters analyzed as such. *Cladistics*, 22, 589-601.

Guisande, C., Pelayo-Villamil, P., Vera, M., Manjarrés-Hernández, A., Carvalho, M. R., Vari, R. P., Jiménez, L. F.,Fernández, C., Martínez, P., Prieto-Piraquive, E., Granado-Lorencio, C. & Duque, S. R. 2012. Ecological factors and diversification among Neotropical characiforms. *International Journal of Ecology*. 610419, 20 pp.

Günther, A. 1864. Catalogue of the Physostomi, containing the families Siluridae, Characinidae, Haplochitonidae, Sternoptychidae, Scolopelidae, Stomiatidae, in the collection of the British Museum. In: *Catalogue of the fishes in the British Museum (London)* 5.

Gusmão-Pompiani, P., Malabarba, L. R., Oliveira, C. & Quagio-Grassiotto, I.. 2009. Spermiogenesis ans spermatozoa ultrastructure in the Serrasalminae (Ostariophysi: Characiformes) with further evidence on the relationships of the piranhas and pacus. *Neotropical Ichthyology*. 7 (3). 385-394.

Hirschmann, A., Fagundes, N. J. R. & Malabarba, L. R. 2017. Ontogenetic changes in mouth morphology triggers conflicting hypotheses of relationship in characid fishes (Ostariophysi: Characiformes). *Neotropical Ichthyology*. 15(1): 16p.

Howes, G. J. 1982. Review of the genus Brycon (Teleostei: Characoidei). *Bulletin of the British Museum* (*Natural History*), *Zoology*, 43(1), 1–47.

Huysseune, A. & Witten, P. E. 2006. Developmental mechanisms underlying tooth patterning in continuously replacing osteichthyan dentitions. *Journal of experimental zoology (Mol Dev Evol)*. 306B: 204-215.

Javonillo, R., Malabarba, L. R., Weitzman, S. H., Burns, J. R. 2010. Relationships among major lineages of characid fishes (Teleostei: Ostariophysi: Characiformes), based on molecular sequence data. *Molecular Phylogenetics and Evolution*. 54(2): 498-511.

Kolmann, M. A., Cohen, K. E., Bemis, K. E., Summers, A. P., Irish, F. J. & Hernandez, L. P. 2019. Tooth and consequences: Heterodonty and dental replacement in piranhas and pacus (Serrasalmidae). *Evolution & Development*. 21(5): 1-16.

Langeani, F. 1998. Phylogenetic study of the Hemiodontidae (Ostariophysi: Characiformes). In Malabarba, L. R., Reis, R. E., Vari, R. P., Lucena, Z. M. S. & Lucena, C. A. S. Eds. Phylogeny and Classification of Neotropical Fishes, Porto Alegre, Edipucrs. 145-160.

Lima, F. C. T. 2017. Revision of the cis-andean species of the genus *Brycon* Müller & Troshcel (Characiformes: Characidae). *Zootaxa*. 4222(1): 1-189.

Lima F. C. T, Malabarba, L. R., Buckup, P. A., da Silva, J. F. P., Vari, R. P., Harold, A., Benine, R., Oyakawa, O. T., Pavanelli, C. S., Menezes, N. A., Lucena, C. A. S., Malabarba, M. C. S. L., Lucena, Z. M. S., Reis, R. E., Langeani, F., Cassati, L., Bertaco, V. A., Moreira, C., Lucinda, P. H. F. 2003. Genera Incertae Sedis in Characidae. In: Reis, R. E., Kullander, S. O., Ferraris, C. J. Jr, orgs. Checklist of the freshwater fishes of South and Central America. Porto Alegre, RS: EDIPUCRS, 106–169.

Lucena, C. A. S. 1998. Relações filogenéticas e definição do gênero *Roeboides* Günther (Ostariophysi, Characiformes, Characidae). *Comunicações do Museu de Ciências e Tecnologia da PUCRS, série Zoologia* 11: 19–59.

Machado-Allison, A. 1983. Estudios sobre la subfamilia Serrasalminae (Teleostei-Characidae). Parte II. Discusión sobre la condición monofilética de la subfamilia. *Acta Biológica Venezuélica*, 11(4): 145-196.

Malabarba, L. R. 1998. Monophyly of the Cheirodontinae, Characters and major clades. In Malabarba, L. R., Reis, R. E., Vari, R. P., Lucena, Z. M. S. & Lucena, C. A. S. Eds. Phylogeny and Classification of Neotropical Fishes, Porto Alegre, Edipucrs. 193-234.

Mattox, G. M. T. & Toledo-Piza, M. 2012. Phylogenetic study of the Characinae (Teleostei: Characiformes: Characidae). *Zoological Journal of the Linnean Society*. 165: 809-915.

Menezes, N. A. & Weitzman, S. H. 2009. Systematics of the Neotropical fish subfamily Glandulocaudinae (Teleostei: Characiformes: Characidae). *Neotropical Ichthyology*. 7(3): 295-370.

Menezes, N. A., Weitzman, S. H. & Quagio-Grassiotto, I. 2013. Two new species and a review of the inseminating freshwater fish genus *Monotocheirodon* (Characiformes: Characidae) from Peru and Bolivia. *Papéis Avulsos de Zoologia*. 53(10): 129-44.

Mirande, J. M. 2010. Phylogeny of the family Characidae (Teleostei: Characiformes): from characters to taxonomy. *Neotropical Ichthyology*. 8 (3). 385-568.

Mirande, J. M. 2019. Morphology, molecules and the phylogeny of Characidae (Teleostei, Characiformes). *Cladistics*. 35: 282-300.

Monod, T. 1950. Notes d'ichthyologieouest-africaine. Bulletin de l'Institut Français d'Afrique Noir. 12 (1): 1-71.

Müller, J. & Troschel, F. H. 1844. Synopsis generum et specierum familiae Characinorum. (Prodromus descriptionis novorum generum et specierum). *Archiv für Naturgeschichte* v. 10 (pt 1): 81-99 + foldout table (opposite p. 99).

Netto-Ferreira, A. L., Birindelli, J. L. O., Sousa, L. M. & Menezes, N. A. 2014. A new species of Rhinopetitia Géry 1964 (Ostariophysi: Characiformes: Characidae) from the rio Teles Pires, rio Tapajós basin, Brazil. *Journal of Fish Biology*. 84(5): 1539-50.

Oliveira C., Avelino, G. S., Abe, K. T., Mariguela, T. C., Benine, R. C., Ortí, G., Vari, R. P. & Castro, R. M. C. 2011. Phylogenetic relationships within the speciose family Characidae (Teleostei: Ostariophysi: Characiformes) based on multilocus analysis and extensive ingroup sampling. *BMC Evolutionary Biology*. 11: 275, 25p.

Ortí, G. & Meyer, A. 1997. The radiation of Characiform fishes and the limits of mitochondrial ribosomal DNA Sequences. *Systematic Biology*. 46 (1) 75-100.

Pastana, M. L. N., Bockmann, F. A. & Datovo, A. 2019. The cephalic lateral-line system of Characiformes (Teleostei: Ostariophysi): anatomy and phylogenetic implications.

Reis, R.E, Kullander, S.O. & Ferraris-JR, C.J. 2003. Check list of the freshwater fishes of South and Central America. Porto Alegre: EDIPUCRS. 729p.

Roberts, T. R. 1967. Tooth function and replacement in characoid fishes. *Stanford Ichthyological Bulletin*. 8: 231-247.

Roberts, T. R. 1974. Osteology and classification of the neotropical characoid fishes of the families Hemiodontidae (including Anodontinae) and Parodontidae. *Bulletin of the Museum of Comparative Zoology* 146(9): 411-472.

Scharcansky, A. & Lucena C. A.S. 2008 Phylogenetic assessment of ultrastructural and histological characters of teeth in the Anostomoidea, Hemiodontidae and Parodontidae (Teleostei: Ostariophysi: Characiformes). *Zootaxa*. 1948: 36-56.

Sidlauskas, B. L. & Vari, R. P. 2008. Phylogenetic relationships within the South American fish family Anostomidae (Teleostei, Ostariophysi, Characiformes). *Zoological Journal of the Linnean Society* 154: 70-210.

Shellis, R. P. & B. K. B. Berkovitz.1976. Observations on the dental anatomy of piranhas (Characidae) with special reference to tooth structure. *Journal of Zoology*, 180: 69-84.

Stiassny, M. L. J. & Jensen, J. S. 1987. Labroid intrarelationships revisited: Morphological complexity, key innovations and the study of comparative diversity. *Bulletin of the Museum of Comparative Zoology*. 151 (5). 269-319.

Taylor, W. R. & van Dyke, G. C. 1985. Revised procedures for staining and clearing small fishes and other vertebrates for bony and cartilage study. *Cybium* 9(2): 107-119.

Thomaz, A. T., Arcila, D., Ortí, G. & Malabarba L. R. 2015 Molecular phylogeny of the subfamily Stevardiinae Gill, 1858 (Characiformes: Characidae): classification and the evolution of reproductive traits. *BMC Evolutionary Biology*. 15:146 25p.

Toledo-Piza, M. 2000. The Neotropical fish subfamily Cynodontinae (Teleostei: Ostariophysi: Characiformes): A phylogenetic study and a revision of *Cynodon* and *Rhaphiodon*. *American Museum Novitates*. 3286: 88p.

Toledo-Piza, M. 2007. Phylogenetic relationships among *Acestrorhynchus* species (Ostariophysi: Characiformes: Acestrorhynchidae). *Zoological Journal of the Linnean Society*. 151: 691-757.

Trapani, J. 2001. Position of developing replacement teeth in teleosts. *Copeia*. 2011(1): 35-51.

Trapani, J., Yamamoto, Y & Stock, D. W. 2005. Ontogenetic transition from unicuspid to multicuspid oral dentition in a teleost fish: *Astyanax mexicanus*, the Mexican tetra (Ostariophysi: Characidae). *Zoological Journal of the Linnean Society*. 145? 523-538.

Tyler, J. C., O'Toole, B. & Winterbottom, R. 2003. Phylogeny of the Genera and Families of Zeiform fishes, with Comments on their Relationships with Tetraodontiforms and Caproids. *Smithsonian Contributions to Zoology* 618. 1-110.

Vari, R. P. 1979. Anatomy, relationships and classification of the families Citharinidae and Distichodontidae (Pisces, Characoidea). *Bulletin of the British Museum (Natural History) Zoology*. 36(2): 261-344.

Vari, R. P. 1983. Phylogenetic relationships of the families Curimatidae, Prochilodontidae, Anostomidae, and Chilodontidae (Pisces: Characiformes). *Smithsonian Contributions to Zoology* 378: 1-60.

Vari, R. P. 1986. *Serrabrycon magoi*, a new genus and species of scale-eating characid (Pisces: Characiformes) from the Upper Río Negro. *Proceedings of the Biological Society of Washington* 99: 328–334.

Vari, R. P. 1989. A phylogenetic study of the Neotropical characiform family Curimatidae (Pisces: Ostariophysi). *Smithsonian Contributions to Zoology* 471: 1-71.

Vari, R. P. 1995. The Neotropical fish family Ctenoluciidae (Teleostei: Ostariophysi: Characiformes): supra and intrafamilial Phylogenetic Relationships, with a revisionary study. Smithsonian Contributions to Zoology. 564: 1-97.

Weitzman, S. H., Menezes, N. A., Evers, H. –G. & Burns, J. R. 2005. Putative relationships among inseminating and externally fertilizing characids, with a description of a new genus and species of Brazilian inseminating fish bearing anal-fin gland in males (Characiformes: Characidae). *Neortropical Ichthyology*. 3 (3). 329-360.

Weitzman, S. H. & Vari, R. P. 1988. Miniaturization in SouthAmerican freshwater fishes: an overview and discussion. *Proceedings of the Biological Society of Washington* 101 (2): 444–465.

Westneat, M. W. 1993. Phylogenetic relationships of the tribe Cheilinini (Labridae: Perciformes). *Bulletin of Marine Science*. 52 (1). 351-394.

Wiley, E. O. & Johnson, G. D. 2010. A Teleost classification based on monophyletic groups. pp 123-182. IN Nelson, J. S., H. –P, Schultze & M. V. H. Wilson (eds.). Origin and Phylogenetic Interrelationships of Teleosts. Verlag Dr. Friedrich Pfeil, München, Germany.

Winterbottom, R. 1974. The Familial Phylogeny of the Tetraodontiforms (Acanthopterygii: Pisces) as Evidenced by their Comparative Miology. *Smithsonian Contributions to Zoology*. 155. 1-201.

Zanata, A. M. & Toledo-Piza, M. 2004. Taxonomic revision of the South American fish genus Chalceus Cuvier (Teleostei: Ostariophysi: Characiformes) with the description of three new species. *Zoological Journal of the Linnean Society*, 140, 103–135.

Zanata, A. M. & Vari, R. P. 2005. The family Alestidae (Ostariophysi: Characiformes), a phylogenetic analysis of a trans-Atlantic clade. *Zoological Journal of the Linnean Society*. 145: 1-144.

Tables

Table 1. List of genera that had species examined in the current study and number of examined genera relative to total number of genera in each family/subfamily.

Family/subfamily	Examined genera	Examined genera/Total genera
Acestrorhynchidae		
Acestrorhinchinae	*Acestrorhynchus*	1/1
Heterocharacinae	*Heterocharax*, *Lonchogenys*	2/4
Roestinae	*Roestes*	1/1
Agoniatidae	*Agoniates*, *Lignobrycon*, *Triportheus*	3/5
Alestidae	*Alestes*, *Brycinus*, *Bryconalestes*, *Hydrocynus*, *Lepidarchus*, *Micralestes*, *Phenacogrammus*	7/20
Anostomidae	*Abramites*, *Laemolyta*, *Leporinus*	3/14
Bryconidae	*Brycon*, *Salminus*	2/4
Chalceidae	*Chalceus*	1/1
Characidae		
Aphyocharacinae	*Aphyocharax*	1/6
Characinae	*Acestrocephalus*, *Charax*, *Cynopotamus*, *Galeocharax*, *Microschemobrycon*, *Phenacogaster*, *Roeboides*	7/9
Cheirodontinae	*Odontostilbe*, *Serrapinnus*	2/16
Exodontinae	*Exodon*	1/3
Stethaprioninae	*Astyanax*, *Gymnocorymbus*, *Poptella*	3/39
Stevardiinae	*Bryconamericus*, *Mimagoniates*	2/45
Incertae sedis	*Trochilocharax*	1/16
Chilodontidae	*Chilodus*	1/2
Citharinidae	*Citharidium*, *Citharinus*	2/3
Crenuchidae	*Characidium*, *Crenuchus*	2/11
Ctenoluciidae	*Boulengerella*	1/2
Curimatidae	*Steindachnerina*	1/8
Cynodontidae	*Cynodon*, *Hydrolycus*, *Rhaphiodon*	3/3
Distichodontidae	*Ichthyborus*, *Nannocharax*, *Xenocharax*	3/16
Erythrinidae	*Hoplias*	1/3
Gasteropelecidae	*Carnegiella*	1/3
Hemiodontidae	*Bivibranchia*, *Hemiodus*	2/5
Hepsetidae	*Hepsetus*	1/1
Iguanodectidae	*Bryconops*, *Iguanodectes*, *Piabucus*	3/3
Lebiasinidae	*Lebiasina*, *Nannostomus*	2/7
Parodontidae	*Apareiodon*, *Parodon*	2/3
Prochilodontidae	*Prochilodus*	1/3
Serrasalmidae	*Catoprion*, *Myloplus*, *Serrasalmus*	3/16
	Total	66/273

Figures

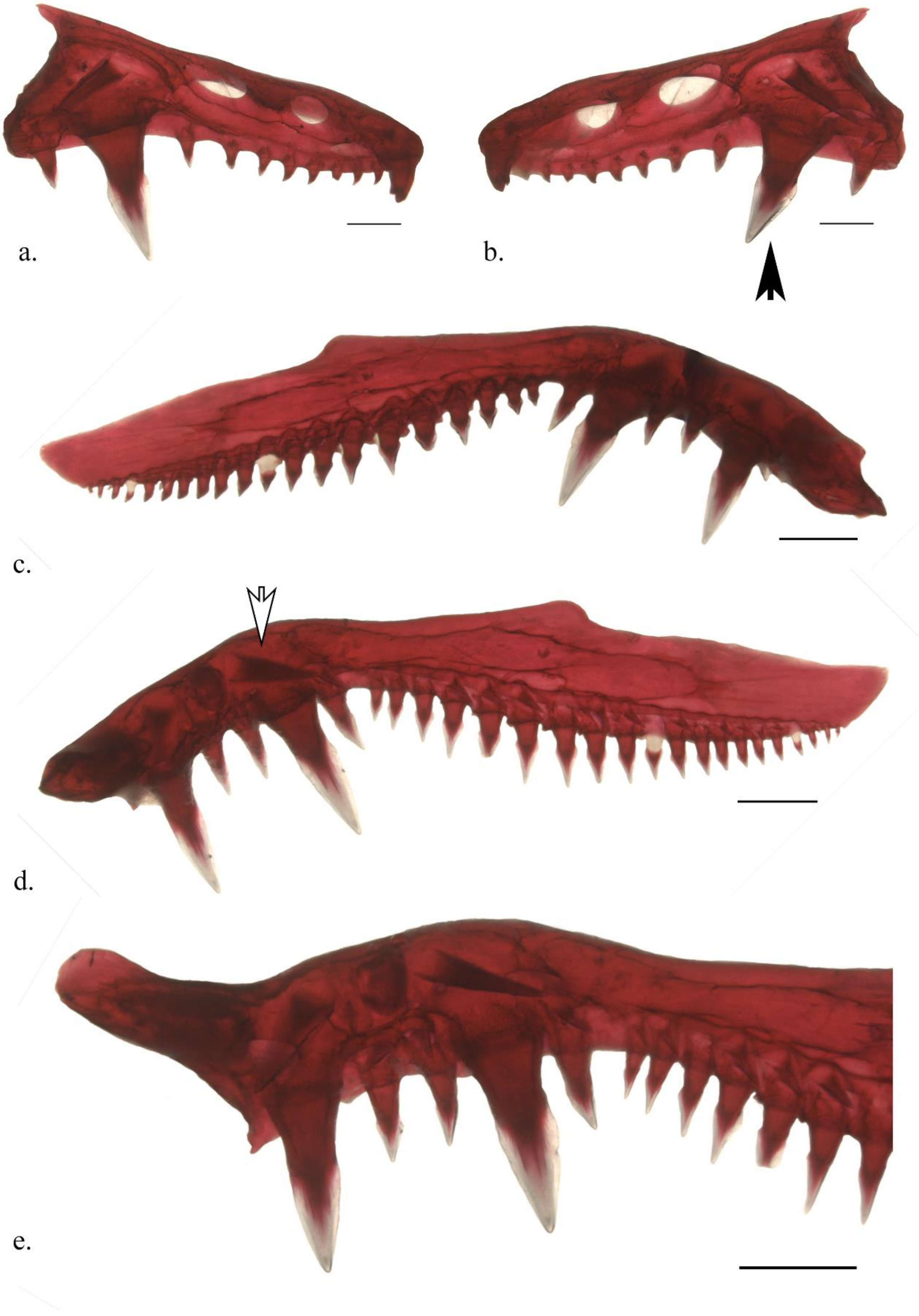


Figure 1. *Acestrorhynchus microlepis* MZUSP 91854 90.2 mm SL **a.** right premaxilla labial view; **b.** right premaxilla lingual view; **c.** right maxilla labial view; **d.** right maxilla lingual view; **e.** detail of anterior portion of right maxilla, lingual view. Black arrow points to unicuspid tooth with lateral cutting-edge; white arrow points to developing replacement tooth inside bony cavity. Scale bar 0.5 mm.

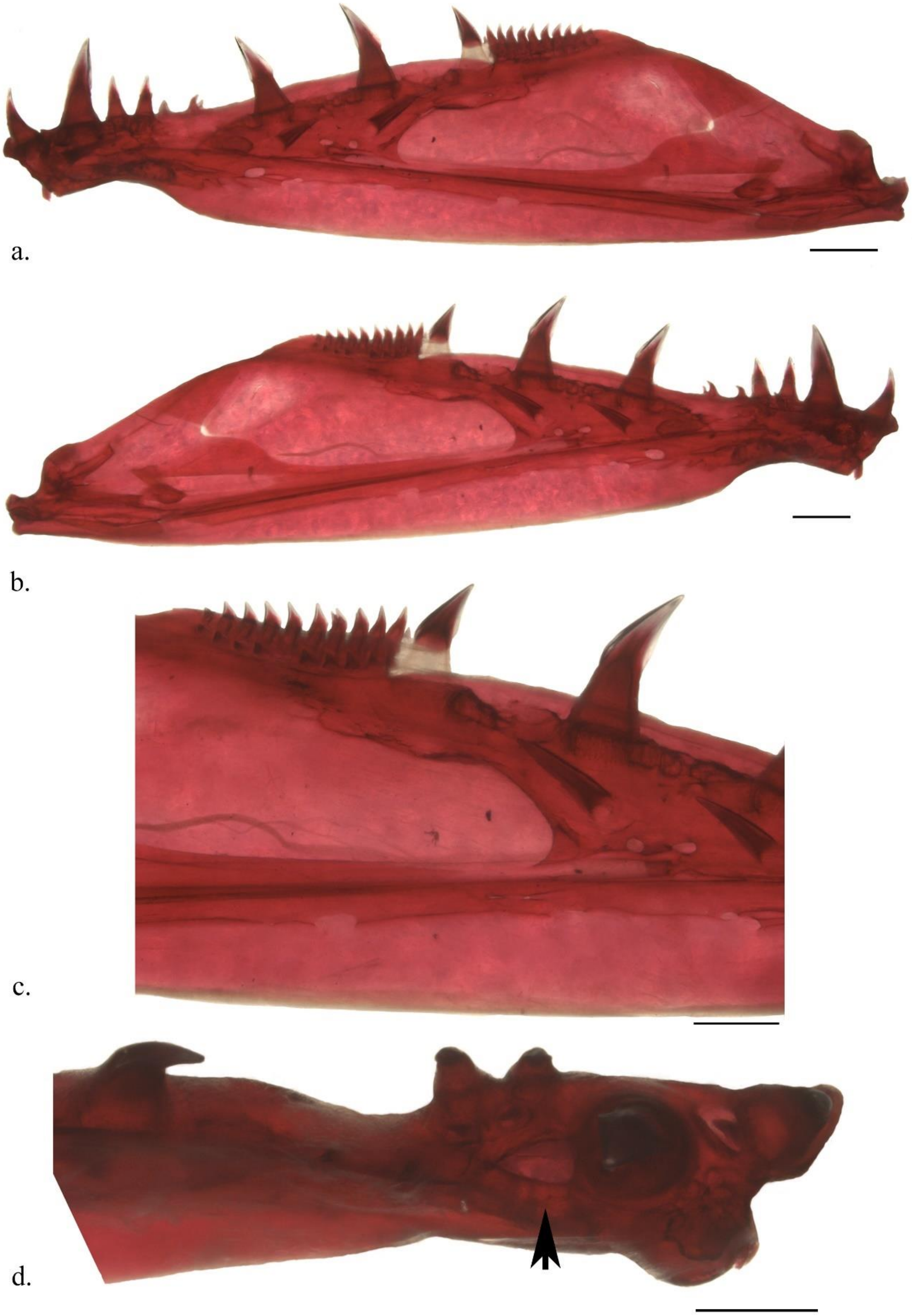


Figure 2. *Acestrorhynchus microlepis* MZUSP 91854 90.2 mm SL **a.** lower jaw, left side, labial view; **b.** lower jaw, left side, lingual view; **c.** detail of midportion of lower jaw, left side, lingual view; **d.** detail of anterior portion of lower jaw, right side, dorsal view. Black arrow points to dorsal opening associated to bony cavity in which replacement teeth are formed. Scale bar 0.5 mm.

a.

b.

Figure 3. *Lonchogenys ilisha* MZUSP 29253 60.9 mm SL **a.** left maxilla, lingual view; **b.** anterior portion of lower jaw, right side, labial view. Black arrow points to labially displaced teeth of outer row. Scale bar 0.5 mm.

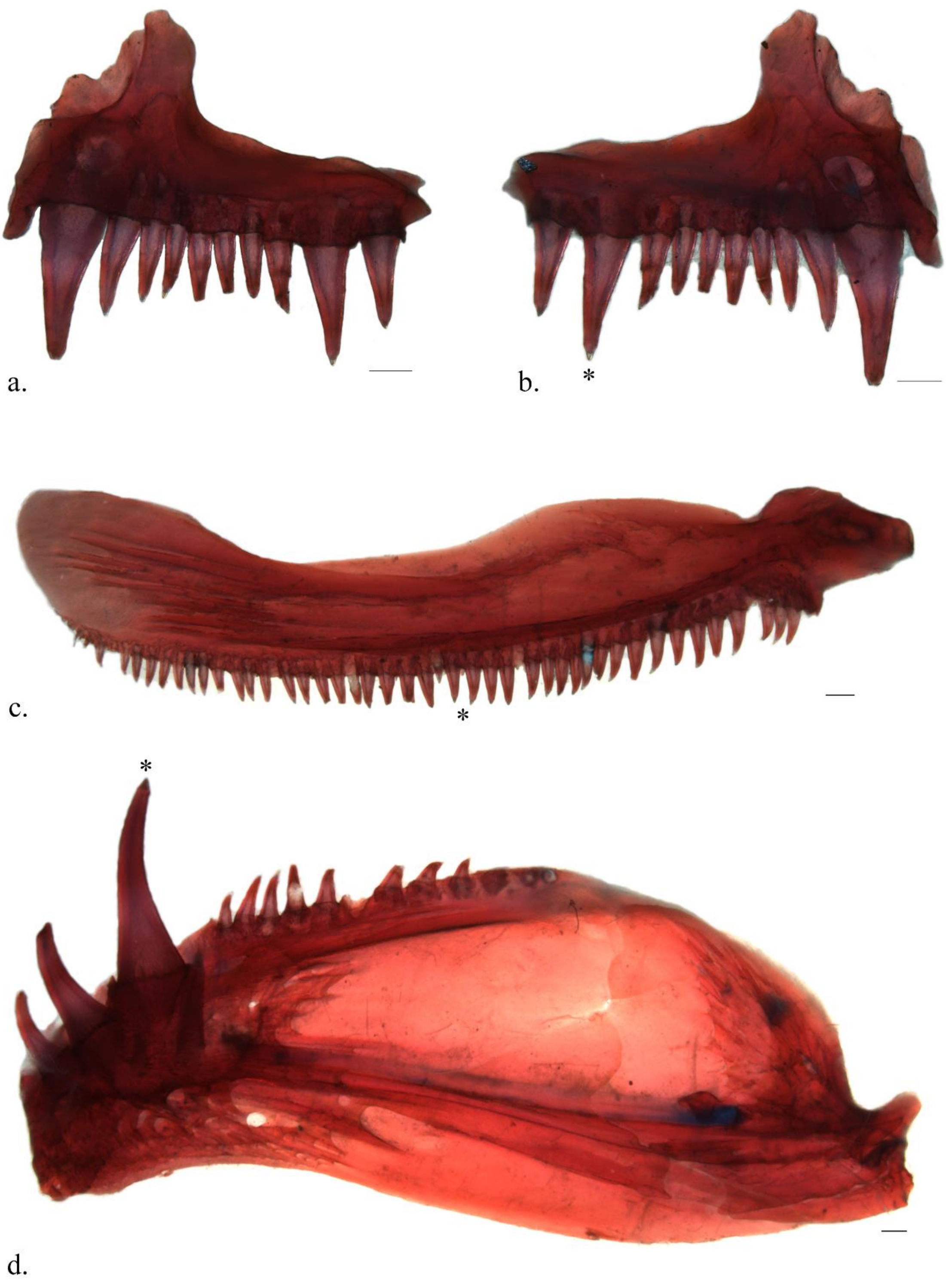


Figure 4. *Roestes molossus* MZUSP 35556 103.9 mm SL **a.** left premaxilla labial view; **b.** left premaxilla lingual view; **c.** left maxilla lingual view; **d.** lower jaw, left side, labial view. * indicates unicuspid teeth with abruptly tapering cusp. Scale bar 0.5 mm.

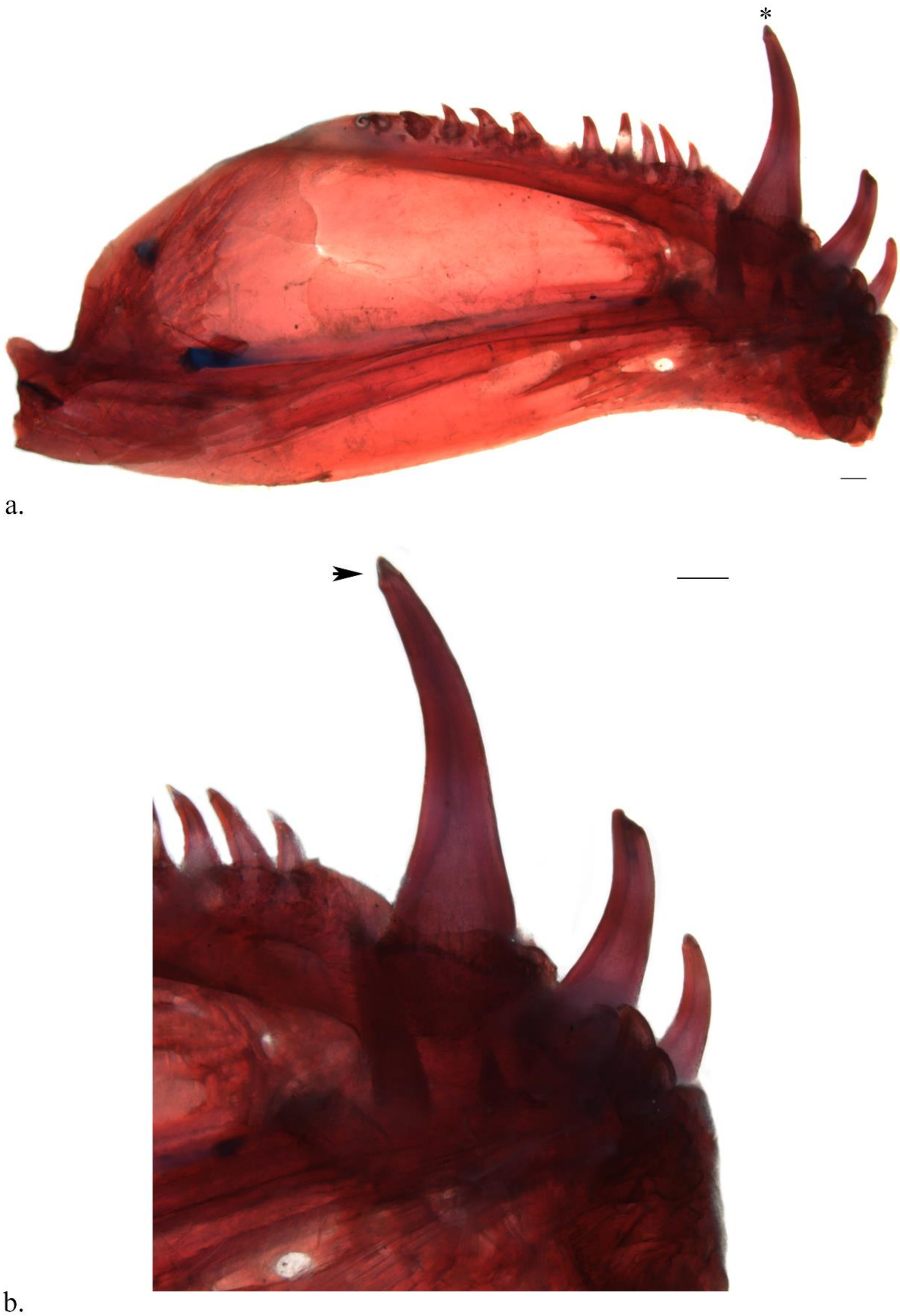


Figure 5. *Roestes molossus* MZUSP 35556 103.9 mm SL **a.** lower jaw, left side, lingual view; **b.** anterior portion of lower jaw, left side, lingual view. * indicates unicuspid teeth with abruptly tapering cusp. Black arrow points to cusp with abrupt taper. Scale bar 0.5 mm.

Figure 6. *Agoniates halecinus* MZUSP 34327 107.7 mm SL **a.** left maxilla lingual view; **b.** lower jaw, right side, lingual view. Black arrow points to replacement tooth formed in individual bone cavity. Scale bar 0.5 mm.

Figure 7. *Triportheus albus* MZUSP 117105 103.9 mm SL **a.** left premaxilla labial view; **b.** left premaxilla lingual view; **c.** upper jaw, ventral view. Black arrow points to replacement tooth of the lateralmost tooth on the middle row formed in a bony cavity. White lettering indicates identity of premaxillary tooth rows, I for inner row, M for middle row and O for outer row. Scale bar 0.5 mm.

a.

b.

c.

Figure 8. *Triportheus albus* MZUSP 117105 103.9 mm **a.** replacement teeth of the inner row of the right premaxilla; **b.** left maxilla, lingual view; **c.** anterior portion of lower jaw, dorsolateral view. Black arrow points to replacement tooth of the medialmost tooth on inner row of premaxilla with cusps arranged in semicircle. White arrow points to right parasymphyseal tooth. Scale bar 0.5 mm.

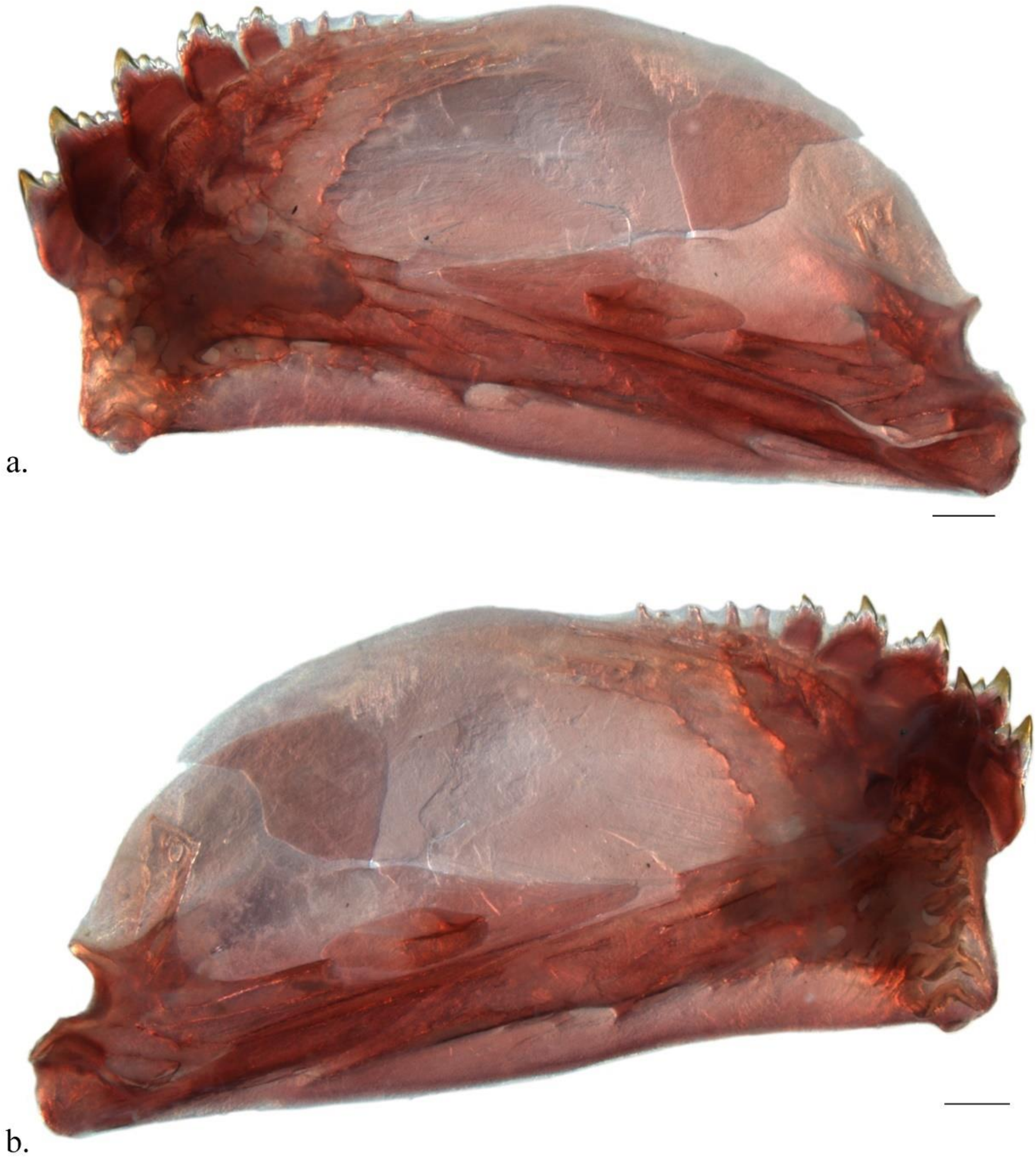


Figure 9. *Triportheus albus* MZUSP 117105 103.9 mm **a.** lower jaw, left side, labial view; **b.** lower jaw, left side, lingual view. Scale bar 0.5 mm.

Figure 10. *Alestes baremoze* BMNH 1982.13.554-557 68.2 mm SL (a., b. and e.) and 68.1 mm SL (c. and d.) **a.** left premaxilla, labial view; **b.** left premaxilla, lingual view; **c.** upper jaw, labial view; **b.** upper jaw, lingual view; **e.** left maxilla, labial view. Black arrow points to additional cusp on concave face of tooth on inner row of premaxilla. * indicates replacement teeth of outer row formed in bony cavity. Scale bar 0.5 mm.

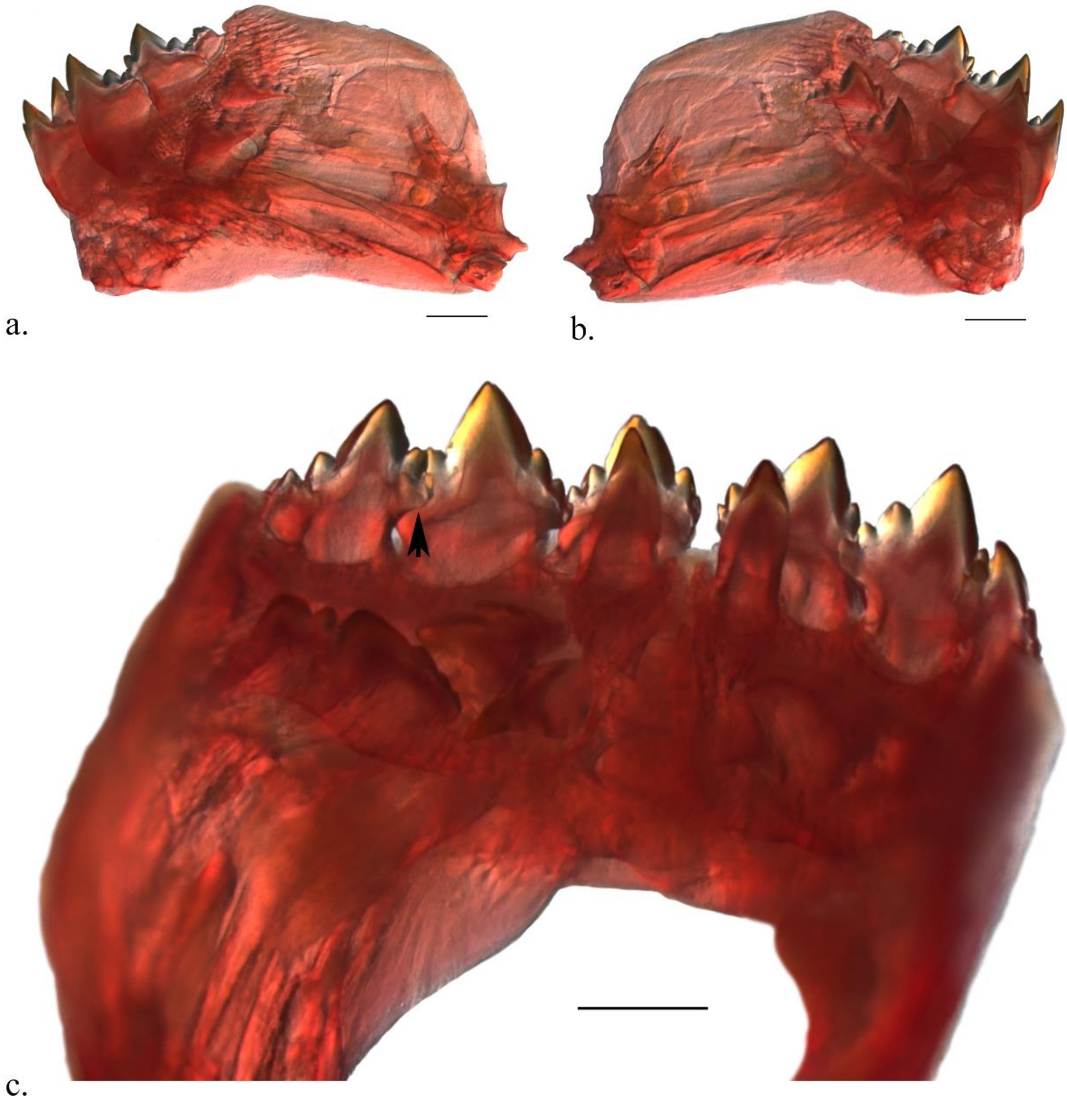


Figure 11. *Alestes baremoze* BMNH 1982.13.554-557 68.2 mm SL (a. and b.) and 68.1 mm SL (c.) **a.** lower jaw, left side, labial view; **b.** lower jaw, left side, lingual view; **c.** lower jaw, lingual view. Black arrow points to lateral projection on dentary teeth overlapping adjacent teeth. Scale bar 0.5 mm.

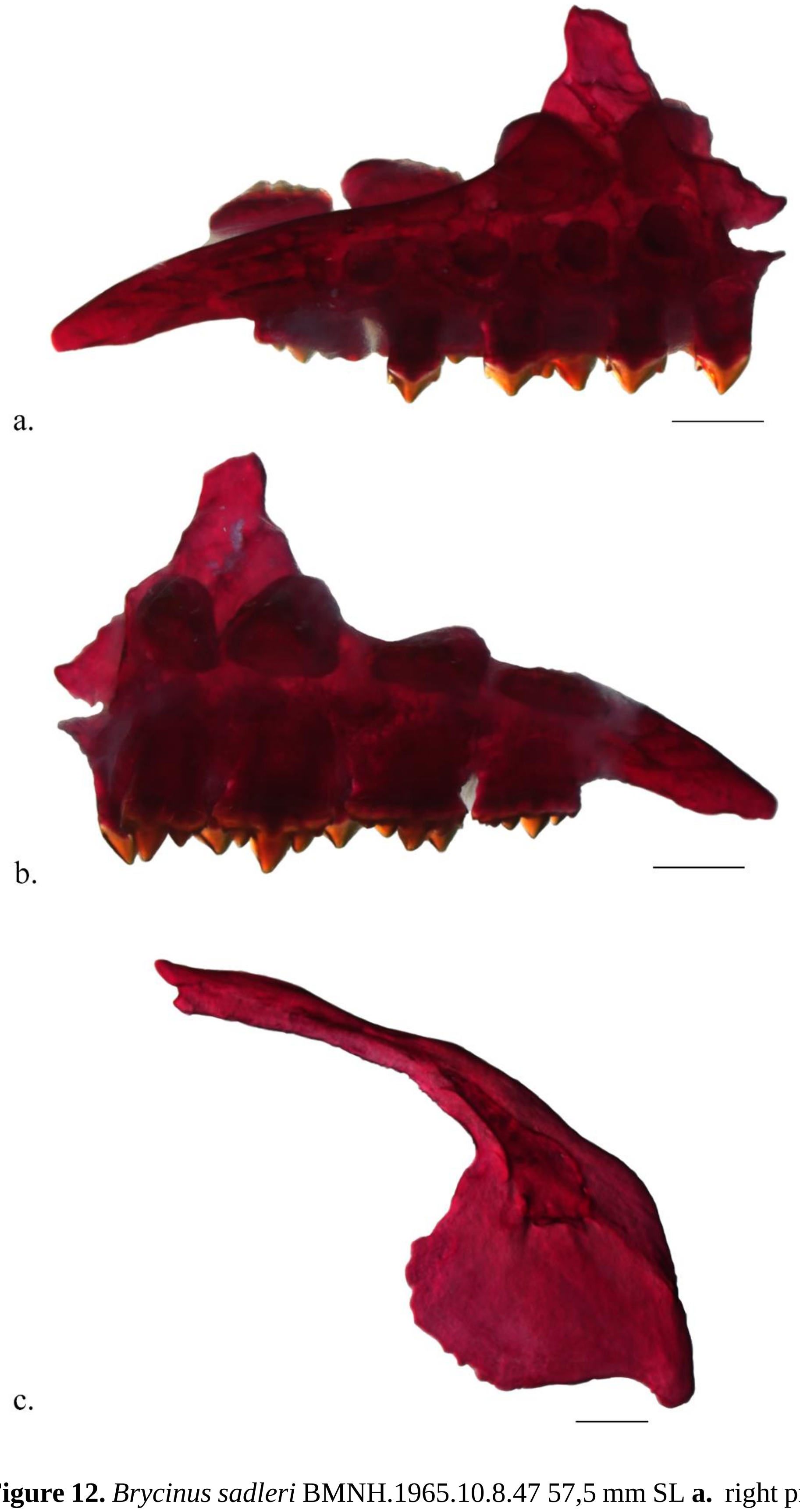


Figure 12. *Brycinus sadleri* BMNH.1965.10.8.47 57,5 mm SL **a.** right premaxilla, labial view; **c.** right premaxilla, lingual view; **b.** left maxilla, labial view. Scale bar 0.5 mm.

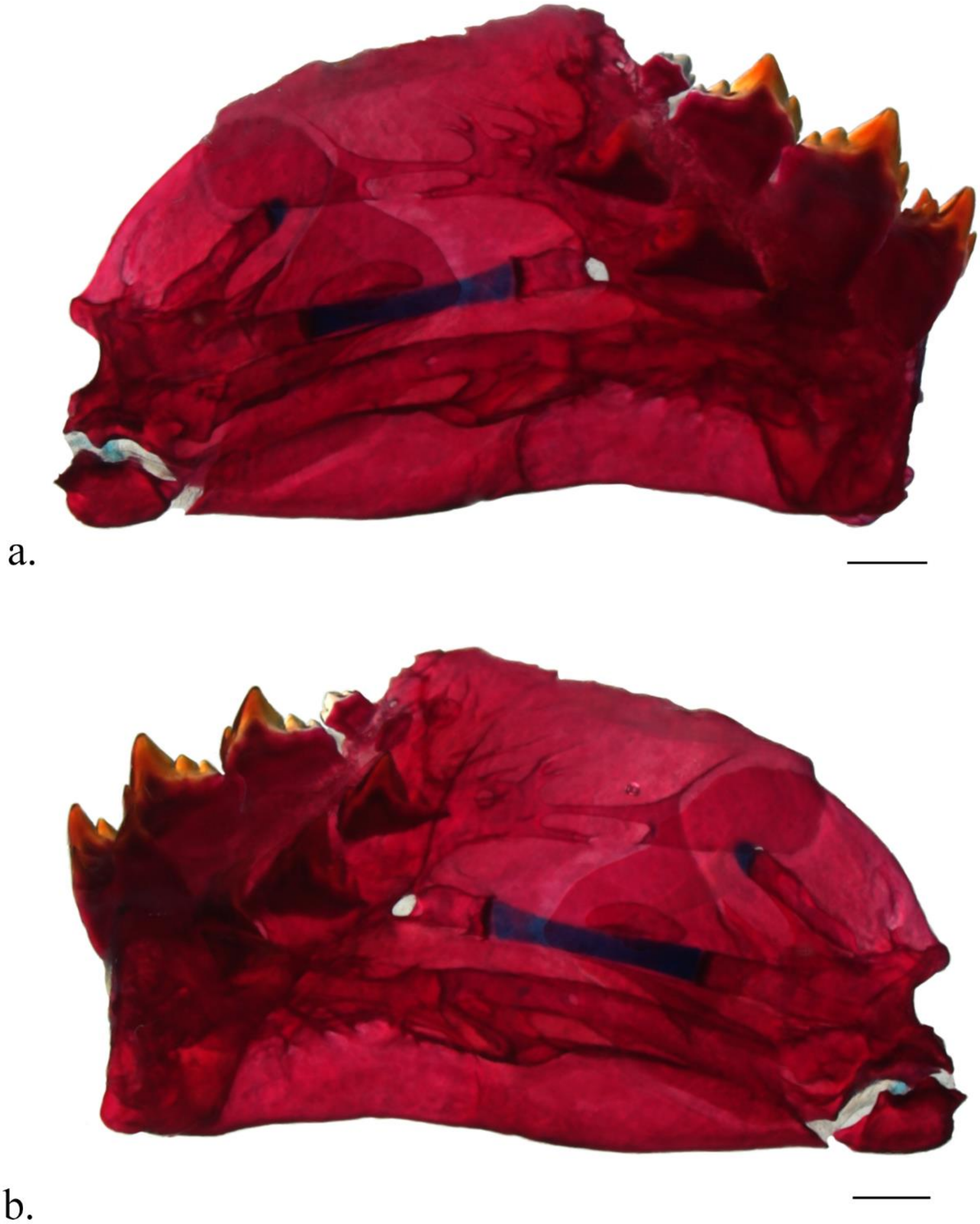


Figure 13. *Brycinus sadleri* BMNH.1965.10.8.47 57,5 mm SL **a.** lower jaw, right side, labial view; **b.** lower jaw, right side, lingual view. Scale bar 0.5 mm.

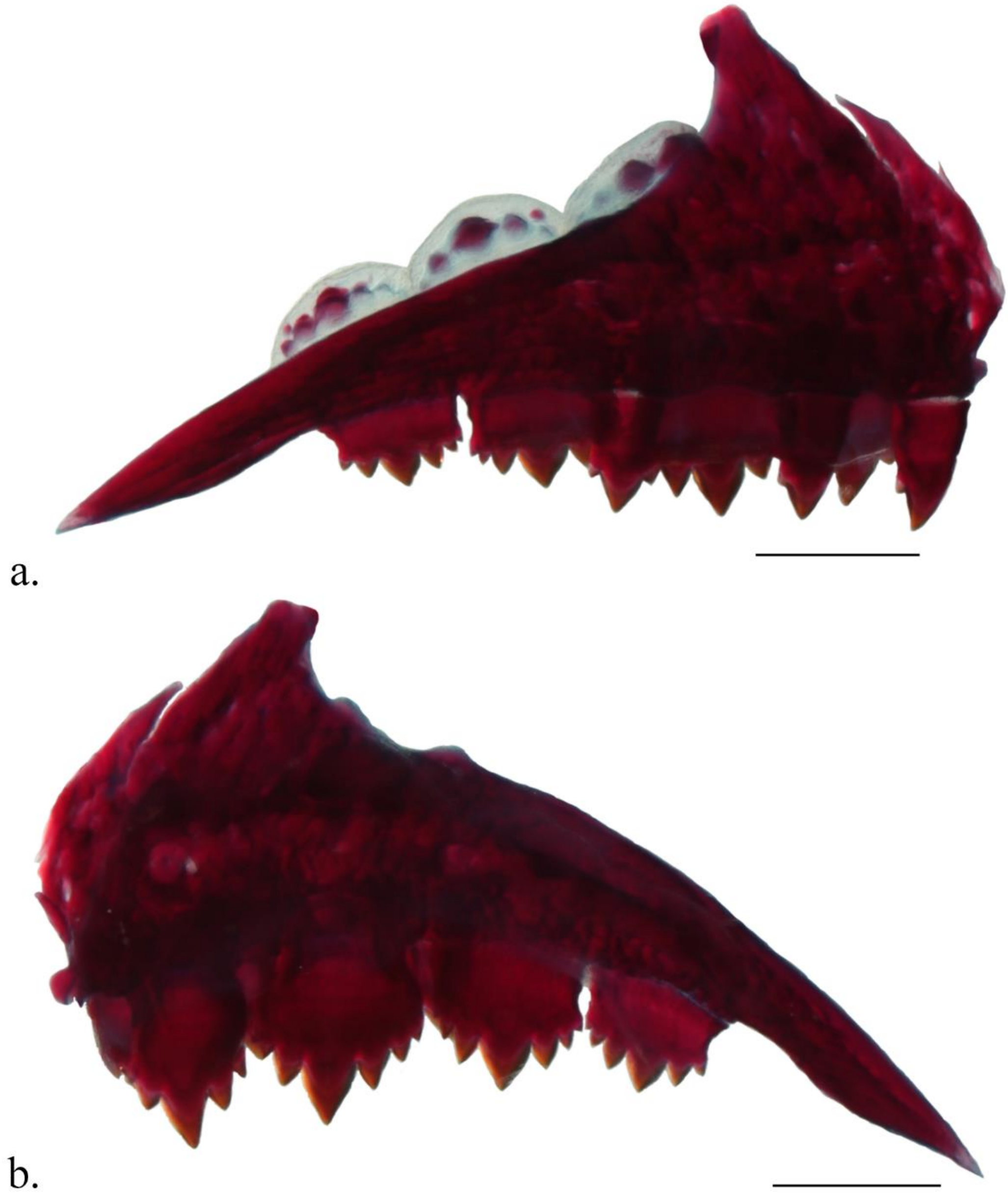


Figure 14. *Bryconalestes longipinnis* BMNH 1981.2.17.814 36,1 mm SL. **a.** right premaxilla, labial view; b**.** right premaxilla, lingual view. Scale bar 0.5 mm.

a.

b.

Figure 15. *Bryconalestes longipinnis* BMNH 1981.2.17.814 36,1 mm SL. **a.** lower jaw, right side, lingual view; **b.** lower jaw, right side, labial view. Scale bar 0.5 mm.

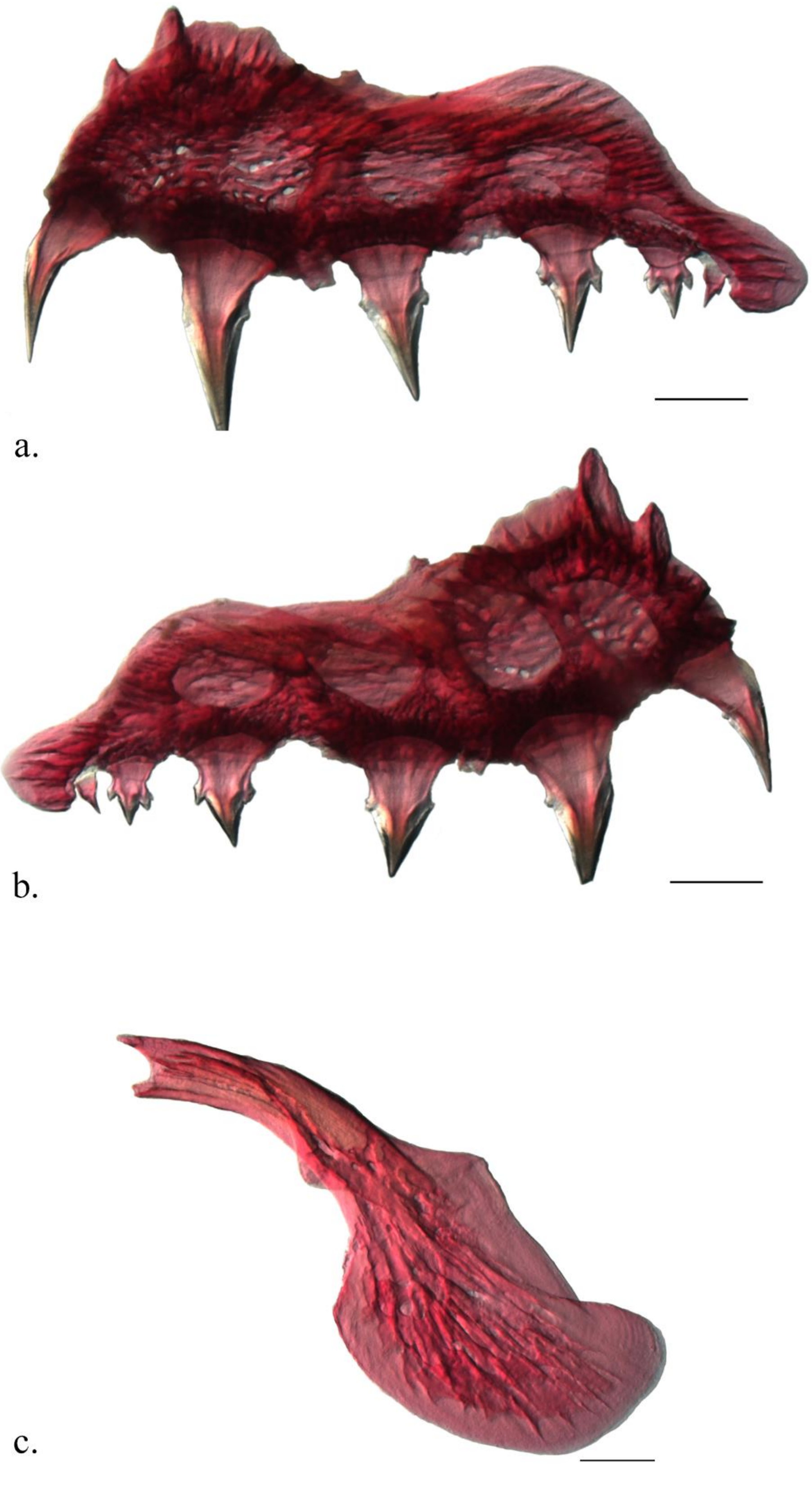


Figure 16. *Hydrocynus forskahlii* BMNH 1981.2.17.760-764 44.1 mm SL. **a.** left premaxilla, labial view; **b.** left premaxilla lingual view; **c.** maxilla labial view. Scale bar 0.5 mm.

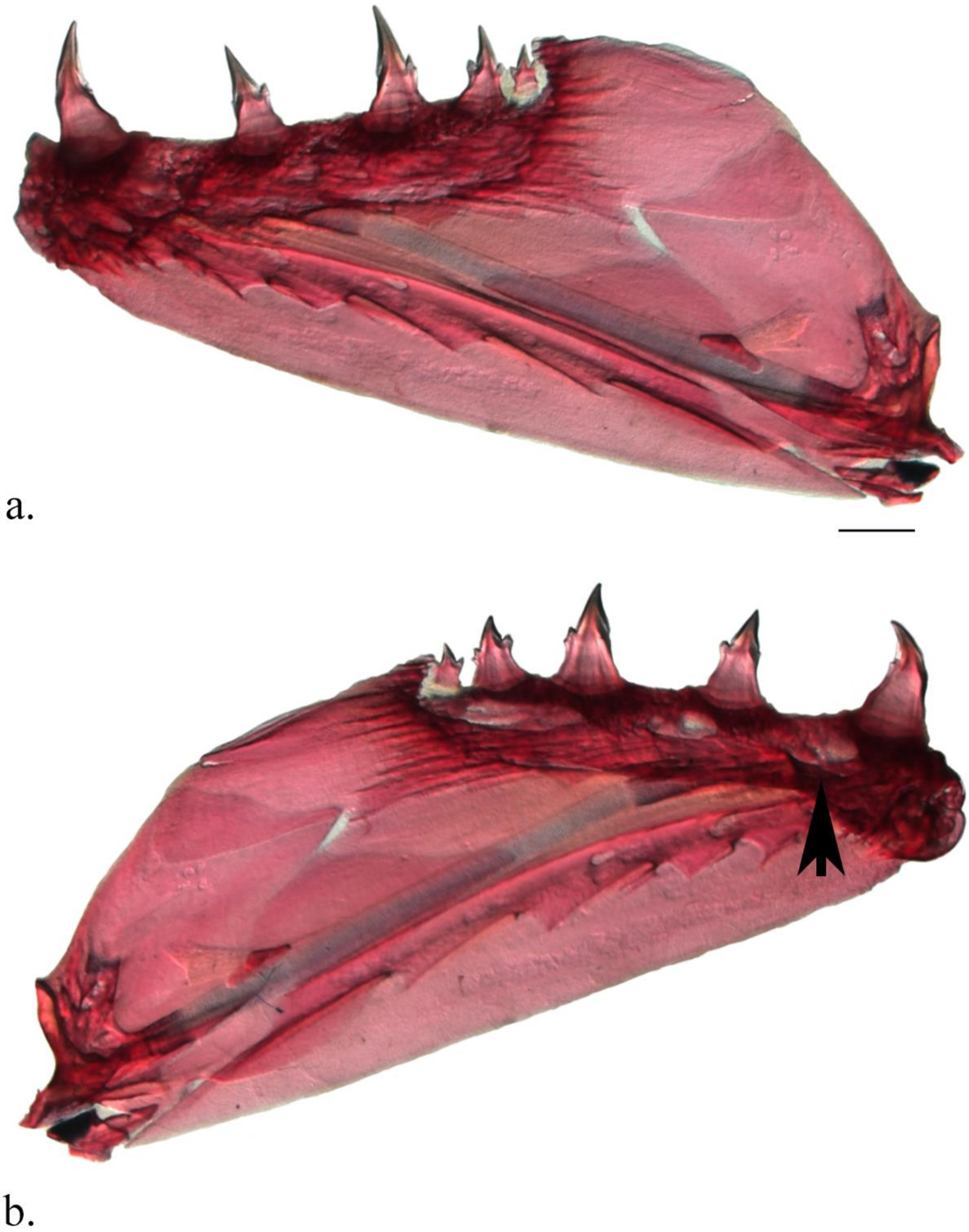


Figure 17. *Hydrocynus forskahlii* BMNH 1981.2.17.760-764 44.1 mm SL. **a**. lower jaw, left side, labial view; **b.** lower jaw left side lingual view. Black arrow point to individual bony cavity in which replacement tooth is formed. Scale bar 0.5 mm.

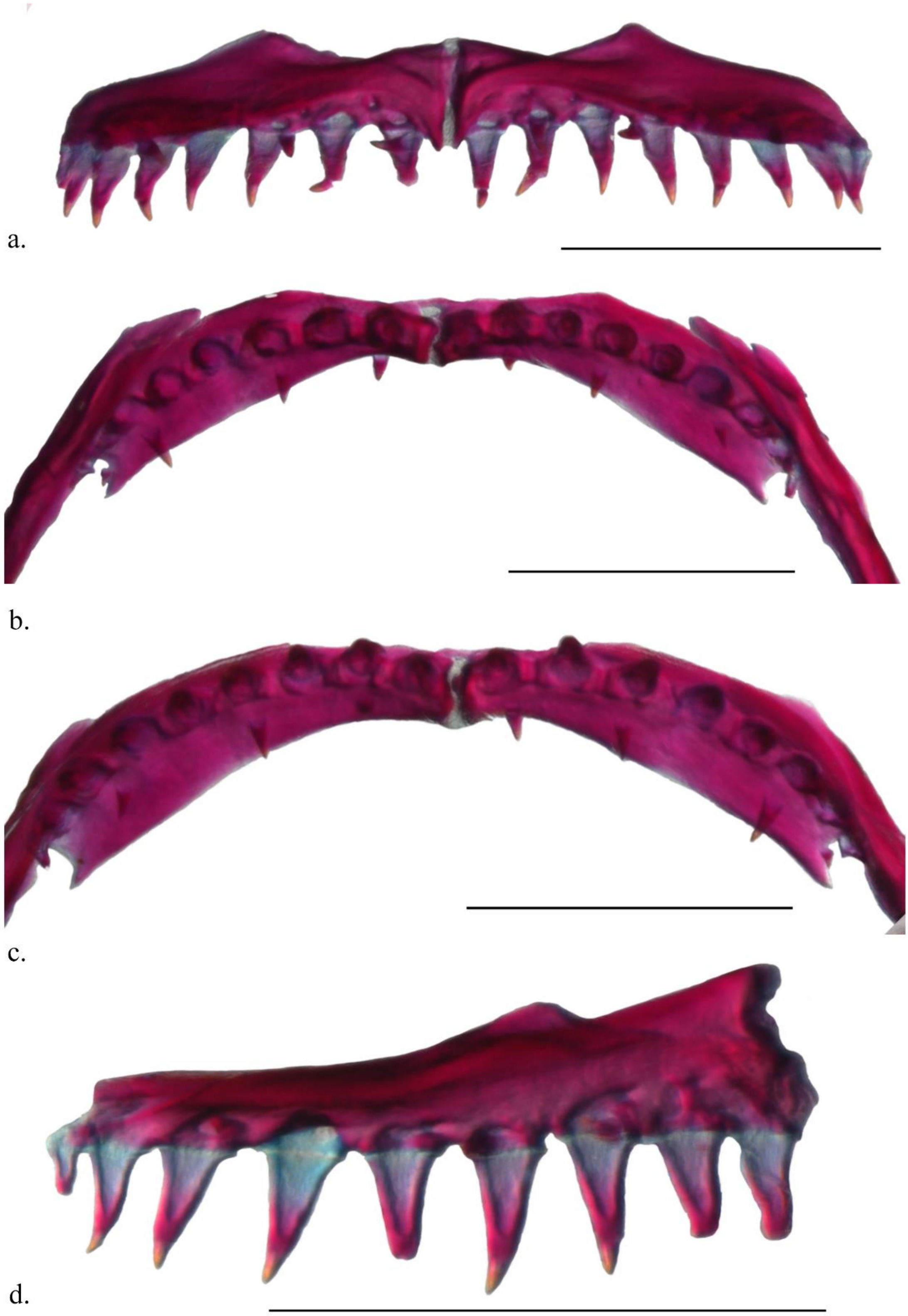


Figure 18. *Lepidarchus adonis* BMNH 1984.9.11.2 18.5 mm SL. **a.** premaxillae labial view; **b.** anterior portion of upper jaw, dorsal view; **c.** anterior portion of upper jaw, ventral view; **d.** right premaxilla labial view. Scale bar 0.5 mm.

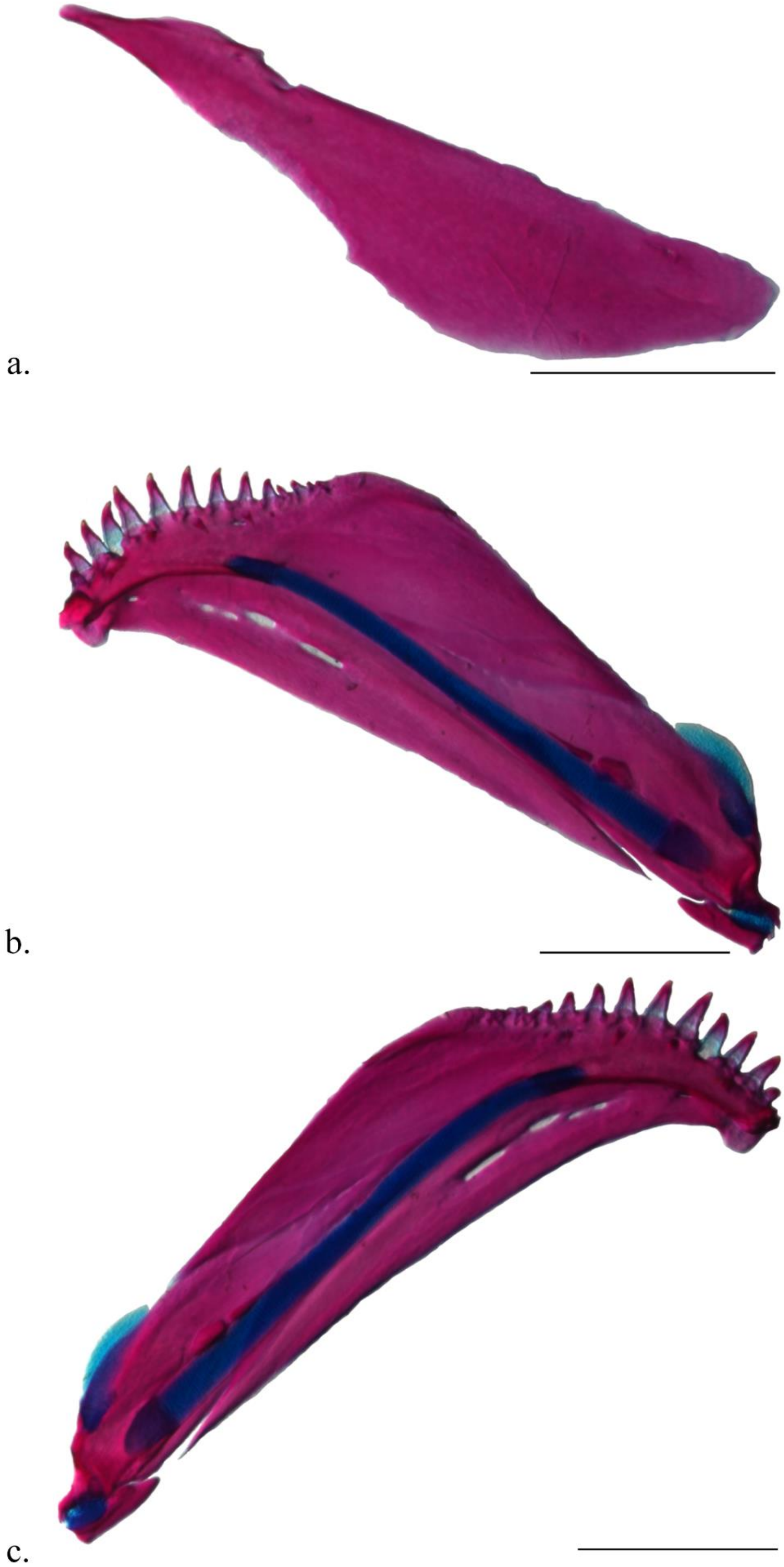


Figure 19. *Lepidarchus adonis* BMNH 1984.9.11.2 18.5 mm SL. **a.** left maxilla, labial view; **b.** lower jaw, lingual view; **c.** lower jaw labial view. Scale bar 0.5 mm.

Figure 20. *Micralestes acutidens* MZUSP 62625 51.9 mm SL. Anterior portion of lower jaw, dorsal view. Black arrow points bony cavities of replacement teeth of main row and replacement tooth of parasymphyseal tooth coalesced together. * indicates multicuspid parasymphyseal tooth. Scale bar 0.5 mm.

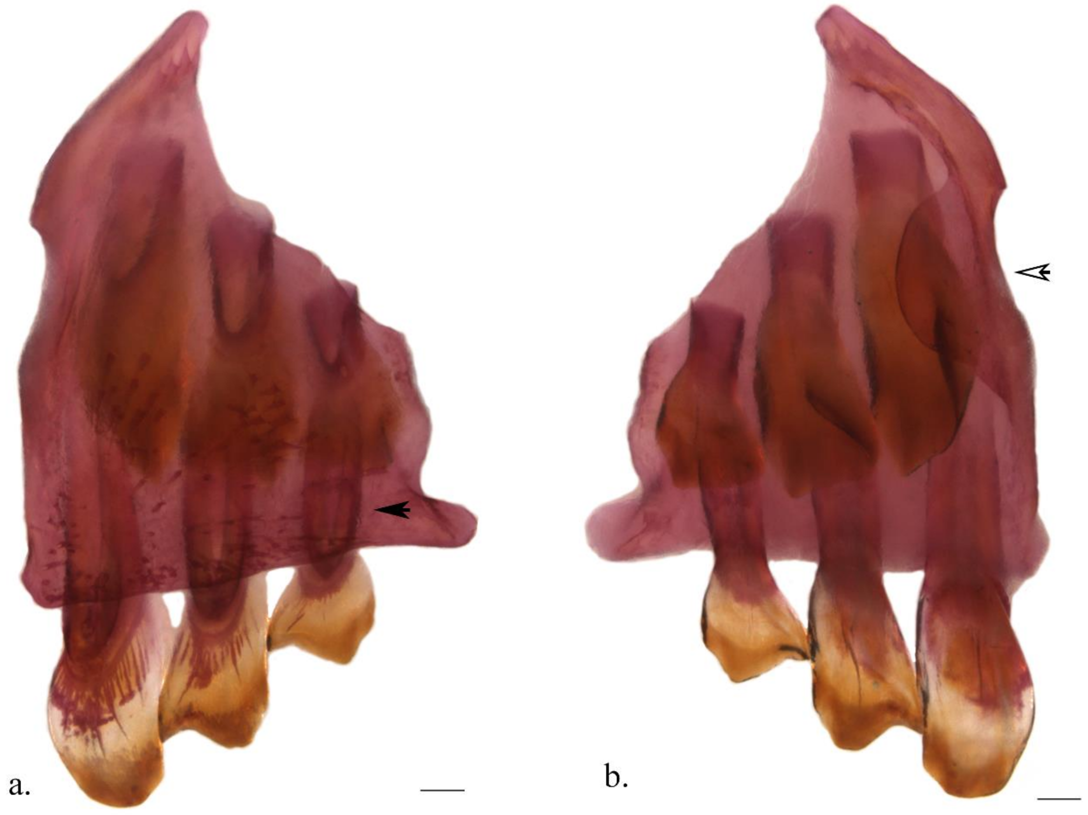


Figure 21. *Leporinus bahiensis* MZUSP 112246 87.5 mm SL. **a.** left premaxilla, labial view; **b.** left premaxilla lingual view. Black arrow points to pleurodont implantation of tooth. White arrow points to bony lamella partially covering replacement tooth of medialmost premaxillary tooth. Scale bar 0.5 mm.

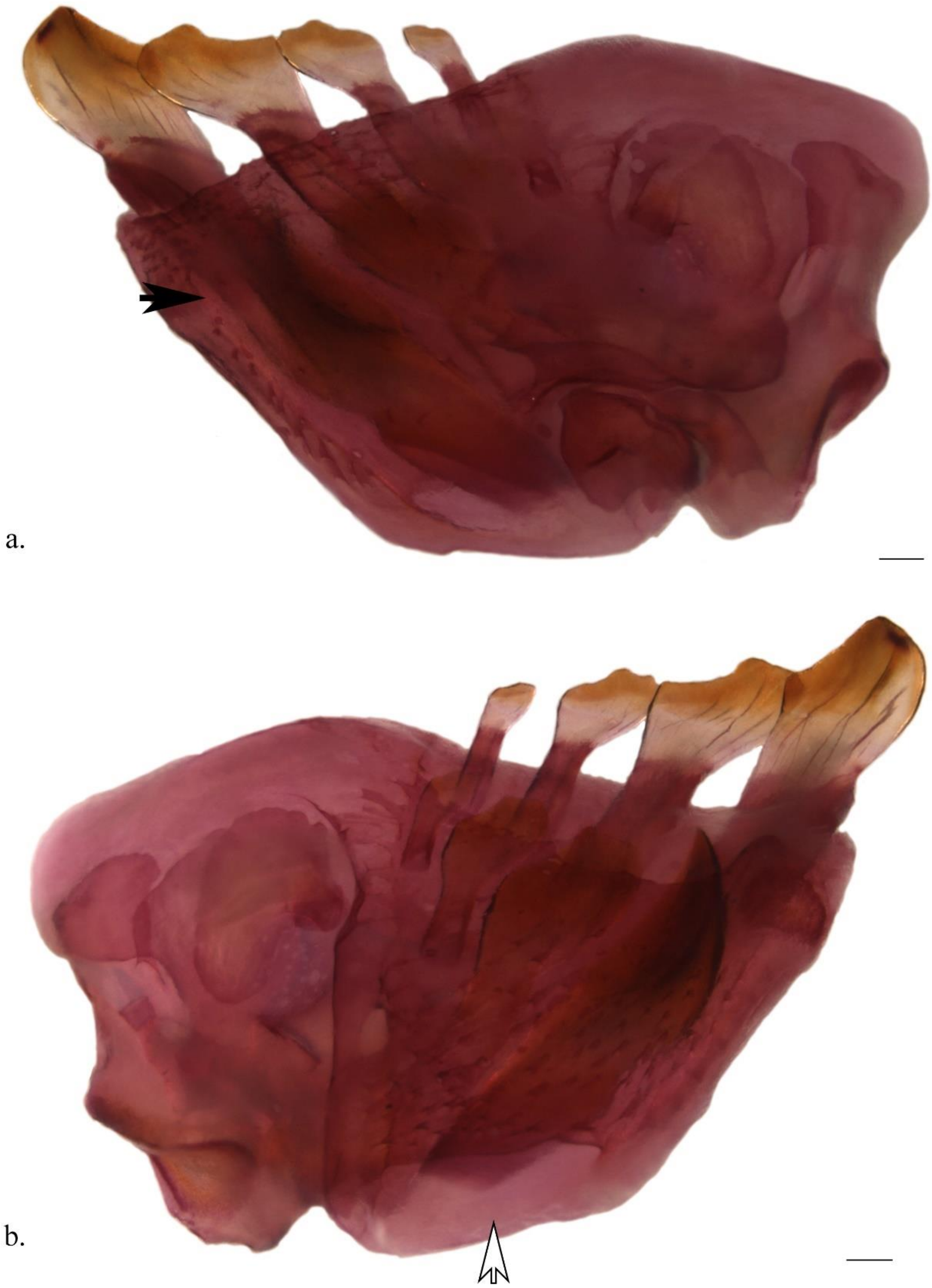


Figure 22. *Leporinus bahiensis* MZUSP 112246 87.5 mm SL. **a.** lower jaw, left side, labial view; **b.** lower jaw, left side, lingual view. Black arrow points to pleurodont implantation of tooth. White arrow points to ample ventral opening on bony cavity in which replacement teeth are formed. Scale bar 0.5 mm.

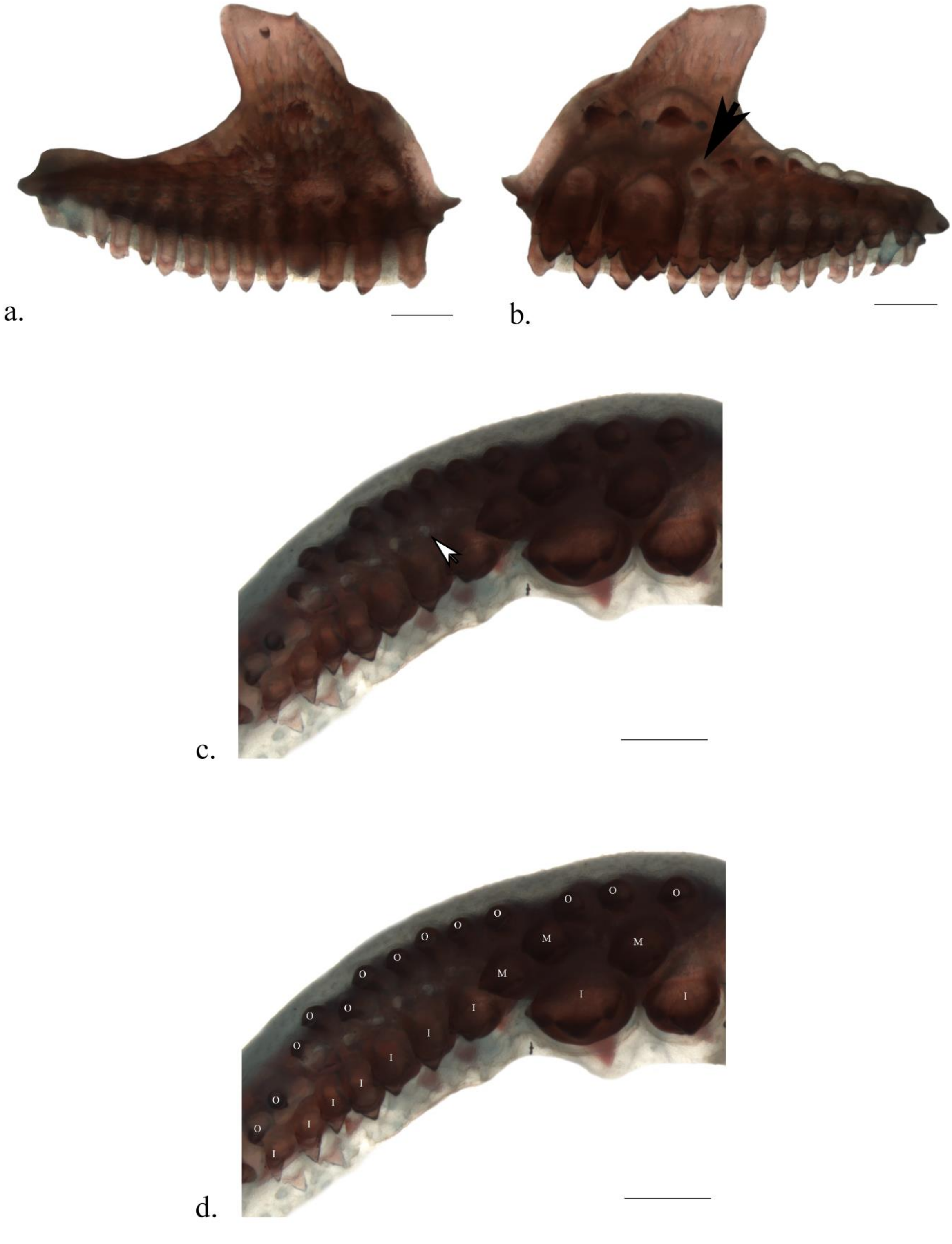


Figure 23. *Brycon amazonicus* MZUSP 74668 50.2 mm SL. **a.** right premaxilla, labial view; **b.** right premaxilla, lingual view; **c.** and **d.** upper jaw, right side, ventral view. Black arrow points to replacement tooth of lateralmost functional tooth on middle row on premaxilla. White arrow points to opening on ventral margin of premaxilla associated to developing replacement tooth of outer row. White lettering indicates identity of premaxillary tooth rows, I for inner row, M for middle row and O for outer row. Scale bar 0.5 mm.

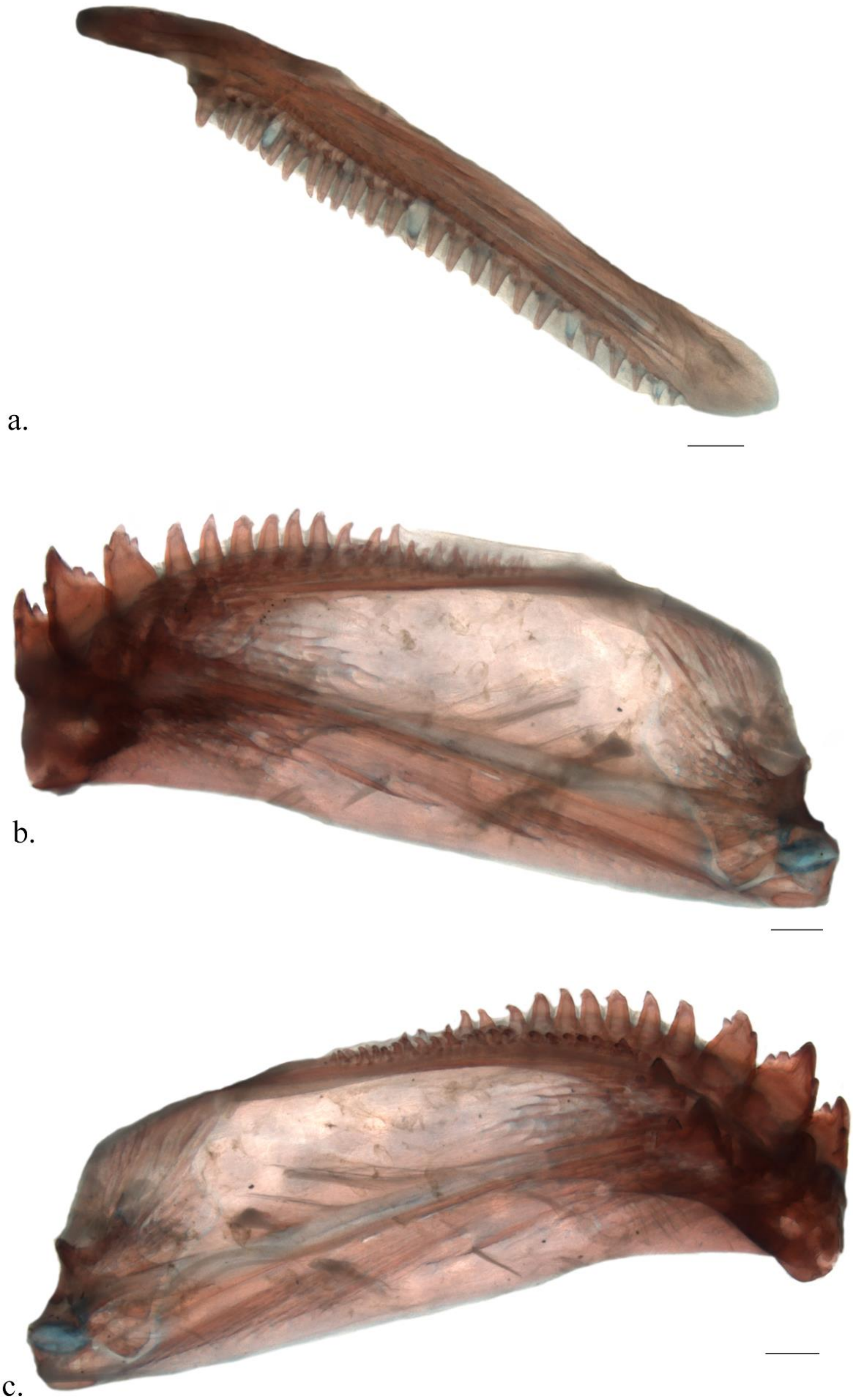


Figure 24. *Brycon amazonicus* MZUSP 74668 50.2 mm SL. **a.** right maxilla, lingual view; **b.** lower jaw, left side, labial view; **c.** lower jaw, left side, lingual view. Scale bar 0.5 mm.

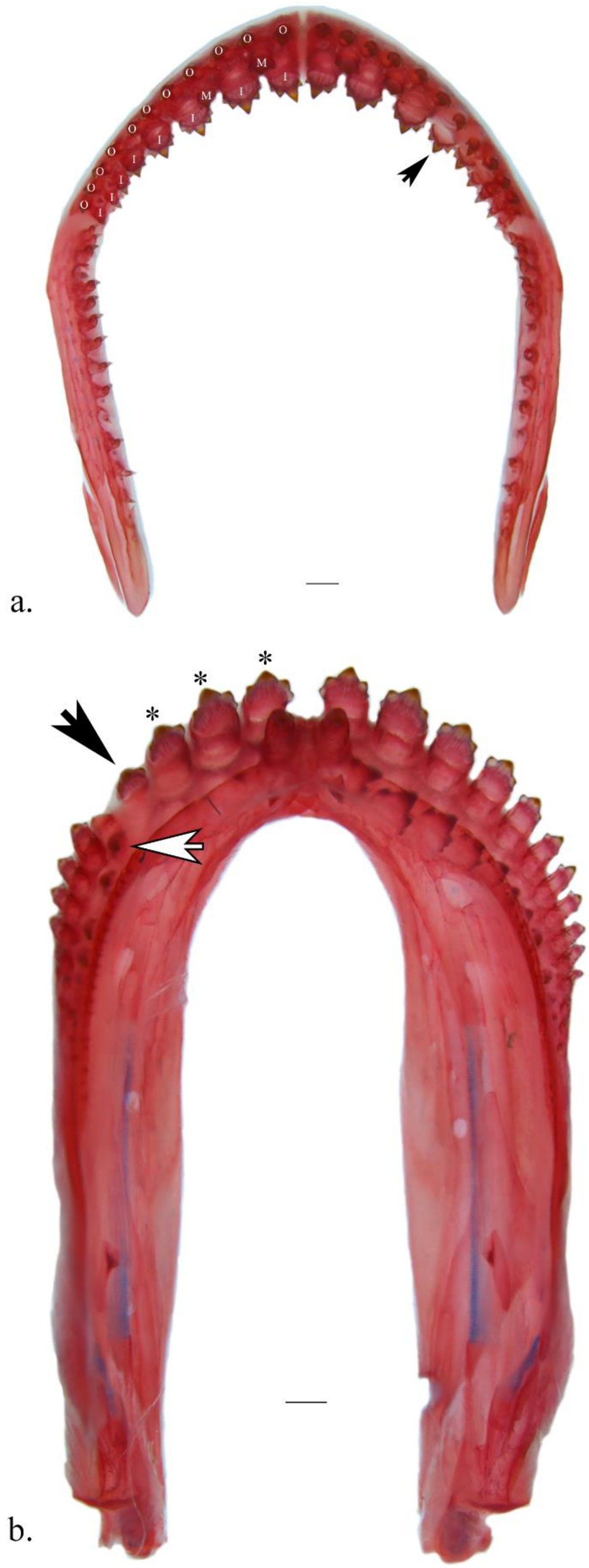


Figure 25. *Chalceus epakros* MZUSP 30754 71.3 mm SL. **a.** upper jaw, ventral view; **b.** lower jaw, dorsal view. Black arrows point to replacement tooth assuming functional position, uncalcified base. White arrow points to medialmost replacement tooth still inside the bony cavity. * indicates recently replaced teeth. White lettering indicates identity of premaxillary tooth rows, I for inner row, M for middle row and O for outer row. Scale bar 0.5 mm.

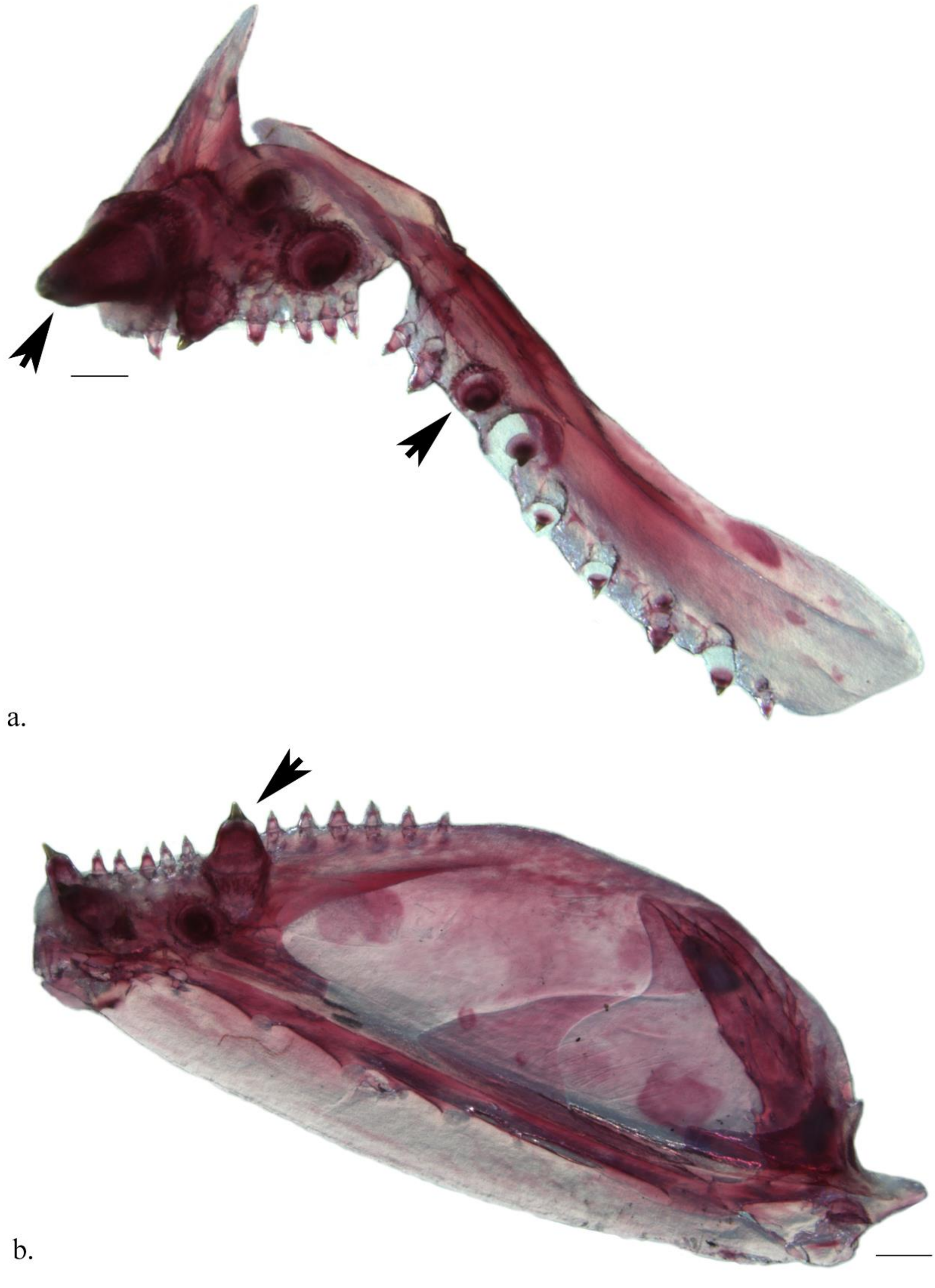


Figure 26. *Roeboides affinis* MZUSP 34705 63.3 mm SL. **a.** upper jaw, left side, labial view; **b.** lower jaw, left side. Black arrows indicate mamilliform teeth. Scale bar 0.5 mm.

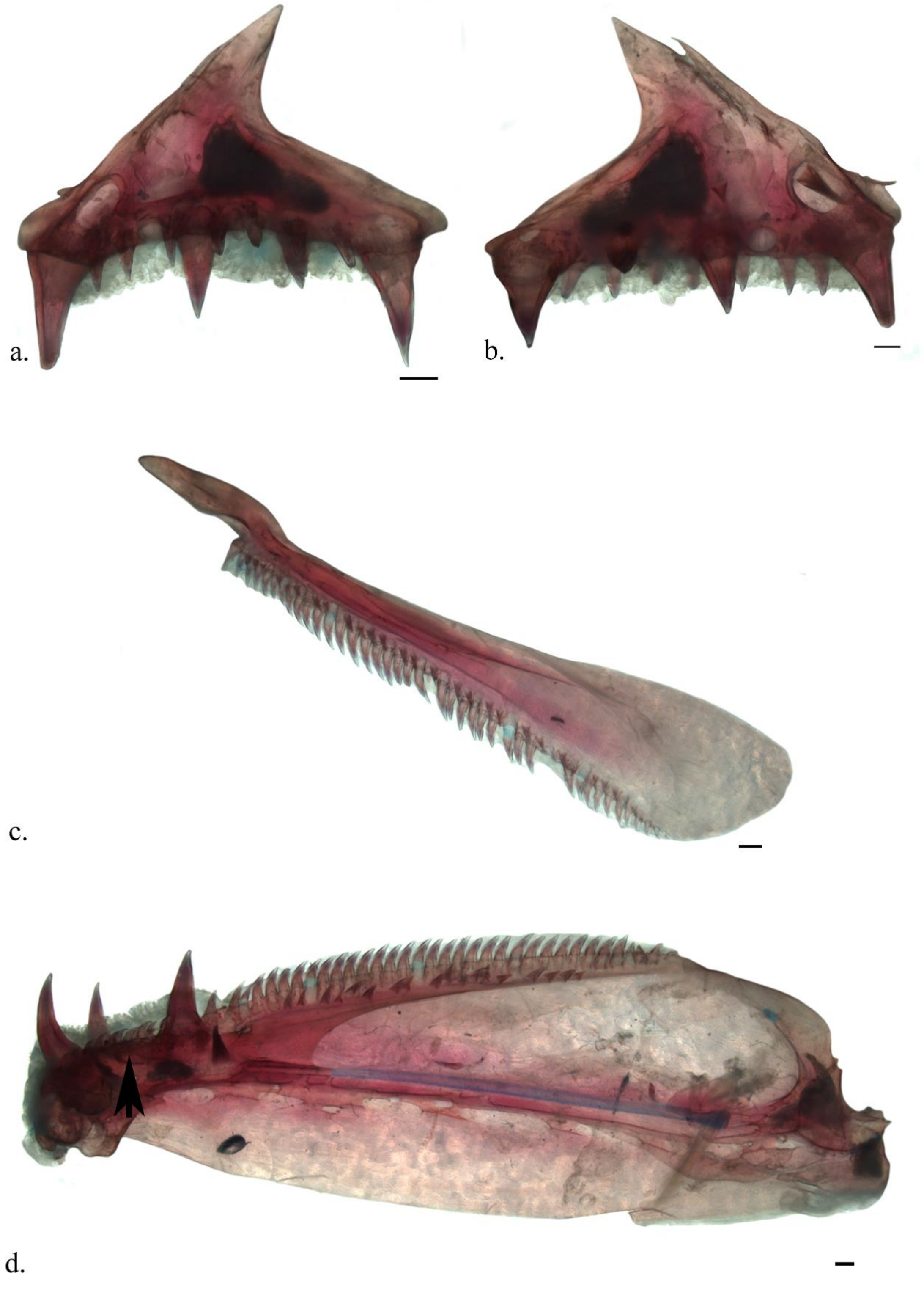


Figure 27. *Acestrocephalus stigmatus* MZUSP 94216 85.0 mm SL. **a.** left premaxilla, labial view; **b.** left premaxilla, lingual view; **c.** right maxilla, lingual view; **d.** lower jaw, right side, lingual view. Black arrow point to inner row of small conical teeth on dentary. Scale bar 0.5 mm.

Figure 28. *Astyanax novae* MZUSP 97863 52.1 mm SL. **a.** right premaxilla, labial view, **b.** left premaxilla, labial view; **c.** right premaxilla, lingual view; **d.** left premaxilla, lingual view. Scale bar 0.5 mm.

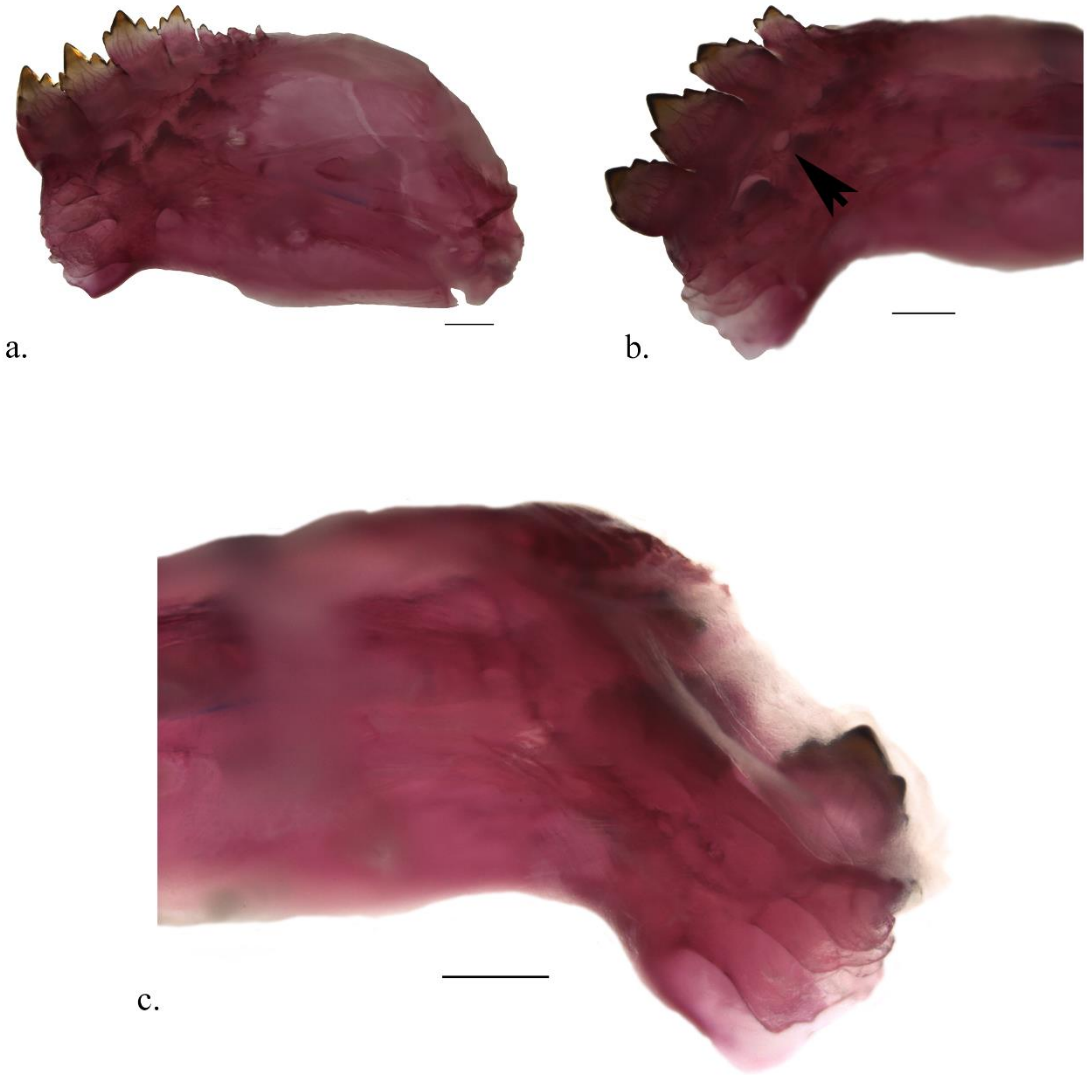


Figure 29. *Astyanax novae* MZUSP 97863 52.1 mm SL. **a.** lower jaw, right side, lingual view, **b.** anterior portion, lower jaw, dorsal view; **c.** anterior portion of lower jaw left side, dorsal view. Black arrow point to individual dorsal openings associated to developing replacement teeth on dentary. Scale bar 0.5 mm.

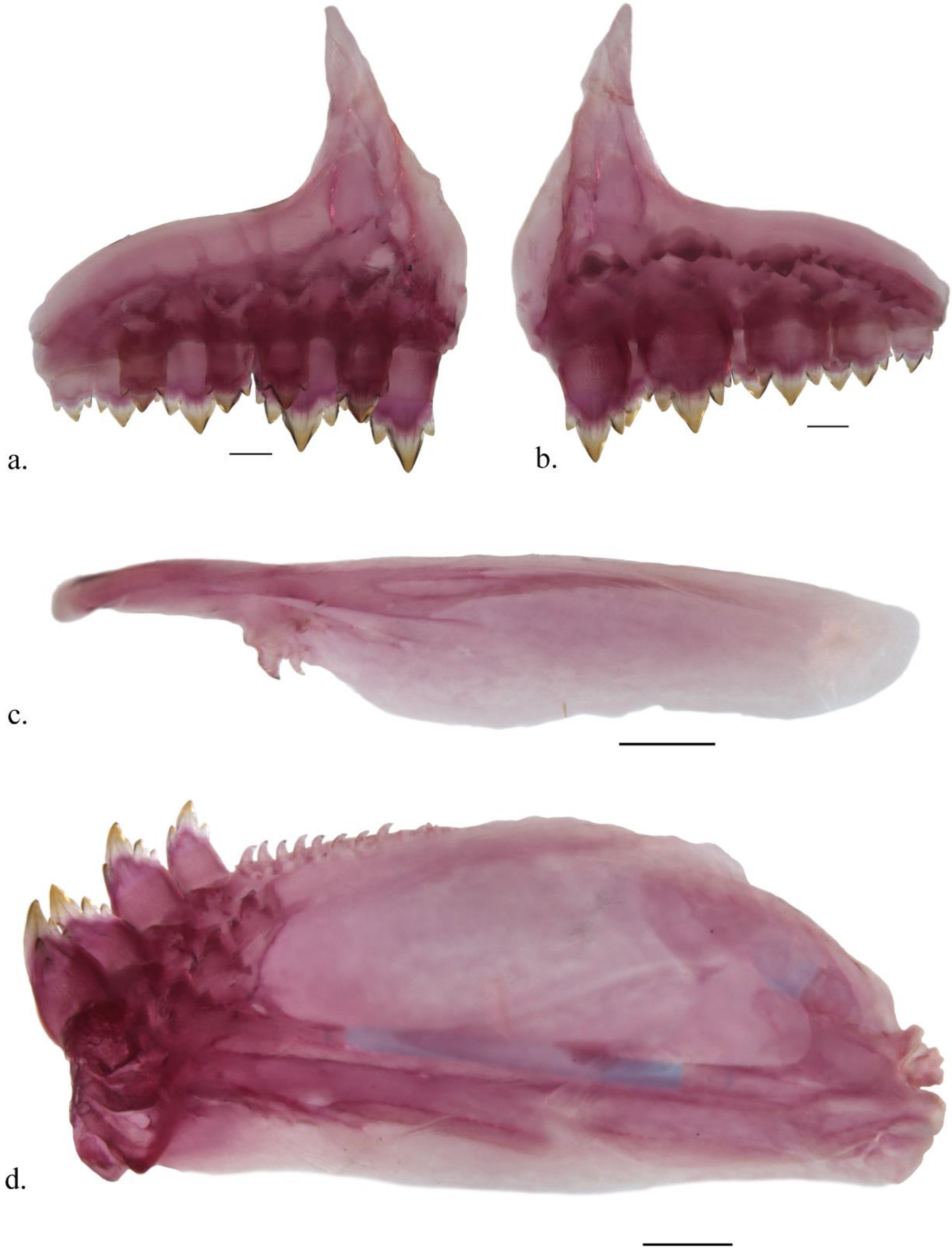


Figure 30. *Poptella compressa* MZUSP 91879 43.2 mm SL. **a.** right premaxilla, labial view; **b.** right premaxilla lingual view; **c.** right maxilla, lingual view; **d.** lower jaw, right side, lingual view. Scale bar 0.5 mm.

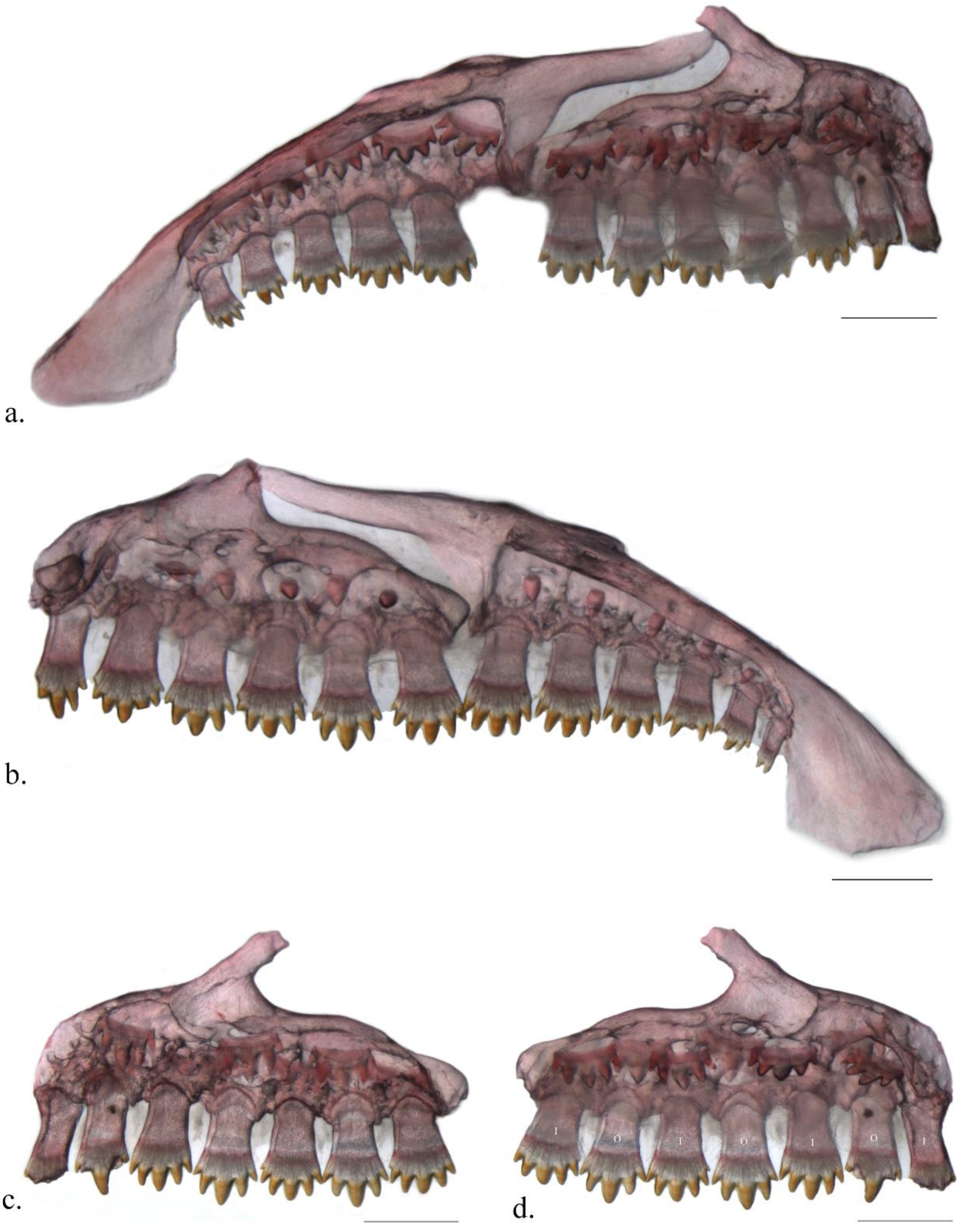
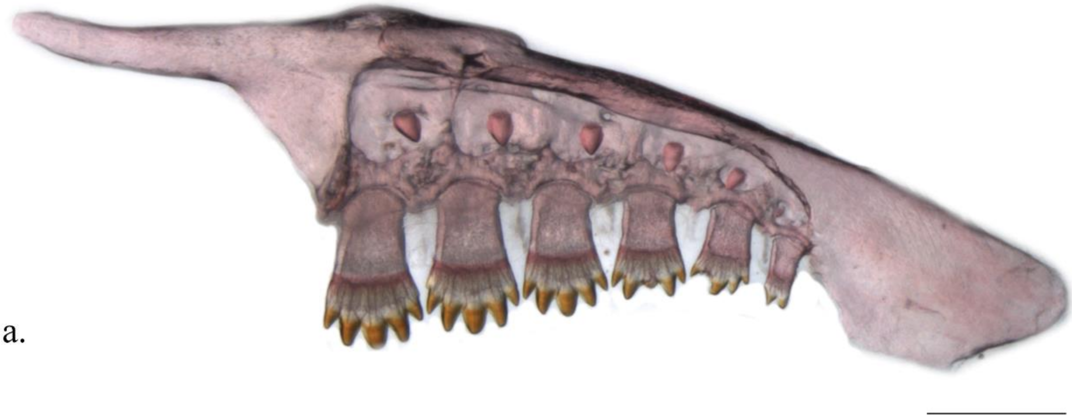


Figure 31. *Bryconamericus lethostigmus* MZUSP 41824 51.2 mm SL. **a.** upper jaw, left side, lingual view; **b.** upper jaw, right side, lingual view; **c.** left premaxilla, labial view; **d.** left premaxilla, lingual view. White lettering indicates identity of premaxillary tooth rows, I for inner row and O for outer row. Scale bar 0.5 mm.



a.

b.

Figure 32. *Bryconamericus lethostigmus* MZUSP 41824 51.2 mm SL. **a.** right maxilla, lingual view; **b.** lower jaw, ventral view. Scale 0.5 mm.

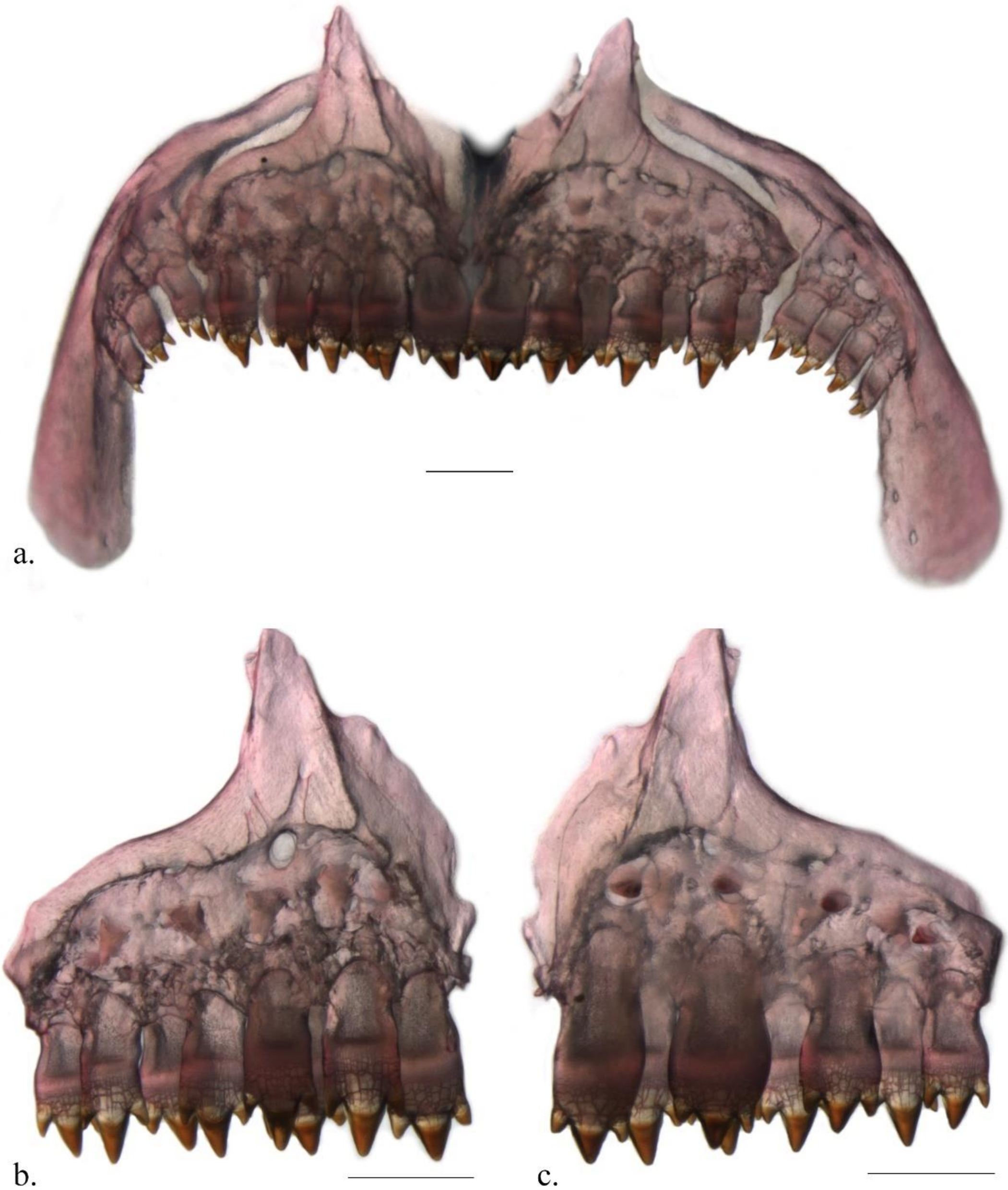


Figure 33. *Bryconamericus* sp. MZUSP 41824 51.2 mm SL. **a.** upper jaw, labial view; **b.** right premaxilla, labial view; **c.** right premaxilla, lingual view. Scale bar 0.5 mm.

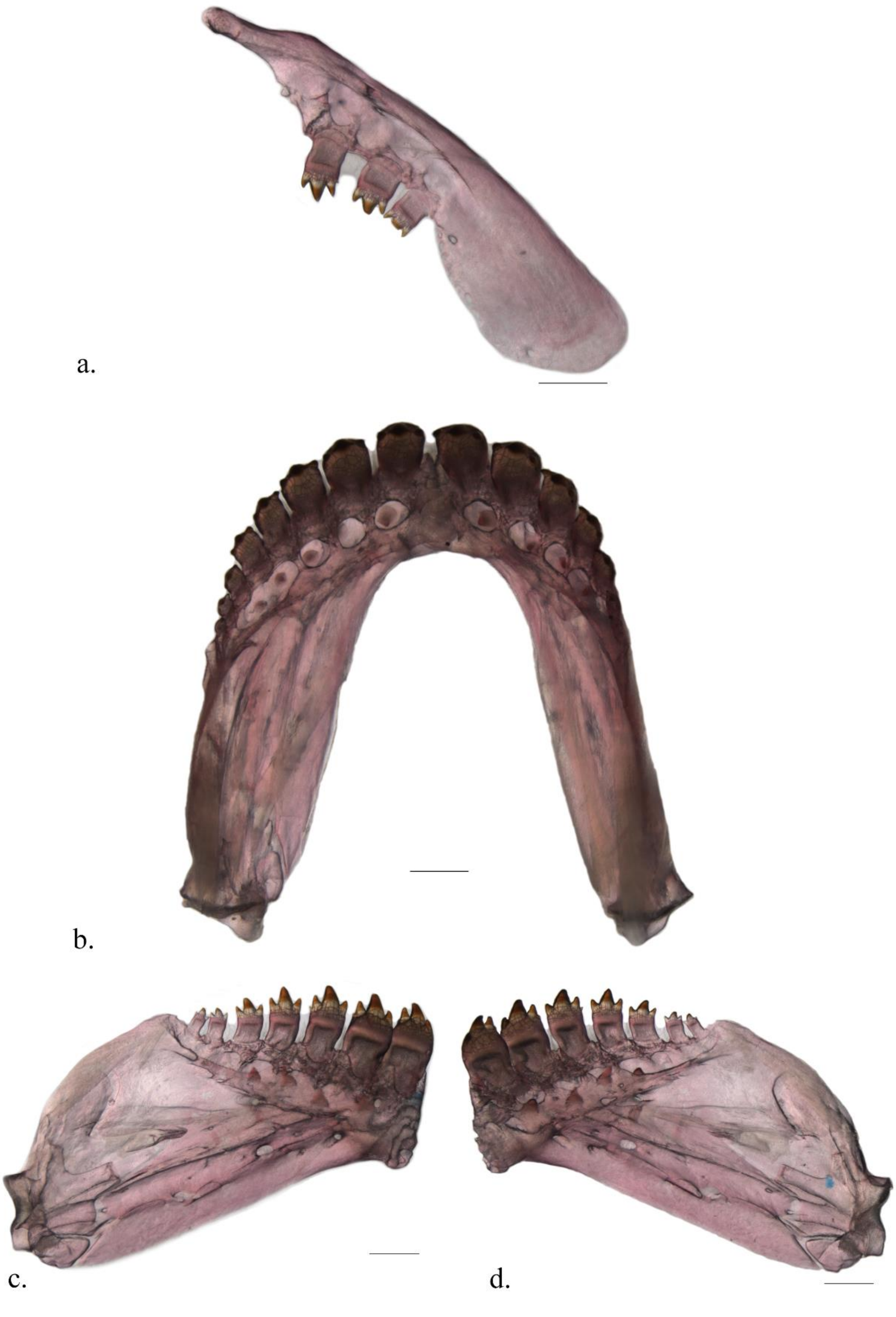


Figure 34. *Bryconamericus* sp. MZUSP 41824 51.2 mm SL. **a.** right maxilla, lingual view; **b.** lower jaw, dorsal view; **c.** lower jaw, right side, labial view; **d.** lower jaw, right side, lingual view. Scale bar 0.5 mm.

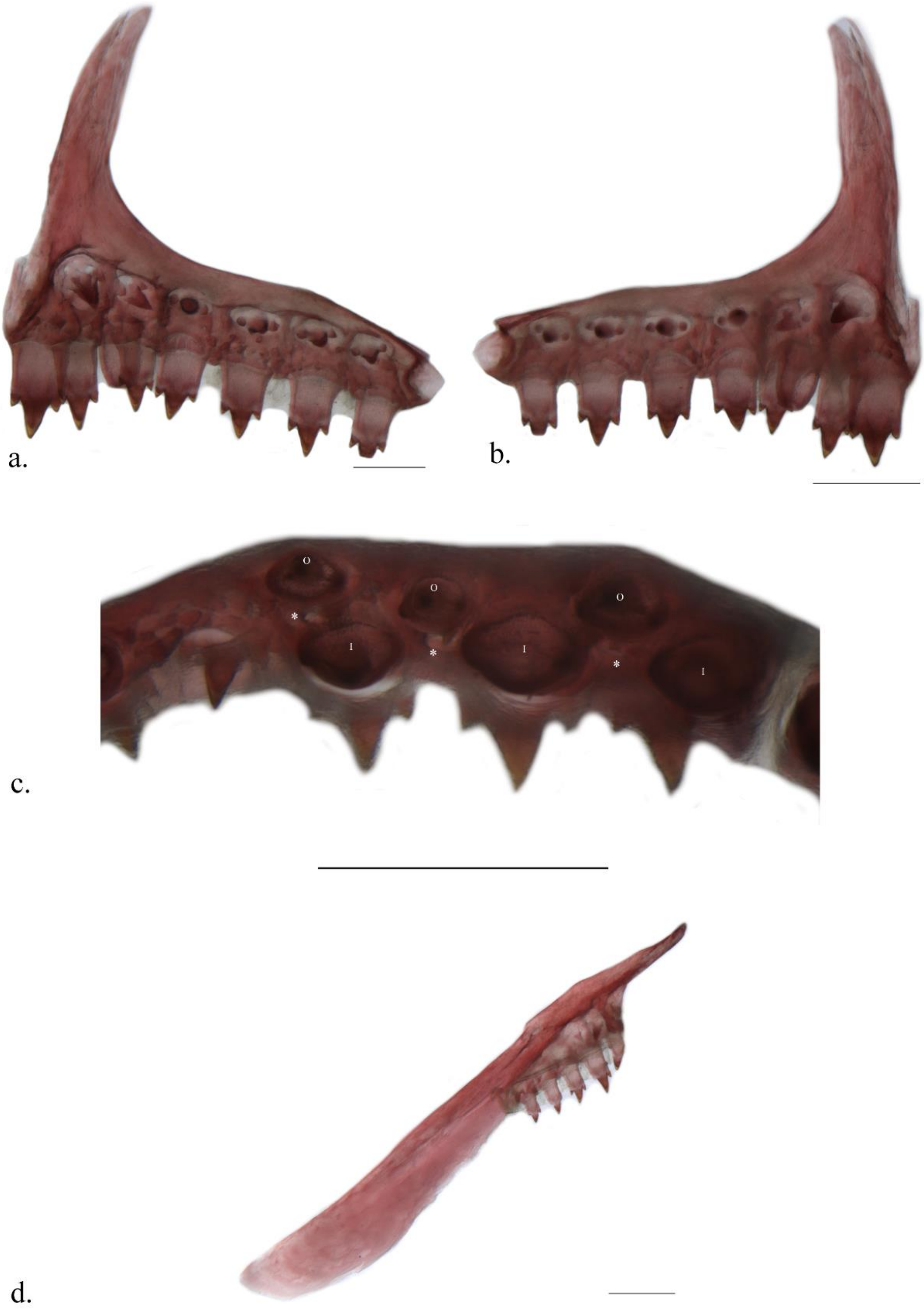


Figure 35. *Mimagoniates microlepis* MZUSP 78942 38.4 mm SL (c) and 48.1 mm SL (a, b and d). **a.** left premaxilla, labial view; **b.** left premaxilla, lingual view; **c.** upper jaw, right side, ventral view; **d.** left maxilla, lingual view. White lettering indicates identity of premaxillary tooth rows, I for inner row and O for outer row. * indicates openings on the ventral surface of the premaxilla associated to developing replacement teeth of outer row. Scale bar 0.5 mm.

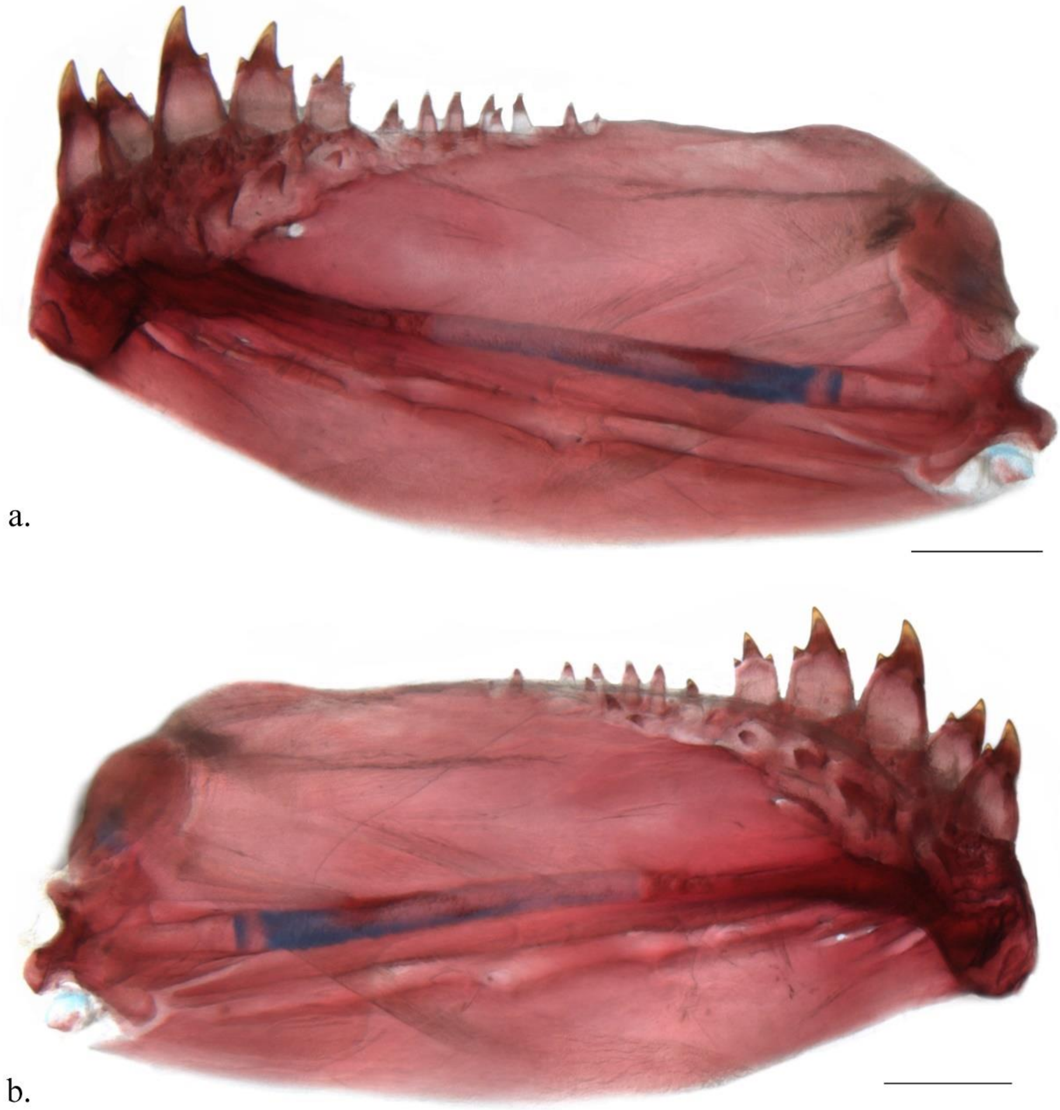


Figure 36. *Mimagoniates microlepis* MZUSP 78942 48.1 mm SL. **a.** lower jaw, left side, labial view; **b.** lower jaw, left side, lingual view. Scale bar 0.5 mm.

Figure 37. *Chilodus punctaus* MZUSP 21359 62.1 mm SL. **a.** upper jaw, lingual view; **b.** lower jaw, ventral view. Scale bar 0.5 mm.

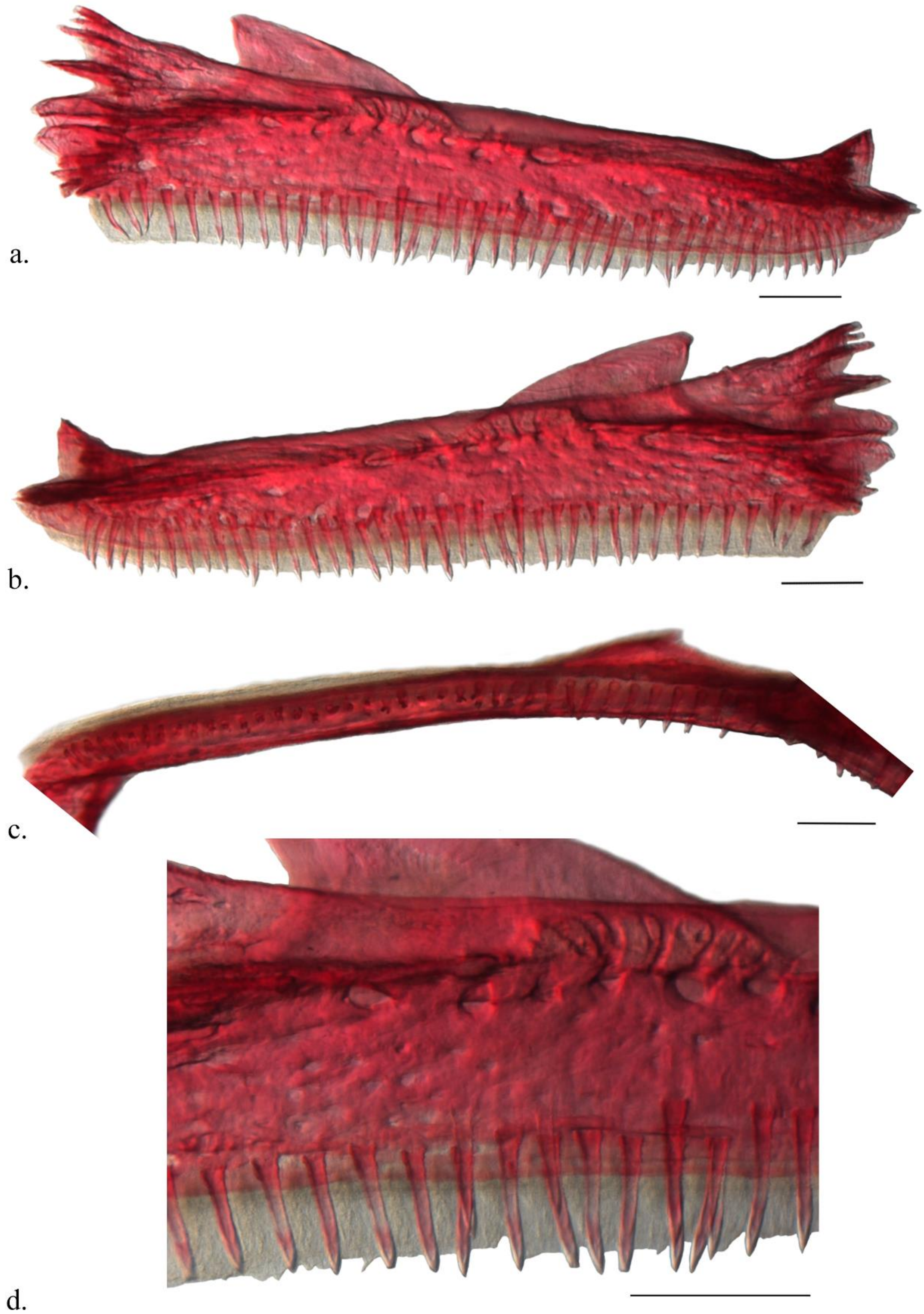


Figure 38. *Citharidium ansorgii* BMNH 1902.11.10.93 58.8 mm SL. **a.** left premaxilla, labial view; **b.** left premaxilla, lingual view; **c.** left premaxilla ventral view; **d.** midportion of left premaxilla, labial view. Scale bar 0.5 mm.

a.

b.

Figure 39. *Citharidium ansorgii* BMNH 1902.11.10.93 58.8 mm SL. **a.** midportion of left premaxilla, lingua view; **b.** left maxilla, labial view. Scale bar 0.5 mm.

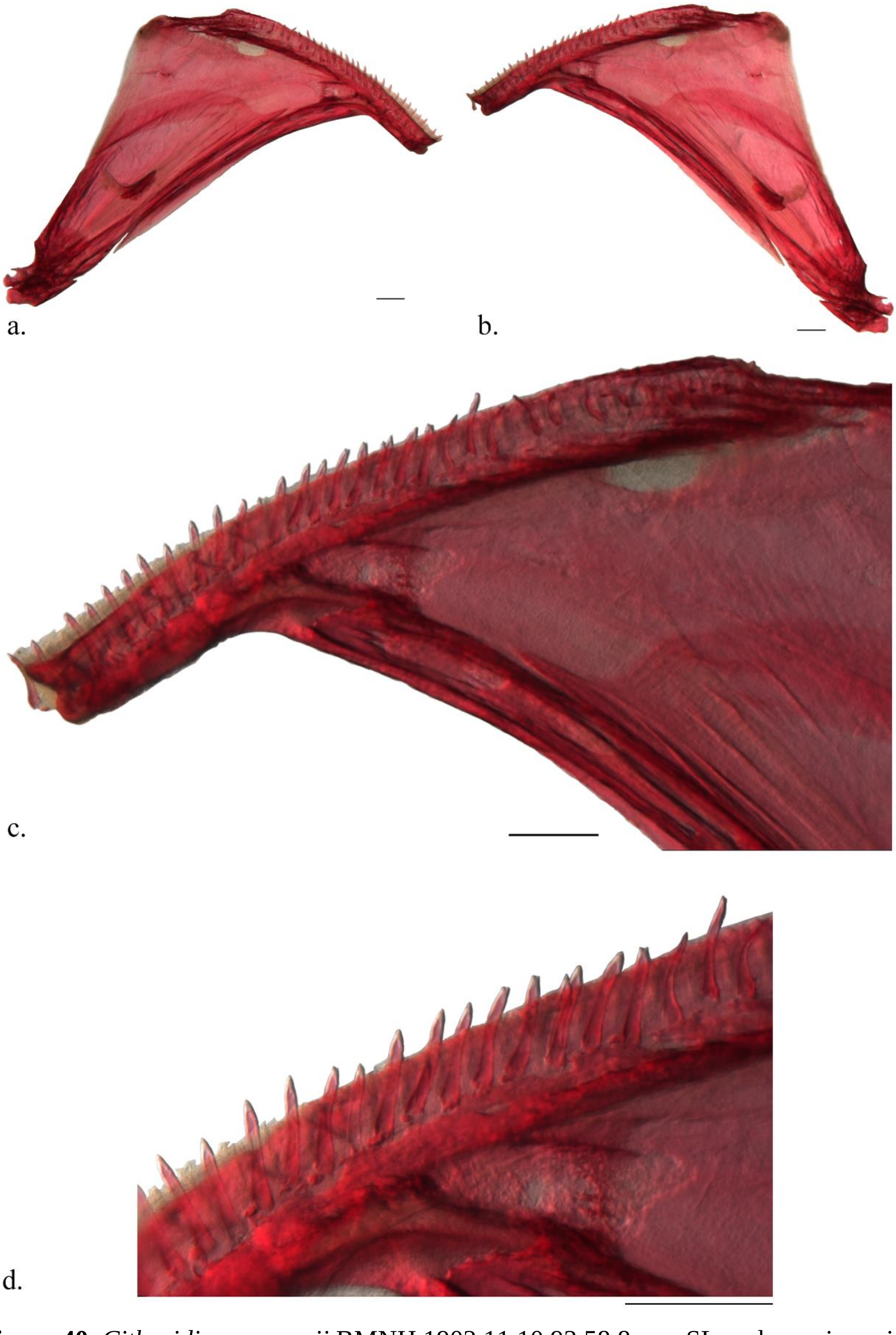


Figure 40. *Citharidium ansorgii* BMNH 1902.11.10.93 58.8 mm SL. **a.** lower jaw, right side, ventral view **b.** lower jaw, right side, dorsal view; **c.** anterior portion of lower jaw, right side, dorsal view; **d.** detail of anterior portion of lower jaw, right side, dorsal view Scale bar 0.5 mm.

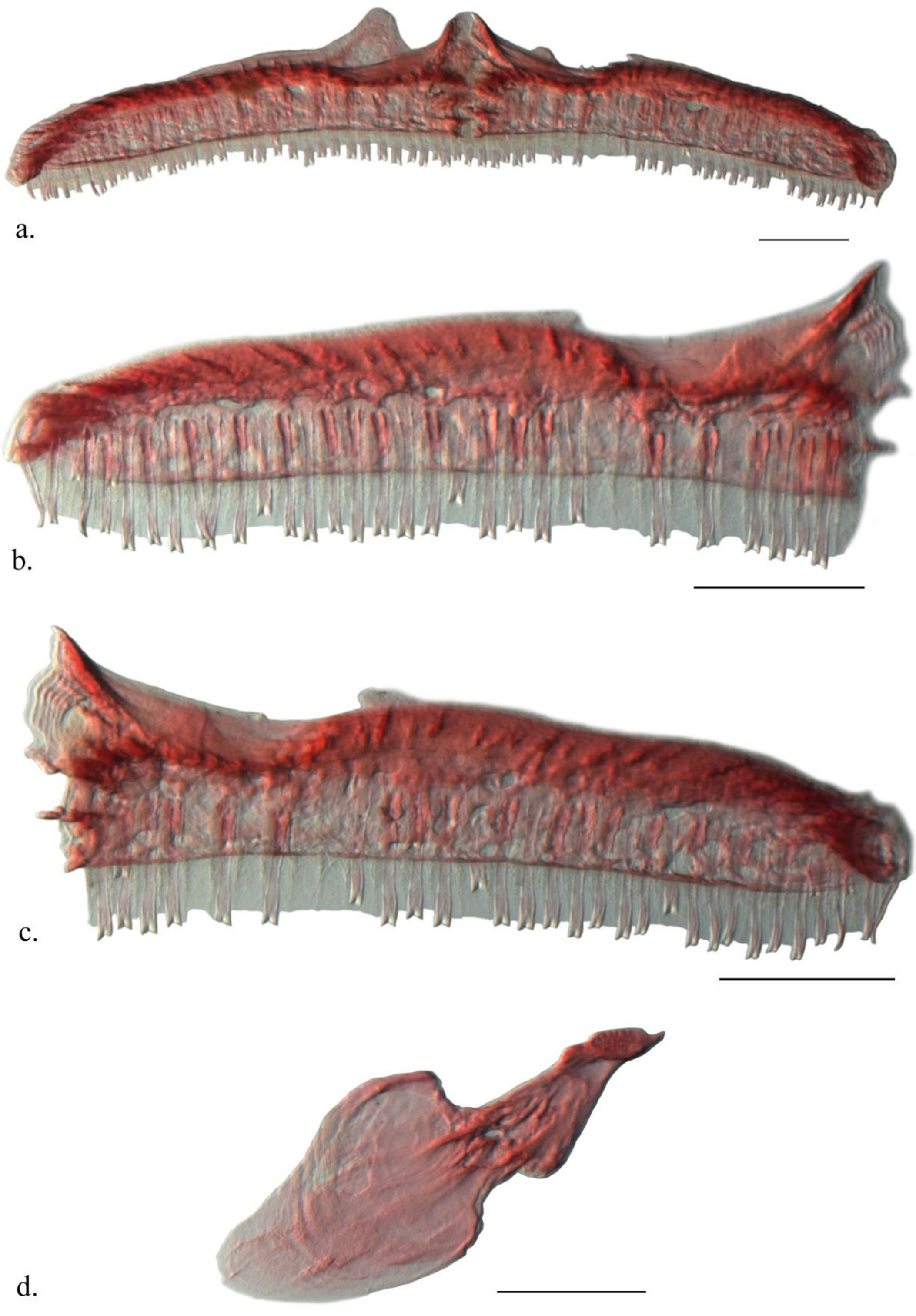


Figure 41. *Citharinus citharu* BMNH 1904.10.25.38-43 46.3 mm SL. **a.** premaxillae, labial view; **b.** right premaxilla, labial view; **c.** right premaxilla, lingual view; **d.** right maxilla, labial view. Scale bar 0.5 mm.

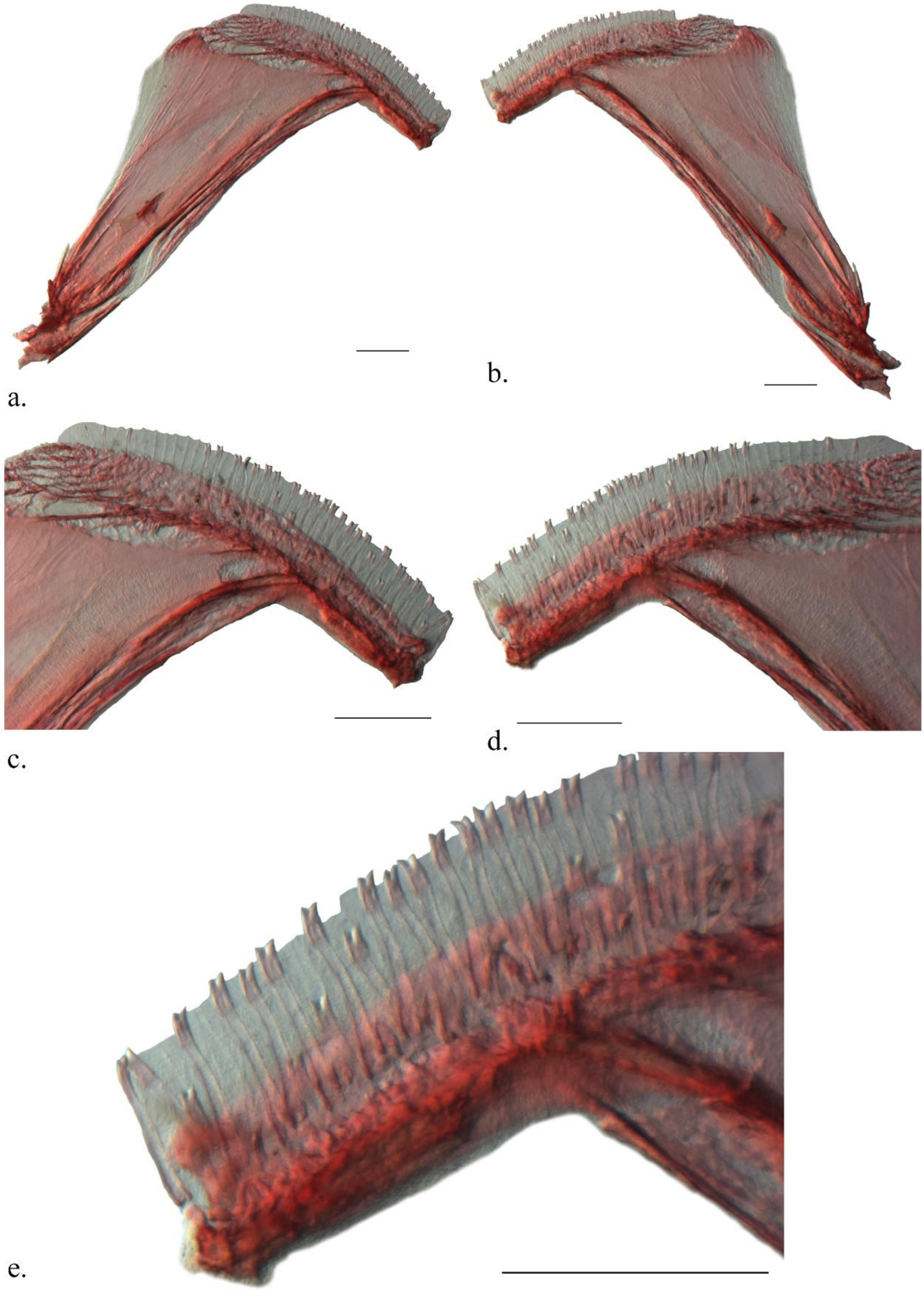


Figure 42. *Citharinus citharu* BMNH 1904.10.25.38-43 46.3 mm SL. **a.** right lower jaw, ventral view; **b.** right lower jar, lingual view; **c.** anterior portion of right lower jaw, ventral view; **d.** anterior portion of right lower jar, lingual view; **e.** detail of anterior portion of right lower jar, lingual view. Scale bar 0.5 mm.

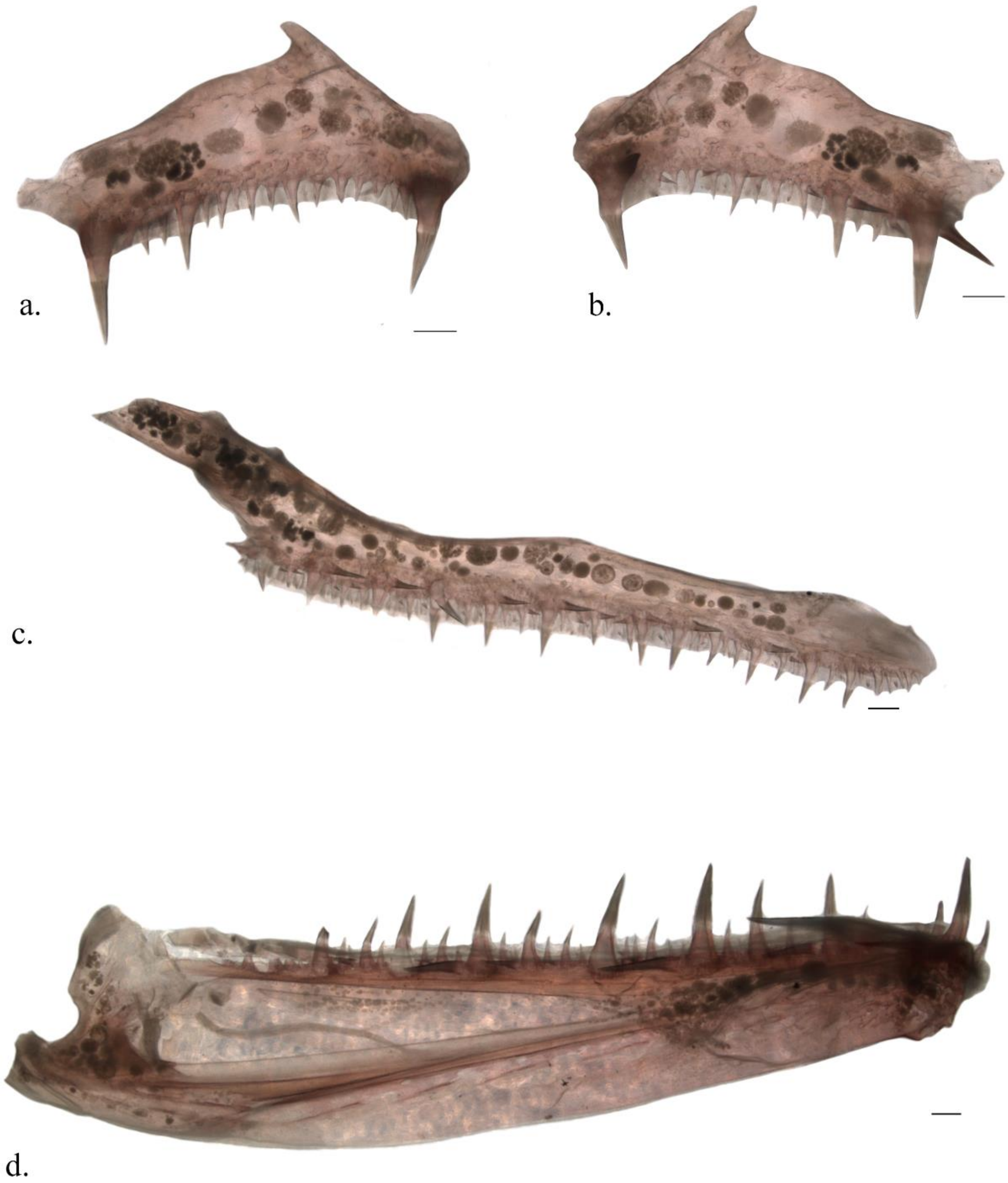


Figure 43. *Cynodon gibbus* MZUSP 89905 103.8 mm SL. **a.** right premaxilla, labial view; **b.** right premaxilla, lingual view; **c.** right maxilla, lingual view; **d.** lower jaw, left side, lingual view. Scale bar 0.5 mm.

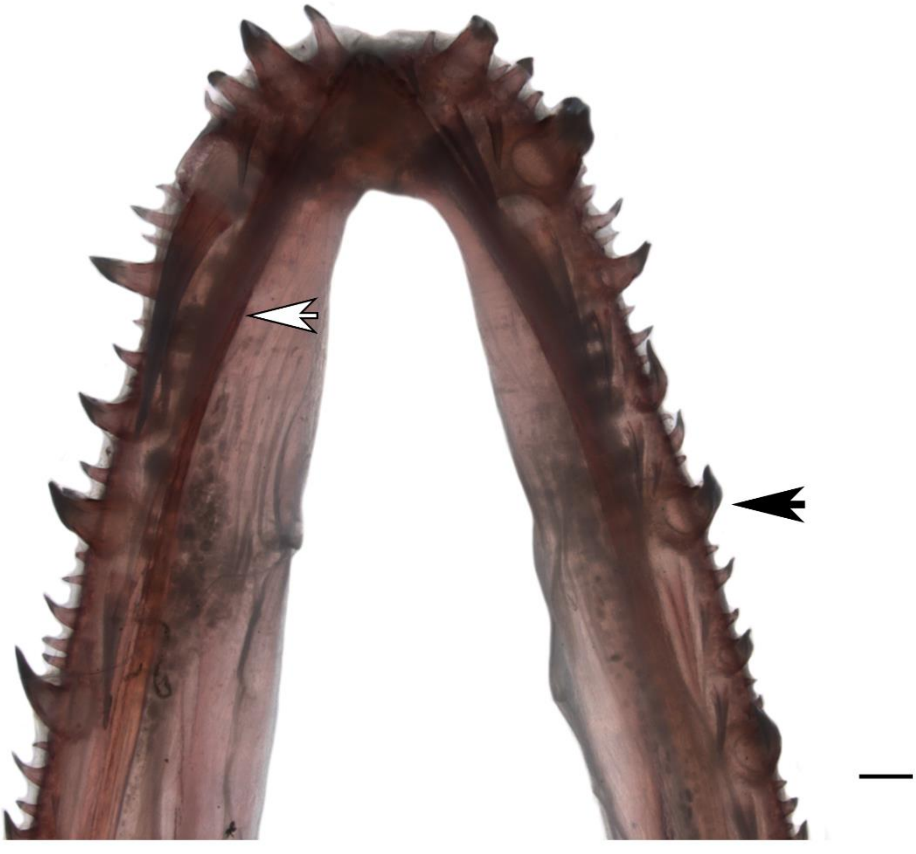


Figure 44. *Cynodon gibbus* MZUSP 89905 103.8 mm SL. **a.** lower jaw, dorsal view; **b.** anterior portion of lower jaw, dorsal view. Black arrow points to unicuspid tooth with lateral cutting-edge. White arrow points to shallow trench in which the replacement teeth of the outer row of the dentary are formed Scale bar 0.5 mm.

a.

b.

Figure 45. *Ichthyborus quadrilineatus* BMNH 1912.4.1.55 66.1 mm SL. **a.** upper jaw, ventral view; **b.** upper jaw, labial view of left side. Scale bar 0.5 mm.

Figure 46. *Ichthyborus quadrilineatus* BMNH 1912.4.1.55 66.1 mm SL. **a.** lower jaw, ventral view; **b.** lower jaw, labial view of left side. Black arrow points to symphyseal tooth. Scale bar 0.5 mm.

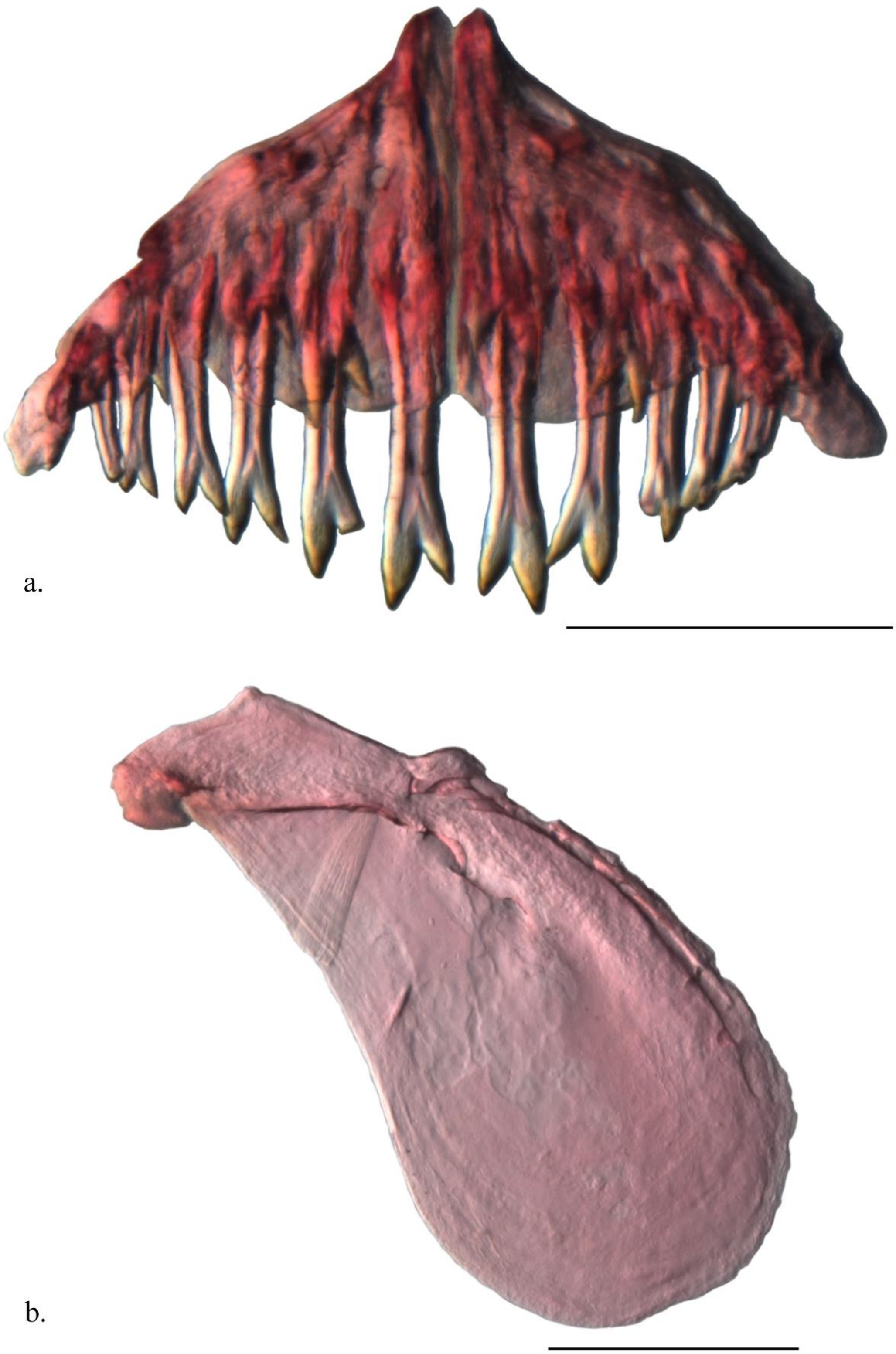


Figure 47. *Nannocharax* aff. *multifasciatus* BMNH 1976.3.18.2350-2352 34.1 mm SL. **a.** premaxillae, labial view; **b.** right maxilla, lingual view. Scale bar 0.5 mm.

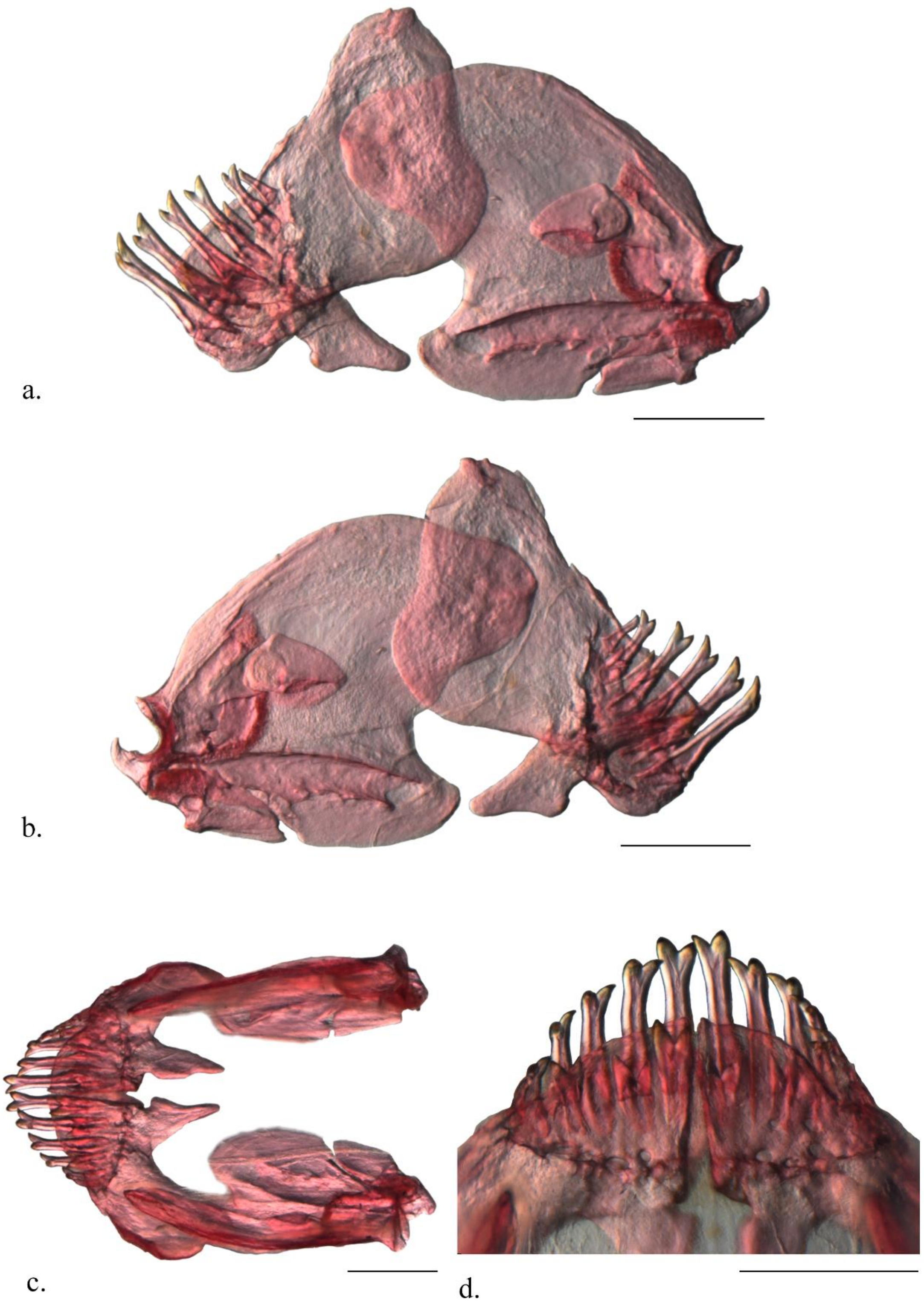


Figure 48. *Nannocharax* aff. *multifasciatus* BMNH 1976.3.18.2350-2352 34.1 mm SL. **a.** lower jaw, left side, labial view; **b.** lower jaw, left side, lingual view; **c.** lower jaw, dorsal view; **d.** anterior portion of lower jaw, ventral view. Scale bar 0.5 mm.

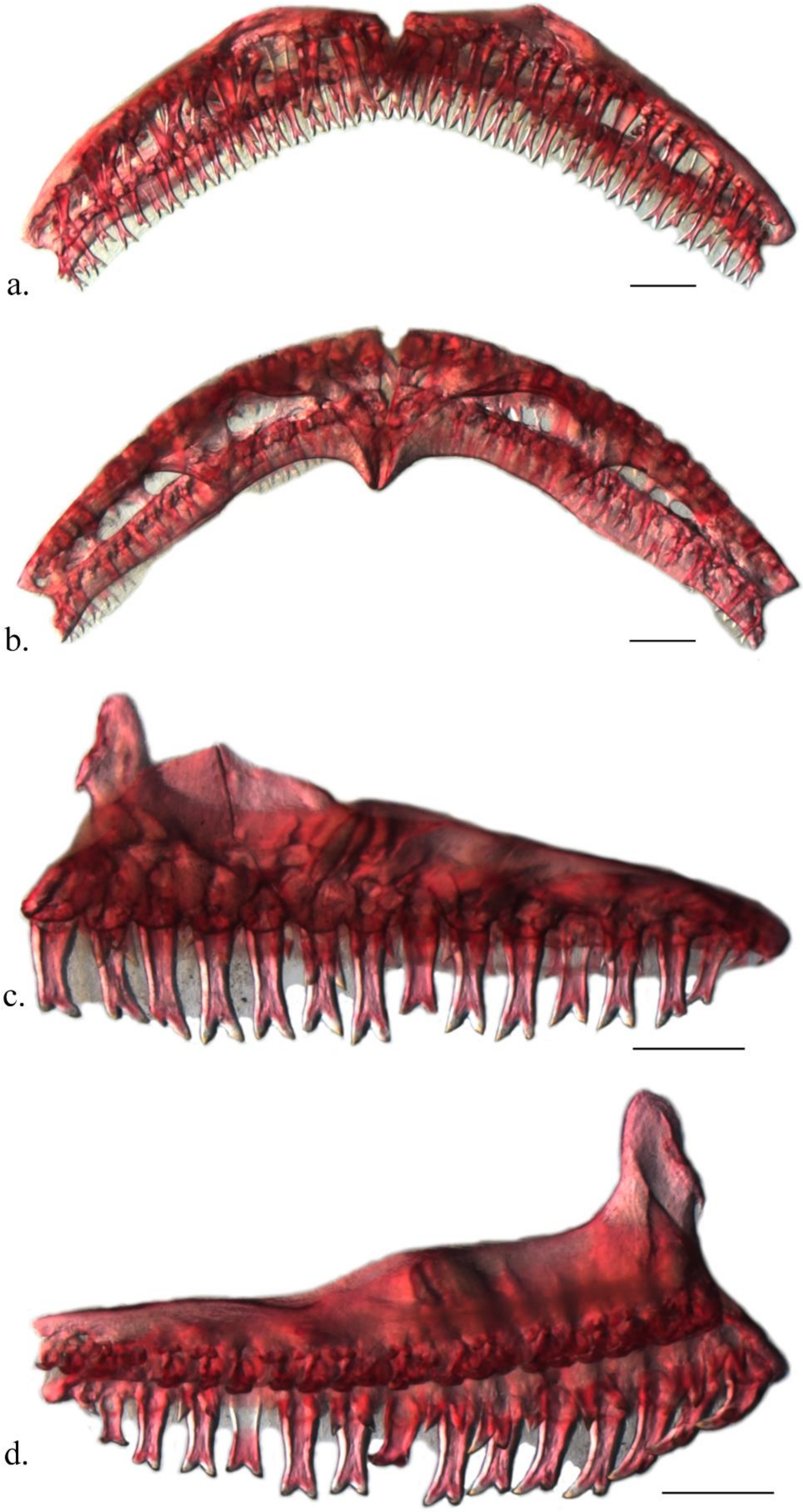


Figure 49. *Xenocharax spilurus* BMNH 1896.5.5.86 66.0 mm SL. **a.** premaxillae, ventral view; **b.** premaxillae ventral view; **c.** left premaxilla, labial view; **d.** left premaxilla lingual view. Scale bar 0.5 mm.

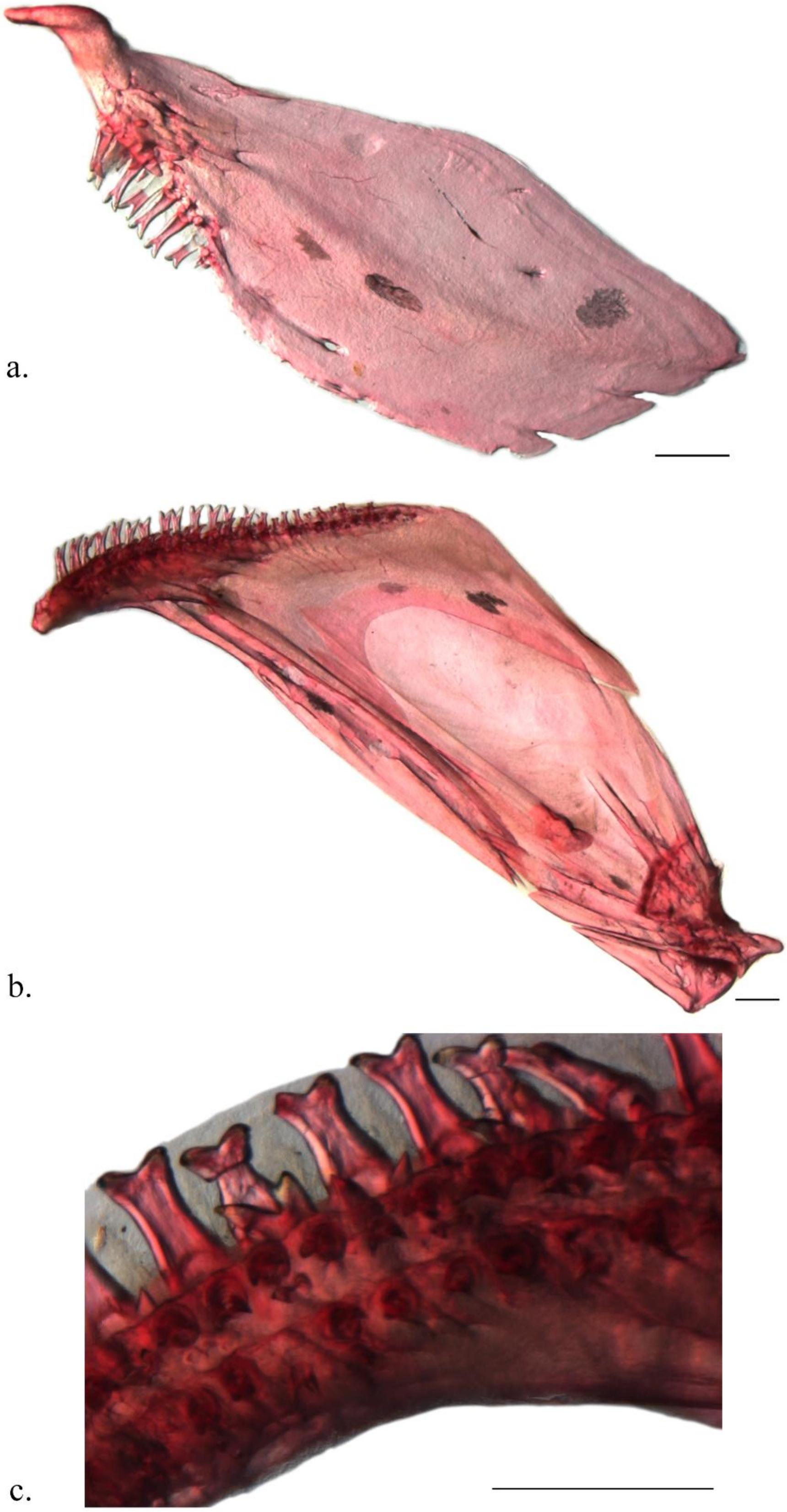


Figure 50. *Xenocharax spilurus* BMNH 1896.5.5.86 66.0 mm SL. **a.** right maxilla, lingual view; **b.** lower jaw, right side, lingual view; **c.** detail of anterior portion of lower jaw, right side, dorsal view. Scale bar 0.5 mm.

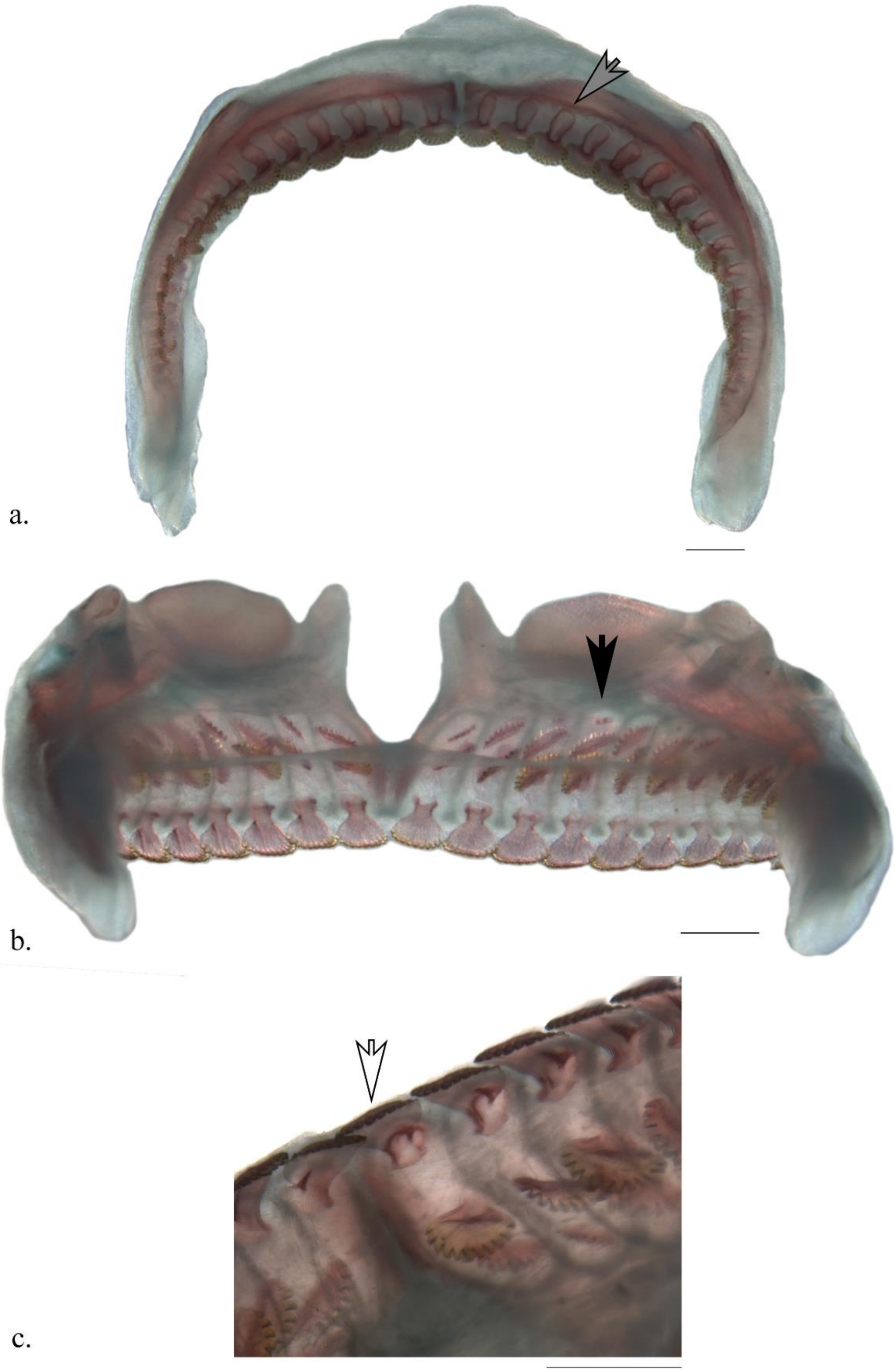


Figure 51. *Hemiodous microlepis* MZUSP 89300 73.0 mm SL. **a.** upper jaw, ventral view; **b.** upper jaw, lingual view; **c.** detail of midportion of right premaxilla, ventral view. Black arrow points to three preformed replacement teeth on the premaxilla. White arrow points to cusps arranged in almost straight line. Gray arrow points to teeth not directly associated to underlying bone, embedded in soft tissue. Scale bar 0.5 mm.

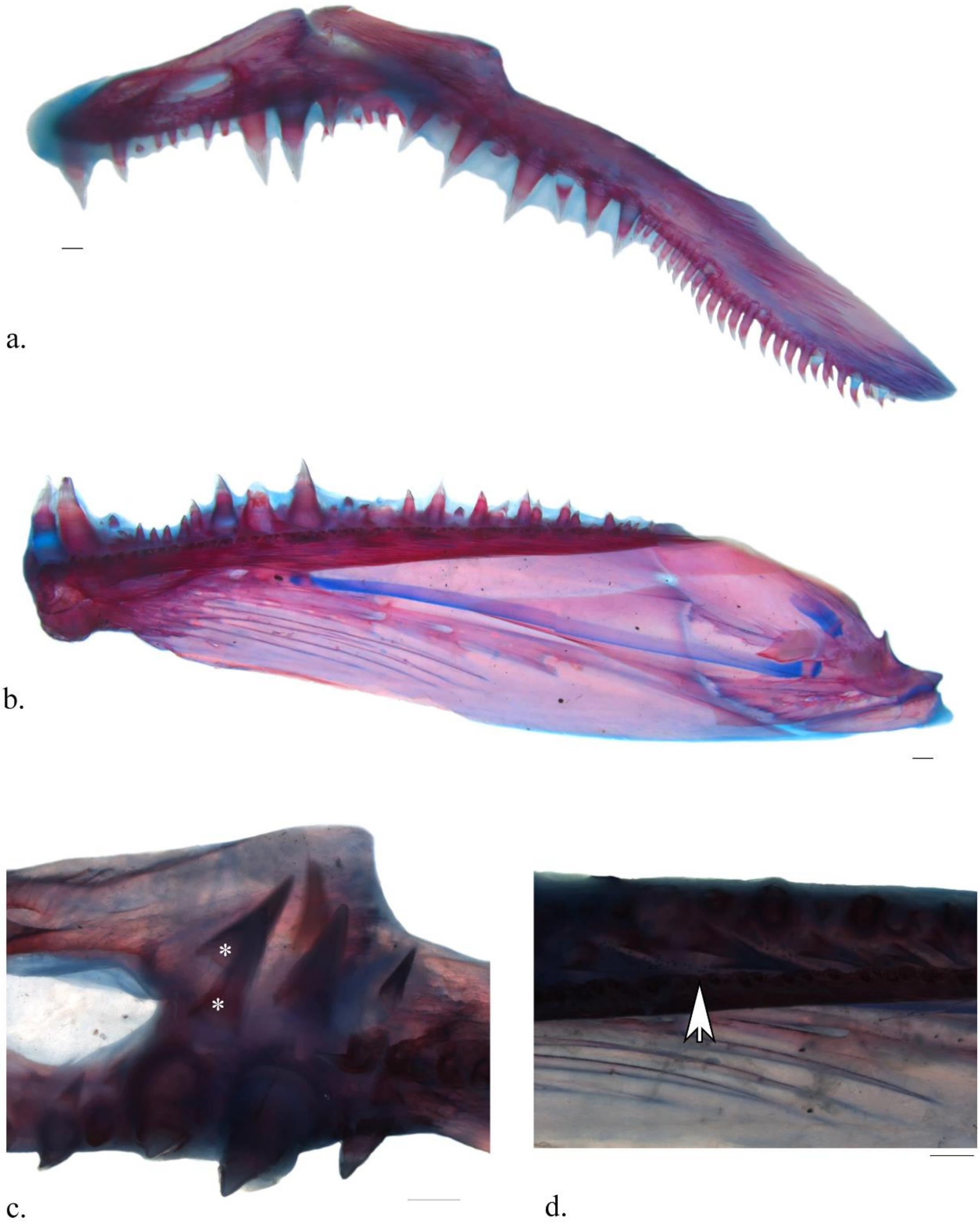


Figure 52. *Hepsetus odoe* MZUSP 84869 111.6 mm SL. **a.** upper jaw, left side, labial view; **b.** lower jaw, right side, lingual view; **c.** detail right premaxilla, ventral view; **d.** detail lower jaw dorsal view. White arrow points to shallow trench where replacement teeth of the main row of dentary are formed. * indicates two preformed replacement teeth on the premaxilla. Scale bar 0.5 mm.

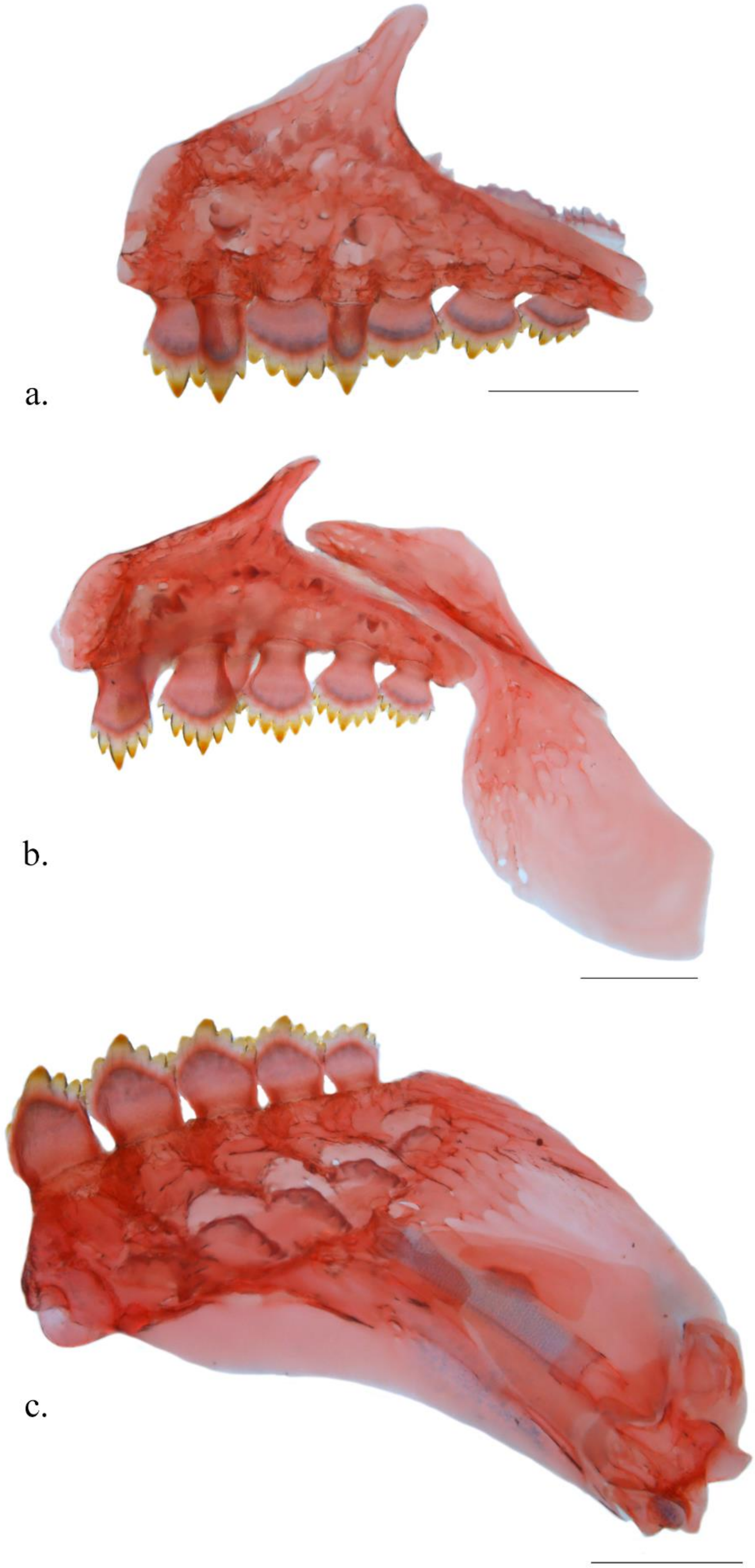
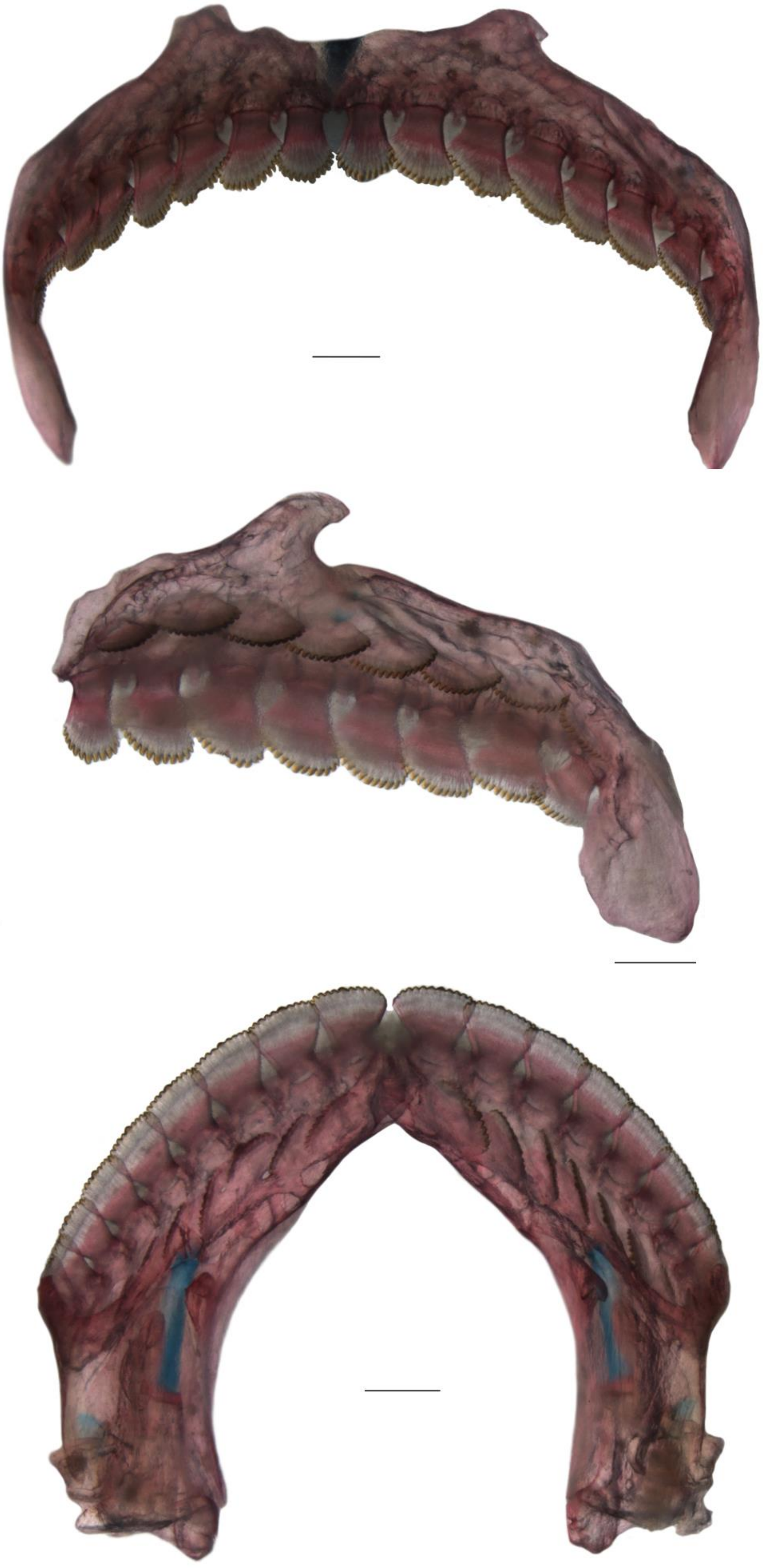


Figure 53. *Iguanodectes geisleri* MZUSP 29616 34.8 mm SL. **a.** left premaxilla, labial view; **b.** upper jaw, right side, lingual view; **c.** lower jaw, left side, labial view. Scale bar 0.5 mm.



a.

b.

c.

Figure 54. *Piabucus melanostoma* MZUSP 95080 77.3 mm SL. **a.** upper jaw, labial view; **b.** upper jaw, right side, lingual view; **c.** lower jaw, dorsal view. Scale bar 0.5 mm.

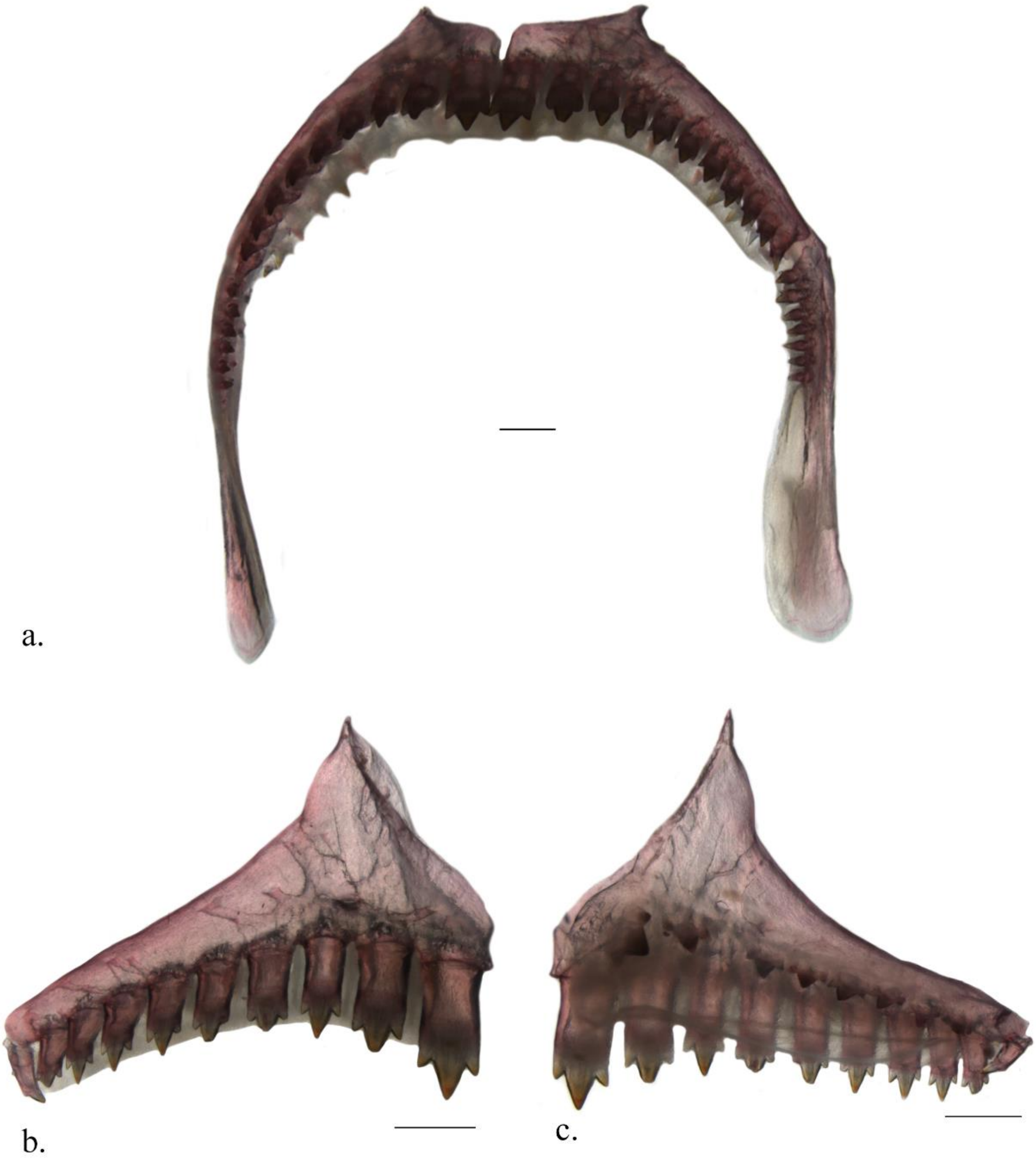


Figure 55. *Lebiasina* sp. MZUSP 108870 52.9 mm SL. **a.** upper jaw, ventral view; **b.** left premaxilla, labial view; **c.** left premaxilla, lingual view. Scale bar 0.5 mm.

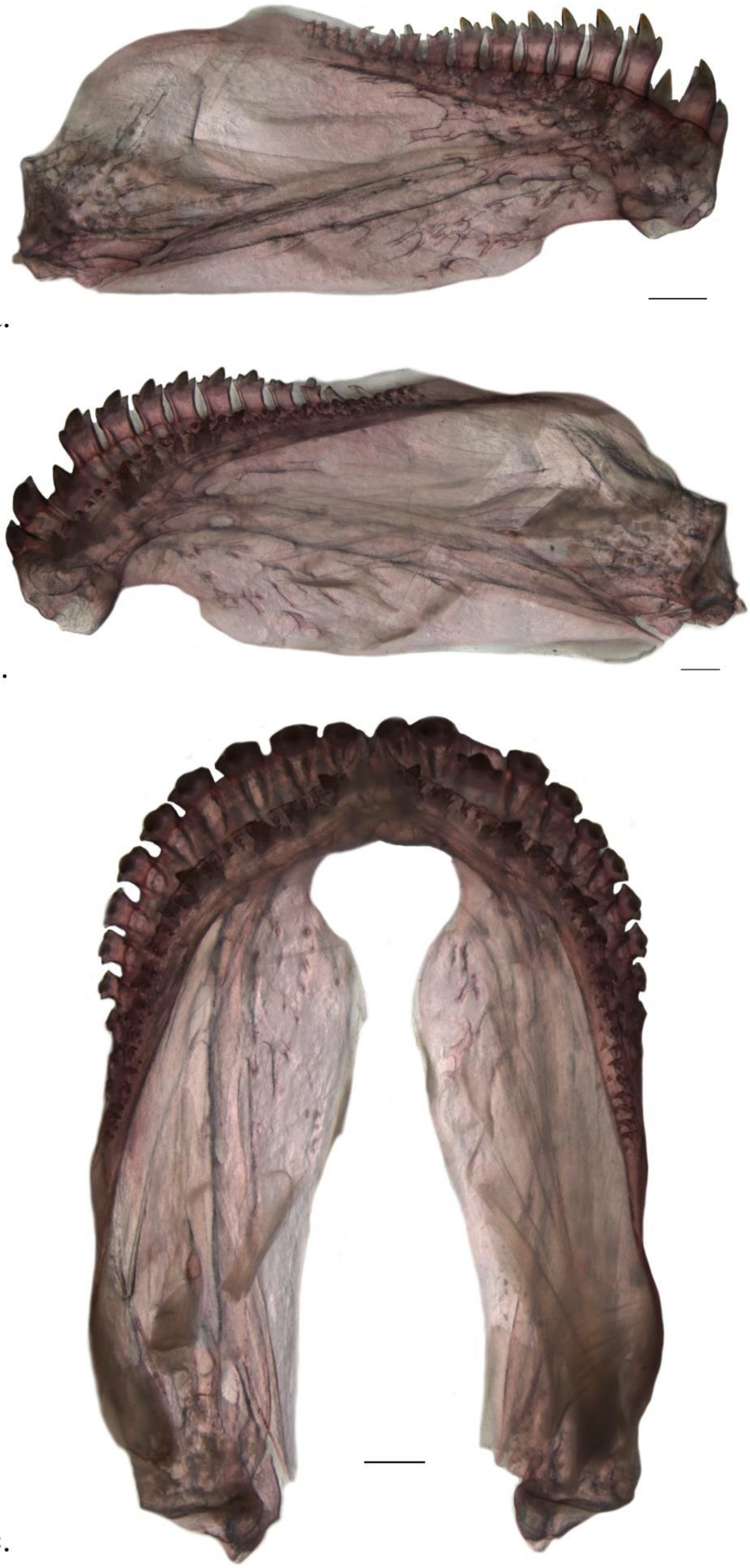

a.
b.
c.

Figure 56. *Lebiasina* sp. MZUSP 108870 52.9 mm SL. **a.** lower jaw, right side, labial view; **b.** lower jaw, right side, lingual view; **c.** lower jaw, dorsal view. Scale bar 0.5 mm.

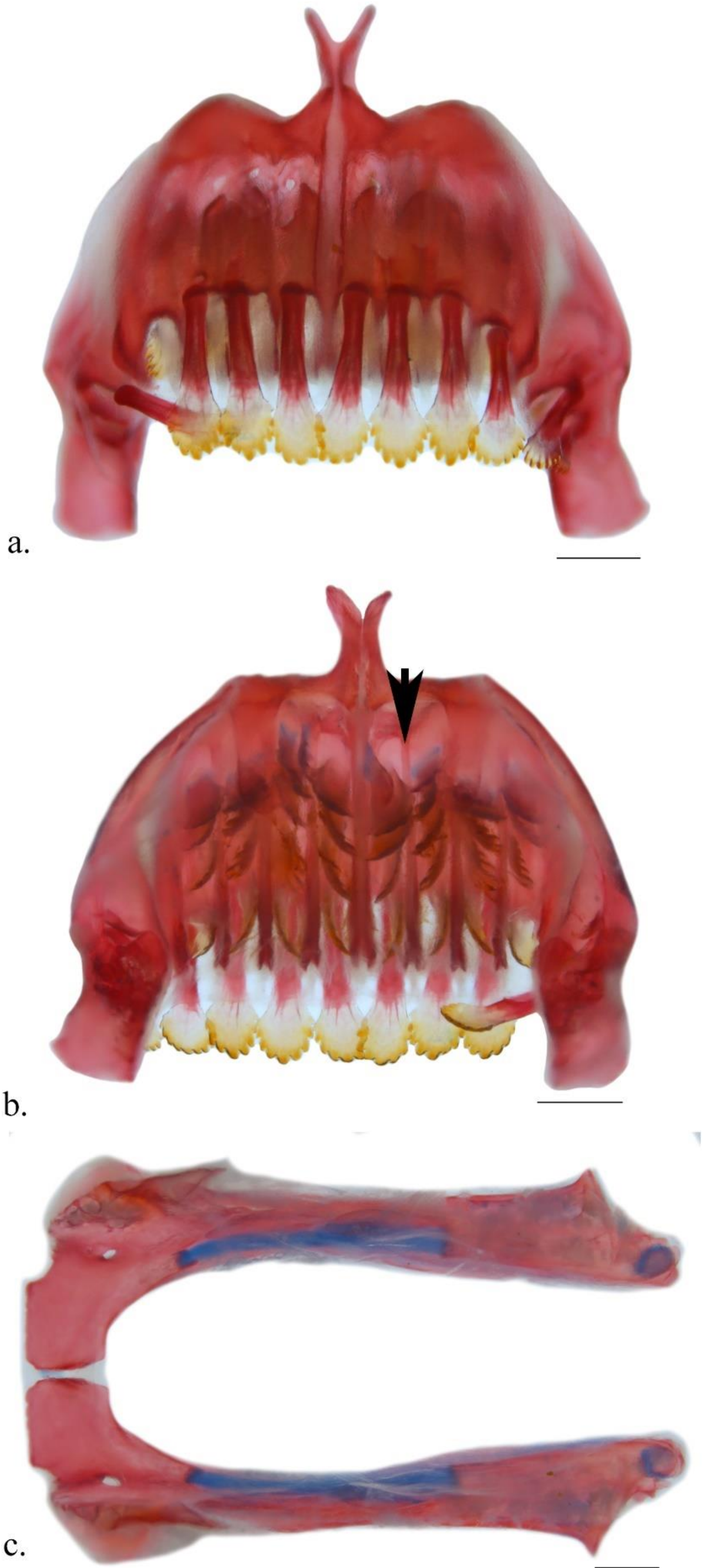


Figure 57. *Apareiodon ibitiensis* MZUSP 58429 68.0 mm SL. **a.** upper jaw, labial view; **b.** upper jaw, lingual view; **c.** lower jaw, dorsal view. Black arrow points to bony lamella that separates the rows of preformed replacement teeth. Scale bar 0.5 mm.

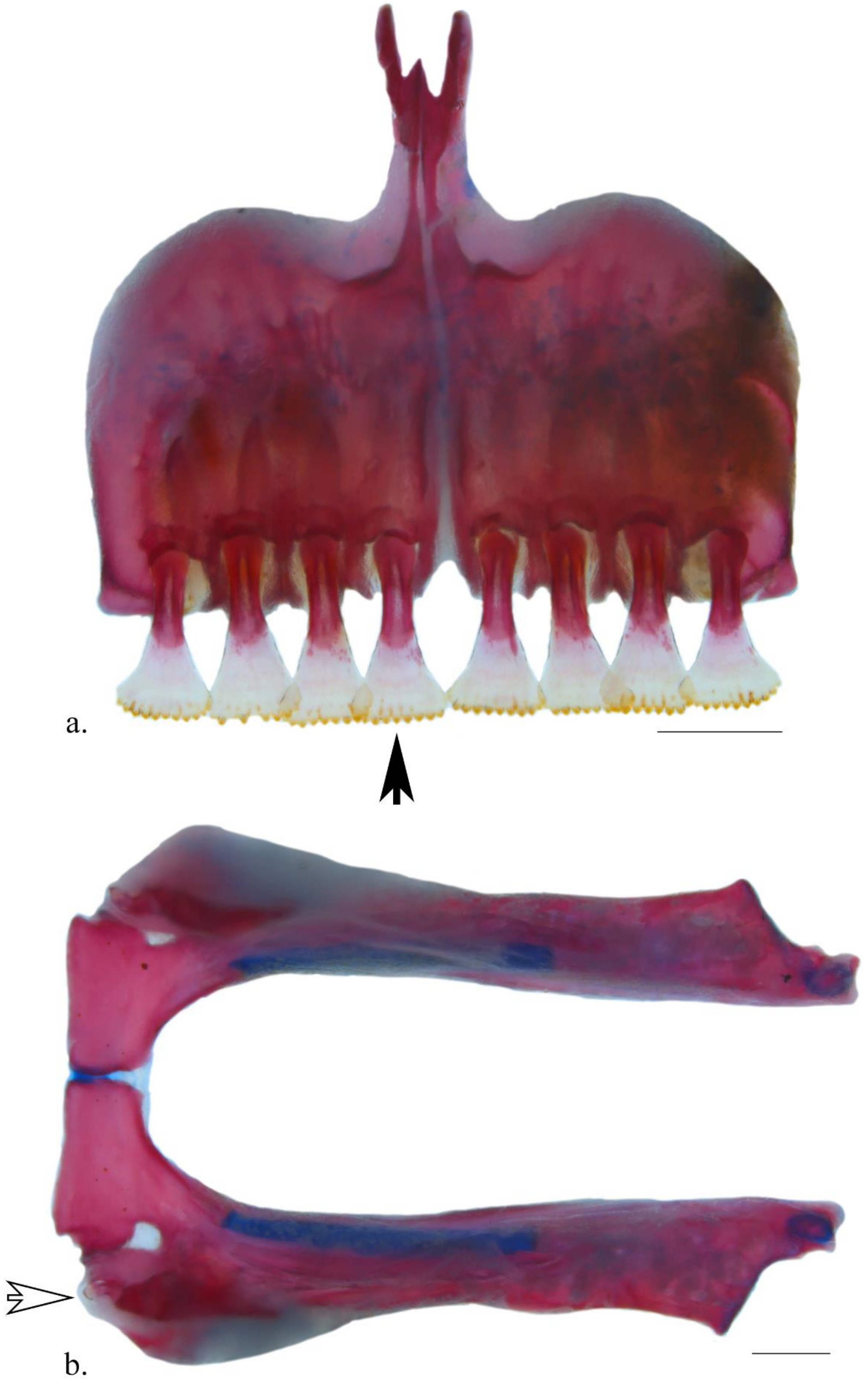


Figure 58. *Parodon* cf**.** *pongoensis* MZUSP 94916 62.7 mm SL. **a.** premaxillae, labial view; **b.** lower jaw, dorsal view. Black arrow points to cusps reaching same transversal line distally. White arrow points to unicuspid dentary teeth. Scale bar 0.5 mm.

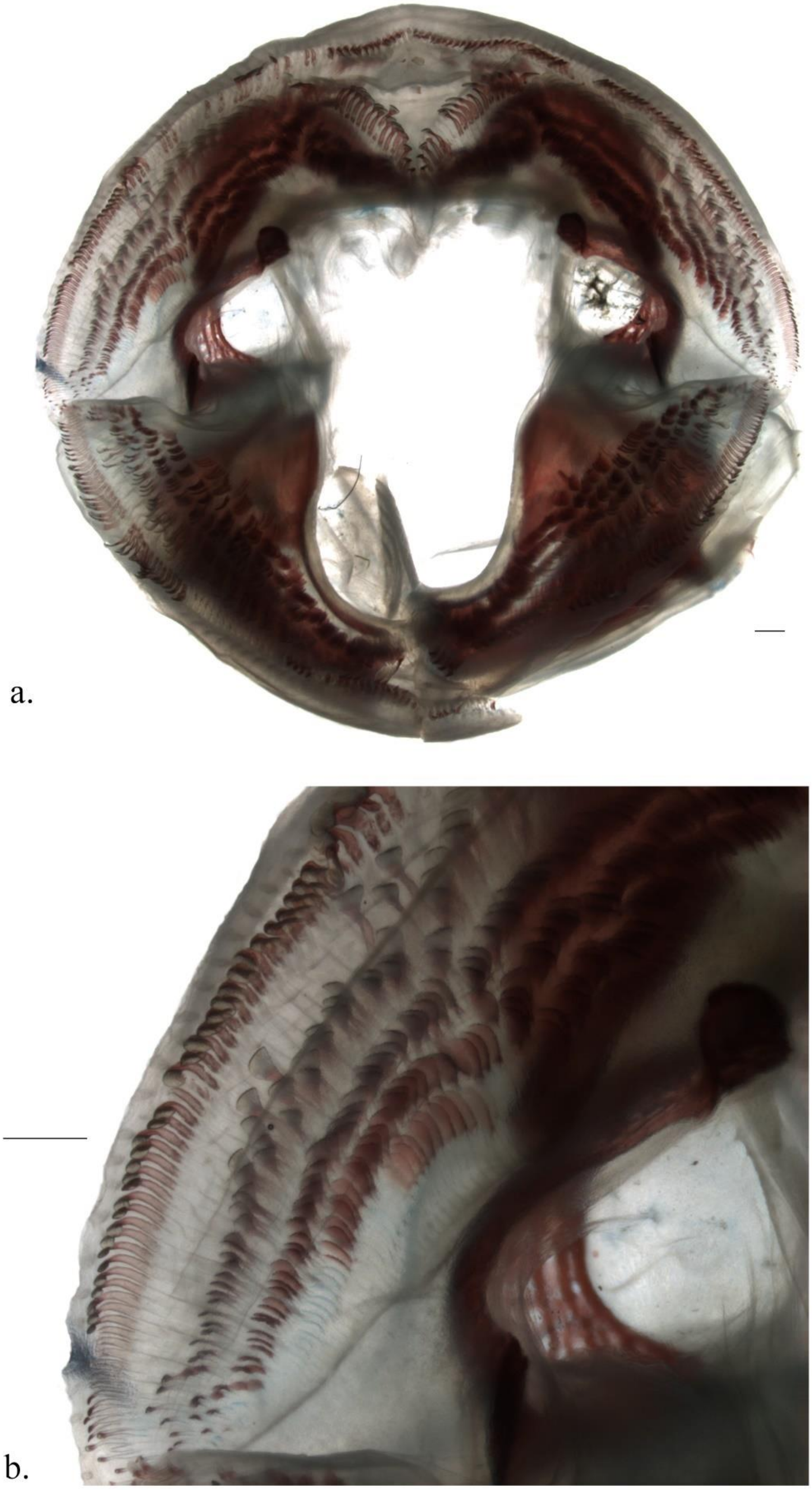


Figure 59. *Prochilodus lineatus* MZUSP 20809 93.1 mm SL. **a.** open jaws, anterior view; **b.** lateral portion of right premaxilla, lingual view. Scale bar 0.5 mm.

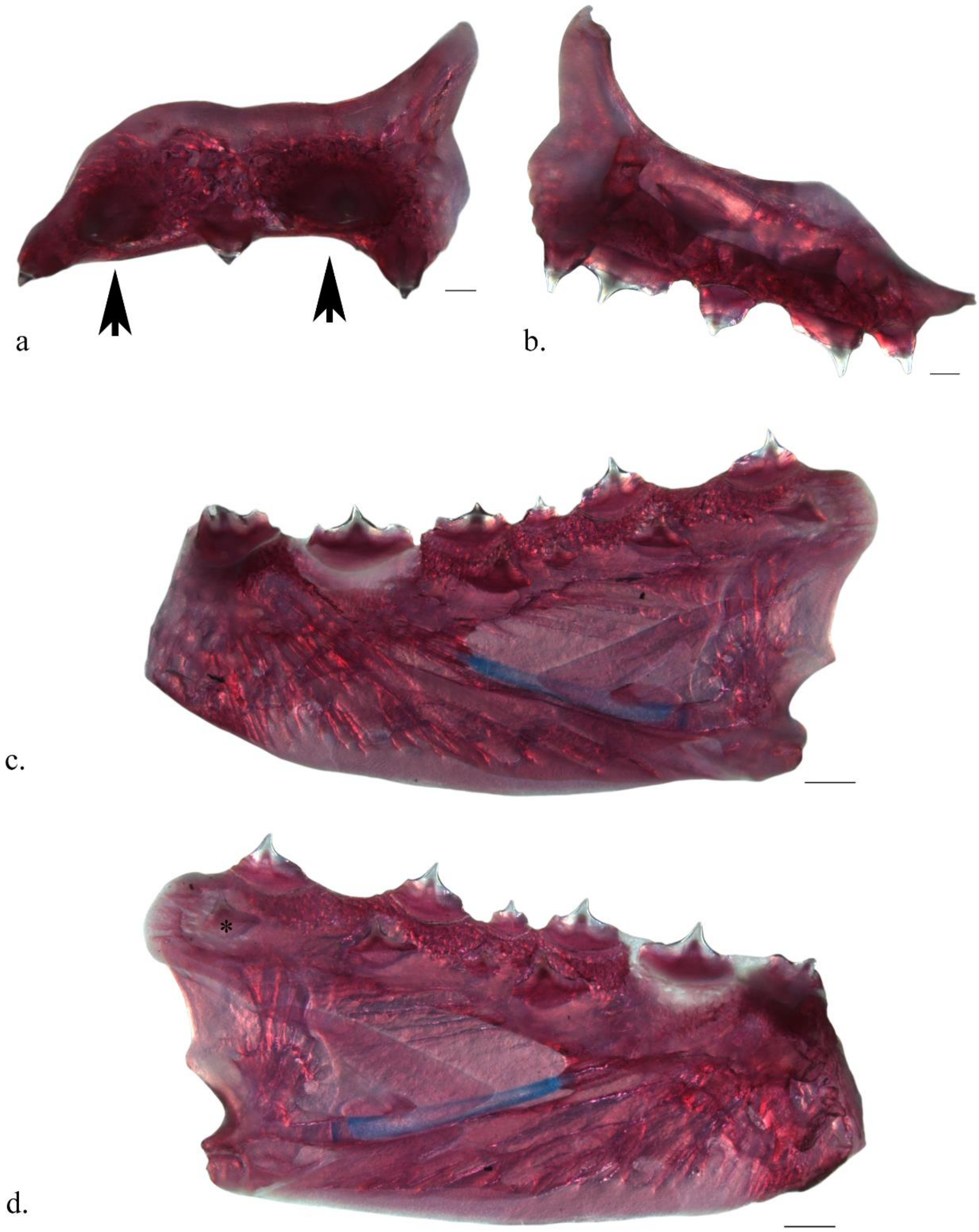


Figure 60. *Catoprion mento* MZUSP 113306 47.5 mm SL. **a.** right premaxilla, labial view; **b.** right premaxilla, lingual view; **c.** lower jaw, left side, labial view; **d.** lower jaw, left side, lingual view. Black arrow points to labially displaced teeth on premaxilla. * indicates replacement teeth formed in individual bony cavity. Scale bar 0.5 mm.

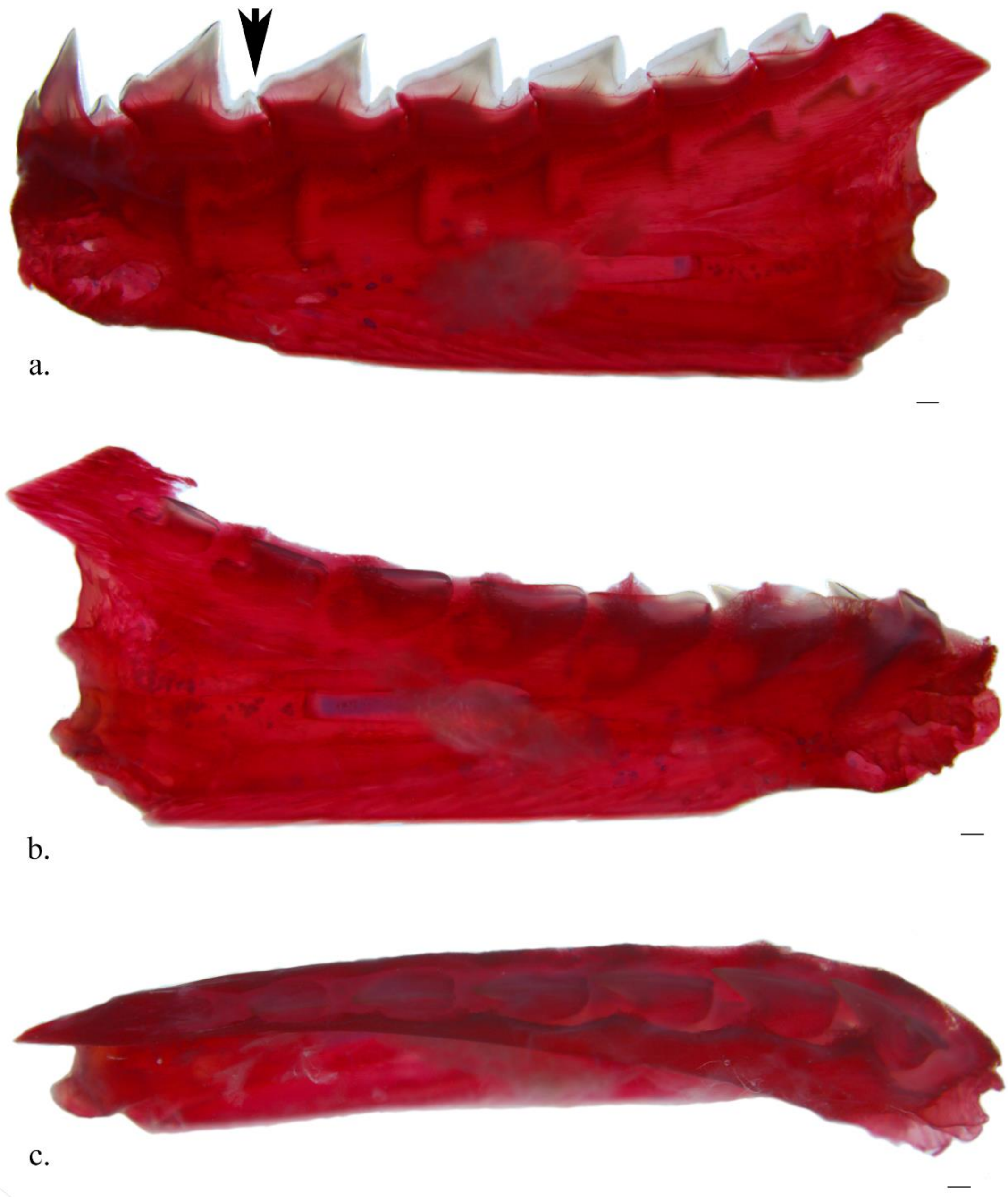
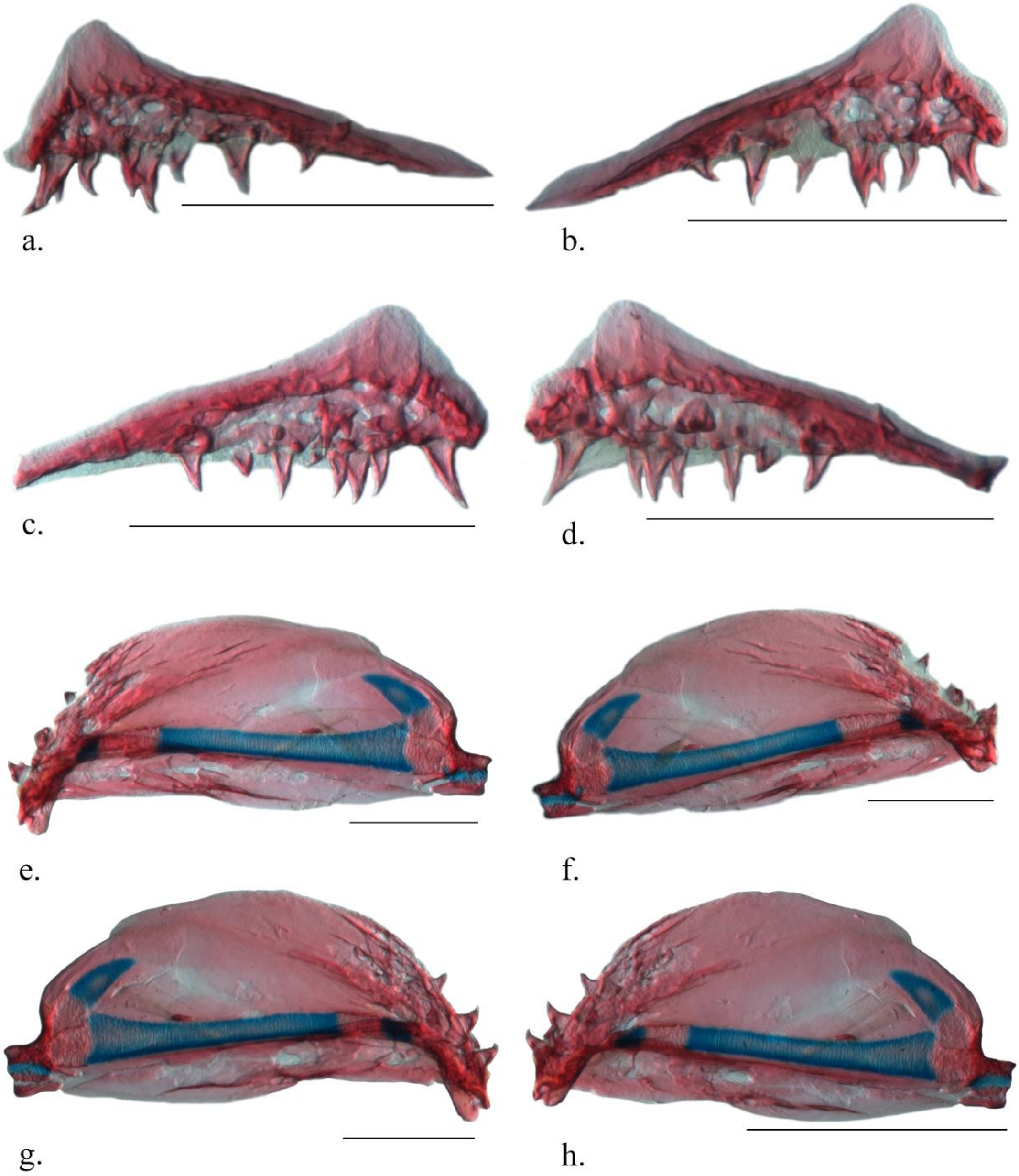


Figure 61. *Serrasalmus elongatus* MZUSP 5613 137.3 mm SL. **a.** right premaxilla, lingual view **b.** left premaxilla, lingual view. Scale bar 0.5 mm.

Figure 62. *Serrasalmus elongatus* MZUSP 5613 137.3 mm SL. **a.** lower jaw, right side, lingual view; **b.** lower jaw, left side, lingual view; **c.** lower jaw, left side, dorsal view. Black arrow points to articulation among adjacent teeth. Scale bar 0.5 mm.

Figure 63. Strict consensus cladogram of nine most-parsimonious hypothesis, length 29.02036.



a. b. c. d. e. f. g. h.

Figure 64. *Brycinus ferox* BMNH 1981.8.21.11-15 16.1 mm SL. **a.** right premaxilla, labial view; **b.** right premaxilla, lingual view; **c.** left premaxilla, labial view; **d.** left premaxilla, lingual view; **e.** lower jaw, left side, labial view; **f.** lower jaw, left side, lingual. View; **g.** lower jaw, right side, labial view; lower jaw, right side, lingual view. Scale bar 0.5 mm.

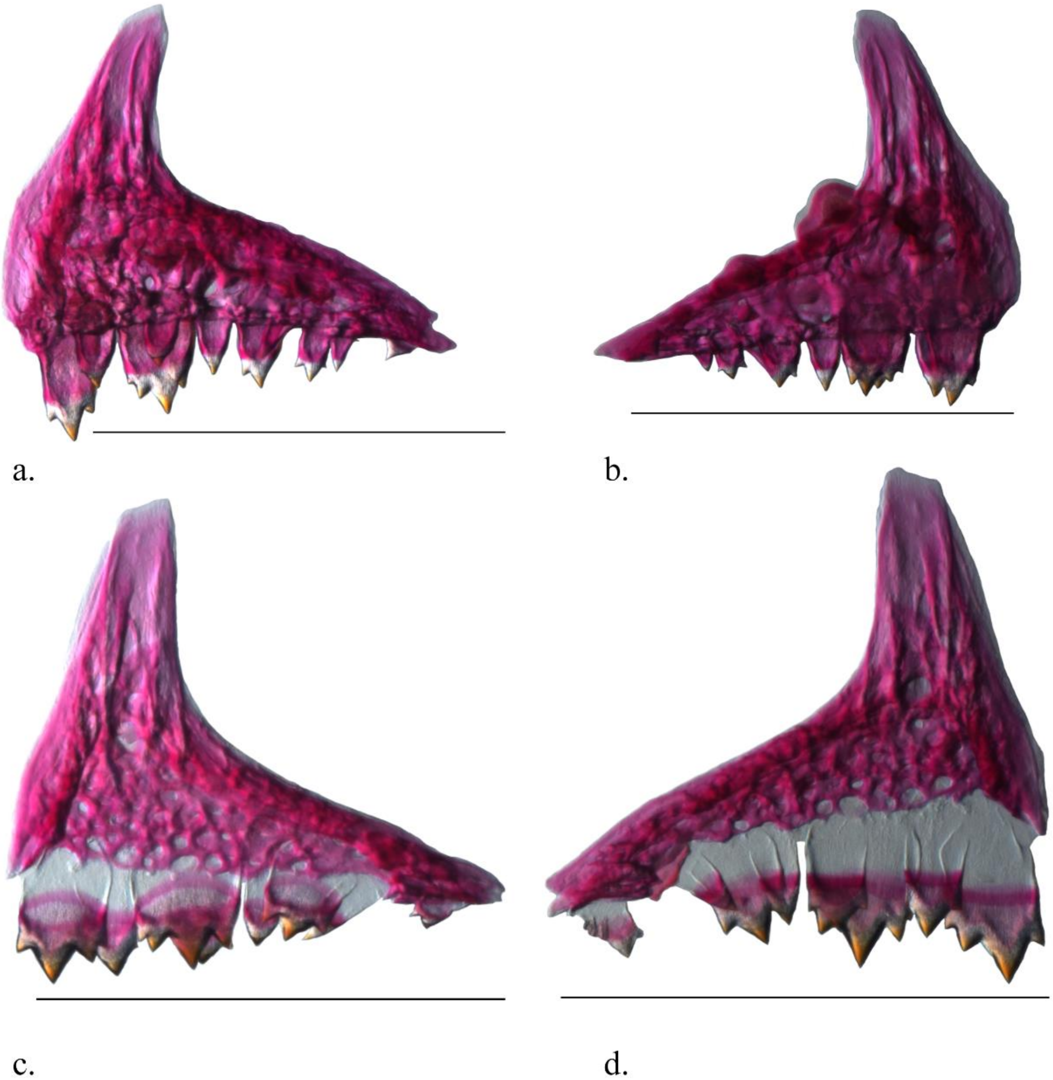


Figure 65. *Astyanax lacustris*, uncatalogued. **a.** left premaxilla, labial view; **b.** left premaxilla, lingual view; **c.** right premaxilla, lingual view; **d.** right premaxilla, labial view. Scale bar 0.5 mm.

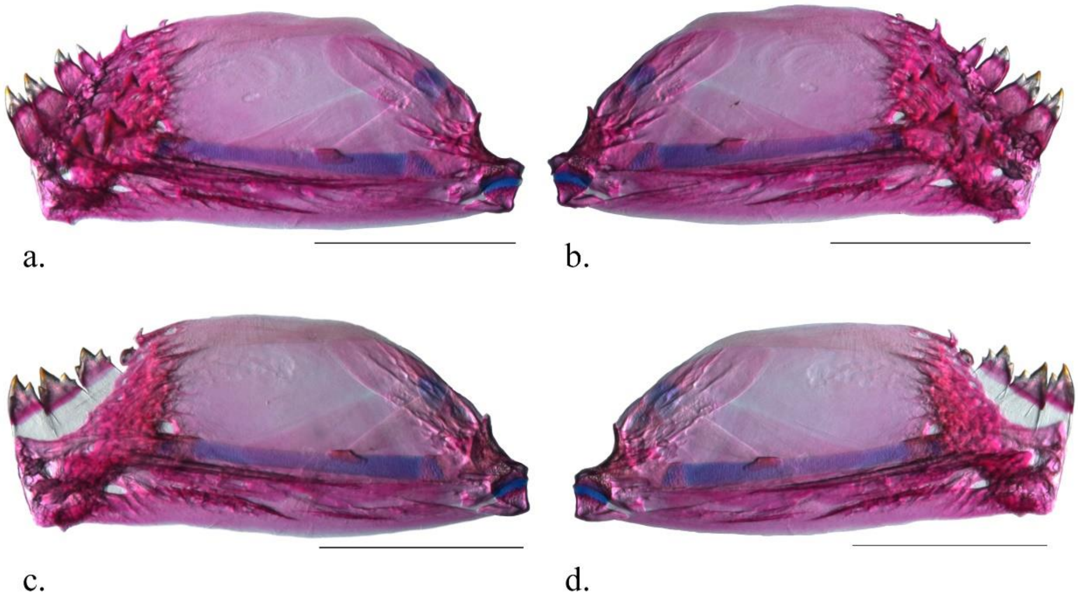


Figure 66. *Astyanax lacustris*, uncatalogued. **a.** lower jaw left side, labial view; **b.** lower jaw left side, lingual view; **c.** lower jaw right side, lingual view; **d.** lower jaw right side, labial view. Scale bar 0.5 mm.

Appendix

Appendix 1. List of examined material

Acestrorhynchidae
Acestrorhynchinae
Acestrorhynchus microlepis **MZUSP 20591** C&S 107.4 mm SL; **MZUSP 91854** C&S 90.2 mm SL
Acestrorhynchus pantaneiro **MZUSP 59717** C&S 78.9 mm SL
Heterocharacinae
Heterocharax virgulatus **MZUSP 29227** 2 C&S 34.9-36.0 mm SL
Lonchogenys ilisha **MZUSP 29253** 2 C&S 53.1-60.9 mm SL
Roestinae
Roestes molossus **MZUSP 35556** C&S 103.9 mm SL
Agoniatidae
Lignobrycon myersi **uncatalogued** C&S 103.2 mm SL
Agoniates halecinus **MZUSP 34327** C&S 107.7 mm SL
Triportheus albus **MZUSP 117105** C&S 103.9 mm SL
Triportheus angulatus **MZUSP 27314** C&S 91.0 mm SL
Alestidae
Alestes baremoze **BMNH 1982.13.554-557** 3 C&S 68.1-74.0 mm SL
Alestes macrophthalmus **BMNH 1985.6.13.15-17** C&S 44.1-46.0 mm SL and **BMHN 1955.12.20.670** C&S 73,3 mm SL
Brycinus sadleri **BMNH.1966.7.7.14** C&S 75.7 mm SL; **BMNH.1965.10.8.47** C&S 57,5 mm SL
Brycinus lateralis **BMNH 1965.3.12.375-376** 2 C&S 22.5-35.4 mm SL
Brycinus imberi **BMNH 1969.9.25.61** C&S 45.1 mm SL

Bryconalestes longipinnis **BMNH 1981.2.17.814** C&S 36,1 mm SL
Hydrocynus forskahlii **BMNH 1981.2.17.760-764** 3 C&S 33.6-50.9 mm SL
Lepidarchus adonis **BMNH 1984.9.11.2** C&S 18.5 mm SL and **uncatalogued** 3 C&S 21.1-23.9 mm SL
Micralestes acutidens **MZUSP 62625** C&S 35.5-51.9 mm SL
Phenacogrammus **cf.** ***interruptus*** **BMNH 1954.3.14.60-61** 2 C&S 37.9-38.7 mm SL
Anostomidae
Abramites hypselonotus **MZUSP 20929** 2 C&S 51.6-58.4 mm SL
Laemolyta proxima **MZUSP 111373** 2 C&S 102.6-117.5 mm SL
Leporinus bahiensis **MZUSP 112246** C&S 87.5 mm SL
Leporinus desmotes **MZUSP 88050** C&S 77.1 mm SL
Bryconidae
Brycon amazonicus **MZUSP 74668** 3 C&S 50.2, 51.4 and 57.4 mm SL and **MZUSP 82418** C&S 78.5 mm SL
Brycon falcatus **MZUSP 38255** C&S 112.3 mm SL
Brycon pesu **MZUSP 111757** C&S 69.6 mm SL
Salminus brasiliensis **MZUSP 85578** C&S 77.8 mm SL
Chalceidae
Chalceus epakros **MZUSP 30754** C&S 71.3 mm SL
Characidae
Aphyocharacinae
Aphyocharax **cf.** ***avary*** **MZUSP 115619** C&S 36.1 mm SL
Aphyocharax difficilis **MZUSP 27045** C&S 59.4 mm SL
Characinae
Charax stenopterus **MZUSP 9161** C&S 67.8 mm SL
Roeboides affinis **MZUSP 34705** C&S 63.3 mm SL
Acestrocephalus stigmatus **MZUSP 94216** C&S 85.0 mm SL
Cynopotamus xinguano **MZUSP 94196** C&S 97.9 mm SL
Galeocharax gulo **MZUSP 27982** C&S 103.8 mm SL
Microschemobrycon callops **MZUSP 92953** C&S 31.6-31.1 mm SL
Phenacogaster tegatus **MZUSP 35889** C&S 36.4 mm SL
Cheirodontinae
Odontostilbe **sp. MZUSP 4011** C&S 37.4-40.9 mm SL
Serrapinnus calliurus **MZUSP 105177** C&S 29.2-29.7 mm SL
Exodontinae
Exodon paradoxus **MZUSP 5165** C&S 55.4 mm SL
Stethaprioninae
Astyanax multidens **MZUSP 117920** C&S 39.8 mm SL
Astyanax novae **MZUSP 97863** C&S 52.1 mm SL
Gymnocorymbus ternetzi **MZUSP 96717** 2 C&S 36.0-38.5 mm SL
Poptella compressa **MZUSP 91879** C&S 43.2 mm SL
Stevardiinae
Bryconamericus lethostigmus **MZUSP 41824** 2 C&S 40.6-51.2 mm SL
Bryconamericus **sp. MZUSP 41824** 2 C&S 47.9-48.3 mm SL
Mimagoniates **cf.** ***microlepis*** **MZUSP 78942** 2 C&S 38.4-48.1 mm SL
Incertae sedis
Trochilocharax ornatus uncatalogued 3 C&S 12.1-15.8 mm SL female
Chilodontidae
Chilodus punctaus **MZUSP 21359** C&S 62.1 mm SL
Citharinidae
Citharidium ansorgii **BMNH 1902.11.10.93** C&S 58.8 mm SL
Citharinus citharu **BMNH 1904.10.25.38-43** C&S 40.7-46.3 mm SL

Crenuchidae
Characidiinae
***Characidium* cf. *zebra* MZUSP 114369** C&S 29.5 mm SL
Crenuchinae
***Crenuchus spilurus* MZUSP 69216** C&S 33.2 mm SL
Ctenoluciidae
***Boulengerella maculata* MZUSP 92845** C&S 131.1 mm SL
***Boulengerella lateristriga* MZUSP 32138** C&S 145.4 mm SL
Curimatidae
***Steindachnerina insculpta* MZUSP 28825** 2 C&S 88.7-103.6 mm SL
Cynodontidae
***Cynodon gibbus* MZUSP 89905** C&S 103.8 mm SL
***Hydrolycus tatauaia* MZUSP 99870** C&S 118.3 mm SL
***Rhaphiodon vulpinus* MZUSP 15219** C&S 102.8 mm SL
Distichodontidae
***Ichthyborus quadrilineatus* BMNH 1912.4.1.55** C&S 66.1 mm SL
***Nannocharax* aff. *multifasciatus* BMNH 1976.3.18.2350-2352** 2 C&S 32.4-34.1 mm SL
***Xenocharax spilurus* BMNH 1896.5.5.86** C&S 66.0 mm SL
Erythrinidae
***Hoplias malabaricus* MZUSP 22111** C&S 94.0 mm SL and **MZUSP 47718** C&S 69.4 mm SL
Gasteropelecidae
***Carnegiella strigata* MZUSP 118760** C&S 25.4 mm SL
Hemiodontidae
***Bivibranchia fowleri* MZUSP 97389** 2 C&S 44.0-77.3 mm SL
***Hemiodous microlepis* MZUSP 89300** C&S 73.0 mm SL
Hepsetidae
***Hepsetus odoe* MZUSP 84869** C&S 111.6 mm SL
Iguanodectidae
***Bryconops disruptus* MZUSP 109605** C&S 59.3 mm SL
***Iguanodectes geisleri* MZUSP 29616** C&S 34.8 mm SL
***Piabucus melanostoma* MZUSP 95080** C&S 77.3 mm SL
Lebiasinidae
Lebiasininae
***Lebiasina* sp. MZUSP 108870** 2 C&S 42.8-52.9 mm SL
Pyrrhulininae
***Nannostomus unifasciatus* MZUSP 97737** C&S 34.1 mm SL
Parodontidae
***Apareiodon ibitiensis* MZUSP 58429** C&S 68.0 mm SL
***Parodon* cf. *pongoensis* MZUSP 94916** C&S 62.7 mm SL
Prochilodontidae
***Prochilodus lineatus* MZUSP 20809** C&S 93.1 mm SL
Serrasalmidae
***Catoprion mento* MZUSP 113306** C&S 47.5 mm SL
***Myloplus arnoldi* MZUSP 111316** 2 C&S 63.5-73.9 mm SL
***Serrasalmus elongatus* MZUSP 5613** C&S 137.3 mm SL

Appendix 2.
Table. Specimens counts and normalized values used for characters # 0 and 1. Inapplicable characters are indicated by *in*.

Taxon	#0	#o norm.	#1	#1 norm.
Abramites hypselonotus	in.	-	in.	-

Acestrocephalus stigmatus	9	0.189	45	0.746
Acestrorhynchus microlepis	in.	-	29	0.475
Acestrorhynchus pantaneiro	in.	-	35	0.576
Agoniates halecinus	4	0.054	30	0.492
Alestes baremoze	3	0.027	in.	-
Alestes macrophthalmus	3	0.027	in.	-
Apareiodon ibitiensis	in.	-	2	0.017
Aphyocharax avary	in.	-	15	0.237
Aphyocharax difficilis	in.	-	13	0.203
Astyanax multidens	4	0.054	6	0.085
Astyanax novae	4	0.054	1	0.000
Bivibranchia fowleri	in.	-	7	0.102
Boulengerella lateristriga	in.	-	16	0.254
Boulengerella maculata	in.	-	13	0.203
Brycinus imberi	4	0.054	in.	-
Brycinus lateralis	4	0.054	in.	-
Brycinus sadleri	4	0.054	in.	-
Brycon amazonicus	13	0.297	26	0.424
Brycon falcatus	9	0.189	25	0.407
Brycon pesu	10	0.216	22	0.356
Bryconalestes longipinnis	3	0.027	in.	-
Bryconamericus lethostigmus	in.	-	6	0.085
Bryconamericus sp.	in.	-	4	0.051
Bryconops disruptus	5	0.081	in.	-
Carnegiella strigata	in.	-	1	0.000
Catoprion mento	in.	-	in.	-
Chalceus epakros	12	0.270	15	0.237
Characidium zebra	in.	-	in.	-
Charax stenopterus	5	0.081	44	0.729
Chilodus punctatus	in.	-	in.	-
Citharidium ansorgii	39	1.000	in.	-
Citharinus citharu	34	0.865	in.	-
Crenuchus spilurus	in.	-	in.	-
Cynodon gibbus	in.	-	60	1.000
Cynopotamus xinguano	9	0.189	50	0.831
Exodon paradoxus	in.	-	7	0.102
Galeocharax gulo	11	0.243	45	0.746
Gymnocorymbus ternetzi	5	0.081	2	0.017
Hemiodus microlepis	in.	-	9	0.136
Hepsetus odoe	in.	-	33	0.542
Heterocharax virgulatus	in.	-	26	0.424
Hoplias malabaricus	in.	-	42	0.695
Hydrocynus forskahlii	in.	-	in.	-
Hydrolycus tatauaia	in.	-	59	0.983
Ichthyborus quadrilineatus	25	0.622	in.	-

Iguanodectes geisleri	2	0.000	in.	-
Laemolyta proxima	in.	-	in.	-
Lebiasina sp.	in.	-	7	0.102
Lepidarchus adonis	in.	-	in.	-
Leporinus bahiensis	in.	-	in.	-
Leporinus desmotes	in.	-	in.	-
Lignobrycon myersi	in.	-	17	0.271
Lonchogenys ilisha	3	0.027	52	0.864
Micralestes acutidens	3	0.027	in.	-
Microschemobrycon callops	in.	-	8	0.119
Mimagoniates microlepis	3	0.027	5	0.068
Myloplus arnoldi	3	0.027	in.	-
Nannocharax multifasciatus	6	0.108	in.	-
Nannostomus unifasciatus	in.	-	1	0.000
Odontostilbe sp.	in.	-	2	0.017
Parodon pongoensis	in.	-	2	0.017
Phenacogaster tegatus	7	0.135	31	0.508
Phenacogrammus interruptus	2	0.000	in.	-
Piabucus melanostoma	in.	-	2	0.017
Poptella compressa	4	0.054	2	0.017
Prochilodus lineatus	in.	-	in.	-
Rhaphiodon vulpinus	in.	-	49	0.814
Roeboides affinis	in.	-	9	0.136
Roestes molossus	in.	-	48	0.797
Salminus brasiliensis	8	0.162	30	0.492
Serrapinnus calliurus	in.	-	3	0.034
Serrasalmus elongatus	in.	-	in.	-
Steindachnerina insculpta	in.	-	in.	-
Triportheus albus	4	0.054	2	0.017
Triportheus angulatus	7	0.135	2	0.017
Trochilocharax ornatus	in.	-	10	0.153
Xenocharax spilurus	16	0.378	7	0.102

Appendix 3.

Data matrix qualitative characters (# 2-58).

Abramites hypselonotus 0 - - - 0 0 1 1
0 0 0 0 0 0 0 0 - - -
- 0 - 1 - - 0 1 - - -
- - - - - - 0 0 0 0 -
0 0 0 0 - - 1 1 1 0 0
1 0 0 - 0

Acestrocephalus stigmatus 0 - - - 0 0 0 0
0 0 0 0 0 0 1 0 0 1 0
- 0 - 0 0 0 1 0 0 0 1
0 0 - 0 1 0 0 0 0 0 -

0	1	0	1	1	-	0	1	1	1	0
0	0	0	-	0						
Acestrorhynchus microlepis			0	-	-	-	0	1	0	0
0	0	0	0	1	0	0	0	-	-	-
-	0	-	0	-	-	0	0	1	0	1
0	2	-	0	1	0	0	1	0	0	-
0	1	0	1	1	-	0	1	1	1	0
0	1	0	-	1						
Acestrorhynchus pantaneiro			0	-	-	-	0	1	0	0
0	0	0	0	1	0	0	1	-	-	-
-	0	-	0	-	-	0	0	1	0	1
0	2	-	0	1	0	0	1	1	0	-
0	1	0	1	1	-	0	1	1	1	0
0	1	0	-	1						
Agoniates halecinus		1	1	0	0	0	0	0	0	0
0	0	0	1	0	1	0	1	1	0	1
0	0	0	0	0	1	0	0	0	1	0
1	-	0	1	0	0	1	0	1	0	0
0	0	1	1	0	0	1	1	1	0	0
1	0	0	1							
Alestes baremoze		1	1	0	0	0	0	0	0	0
0	1	0	1	1	1	0	0	0	-	0
0	1	0	0	1	1	1	-	-	-	-
-	-	-	-	-	0	1	0	1	0	0
0	0	0	-	1	0	1	1	0	0	0
0	0	0	1							
Alestes macrophthalmus			1	1	0	0	0	0	0	0
0	0	1	0	1	1	1	0	0	0	-
0	0	1	0	0	1	1	1	-	-	-
-	-	-	-	-	-	0	1	0	1	0
0	0	0	0	-	1	0	1	1	0	0
0	0	0	0	1						
Apareiodon ibitiensis		1	1	0	0	0	0	0	1	0
0	0	0	0	0	0	2	-	-	-	-
0	1	1	-	-	1	0	0	1	0	0
1	1	1	1	-	1	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-							
Aphyocharax avary		1	1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	-	-	-	1
0	0	0	-	-	1	0	0	0	1	0
1	0	0	1	0	0	1	0	0	-	0
0	0	1	0	0	0	1	1	1	0	0
0	0	-	1							
Aphyocharax difficilis			1	1	0	0	0	0	0	0
0	0	0	0	0	0	0	0	-	-	-
1	0	0	0	-	-	1	0	0	0	2
0	1	0	0	1	0	0	1	0	0	-
0	0	0	1	1	0	0	1	1	1	0
0	0	0	-	1						

Astyanax multidens		1	1	0	0	0	0	0	0	0
0	1	0	1	0	1	0	0	1	0	1
0	0	0	0	0	1	0	1	0	0	0
0	0	0	1	0	0	1	0	0	-	0
0	0	1	1	0	0	1	1	1	0	0
0	0	-	0							
Astyanax novae		1	1	0	0	0	0	0	0	0
0	1	0	1	0	1	0	0	0	-	0
0	0	0	0	1	1	0	0	-	0	0
-	-	0	-	0	0	1	0	0	-	0
0	0	1	1	0	0	1	1	1	0	0
0	0	-	0							
Bivibranchia fowleri		1	1	0	0	0	0	-	0	0
0	0	0	0	0	0	0	-	-	-	1
0	1	2	-	-	1	0	0	0	0	0
0	1	2	1	0	1	-	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-							
Boulengerella lateristriga			0	-	-	-	0	1	0	1
0	0	0	0	0	0	0	0	-	-	-
-	0	-	0	-	-	1	0	0	0	2
0	1	-	0	0	0	0	0	0	0	-
0	0	0	0	-	-	0	0	-	-	-
-	-	0	-	1						
Boulengerella maculata			0	-	-	-	0	1	0	1
0	0	0	0	0	0	0	0	-	-	-
-	0	-	0	-	-	1	0	0	0	2
0	1	-	0	0	0	0	0	0	0	-
0	0	0	0	-	-	0	0	-	-	-
-	-	0	-	1						
Brycinus imberi		1	1	0	0	0	0	0	0	0
0	1	0	1	1	1	0	0	1	0	0
0	1	0	0	1	1	1	-	-	-	-
-	-	-	-	-	0	1	0	1	0	0
0	0	0	-	1	0	1	1	0	0	0
0	0	1	1							
Brycinus lateralis		1	1	0	0	0	0	0	0	0
0	1	0	1	1	1	0	0	1	0	0
0	1	0	0	1	1	1	-	-	-	-
-	-	-	-	-	0	1	0	1	0	0
0	0	0	-	1	0	1	1	0	0	0
0	0	1	1							
Brycinus sadleri		1	1	0	0	0	0	0	0	0
0	1	0	1	1	1	0	0	1	0	0
0	1	0	0	1	1	1	-	-	-	-
-	-	-	-	-	0	1	0	1	0	0
0	0	0	-	1	0	1	1	0	0	0
0	0	1	1							
Brycon amazonicus		1	1	0	0	0	0	0	0	0
0	1	0	1	0	2	0	0	1	0	1

0 0 0 0 0 1 0 1 0 1 0
1 0 0 1 0 0 1 0 1 0 0
1 0 0 - 0 0 1 1 0 0 0
0 0 0 0

Brycon falcatus 1 1 0 0 0 0 0 0
0 0 1 0 1 0 2 0 0 1 0
1 0 0 0 0 0 1 0 1 0 1
0 1 0 0 1 0 0 1 0 1 0
0 1 0 0 - 0 0 1 1 0 0
0 0 0 0 0

Brycon pesu 1 1 0 0 0 0 0 0 0 0
1 0 1 0 2 0 0 1 0 1 0
0 0 0 0 1 0 1 0 1 0 1
0 0 1 0 0 1 0 1 0 0 1
0 0 - 0 0 1 1 0 0 0 0
0 0 0

Bryconalestes longipinnis 1 1 0 0 0 0 0 0
0 0 1 0 1 1 1 0 0 1 0
1 0 1 0 0 1 1 1 - - -
- - - - - - 0 1 0 1 0
0 0 0 0 - 1 0 1 1 0 0
0 0 0 1 1

Bryconamericus lethostigmus 1 1 0 0 0 0 0
1 0 0 1 0 0 0 1 0 0 1
0 1 0 1 0 0 0 1 0 0 0
1 0 1 1 0 1 0 0 0 0 0
- 0 0 0 0 - 1 0 1 1 1
0 0 0 0 - 1

Bryconamericus **sp.** 1 1 0 0 0 0 0 0 0
0 1 0 0 0 1 0 0 1 0 1
0 1 0 0 0 1 0 0 0 0 0
1 0 0 1 0 0 0 0 0 - 0
0 0 0 - 0 0 1 1 1 0 0
0 0 - 0

Bryconops disruptus 1 1 0 0 0 0 0 0 0
0 1 0 1 0 1 0 0 1 0 1
0 0 0 0 1 1 1 - - - -
- - - - - 0 1 0 0 - 0
0 0 1 1 0 0 1 1 0 0 0
0 0 - 1

Carnegiella strigata 1 1 0 0 0 0 0 0 0
0 1 0 1 0 0 0 - - - 1
0 0 0 - - 1 0 0 0 0 0
1 - 0 1 - 0 1 0 0 - 0
0 0 1 0 0 0 1 1 1 0 0
0 0 - 1

Catoprion mento 1 1 0 0 0 0 0 0 0
1 0 0 0 0 - 0 - 1 0 -
1 - 0 - - 1 1 - - - -
- - - - - 0 1 0 0 - 0

0	0	0	-	0	0	1	1	-	1	0
1	0	-	0							
Chalceus epakros		1	1	0	0	0	0	0	0	0
0	1	0	1	0	2	0	0	1	0	1
0	0	0	0	1	1	0	1	0	1	0
1	0	0	1	0	0	1	0	1	1	0
1	0	0	-	0	0	1	1	0	0	0
0	0	0	1							
Characidium zebra		1	1	0	0	0	0	0	0	0
0	0	0	1	0	0	0	-	-	-	1
0	0	0	-	-	1	1	-	-	-	-
-	-	-	-	-	0	1	0	0	-	0
0	0	0	-	0	0	1	1	0	0	0
0	0	-	0							
Charax stenopterus		0	-	-	-	0	0	0	0	0
0	0	0	0	0	1	0	-	-	-	-
0	-	0	0	0	0	0	0	0	1	0
0	-	0	1	0	0	0	0	0	-	0
0	0	1	0	-	0	1	1	1	0	0
0	0	-	0							
Chilodus punctatus		0	-	-	-	0	0	-	0	0
0	0	0	0	0	0	0	-	-	-	-
0	-	2	-	-	0	1	-	-	-	-
-	-	-	-	-	0	0	0	0	-	0
0	0	0	-	-	2	0	-	-	-	-
-	0	-	0							
Citharidium ansorgii		1	0	-	1	0	0	0	0	0
0	0	0	1	0	0	0	0	1	1	-
0	-	1	1	0	-	1	-	-	-	-
-	-	-	-	-	0	1	0	0	-	0
0	0	0	-	0	1	1	1	0	0	0
0	0	-	0							
Citharinus citharu		1	0	-	1	0	0	0	0	0
0	0	0	0	0	0	0	0	1	1	-
0	-	1	1	0	-	1	-	-	-	-
-	-	-	-	-	0	0	0	0	-	0
0	0	0	-	0	1	1	1	0	0	0
0	0	-	0							
Crenuchus spilurus		1	1	-	0	0	0	0	0	0
0	0	0	0	0	0	0	-	-	-	1
0	0	0	-	-	1	1	-	-	-	-
-	-	-	-	-	0	1	0	0	-	0
1	0	1	-	1	0	1	1	0	0	0
0	0	-	0							
Cynodon gibbus		0	-	-	-	0	1	0	0	0
0	0	0	1	0	0	0	-	-	-	-
0	-	0	-	-	1	0	1	0	1	0
0	-	0	1	0	0	1	0	0	-	0
1	0	0	-	-	0	1	0	0	0	0
0	0	-	1							

Cynopotamus xinguano 0 - - - 0 0 0 0
0 0 0 0 0 0 1 0 0 1 0
- 0 - 0 0 0 1 0 0 0 1
0 0 - 0 1 0 0 0 0 0 -
0 0 0 1 1 - 0 1 1 1 0
0 0 0 - 0
Exodon paradoxus 0 - - - 0 0 0 0 0
1 0 0 1 0 - 0 - - - -
1 - 0 0 - 1 0 1 0 1 1
2 - 0 1 0 0 1 0 0 - 0
- 1 - - - 0 1 - - 0 0
1 0 - 1
Galeocharax gulo 0 - - - 0 0 0 0 0
0 0 0 0 0 1 0 0 1 0 -
0 - 0 0 0 1 0 0 0 1 0
0 - 0 1 0 0 0 0 0 - 0
1 0 1 1 - 0 1 1 1 0 0
0 0 - 0
Gymnocorymbus ternetzi 1 1 0 0 0 0 0 0
0 0 1 0 1 0 1 0 0 1 0
1 0 0 0 0 1 1 0 - 0 0
0 0 0 0 1 0 0 1 0 0 -
0 0 0 1 1 0 0 1 1 1 0
0 0 0 - 0
Hemiodus microlepis 1 1 1 0 0 0 0 1 0
0 0 0 0 0 0 2 - - - 2
0 1 2 - - 1 0 0 1 1 0
0 1 2 1 0 1 - - - - -
- - - - - - - - - - -
- - - -
Hepsetus odoe 0 - - - 0 1 0 0 0
0 0 0 1 0 - 2 - - - -
0 - 0 0 - 1 0 1 2 1 0
0 - 0 1 0 0 1 1 0 - 0
1 0 0 - - 0 1 0 0 0 0
0 0 - 1
Heterocharax virgulatus 0 - - - 1 0 0 0
0 0 0 0 0 0 0 0 - - -
- 0 - 0 - - 1 0 0 0 1
0 1 - 0 1 1 0 0 0 0 -
0 0 0 1 1 - 0 1 1 1 0
0 0 0 - 1
Hoplias malabaricus 0 - - - 0 1 0 0 0
0 0 0 1 0 0 1 - - - -
0 - 0 - - 0 0 1 2 1 0
0 - 0 0 0 0 1 2 0 - 0
0 0 1 1 - 0 1 1 0 0 0
0 0 - 0
Hydrocynus forskahlii 1 1 0 0 0 0 0 0
1 0 0 0 0 0 0 0 - - -

1	0	-	0	-	-	1	1	-	-	-
-	-	-	-	-	-	0	0	0	0	-
0	0	0	0	-	1	0	1	1	-	0
0	1	0	-	1						
Hydrolycus tatauaia		0	-	-	-	0	1	0	0	0
0	0	0	1	0	0	1	-	-	-	-
0	-	0	-	-	1	0	1	0	1	0
0	-	0	1	0	0	1	0	0	-	0
1	0	1	1	-	0	1	0	0	0	0
0	0	-	1							
Ichthyborus quadrilineatus			1	0	-	0	0	0	1	1
0	0	0	0	1	0	0	0	0	1	1
-	0	-	0	1	0	-	1	-	-	-
-	-	-	-	-	-	0	1	0	0	-
1	0	0	0	-	0	0	1	1	0	0
0	0	1	-	0						
Iguanodectes geisleri		1	1	0	0	0	0	0	1	0
0	1	0	1	0	1	0	0	1	0	2
0	1	0	0	1	1	1	-	-	-	-
-	-	-	-	-	0	0	0	0	-	0
0	0	0	-	1	0	1	1	0	0	0
0	0	-	1							
Laemolyta proxima		1	1	1	1	0	0	1	1	0
0	0	0	0	0	0	0	-	-	-	2
0	1	1	-	-	0	1	-	-	-	-
-	-	-	-	-	0	1	0	0	-	0
0	0	0	-	-	1	1	1	0	0	1
0	0	-	0							
***Lebiasina* sp.**	1	1	0	0	0	0	0	0	0	0
0	0	0	0	0	0	-	-	-	1	0
0	0	-	-	1	0	1	0	0	0	0
0	0	0	0	0	1	0	0	-	0	1
0	0	-	1	0	1	1	0	0	0	0
0	-	0								
Lepidarchus adonis		0	-	-	-	0	0	0	0	0
0	0	0	0	0	0	0	-	-	-	-
0	-	0	-	-	1	1	-	-	-	-
-	-	-	-	-	0	0	0	0	-	0
0	0	0	-	-	0	0	-	-	-	-
-	-	-	1							
Leporinus bahiensis		0	-	-	-	0	0	1	1	0
0	0	0	0	0	0	0	-	-	-	-
0	-	1	-	-	0	1	-	-	-	-
-	-	-	-	-	0	0	0	0	-	0
0	0	0	-	-	1	1	1	0	0	1
0	0	-	0							
Leporinus desmotes		0	-	-	-	0	0	1	1	0
0	0	0	0	0	0	0	-	-	-	-
0	-	1	-	-	0	1	-	-	-	-
-	-	-	-	-	0	0	0	0	-	0

0 0 0 - - 1 1 1 0 0 1
0 0 - 0
Lignobrycon myersi 1 1 0 0 0 0 0 0 0
0 0 0 1 0 1 0 0 1 0 1
0 0 0 0 1 1 0 1 0 1 0
1 0 0 1 0 0 1 0 0 - 0
0 0 1 1 0 0 1 1 1 0 0
0 0 - 1
Lonchogenys ilisha 0 - - - 1 0 0 0 0
0 0 0 0 0 0 0 - - - -
0 - 0 - - 0 0 0 0 1 0
0 - 0 0 1 0 0 0 0 - 0
1 1 1 1 - 0 1 1 0 0 0
0 0 - 0
Micralestes acutidens 1 1 0 0 0 0 0 0
0 0 1 0 1 0 1 0 0 0 -
1 0 1 0 0 1 1 1 - - -
- - - - - - 0 1 0 1 1
0 0 0 0 - 1 0 1 1 0 0
0 0 0 1 1
Microschemobrycon callops 1 1 0 0 0 0 0 0
0 0 0 0 0 0 0 0 - - -
1 0 0 0 - - 1 0 1 0 0
0 0 0 0 1 0 0 1 0 0 -
0 0 0 1 0 0 0 1 1 0 0
0 0 0 - 0
Mimagoniates microlepis 1 1 0 0 0 0 0 0
0 0 1 0 0 0 1 0 1 1 0
1 0 0 0 0 1 1 0 0 0 0
0 1 0 0 1 0 0 1 0 0 -
0 0 0 1 0 0 0 1 1 1 0
0 0 0 - 1
Myloplus arnoldi 1 1 0 - 0 0 0 2 0
0 1 0 1 0 1 0 0 0 - 0
0 0 0 0 1 1 1 - - - -
- - - - - 0 1 0 1 0 0
0 0 1 1 1 0 1 1 1 0 0
0 0 0 0
Nannocharax multifasciatus 1 0 - 0 0 0 1
0 0 0 0 0 1 0 0 0 0 1
1 - 0 - 0 1 0 - 1 - -
- - - - - - - 0 1 0 0
- 0 0 0 0 - 1 0 1 1 0
0 0 0 1 - 0
Nannostomus unifasciatus 1 1 1 1 0 0 0 1
0 0 0 0 0 0 0 0 - - -
2 0 1 0 - - 1 0 0 0 0
0 1 1 0 0 0 0 0 0 0 -
0 0 0 0 - 1 0 1 1 0 0
0 0 0 - 1

***Odontostilbe* sp.** 1 1 0 0 0 0 0 1 0
0 1 0 0 0 0 0 - - - 2
0 1 0 - - 1 0 0 0 0 0
0 1 0 1 0 0 1 0 0 - 0
0 0 1 0 1 0 1 1 1 0 0
0 0 - 1
Parodon pongoensis 1 1 1 1 0 0 0 1 0
0 0 0 0 0 0 2 - - - 2
0 1 1 - - 1 0 0 1 0 0
1 1 1 1 0 0 0 - 0 - 0
0 0 0 - - 2 - - - - -
- - - -
Phenacogaster tegatus 1 1 0 0 0 0 0 0
0 0 1 0 1 0 1 0 0 1 0
1 0 0 0 - 0 1 0 0 0 1
0 0 - 0 1 0 0 1 0 0 -
0 0 0 1 0 0 0 1 1 1 0
0 0 0 - 1
Phenacogrammus interruptus 1 1 0 0 0 0 0
0 0 0 1 0 1 0 1 0 1 -
- 1 0 1 0 0 1 1 1 - -
- - - - - - - 0 1 0 1
1 0 0 0 0 - 1 0 1 1 0
0 0 0 0 1 1
Piabucus melanostoma 1 1 1 0 0 0 0 1
0 0 1 0 0 0 0 0 - - -
2 0 1 0 - - 1 0 0 0 0
0 1 1 0 1 0 0 0 0 0 -
0 0 0 0 - 1 0 1 1 0 0
0 0 0 - 1
Poptella compressa 1 1 0 0 0 0 0 0 0
0 1 0 1 0 1 0 0 1 0 1
0 0 0 0 1 1 0 - 0 0 0
0 0 0 1 0 0 1 0 0 - 0
0 0 1 1 0 0 1 1 1 0 0
0 0 - 1
Prochilodus lineatus 0 - - - 0 0 0 1 0
0 0 0 0 0 - 2 - - - -
0 - 2 - - 0 1 - - - -
- - - - - 0 0 2 0 - 0
0 0 0 - - 2 0 - - - -
- - - 0
Rhaphiodon vulpinus 0 - - - 0 1 0 0
0 0 0 0 1 0 0 0 - - -
- 0 - 0 - - 1 0 1 0 1
0 0 - 0 1 0 0 1 0 0 -
0 0 0 1 1 - 0 1 0 0 0
0 0 0 - 1
Roeboides affinis 0 - - - 0 0 0 0 0
1 0 0 0 0 - 0 - - - -

1	-	0	0	-	1	0	0	0	1	1
1	-	0	1	0	0	0	0	0	-	0
0	1	-	-	-	0	1	1	1	0	0
1	0	-	1							
Roestes molossus		0	-	-	-	1	0	0	0	0
0	0	0	0	0	0	0	-	-	-	-
0	-	0	-	-	0	0	0	0	1	0
1	-	0	1	0	0	0	0	0	-	0
1	1	1	1	-	0	1	1	1	0	0
0	0	-	0							
Salminus brasiliensis		0	-	-	-	0	1	0	0	0
0	0	0	0	0	1	0	0	1	0	-
0	-	0	0	0	1	0	0	0	1	0
1	-	0	1	0	0	1	0	0	-	0
1	0	0	-	-	0	1	1	0	0	0
0	0	-	0							
Serrapinnus calliurus			1	1	0	0	0	0	0	1
0	0	0	0	0	0	0	0	-	-	-
2	0	1	0	-	-	1	0	0	0	0
0	1	1	0	1	0	0	1	0	0	-
0	0	0	1	0	1	0	1	1	0	0
0	0	0	-	1						
Serrasalmus elongatus			1	1	0	0	0	0	0	2
0	0	1	0	1	0	0	0	-	-	-
1	0	1	0	-	-	1	1	-	-	-
-	-	-	-	-	-	0	1	0	0	-
0	0	0	0	-	1	0	1	1	-	1
0	0	0	-	0						
Steindachnerina insculpta			-	-	-	-	-	-	-	-
-	-	-	1	-	-	-	-	-	-	-
-	-	-	-	-	-	-	1	-	-	-
-	-	-	-	-	-	1	-	-	-	-
-	-	-	-	-	-	-	-	-	-	-
-	-	-	-	-						
Triportheus albus		1	1	0	0	0	0	0	0	0
0	1	0	1	0	2	0	0	0	-	0
0	0	0	0	1	1	0	-	0	0	0
0	0	0	1	0	0	1	0	1	0	0
0	0	1	1	0	0	1	1	1	0	0
0	0	0	0							
Triportheus angulatus			1	1	0	0	0	0	0	0
0	0	1	0	1	0	2	0	0	1	0
0	0	0	0	0	1	1	0	0	0	0
0	0	1	0	1	0	0	1	0	1	0
0	0	0	1	1	0	0	1	1	1	0
0	0	0	0	0						
Trochilocharax ornatus			0	-	-	-	0	0	0	0
0	0	0	0	0	0	0	0	-	-	-
-	1	-	0	-	-	1	0	0	0	2
0	0	-	0	1	0	0	0	0	0	-

	0	0	1	0	-	-	0	0	-	-	0
	0	0	0	-	1						
Xenocharax spilurus			1	0	-	1	0	0	0	0	0
	0	0	0	0	0	1	0	0	1	1	-
	0	0	1	1	0	0	0	0	0	0	0
	0	0	1	0	0	0	0	0	0	-	0
	0	0	0	-	0	1	1	1	0	0	0
	0	1	-	0							

Appendix 4.

List of common synapomorphies based on the nine most-parsimonious trees
Abramites hypselonotus: All trees: No autapomorphies:
Acestrocephalus stigmatus: All trees: No autapomorphies:
Acestrorhynchus microlepis: All trees: Char. 1: 0.542-0.576>0.475
Acestrorhynchus pantaneiro: All trees: Char. 40: 0>1
Agoniates halecinus: All trees: Char. 1: 0.407>0.492; Char. 12: 1>0; Char. 16: 2>1; Char. 18: 0>1; Char. 55: 0>1; Char. 58: 0>1
Alestes baremoze: All trees: No autapomorphies:
Alestes macrophthalmus: All trees: No autapomorphies:
Apareiodon ibitiensis: All trees: No autapomorphies:
Aphyocharax avary: All trees: No autapomorphies:
Aphyocharax difficilis: All trees: Char. 1: 0.237>0.203; Char. 31: 1>2
Astyanax multidens: All trees: Char. 1: 0.017>0.085; Char. 26: 1>0
Astyanax novae: All trees: Char. 1: 0.017>0.000
Bivibranchia fowleri: All trees: Char. 9: 1>0; Char. 17: 2>0; Char. 21: 2>1; Char. 30: 1>0
Boulengerella lateristriga: All trees: No autapomorphies:
Boulengerella maculata: All trees: Char. 1: 0.254>0.203
Brycinus imberi: All trees: No autapomorphies:
Brycinus lateralis: All trees: No autapomorphies:
Brycinus sadleri: All trees: No autapomorphies:
Brycon amazonicus: All trees: Char. 0: 0.216>0.297; Char. 1: 0.407>0.424
Brycon falcatus: All trees: No autapomorphies:
Brycon pesu: All trees: No autapomorphies:
Bryconalestes longipinnis: All trees: Char. 21: 0>1
Bryconamericus lethostigmus: All trees: Char. 1: 0.051>0.085; Char. 31: 0>1
Bryconamericus sp.: All trees: Char. 58: 1>0
Bryconops disruptus: All trees: Char. 28: 0>1; Char. 52: 1>0
Carnegiella strigata: All trees: Char. 1: 0.051>0.000; Char. 14: 0>1; Char. 16: 1>0
Catoprion mento: All trees: Char. 2: 0>1; Char. 28: 0>1 Char. 45: 1>0; Char. 53: 0>1; Char. 58: 1>0
Chalceus epakros: All trees: Char. 0: 0.216>0.270
Characidium zebra: All trees: Char. 14: 0>1
Charax stenopterus: All trees: Char. 1: 0.237-0.508>0.729; Char. 2: 1>0; Char. 27: 1>0; Char. 39: 1>0
Chilodus punctatus: All trees: Char. 9: 1>0
Citharidium ansorgii: All trees: Char. 0: 0.378-0.865>1.000; Char. 14: 0>1; Char. 39: 0>1
Citharinus citharu: All trees: No autapomorphies:

Crenuchus spilurus: All trees: Char. 46: 0>1
Cynodon gibbus: All trees: Char. 1: 0.814-0.983>1.000
Cynopotamus xinguano: All trees: Char. 1: 0.746>0.831
Exodon paradoxus: All trees: Char. 14: 0>1
Galeocharax gulo: All trees: Char. 0: 0.189>0.243
Gymnocorymbus ternetzi: Some trees: Char. 0: 0.054>0.081
Hemiodus microlepis: All trees: Char. 1: 0.017-0.102>0.136; Char. 31: 0>1
Hepsetus odoe: All trees: Char. 17: 0>2; Char. 30: 0>2; Char. 40: 0>1
Heterocharax virgulatus: All trees: Char. 45: 1>0
Hoplias malabaricus: All trees: Char. 1: 0.542-0.576>0.695; Char. 30: 0>2; Char. 36: 1>0; Char. 40: 0>2; Char. 44: 1>0; Char. 58: 1>0
Hydrocynus forskahlii: All trees: Char. 10: 0>1; Char. 39: 1>0; Char. 55: 0>1; Char. 58: 0>1
Hydrolycus tatauaia: All trees: Char. 17: 0>1
Ichthyborus quadrilineatus: All trees: Char. 9: 0>1 Char. 43: 0>1
Iguanodectes geisleri: All trees: Char. 0: 0.027-0.081>0.000; Char. 14: 0>1; Char. 16: 0>1; Char. 26: 0>1; Char. 28: 0>1
Laemolyta proxima: All trees: Char. 39: 0>1
Lebiasina sp.: All trees: Char. 28: 1>0
Lepidarchus adonis: All trees: Char. 28: 0>1
Leporinus bahiensis: All trees: No autapomorphies:
Leporinus desmotes: All trees: No autapomorphies:
Lignobrycon myersi: All trees: Char. 1: 0.237>0.271
Lonchogenys ilisha: All trees: Char. 1: 0.424-0.797>0.864; Char. 33: 1>0; Char. 36: 1>0; Char. 52: 1>0
Micralestes acutidens: All trees: No autapomorphies:
Microschemobrycon callops: All trees: No autapomorphies:
Mimagoniates microlepis: All trees: Char. 18: 0>1; Char. 26: 0>1;
Myloplus arnoldi: All trees: Char. 9: 0>2
Nannocharax multifasciatus: All trees: Char. 0: 0.378-0.622>0.108; Char. 48: 0>1
Nannostomus unifasciatus: All trees: Char. 1: 0.017-0.034>0.000
Odontostilbe sp.: All trees: Char. 33: 1>0
Parodon pongoensis: All trees: No autapomorphies:
Phenacogaster tegatus: All trees: Char. 0: 0.054-0.081>0.135; Char. 14: 0>1
Phenacogrammus interruptus: All trees: Char. 0: 0.027>0.000; Char. 18: 0>1;
Piabucus melanostoma: All trees: No autapomorphies:
Poptella compressa: Some trees: Char. 0: 0.081>0.054
Prochilodus lineatus: All trees: Char. 17: 0>2; Char. 40: 0>2
Rhaphiodon vulpinus: All trees: Char. 44: 1>0
Roeboides affinis: All trees: No autapomorphies:
Roestes molossus: All trees: No autapomorphies:
Salminus brasiliensis: All trees: Char. 16: 0>1; Char. 58: 1>0
Serrapinnus calliurus: All trees: Char. 12: 1>0
Serrasalmus elongatus: All trees: Char. 9: 1>2; Char. 14: 0>1; Char. 28: 0>1; Char. 53: 0>1; Char. 58: 1>0
Steindachnerina insculpta: All trees: Char. 13: 0>1; Char. 28: 0>1
Triportheus albus: All trees: No autapomorphies:
Triportheus angulatus: All trees: Char. 34: 0>1
Trochilocharax ornatus: All trees: Char. 31: 1>2; Char. 33: 1>0; Char. 50: 1>0
Xenocharax spilurus: All trees: Char. 16: 0>1; Char. 28: 1>0

Node 79: All trees: Char. 2: 1>0
Node 80: All trees: Char. 8: 0>1; Char. 54: 0>1
Node 81: All trees: Char. 3: 0>1; Char. 9: 0>1
Node 82: All trees: No synapomorphies
Node 83: All trees: Char. 44: 0>1
Node 84: All trees: Char. 0: 0.162>0.189; Char. 1: 0.254-0.492>0.746; Char. 16: 0>1; Char. 33: 1>0; Char. 58: 1>0
Node 85: All trees: Char. 0: 0.054-0.081>0.162
Node 86: All trees: Char. 2: 1>0; Char. 39: 1>0
Node 87: All trees: Char. 47: 0>1
Node 88: All trees: Char. 33: 0>1
Node 89: All trees: Char. 16: 1>0
Node 90: All trees: Char. 12: 1>0
Node 91: All trees: Char. 1: 0.068>0.237-0.508; Char. 31: 0>1; Char. 33: 1>0
Node 92: All trees: Char. 1: 0.051>0.068
Node 93: All trees: Char. 23: 1>0; Char. 46: 0>1
Node 94: All trees: Char. 9: 1>0; Char. 34: 1>0; Char. 48: 1>0
Node 95: All trees: Char. 16: 0>1
Node 96: All trees: Char. 21: 2>1
Node 97: All trees: Char. 52: 0>1
Node 98: All trees: Char. 39: 0>1
Node 99: All trees: Char. 4: 1>0
Node 100: All trees: Char. 5: 1>0; Char. 12: 0>1
Node 101: All trees: Char. 24: 12>0; Char. 35: 1>0; Char. 49: 2>0
Node 102: All trees: Char. 27: 0>1; Char. 28: 1>0
Node 103: All trees: Char. 49: 1>2
Node 104: All trees: Char. 33: 0>2; Char. 52: 0>1; Char. 55: 0>1
Node 105: All trees: Char. 27: 1>0; Char. 46: 0>1
Node 106: All trees: Char. 1: 0.492>0.542-0.576; Char. 14: 0>1; Char. 29: 0>1; Char. 33: 1>0
Node 107: All trees: Char. 39: 0>1; Char. 44: 0>1
Node 108: All trees: Char. 7: 0>1
Node 109: All trees: Char. 46: 1>0
Node 110: All trees: Char. 1: 0.017>0.407; Char. 21: 0>1; Char. 26: 1>0; Char. 31: 0>1; Char. 33: 0>1
Node 111: All trees: Char. 19: 0>1
Node 112: All trees: Char. 16: 1>2
Node 113: All trees: Char. 41: 0>1
Node 114: All trees: Char. 19: 1>0; Char. 21: 1>0
Node 115: All trees: Char. 58: 1>0
Node 116: All trees: Char. 12: 0>1; Some trees: Char. 1: 0.237>0.017; Char. 31: 1>0; Char. 33: 1>0
Node 117: All trees: Char. 14: 0>1; Char. 16: 0>1 Char. 26: 0>1
Node 118: All trees: Char. 15: 0>1; Char. 23: 0>1; Char. 46: 1>0; Char. 52: 1>0; Char. 58: 0>1
Node 119: All trees: Char. 0: 0.054>0.027; Char. 28: 0>1; Char. 48: 0>1
Node 120: All trees: Char. 5: 1>0; Char. 38: 0>1
Node 121: All trees: Char. 17: 0>2; Char. 30: 0>1
Node 122: All trees: Char. 9: 0>1; Char. 31: 1>2; Char. 36: 1>0
Node 123: All trees: Char. 0: 0.027>0.054

Node 124: All trees: Char. 19: 0>1; Char. 57: 0>1
Node 125: All trees: Char. 0: 0.189>0.216
Node 126: All trees: Char. 0: 0.054-0.135>0.189; Char. 29: 0>1; Char. 44: 0>1; Char. 46: 1>0; Char. 52: 1>0
Node 127: All trees: Char. 1: 0.407>0.356
Node 128: All trees: Char. 39: 0>1
Node 129: All trees: Char. 1: 0.153>0.136; Char. 11: 0>1; Char. 32: 0>1 Char. 55: 0>1
Node 130: All trees: Char. 1: 0.237-0.492>0.153; Char. 22: 0>1; Char. 46: 1>0
Node 131: All trees: Char. 45: 0>1
Node 132: All trees: Char. 26: 0>1; Char. 42: 0>1; Char. 58: 0>1
Node 133: All trees: Char. 28: 0>1; Char. 46: 1>0
Node 134: All trees: Char. 1: 0.237>0.119; Char. 29: 0>1; Char. 31: 1>0; Char. 52: 1>0
Node 135: All trees: Char. 2: 1>0; Char. 50: 1>0 Some trees: Char. 24: 1>2
Node 136: All trees: Char. 44: 0>1
Node 137: All trees: Char. 48: 0>1
Node 138: All trees: Char. 1: 0.542-0.576>0.814-0.983
Node 139: All trees: Char. 51: 1>0
Node 140: All trees: Char. 37: 0>1
Node 141: All trees: Char. 6: 0>1
Node 142: All trees: Char. 46: 0>1
Node 143: All trees: Char. 5: 1>0; Char. 8: 0>1; Char. 14: 0>1; Char. 24: 1>0; Char. 39: 0>1; Char. 49: 1>0
Node 144: All trees: Char. 56: 0>1
Node 145: All trees: Char. 0: 0.216>0.027; Char. 16: 2>1; Char. 23: 0>1; Char. 28: 0>1; Char. 44: 1>0; Char. 48: 0>1; Char. 57: 0>1

Appendix 4.
List of character transformation based on the nine most-parsimonious trees.
Char. 0:
Root: 0.378-0.865
C. citharu: 0.378-0.865 > ?
Node 144: 0.378-0.865 > 0.378-0.622
C. ansorgii: 0.378-0.865 > 1.000
X. spilurus: 0.378-0.622 > 0.378
N. multifasciatus: 0.378-0.622 > 0.108
I. quadrilineatus: 0.378-0.622 > 0.622
Node 102: 0.378-0.865 > 0.027-0.865
L. proxima: 0.378-0.865 > ?
P. lineatus: 0.378-0.865 > ?
C. punctatus: 0.378-0.865 > 0.865
L. desmotes: 0.378-0.865 > ?
L. bahiensis: 0.378-0.865 > ?
A. hypselonotus: 0.378-0.865 > ?
N. unifasciatus: 0.027-0.865 > ?
P. pongoensis: 0.027-0.865 > ?
Node 99: 0.027-0.865 > 0.027-0.081
P. melanostoma: 0.027-0.865 > ?
S. insculpta: 0.027-0.865 > ?
H. microlepis: 0.027-0.865 > ?
B. fowleri: 0.027-0.865 > ?

A. ibitiensis: 0.027-0.865 > ?
I. geisleri: 0.027-0.081 > 0.000
S. calliurus: 0.027-0.081 > ?
Odontostilbe sp.: 0.027-0.081 > ?
S. elongatus: 0.027-0.081 > ?
B. lethostigmus: 0.027-0.081 > ?
Bryconamericus sp.: 0.027-0.081 > ?
C. strigata: 0.027-0.081 > ?
Node 91: 0.027-0.081 > 0.054-0.081
M. microlepis: 0.027-0.081 > 0.027
P. tegatus: 0.054-0.081 > 0.135
C. stenopterus: 0.054-0.081 > 0.081
A. avary: 0.054-0.081 > ?
M. callops: 0.054-0.081 > ?
A. difficilis: 0.054-0.081 > ?
C. zebra: 0.054-0.081 > ?
Node 131: 0.054-0.081 > 0.027-0.081
Node 85: 0.054-0.081 > 0.162
L. myersi: 0.054-0.081 > ?
H. forskahlii: 0.054-0.081 > ?
Node 84: 0.162 > 0.189
P. compressa: 0.054-0.081 > 0.054
B. disruptus: 0.054-0.081 > 0.081
Lebiasina sp.: 0.054-0.081 > ?
C. spilurus: 0.054-0.081 > ?
T. ornatus: 0.027-0.081 > ?
R. molossus: 0.027-0.081 > ?
L. adonis: 0.162 > ?
Node 114: 0.054-0.081 > 0.054
G. ternetzi: 0.054-0.081 > 0.081
A. multidens: 0.054-0.081 > 0.054
R. affinis: 0.027-0.081 > ?
L. ilisha: 0.027-0.081 > 0.027
H. virgulatus: 0.027-0.081 > ?
G. gulo: 0.189 > 0.243
E. paradoxus: 0.027-0.081 > ?
C. mento: 0.027-0.081 > ?
B. maculata: 0.162 > ?
B. lateristriga: 0.162 > ?
Node 119: 0.054 > 0.027
Node 111: 0.054 > 0.054-0.135
H. odoe: 0.162 > ?
H. malabaricus: 0.162 > ?
T. angulatus: 0.054-0.135 > 0.135
C. gibbus: 0.162 > ?
A. pantaneiro: 0.162 > ?
A. microlepis: 0.162 > ?
Node 126: 0.054-0.135 > 0.189
A. halecinus: 0.054-0.135 > 0.054
Node 123: 0.027 > 0.054

R. vulpinus: 0.162 > ?
H. tatauaia: 0.162 > ?
Node 125: 0.189 > 0.216
B. amazonicus: 0.216 > 0.297
Node 145: 0.216 > 0.027
C. epakros: 0.216 > 0.270
P. interruptus: 0.027 > 0.000
Char. 1:
Root: 0.017-0.102
C. citharu: 0.017-0.102 > ?
C. ansorgii: 0.017-0.102 > ?
X. spilurus: 0.017-0.102 > 0.102
N. multifasciatus: 0.017-0.102 > ?
I. quadrilineatus: 0.017-0.102 > ?
L. proxima: 0.017-0.102 > ?
Node 101: 0.017-0.102 > 0.017-0.034
P. lineatus: 0.017-0.102 > ?
C. punctatus: 0.017-0.102 > ?
L. desmotes: 0.017-0.102 > ?
L. bahiensis: 0.017-0.102 > ?
A. hypselonotus: 0.017-0.102 > ?
N. unifasciatus: 0.017-0.034 > 0.000
P. pongoensis: 0.017-0.102 > 0.017
P. melanostoma: 0.017-0.034 > 0.017
S. insculpta: 0.017-0.102 > ?
H. microlepis: 0.017-0.102 > 0.136
B. fowleri: 0.017-0.102 > 0.102
A. ibitiensis: 0.017-0.102 > 0.017
I. geisleri: 0.017-0.034 > ?
S. calliurus: 0.017-0.034 > 0.034
Node 96: 0.017-0.034 > 0.017-0.051
Odontostilbe sp.: 0.017-0.034 > 0.017
Node 95: 0.017-0.051 > 0.051
S. elongatus: 0.017-0.051 > ?
B. lethostigmus: 0.051 > 0.085
Node 92: 0.051 > 0.068
C. strigata: 0.051 > 0.000
Node 91: 0.068 > 0.237-0.508
P. tegatus: 0.237-0.508 > 0.508
Node 89: 0.237-0.508 > 0.237
C. stenopterus: 0.237-0.508 > 0.729
Node 134: 0.237 > 0.119
Node 133: 0.119 > 0.102-0.119
Node 86: 0.237 > 0.237-0.492
A. difficilis: 0.237 > 0.203
C. zebra: 0.102-0.119 > ?
Node 85: 0.237-0.492 > 0.254-0.492
Node 116: 0.237 > 0.017-0.237
L. myersi: 0.237 > 0.271
H. forskahlii: 0.102-0.119 > ?

Node 130: 0.237-0.492 > 0.153
Node 141: 0.237-0.492 > 0.424-0.797
Node 84: 0.254-0.492 > 0.746
Node 115: 0.017-0.237 > 0.017
P. compressa: 0.017-0.237 > 0.017
B. disruptus: 0.017-0.237 > ?
Lebiasina sp.: 0.102-0.119 > 0.102
C. spilurus: 0.102-0.119 > ?
Node 129: 0.153 > 0.136
R. molossus: 0.424-0.797 > 0.797
L. adonis: 0.254-0.492 > ?
C. xinguano: 0.746 > 0.831
A. multidens: 0.017 > 0.085
Node 128: 0.136 > 0.102-0.136
L. ilisha: 0.424-0.797 > 0.864
H. virgulatus: 0.424-0.797 > 0.424
Node 107: 0.254-0.492 > 0.492
Node 122: 0.254-0.492 > 0.254
A. novae: 0.017 > 0.000
E. paradoxus: 0.102-0.136 > 0.102
C. mento: 0.102-0.136 > ?
Node 106: 0.492 > 0.542-0.576
B. maculata: 0.254 > 0.203
M. arnoldi: 0.017 > ?
Node 138: 0.542-0.576 > 0.814-0.983
H. odoe: 0.542-0.576 > 0.542
H. malabaricus: 0.542-0.576 > 0.695
Node 110: 0.017 > 0.407
A. macrophthalmus: 0.017 > ?
A. baremoze: 0.017 > ?
C. gibbus: 0.814-0.983 > 1.000
A. pantaneiro: 0.542-0.576 > 0.576
A. microlepis: 0.542-0.576 > 0.475
A. halecinus: 0.407 > 0.492
B. longipinnis: 0.017 > ?
R. vulpinus: 0.814-0.983 > 0.814
H. tatauaia: 0.814-0.983 > 0.983
B. sadleri: 0.017 > ?
B. lateralis: 0.017 > ?
B. imberi: 0.017 > ?
Node 127: 0.407 > 0.356
B. amazonicus: 0.407 > 0.424
Node 132: 0.356 > 0.237-0.356
C. epakros: 0.237-0.356 > 0.237
P. interruptus: 0.237-0.356 > ?
M. acutidens: 0.237-0.356 > ?
Char. 2:
Root: 1
Node 135: 1 > 0
Node 79: 1 > 0

C. stenopterus: 1 > 0
Node 86: 1 > 0
C. mento: 0 > 1
Char. 3:
Root: 0
Node 81: 0 > 1
Char. 4:
Root: 1
Node 120: 1 > 01
Node 99: 1 > 0
H. microlepis: 01 > 1
B. fowleri: 01 > 0
A. ibitiensis: 01 > 0
Char. 5:
Root: 1
Node 143: 1 > 0
Node 100: 1 > 0
Node 120: 1 > 0
Char. 6:
Root: 0
Node 141: 0 > 1
Char. 7:
Root: 0
Node 108: 0 > 1
Char. 8:
Root: 0
Node 143: 0 > 1
Node 80: 0 > 1
Char. 9:
Root: 0
Node 81: 0 > 1
I. quadrilineatus: 0 > 1
C. punctatus: 1 > 0
B. fowleri: 1 > 0
S. elongatus: 1 > 2
Node 94: 1 > 0
Node 122: 0 > 1
M. arnoldi: 0 > 2
Char. 10:
Root: 0
H. forskahlii: 0 > 1
Char. 11:
Root: 0
Node 129: 0 > 1
Char. 12:
Root: 0
Node 100: 0 > 1
S. calliurus: 1 > 0
Node 90: 1 > 0
Node 116: 0 > 1

A. halecinus: 1 > 0
Char. 13:
Root: 0
S. insculpta: 0 > 1
Char. 14:
Root: 0
C. ansorgii: 0 > 1
Node 143: 0 > 1
I. geisleri: 0 > 1
S. elongatus: 0 > 1
C. strigata: 0 > 1
P. tegatus: 0 > 1
Node 117: 0 > 1
C. zebra: 0 > 1
E. paradoxus: 0 > 1
Node 106: 0 > 1
Char. 15:
Root: 0
Node 118: 0 > 1
Char. 16:
Root: 0
X. spilurus: 0 > 1
I. geisleri: 0 > 1
Node 95: 0 > 1
C. strigata: 1 > 0
Node 89: 1 > 0
Node 117: 0 > 1
Node 84: 0 > 1
S. brasiliensis: 0 > 1
Node 112: 1 > 2
A. halecinus: 2 > 1
Node 145: 2 > 1
Char. 17:
Root: 0
Node 121: 0 > 2
P. lineatus: 0 > 2
B. fowleri: 2 > 0
Node 105: 0 > 01
H. odoe: 0 > 2
H. malabaricus: 01 > 1
A. pantaneiro: 01 > 1
A. microlepis: 01 > 0
H. tatauaia: 0 > 1
Char. 18:
Root: 0
M. microlepis: 0 > 1
A. halecinus: 0 > 1
P. interruptus: 0 > 1
Char. 19:
Root: 1

Node 114: 1 > 0
Node 111: 0 > 1
Node 124: 0 > 1
Node 145: 1 > 01
M. acutidens: 01 > 0
Char. 20:
Root: 1
Node 81: 1 > 01
Node 99: 01 > 0
Char. 21:
Root: 2
B. fowleri: 2 > 1
Node 96: 2 > 1
Node 114: 1 > 0
Node 110: 0 > 1
B. longipinnis: 0 > 1
Char. 22:
Root: 0
Node 130: 0 > 1
Char. 23:
Root: 01
Node 81: 01 > 1
X. spilurus: 01 > 0
Node 93: 1 > 0
Node 118: 0 > 1
Node 145: 0 > 1
Char. 24:
Root: 1
Node 143: 1 > 0
Node 103: 1 > 12
Node 135: 12 > 2
Node 101: 12 > 0
P. pongoensis: 12 > 1
H. microlepis: 12 > 2
B. fowleri: 12 > 2
A. ibitiensis: 12 > 1
Char. 25:
Root: 1
Node 81: 1 > 01
Node 99: 01 > 0
Char. 26:
Root: 0
I. geisleri: 0 > 1
M. microlepis: 0 > 1
Node 117: 0 > 1
A. multidens: 1 > 0
Node 110: 1 > 0
Node 132: 0 > 1
Char. 27:
Root: 0

Node 102: 0 > 1
C. stenopterus: 1 > 0
Node 141: 1 > 01
R. molossus: 01 > 0
L. ilisha: 01 > 0
H. virgulatus: 01 > 1
Node 105: 1 > 0
Char. 28:
Root: 1
X. spilurus: 1 > 0
Node 102: 1 > 0
S. insculpta: 0 > 1
I. geisleri: 0 > 1
S. elongatus: 0 > 1
Node 133: 0 > 1
B. disruptus: 0 > 1
Lebiasina sp.: 1 > 0
L. adonis: 0 > 1
C. mento: 0 > 1
Node 119: 0 > 1
Node 145: 0 > 1
Char. 29:
Root: 0
Node 134: 0 > 1
Node 117: 0 > 01
L. myersi: 01 > 1
Node 114: 01 > 0
A. multidens: 01 > 1
Node 128: 0 > 01
E. paradoxus: 01 > 1
Node 106: 0 > 1
Node 126: 0 > 1
Char. 30:
Root: 0
Node 121: 0 > 1
B. fowleri: 1 > 0
H. odoe: 0 > 2
H. malabaricus: 0 > 2
Char. 31:
Root: 0
H. microlepis: 0 > 1
B. lethostigmus: 0 > 1
Node 91: 0 > 1
Node 134: 1 > 0
A. difficilis: 1 > 2
Node 116: 1 > 01
Node 115: 01 > 0
P. compressa: 01 > 0
T. ornatus: 1 > 2
Node 122: 1 > 2

Node 110: 0 > 1
Char. 32:
Root: 0
Node 129: 0 > 1
Char. 33:
Root: 01
X. spilurus: 01 > 0
Node 101: 01 > 1
P. pongoensis: 01 > 1
H. microlepis: 01 > 0
B. fowleri: 01 > 0
A. ibitiensis: 01 > 1
Odontostilbe sp.: 1 > 0
Node 91: 1 > 0
Node 88: 0 > 1
Node 116: 1 > 01
Node 84: 1 > 0
Node 115: 01 > 0
P. compressa: 01 > 0
T. ornatus: 1 > 0
Node 128: 1 > 12
L. ilisha: 1 > 0
E. paradoxus: 12 > 2
Node 106: 1 > 0
Node 104: 0 > 2
Node 110: 0 > 1
Char. 34:
Root: 01
X. spilurus: 01 > 0
Node 102: 01 > 1
Node 94: 1 > 0
T. angulatus: 0 > 1
Char. 35:
Root: 1
Node 101: 1 > 0
Node 120: 1 > 12
H. microlepis: 12 > 2
B. fowleri: 12 > 2
A. ibitiensis: 12 > 1
Char. 36:
Root: 01
X. spilurus: 01 > 0
Node 121: 01 > 1
Node 100: 01 > 1
N. unifasciatus: 01 > 0
Node 133: 1 > 01
Lebiasina sp.: 01 > 0
L. ilisha: 1 > 0
Node 122: 1 > 0
H. malabaricus: 1 > 0

Char. 37:
Root: 0
Node 140: 0 > 1
Char. 38:
Root: 0
Node 120: 0 > 1
Char. 39:
Root: 0
C. ansorgii: 0 > 1
Node 143: 0 > 1
L. proxima: 0 > 1
Node 98: 0 > 1
Node 95: 1 > 01
B. lethostigmus: 01 > 0
Node 93: 01 > 1
Bryconamericus sp.: 01 > 0
C. stenopterus: 1 > 0
Node 86: 1 > 0
H. forskahlii: 1 > 0
Node 128: 0 > 1
Node 107: 0 > 1
Char. 40:
Root: 0
P. lineatus: 0 > 2
H. odoe: 0 > 1
H. malabaricus: 0 > 2
A. pantaneiro: 0 > 1
Char. 41:
Root: 0
Node 113: 0 > 1
Char. 42:
Root: 0
Node 132: 0 > 1
Char. 43:
Root: 0
I. quadrilineatus: 0 > 1
Char. 44:
Root: 0
Node 136: 0 > 1
Node 141: 0 > 01
R. molossus: 01 > 1
Node 83: 0 > 1
L. ilisha: 01 > 1
H. virgulatus: 01 > 0
Node 107: 0 > 1
H. malabaricus: 1 > 0
Node 126: 0 > 1
R. vulpinus: 1 > 0
Node 145: 1 > 0
Char. 45:

Root: 0
Node 131: 0 > 1
H. virgulatus: 1 > 0
C. mento: 1 > 0
Char. 46:
Root: 0
Node 98: 0 > 01
S. calliurus: 01 > 1
Node 96: 01 > 0
Odontostilbe sp.: 01 > 1
Node 93: 0 > 1
Node 133: 1 > 0
Node 130: 1 > 0
Node 109: 1 > 0
C. spilurus: 0 > 1
Node 105: 0 > 1
Node 118: 1 > 0
Node 142: 0 > 1
Node 126: 1 > 0
Char. 47:
Root: 0
Node 87: 0 > 1
Char. 48:
Root: 0
Node 81: 0 > 01
N. multifasciatus: 0 > 1
Node 101: 01 > 1
Node 94: 1 > 0
Node 137: 0 > 1
Node 119: 0 > 1
Node 145: 0 > 1
Char. 49:
Root: 1
Node 143: 1 > 0
Node 103: 1 > 2
Node 101: 2 > 0
Char. 50:
Root: 1
Node 135: 1 > 0
Node 109: 1 > 01
T. ornatus: 1 > 0
L. adonis: 01 > 0
Node 107: 01 > 1
Node 122: 01 > 0
Char. 51:
Root: 1
Node 139: 1 > 0
Char. 52:
Root: 0
Node 97: 0 > 1

Node 134: 1 > 0
Node 109: 1 > 01
B. disruptus: 1 > 0
L. ilisha: 1 > 0
Node 107: 01 > 0
Node 118: 1 > 0
Node 104: 0 > 1
Node 126: 1 > 0
Char. 53:
Root: 0
S. elongatus: 0 > 1
C. mento: 0 > 1
Char. 54:
Root: 0
Node 80: 0 > 1
Char. 55:
Root: 0
H. forskahlii: 0 > 1
Node 129: 0 > 1
Node 104: 0 > 1
A. halecinus: 0 > 1
Char. 56:
Root: 0
Node 144: 0 > 1
Char. 57:
Root: 0
Node 124: 0 > 1
Node 145: 0 > 1
Char. 58:
Root: 0
Node 102: 0 > 01
Node 101: 01 > 1
S. elongatus: 1 > 0
Bryconamericus sp.: 1 > 0
Node 90: 1 > 01
C. stenopterus: 01 > 0
Node 88: 01 > 1
Node 134: 01 > 0
H. forskahlii: 0 > 1
Node 141: 1 > 01
Node 84: 1 > 0
Node 115: 1 > 0
R. molossus: 01 > 0
L. ilisha: 01 > 0
H. virgulatus: 01 > 1
C. mento: 1 > 0

Chapter 2

Skeletal development and ossification sequence of the characiforms *Astyanax lacustris* (Lütken 1875) (Ostariophysi: Characidae) and *Ctenolucius hujeta* (Valenciennes, 1850) (Ostariophysi: Ctenoluciidae)

Abstract

Detailed information about the skeletogenesis in Characiformes is still scarce and to this date there is only one complete sequence of ossification available in the literature. We herein studied the skeletal development of the small sized characid *Astyanax lacustris* and the ctenoluciid *Ctenolucius hujeta* presenting the ossification sequence of the complete skeleton for both species. This study was based on 111 specimens of *A. lacustris* (2.9 mm NL to 27.6 mm SL) and 100 specimens of *C. hujeta* (3.5 mm NL to 35.5 mm SL). Specimens were cleared and double stained and the presence of an ossification was scored whenever mineralization was detected. For both species the first ossifications to appear were the tooth plates associated to ceratobranchial 4 and pharyngobranchial 4, the cleithrum and the opercle at 2.9 mm NL for *A. lacustris* and 3.5 mm NL for *C. hujeta*. The first bones of the neurocranium to appear in both species are the basioccipital (3.7 mm NL in *A. lacustris* and 3.8 mm NL in *C. hujeta*) and parasphenoid (4.0 mm NL in *A. lacustris* and 4.1 mm NL in *C. hujeta*). The hyopalatine arch begins ossification with the quadrate and symplectic in *A. lacustris* (4.3 mm NL) and quadrate in *C. hujeta* (4.7 mm NL). In the branchial arches are the first elements to ossify are ceratobranchial 5 (4.0 mm NL in *A. lacustris* and 3.7 mm NL in *C. hujeta*). In the axial skeleton the first bones to appear in both species are the vertebral centra (at 4.9 mm NL in *A. lacustris* and at 7.1 mm SL in *C. hujeta*). The Weberian apparatus starts to ossify with the four vertebral centra in both species (at 4.9 mm NL in *A. lacustris* and at 7.1 mm SL in *C. hujeta*). Diagrams for the complete sequence are presented for both species. Comparative analyses were conducted for the sequences of *A. lacustris*, *C. hujeta* and the already published sequence of *S. brasiliensis*. The sequences are compared within osteological complexes for the sequence within that complex as well as in the context of the entire sequence.

Differences were observed regarding the sequence of ossification within an osteological complex; the relative intervals between the ossification of the first and last element in an osteological complex, as well as shift of an entire osteological complex in the complete sequence.

Introduction

The study of ontogeny is a valuable resource utilized by comparative anatomists in order to understand in more detail the nature and homology of several morphological characters, and complements information based on the examination of adult specimens (Nelson, 1978; 1985; Britz & Johnson, 2002; 2005; Fraser et al., 2012). In addition, the study of ossification sequences is important in order to identify and understand heterochronic events that might be present in cases of miniaturization (Britz & Conway, 2009; Britz *et al*., 2009; Mattox *et al*. 2016).

Among the Ostariophysi studies on the skeletal development and ossification sequence were carried out for the Gonorhynchiformes (Taki *et al*., 1986; 1987; Kohno *et al*., 1996; Arratia & Bagarinao, 2010), non neotropical Siluriformes (Adriaens *et al*., 1997; Adriaens & Verraes, 1998) and Cypriniformes (Vandewalle *et al*., 1992; Cubbage & Mabee, 1996; Bird & Mabee, 2003; Engeman et al., 2009; Conway *et al*., 2017), the available information is scarce for Gymnotiformes and neotropical Siluriformes (Geerinckx et al., 2007) and Characiformes.

Studies on the ontogeny of the skeleton of the Characiformes are still scarce and most of them deal with only part of the skeleton. Bertmar (1959) published a monograph on the development of the neurocranium and visceral arches of *Hepsetus odoe* (Hepsetidae), the author focused on the development of chondral elements, rarely referring to ossified structures. Vandewalle *et al*. (2005) presented a study on the chondrogenesis and osteogenesis of the cranial skeleton of *Brycon moorei*. More recently, Walter (2013) presented a study on the chondrogenesis and osteogenesis of the cranium of the characid *Moenkhausia sanctaefilomenae* and Carvalho and Vari (2015) presented a study on the development of the mandibular, hyoid and branchial arches of *Prochilodus argenteus* (Prochilodontidae) with a discussion on the basal developmental patterns in Ostariophysi. Mattox *et al*. (2014) were the first to present a study on the development of the complete skeleton within the Characiformes, the authors proposed a sequence of ossification of the complete skeleton for *Salminus brasiliensis*.

The proposal of additional sequences of ossification for the complete skeleton constitutes an important source of information not only on the development of the selected taxa, but also enable the comparison among sequences of ossification of the complete skeleton of other representatives of the Characiformes and possibly identifying differences with phylogenetic significance.

We herein describe the skeletogenesis of the characid *Astyanax lacustris* (Lütken 1875) and the ctenoluciid *Ctenolucius hujeta* (Valenciennes, 1850). Developmental studies for the two selected species and related taxa are restricted to the cranial region of *Astyanax mexicanus* comparing the development of morphological modifications of the cave-dwelling form to the surface form (Powers *et al*. 2017; Powers *et al*. 2018) and the ontogeny of element of elements of the Weberian apparatus for *Ctenolucius hujeta*. (Hoffmann & Britz 2006; Britz & Hoffmann 2006). We provide a general sequence of ossification for each species. The proposed sequences are compared to the sequence proposed for *Salminus brasiliensis* by the Mattox *et al*. (2014) in a first attempt of a comparative analysis of sequence of ossification of the skeleton within Characiformes.

Material and Methods

Specimens of *Astyanax lacustris*, including adults, were obtained at Estação de Hidrobiologia e Aquicultura de Paraibuna - Companhia Energética de São Paulo, from stocks of farmed specimens. The species was selected because it represents a generalized form of a relatively small sized Characidae allied with practical reasons since specimens were easily available in sufficient numbers needed for this comprehensive study. Specimens of *Ctenolucius hujeta* were aquarium bred by Dr. Ralf Britz. Specimens of this species were also available specimens in large numbers, the osteology of the adults of this species is well documented (Roberts, 1969; Vari, 1995) and it presents several morphological differences in relation to *Astyanax lacustris* and *Salminus brasiliensis*, the latter being the only species with a complete ontogenetic sequence of ossification proposed (Mattox *et al*., 2014).

Specimens of both species were preserved in a solution of 4% buffered formalin for approximately 48 hours, rinsed in water and preserved in 70% ethanol. The series of *Astyanax lacustris* is comprised of 111 specimens of ranging from 2.9 mm NL to 27.6 mm SL. The series of *Ctenolucius hujeta* is comprised of 100 examined specimens ranging from 3.5 mm NL to 35.5 mm SL. Comparisons between the observed conditions of the developing skeletal elements and the conditions observed in adults were done through the examination of cleared and stained adult specimens for *Astyanax lacustris*, and information available in the literature for *Ctenolucius hujeta* (Roberts, 1969; Vari, 1995). All specimens were cleared and double stained with alcian blue (cartilage) and alizarin (bone) following Taylor & Van Dyke (1985), they were gradually transferred through a series of glycerol up to 80% glycerol. Specimens had their notochord length (NL) taken up to the size in which a clear vertical distal margin of the ossified hypural 3 was present. Standard length (SL) was taken from specimens that already showed a hypural 3 cartilage. Specimens in intermediate stages (hypural cartilage 3 present but not yet ossified and with a distinct vertical margin) had both NL and SL taken. Specimens were photographed using a Zeiss Axiocam camera attached to a Zeiss V20 stereomicroscope using the Z-stack option, the images obtained were stacked with the Helicon Focus software.

Terminology of cartilages follows Mattox *et al*. (2014). Data analysis was based on the methods described by Cubbage & Mabee (1996), Mabee *et al*. (2000) and Bird & Mabee (2003). In order to facilitate comparisons between sequences, selection of the bony elements was done as described by Mattox *et al*. (2014): the angular and articular were are two independent ossifications, since they start ossifying separately and later fuse in ontogeny, however it was not possible to resolve which ossification appears first, therefore they are treated as a single element in the descriptions; the anterior portion of the notochord was considered part of the basioccipital; the four branchiostegal rays were treated as a single element but their detailed individual development is provided in the description; pectoral- and pelvic-fin rays were included as ossifications; each of the three postcleithra and pelvic-fin radials were scored separately, pectoral-fin radial were scored as a unit; the four Weberian vertebral centra were scored separately and the remaining vertebral centra were coded as a single unit; the os suspensorium was treated as a single element; all supraneurals (except supraneural 3 in the Weberian apparatus) were coded as a single unit; epurals were considered individually; and dorsal and ventral procurrent caudal-fin rays were coded separately; the ossification of the sclerotic was not observed in any of the specimens available for this study.

The presence of a bone was coded in a specimen of a given size whenever there were signs of ossification such as alizarin staining and/or condensation of translucid mineralized tissue along cartilaginous or ligamentous elements. The sequence of ossification of *Astyanax lacustris* and *Ctenolucius hujeta* are presented diagrammatically

(Figs. 1-3 and 4-6 respectively). In the diagrams, thin vertical lines connected to thin horizontal bars represent the length (NL or SL) of the first appearance of a given ossification. Thin horizontal bars represent the length interval in which ossification may be either present or absent, and thick horizontal bars represent the lengths intervals over which an ossification is always present (i. e., fixed presence sensu Cubbage & Mabee, 1996 and Bird & Mabee, 2003). The description of the skeleton development of *A. lacustris* and *C. hujeta* is organized by anatomical complexes.

Comparative analyses of the available complete developmental sequences were carried out following the methodology proposed by Nunn & Smith (1998) and Smith (2001). The analysis begins by ordering for each species the developmental events, herein represented by the ossification of each bone (i.e. fixed presence sensu Cubbage & Mabee, 1996), according to their relative timing. Bones that are absent in any given taxon, or did not have their ossification observed in the available series were removed from the sequence of the remaining species, so only the ossifications of shared by all species were compared (*e. g. Astyanax* lacks the supraorbital, this bone was omitted from the sequences of *Ctenolucius* and *Salminus* when compared to *Astyanax*; ossified pectoral radials were not observed in the sequence of *Ctenolucius*, therefore this event was omitted form the sequence of *Astyanax* and *Salminus* sequences when compared to *Ctenolucius*). Ranks are given to each ossification based on their order of appearance in the sequence. In case of tied data (i.e. sequence is unresolved with two or more events occurring simultaneously), the rank given is the average rank for the tied events (Nunn & Smith, 1998).

Thus, using the complete ossification sequence of *Salminus* as an example: the dentary, opercle and premaxilla are tied for fourth in the series they were each given the rank of 5 ([4 + 5 + 6]/3). The hyomandibular and the urohyal are tied for 13th in the series, they were both given the rank of 13.5 ([13 + 14]/2). The sequence of *Salminus brasiliensis* (Mattox *et al*., 2014) is the only complete ossification sequence available for Characiformes, thus it was used herein as a reference sequence, the ordering of the developmental events of this species was used as a basis of comparison with the other two species. The events of *Astyanax* and *Ctenolucius* were plotted in line graphs as a function of the ranks of the reference sequence. An ossification with a rank plotted above the rank of the reference sequence indicates a delay (higher ranks are given to bones that ossify later in the sequence), whereas an ossification plotted below the rank of the reference sequence indicates acceleration (lower ranks are given to structures that appear early in the sequence). The sequences of the three species are compared simultaneously: (i) for the complete sequence ranks in order to identify possible changes in the ossification sequence of entire complexes, or some of its elements, within the entire ossification sequence; and (ii) for the sequence within each osteological complex in order to identify possible changes in the ossification sequence of the elements within a given complex.

Results

Astyanax lacustris

Neurocranium – olfactory region. Most common sequence of ossification: lateral ethmoid – mesethmoid – vomer – nasal.

Lateral ethmoid: The paired lateral ethmoid first appears perichondrally ossified at 6.9 mm SL with fixed presence at 8.7 mm SL. At this size a distinct ossification is associated to the entire margin of the foramen in the middle region of the *lamina orbitonasalis*. At 11.0 mm SL the ossification has reached the ventral margin of the lamina *orbitonasalis*. At 14.0 mm SL the lateral ethmoid has a lateral projection of lamellar bone, and has almost completely replaced the mid-portion of the cartilage. At 20.7 mm SL the cartilage of the lamina orbitonasalis is only visible between the fully ossified lateral ethmoid and the ventral surface of the anterior portion of the frontal.

Mesethmoid: The mesethmoid is an endochondral bone that first appears at 8.4 mm SL and is present in every specimen from 9.2 mm SL. The perichondral ossification center lies on the anterior portion of the ethmoid plate covering its dorsal surface, close to the developing premaxillae. At 11.0 mm SL the ossification of the mesethmoid has advanced posteriorly extending to just short from the anterior margin of the frontal. Lateral projections associated to the dorsal tip of the ascending process of the premaxilla are already evident. The cartilage on the mesethmoid plate is completely replaced by bone at the anterior portion of the mesethmoid by 14.0 mm SL.

Vomer: The vomer is a dermal bone that ossifies on the ventral surface of the ethmoid plate and it first appears at 8.8 mm SL with fixed presence from 9.7 mm SL. At this size, the vomer has a triangular shape, and at 11.0 mm SL the posterior portion of the vomer ventrally overlaps the anterior portion of the parasphenoid. At 20.7 mm SL the vomer is separated from the mesethmoid anteriorly by a thin strip of cartilage that remained from the ethmoid plate.

Nasal: The nasal first appears as a dermal ossification at 10.1 mm SL and is consistently present at 12.1 mm SL. At 14.0 mm SL the nasal has as a small ossified laterosensory canal, just posterior to the lateral wings of the mesethmoid, aligned with the canal on the frontal but not connecting to it. By 20.7 mm SL the nasal has a well-developed ossified canal, just lateral to the ascending process of the premaxilla.

Neurocranium – orbital region. Most common sequence of ossification: parasphenoid – frontal – pterosphenoid – orbitosphenoid.

Parasphenoid: The parasphenoid first appears at 3.6 mm NL and is consistently present from 4.0 mm NL. Its center of ossification is observed on approximately half the horizontal length of the tarabeculae, anterior and yet with no connection to the ossified anterior extremity of the notochord. At 4.1 mm NL the posterior portion of the parasphenoid reaches and overlaps the ossified anterior extremity of the notochord. By 5.1 mm NL the parasphenoid ossification reaches the vertical through the center of the orbit anteriorly. At 11.0 mm SL the posterior portion of the parasphenoid overlaps ventrally the anterior portion of the basioccipital. The posterolateral projections of the parasphenoid reach but not touch the prootic, the contact between said projections and the prootic is observed at 14.0 mm SL. the parasphenoid is rather straight from a lateral view.

Frontal: The frontal first appears and is consistently present as a dermal ossification at 5.9 mm SL. Its ossification center is observed associated to the medial surface of the *taenia marginalis* at approximately at the vertical line through the orbit. By 11.0 mm SL the frontal reaches anteriorly the vertical through the *lamina orbitonsalis*, and the parietal posteriorly, not overlapping it yet. At this size the ossification has advanced medially on the epiphyseal bar just reaching the contralateral frontal, the medial portion of the ossification on the epiphyseal bar has some indentations that will fit on the indentations of the contralateral frontal. The lamellar portion has advanced roughly half-way both anterior and posterior to the epiphyseal bar. The ossification on the epiphyseal bar reaches the contralateral frontal at 14.0 mm SL. At 20.7 mm SL the anterior and posterior fontanels are still conspicuous.

Pterosphenoid: The pterosphenoid first appears at 6.8 mm SL and is consistently present from 8.5 mm SL. At this length, an ossification center is visible at the medial surface of the *taenia marginalis* posterior to the epiphyseal bar, at the vertical through of the lateral projections of the parasphenoid. By 11.0 mm SL the ossification has two conspicuous foramina but falls short of all adjacent bones. At 20.7 the pterosphenoid is separated from the orbitosphenoid, anteriorly, the frontal dorsally, the sphenotic posteriorly and the prootic posteroventrally by thin strips of cartilage and connective tissue.

Orbitosphenoid: The orbitosphenoid first appears as a perichondral ossification at 8.1 mm SL and is consistently present from 9.2 mm SL. Its ossification center medial to the *taenia marginalis* the ossification advances mainly ventromedially. The orbitosphenoid has completely replaced the cartilage at its mid-point at 11.0 mm SL. At 14.0 mm SL the contralateral orbitosphenoids fuse together ventrally. By 20.7 mm SL the orbitosphenoid has a median flange projecting anteroventrally, both anterior and posterior margins are concave.

Neurocranium – otic region. Most common sequence of ossification: prootic – sphenotic – intercalar – pterotic – parietal – epiotic.

Prootic: The prootic first appears and is consistently present as a prichondral ossification from 6.2 mm SL, its ossification center associated to the anterior region of the ear capsule on the anterior margin of the *trigemonifacialis* foramen. At 11.0 mm SL the prootic overlaps posteriorly with anterodorsal projections of the basioccipital. At 20.7 mm SL the prootic contacts the sphenotic laterally, but still is separated from the pterosphenoid anterodorsally by a thin strip of cartilage.

Sphenotic: The sphenotic first appears at 8.1 mm SL, and is consistently present from 8.3 mm SL. The ossification center is associated to the ear capsule lateral projection that will develop into the sphenotic spine. By 11.0 mm SL the sphenotic just reaches the frontal dorsally. At 14.0 mm SL the ossification advanced medially in the cartilage of the lateral region of the neurocranium. The ossifying sphenotic is separated from the pterosphenoid medially and the prootic ventromedially by small stretches of cartilage. At 20.7 the sphenotic touches the prootic medially.

Intercalar: The intercalar is a small membrane bone that first appears at 8.1 mm SL as an independent ossification at the proximal tip of the ligament that connects the ventral arm of the posttemporal to the neurocranium, slightly ventral to the epiotic ossification center. It is consistently present from 9.2 mm SL, by 11.0 mm SL the intercalar is already incorporated to the posterior region of the neurocranium.

Pterotic: The pterotic first appears as a perichondral ossification at 7.3 mm SL and is consistently present from 9.6 mm SL. the ossification center lies on the lateral portion of the cartilage that forms the otic capsule, posterior to the articulation with the hyosymplectic cartilage. By 11.0 mm SL the ossification still is superficial and falls just short of the hyomandibular fossa anteriorly. At 14.0 mm SL the ossification has advanced anteriorly, covering roughly the posterior quarter of the hyomandibular fossa. At 20.7 mm SL the pterotic still is separated from the sphenotic anteriorly by some cartilage. At this size a canal is visible on the pterotic surface connecting the canal on the frontal anteriorly to the canal on the extrascapular posteriorly.

Parietal: The parietal is a dermal ossification that first appears at 8.9 mm SL and is consistently present at 9.7 mm SL, the ossification center is associated to the *taenia marginalis* posterior to the epiphyseal bar. By 11.0 mm SL the parietal already reaches the frontal anteriorly and dorsally overlaps the developing supraoccipital posteromedially. At 14.0 mm SL the parietal is overlapped by the frontal anteriorly. A developing laterosensory canal, in the shape of a groove lies on the posterior margin of the parietal. The developing canal stretches from the overlap with the supraoccipital medially until the region of the ossifying extrascapular laterally. At 20.7 mm SL the posterior fontanel still is conspicuous.

Epiotic: The epiotic first appears as a perichondral ossification at 8.1 mm SL and is consistently present at 9.9 mm SL. Its ossification center is associated to the cartilage that covers the posterior vertical semicircular canal, at approximately half of its vertical length, where a slight anteromedial curvature is visible. At 11.0 mm SL the ossification is restricted to the posterior surface of the curved region of the cartilage. By 14.0 mm SL the cartilage ate the region of the ossification center has been replaced by bone. At 20.7 mm SL the epiotic is overlapped laterally by the extrascapular and the posttemporal.

Neurocranium – occipital region. Most common sequence of ossification: basioccipital – exoccipital – supraoccipital.

Basioccipital: The basioccipital appears at 2.9 mm NL and is consistently present at 3.8 mm NL as a perichondral ossification of the anterior extremity of the notochord at the base of the cranium between the ear capsules. At 5.8 mm NL the ossification starts to project laterally from the mid portion of the ossified anterior tip of the notochord. From 6.5 mm SL, lateral expansions are visible as well as an anterior lamellar projection, dorsal to the ossified notochord. At 11.0 mm SL the developing basioccipital reaches the parasphenoid anteriorly, the prootic anterolaterally and is advancing posteriorly to cover the ventral surface of the lagenar capsule.

Exoccipital: The exoccipital first appears and is consistently present from 4.9 mm NL as a perichondral ossification of the occipital arch. By 5.1 mm NL the ossification is restricted to the posterior surface of the curved occipital arch. At 5.8 mm NL the perichondral ossification has completely covered the circumference of the cartilages that form the occipital arch. At 6.5 mm SL, the ossification of the exoccipital does not connects with the ossified notochord ventrally. By 11.0 mm SL the ossifying exoccipital has virtually completely covered the occipital foramen.

Supraoccipital: The supraoccipital is a perichondral ossification that first appears at 6.2 mm SL and is consistently present from 7.2 mm SL. The center of ossification is associated to the cartilage on the posterior region of the parietal fontanel. By 11.0 mm SL the supraoccipital spine is fairly evident. Most of the cartilage that forms the posterior margin of the posterior fontanel has been replaced by bone. At 20.7 the posteriormost portion of the supraoccipital ventral to the supraoccipital spine has a shallow groove where a anteriorly projected flange of the supraneural 3 fits in.

Infraorbital series. Most common sequence of ossification: infraorbital 2 – antorbital and infraorbital 1 – infraorbital 3 – infraorbital 4 – infraorbitals 5 and 6. The supraorbital is absent throughout the ontogeny of *Astyanax lacustris*

Infraorbital 2: The infraorbital 2 first appears as a dermal ossification at 11.3 mm SL and is consistently present by 13.0 mm SL. At. 14.0 mm SL the infraorbital 2 is triangular in shape with its narrower portion pointing anteriorly, a thickening of the ossification is visible associated to the developing laterosensory canal. By 20.7 the canal is conspicuous and the lamellar portion ventral to it resembles the infraorbital 2 in adults.

Antorbital: The antorbital first appears as a dermal ossification at 12.5 and is consistently present at 13.9 mm SL. At 14.0 mm SL the antorbital is a splint of dermal bone anterior to the *lamina orbitonasalis* and the ossifying lateral ethmoid, its dorsal tip pointing dorsoposteriorly. At 20.7 mm SL the antorbital is triangular in shape, its narrowest portion pointing dorsally.

Infraorbital 1: The infraorbital 1 first appears at 12.4 mm SL and is consistently present as a dermal ossification at 13.9 mm SL. At 14.0 mm SL the infraorbital 1 dermal bone lamella lying just dorsal to the maxilla. At 20.7 mm SL the canal is completely closed, and small flanges are visible projecting anteriorly and ventroposteriorly to it

Infraorbital 3 The infraorbital 3 first appears and is consistently present as a dermal ossification at 14.1 mm SL. At 20.7 mm SL the infraorbital 3 has a conspicuous canal on its dorsal margin, bordering the ventoposterior margin of the orbit. A dermal bone flange projecting ventroposteriorly is also evident.

Infraorbital 4: The infraorbital 4 first appears and is consistently present as a dermal ossification at 15.7 mm SL. At 20.7 mm SL the canal on the infraorbital 4 is already conspicuous, but the posterior flange is still small.

Infraorbital 5: The infraorbital 5 first appears at 15.7 mm SL and is consistently present as a dermal ossification at 17.4 mm SL. At 20.7 the ossification of the infraorbital 5 is restricted to the completely closed laterosensory canal.

Infraorbital 6: The infraorbital 6 first appears and is consistently present from 17.4 mm SL as a dermal ossification.

Jaws. Most common sequence of ossification: dentary – maxilla and premaxilla – anguloarticular – retroarticular – coronomeckelian.

Dentary: The dentary is a dermal bone that first appears at 2.9 mm SL and is consistently present at 3.5 mm NL. At 5.1 mm NL the dentary already has three small unicuspid teeth, the ossification has advanced posteriorly, already reaching the region of the ossifying angular. By 5.8 mm NL there are six or seven small unicuspid teeth restricted to the anterior portion of the dentary, the contralateral ossified dentaries still do not meet each other at the symphysis. At 11.0 mm SL the contralateral dentaries are connected by interdigitations at the symphysis. There are two rows of teeth separated by a bony cavity where replacement teeth of the outer row are formed. The outer row is formed by three larger, stouter unicuspid teeth and the inner row by more numerous small teeth. By 14.0 mm SL the dentary teeth are larger and some already have additional lateral cusps, the replacement teeth are already formed intraosseously. Small unicuspid teeth are restricted to the portion of the dentary that is laterally overlapped by the maxilla when the mouth is closed. By 20.7 mm SL the dentition is similar to the one observed in adults.

Maxilla: The maxilla is a dermal ossification that first appears at 2.9 mm NL and is consistently present at 3.7 mm NL. By 5.1 mm NL the lamellar portion of the maxilla already overlaps laterally the developing dentary, its posterior tip reaching the ventral margin of the dentary. At 11.0 mm SL the maxilla already has the same aspect as the one of adults.

Premaxilla: The premaxilla is a dermal bone that first appears at 2.9 mm NL and is consistently present at 3.4 mm NL. By 5.1 mm NL the premaxilla has two small unicuspid teeth, the ascending process is starting to develop, at this size visible as a small triangular projection from the dorsal portion of the premaxilla. The ossification already laterally reaches the lamellar portion of the maxilla. By 11.0 mm SL the premaxilla has around 11 teeth slightly smaller than the ones on the outer row of the dentary, tooth row somewhat disorganized. At 14.0 mm SL the premaxillary replacement teeth are tricuspid and formed in soft tissue lingually slated, as they are in adults. By 20.7 mm SL, there clearly are two rows of multicuspid teeth, similar to the condition observed in adults.

Anguloarticular:The anguloarticular is composed by the dermal angular and the endochondral articular. The anguloarticular first appears and is consistently present at 4.9 mm NL at this size both angular and articular are visible. The dermal angular is a bony lamella, triangular in shape, already reaching the posterior margin of the developing dentary anteriorly. The articular ossification still is restricted to the region of Meckel's cartilage that articulated to the developing quadrate. By 5.8 mm NL the articular has reached the region of articulation with the quadrate and both ossifications start to fuse. At 11.0 mm SL the anguloarticular has advanced dorsally almost covering the entire length of the coronoid process.

Retroarticular: The retroarticular first appears at 4.1 mm NL and is consistently present at 4.9 mm NL as an ossification at the posterior extremity of the Meckel's cartilage where the interoperculo-mandibular ligament is associated. At 5.1 mm NL the ossification is restricted to the posterior tip or the Meckel's cartilage. By 11.0 mm SL the retroarticular has a small lamellar bone projection turned anteriorly, and a smaller projection pointing laterally where the interopercle-mandibular ligament is associated to. At 20.7 mm SL the anterior projection is more developed, cartilage still is visible between the retroarticular and the anguloarticular.

Coronomeckelian: the coronomeckelian is an ossification of a region of the Meckel's cartilage associated to the insertion of the *pars stegalis* of the *adductor mandibulae* muscle, it first appears at 8.1 mm SL and is consistently present from 9.2 mm SL. By 11.0 mm SL the coronomeckelian is conspicuous and lies on the Meckel's cartilage, slightly dislocated laterally.

Hyopalatine arch. Most common sequence of ossification: quadrate – symplectic – endopterygoid – hyomandibular – metapterygoid – ectopterygoid – autopalatine.

Quadrate: the quadrate first appears at 3.6 mm NL and is consistently present from 4.3 mm NL. By 5.1 mm NL the quadrate is restricted to the ventroposterior portion of the *pars quadrata* of the palatoquadrate cartilage, only the posterior arm of the quadrate is perichondrally ossified at this stage. Perichondral ossification is visible in the ventroposterior margin of the metapterygoid-quadrate fenestra. By 5.8 mm NL both arms of the quadrate are perichondrally ossified, the ventral half of the margin of the metapterygoid-quadrate fenestra is covered by bone. By 11.0 mm SL the cartilage except for the dorsal tips of both arms and the articulation pad has been completely replaced by bone. At 14.0 mm SL the quadrate has a groove on the ventral surface of its posterior arm where the symplectic fits. At 20.7 cartilage is only visible at the dorsal tip of the anterior arm of the quadrate, that separates it from the endopterygoid and metapterygoid dorsally

Symplectic: the symplectic quadrate first appears at 3.8 mm NL and is consistently present from 4.3 mm NL. By 5.1 mm NL the perichondral ossification of the symplectic already reached the developing quadrate but falls short of the ventral tip of the hyosymplectic cartilage. The symplectic is as long as the ossifying posterior arm of the quadrate at this stage. By 11.0 mm SL the cartilage at the ventral half of the symplectic has been entirely replaced by bone, including its ventral tip, the dorsal half of the symplectic still is perichondrally ossified. At 20.7 the cartilage has been completely replaced by bone

Endopetrygoid: the endopterygoid first appears and is consistently present from 4.9 mm NL. By 5.1 mm NL the endopterygoid is a small dermal bone lamella associated to the dorsal margin of the pterygoid process of the palatoquadrate cartilage, in the same specimen the contralateral endopterygoid is just a dermal bone splint at the same position. By 5.8 mm NL the ossification has progressed posteromedially reaching the portion of the palatoquadrate cartilage where the metapterygoid will ossify. At 11.0 mm SL has expanded, falling just short of the metapterygoid posteriorly and the parasphenoid medially, it has also reached the vertical through the lateral ethmoid anteriorly.

Hyomandibular: the hyomandibular first appears and is consistently present from 5.0 mm NL. At 5.1 mm NL the perichondral ossification of the hyomandibular is restricted to the ventral margin of the foramen on the hyosymplectic cartilage. By 5.8 mm NL the entire margin of the foramen on the hyosymplectic cartilage is covered by bone. The perichondral ossification has progressed ventrally and covers the entire circumference of the hyosymplectic cartilage from the horizontal through the hyomandibular foramen until the horizontal through the dorsalmost portion of the palatoquadrate cartilage where the metapterygoid will ossify. At 11.0 mm SL the cartilage on the mid-section of the hyomandibular has been completely replaced by bone. A lamellar process projecting anteroventrally towards the ossifying metapterygoid is fairly evident. The perichondral ossification has advanced ventrally and almost reaches the region of articulation with the interhyal by 14.0 mm SL. By 20.7 mm SL cartilage is only visible at the condyle that articulates with the opercle and the hyomandibular ventral tip, separating it from the symplectic and interhyal.

Metapterygoid: the metapterygoid first appears 5.8 mm SL and is consistently present from 6.2 mm SL, its ossification center lies in the dorsal margin of the doroposterior portion of the palatoquadrate cartilage. By 11.0 mm SL the metapterygoid is fairly developed, but still perichondrally ossified, a posterodorsal lamellar process turned towards the hyomandibular is already visible, the metapterygoid-quadrate fenestra has roughly its entire dorsal margin ossified. At 14.0 mm SL the metapterygoid has two distinct arms turned posteriorly these arms articulate with the ventral portion of the hyomandibular and form a foramen. Also, at this size a lamellar bone flange projects ventrally from the metapterygoid into the metapterygoid-quadrate fenestra.

Ectopterygoid: the ectopterygoid first appears and is consistently present from 8.1 mm SL. This bone appears as a thin splint of dermal bone associated to the ventral surface of the pterygoid process of the palatoquadrate cartilage. At 11.0 mm SL the ectopterygoid surpasses the endopterygoid and the lateral ethmoid anteriorly. By 14.0 mm SL the ectopterygoid had surpassed the vertical through the articulation of the quadrate and the anguloarticular.

Autopalatine: the autopalatine first appears as a perichondral ossification at 11.0 mm SL and is consistently present from 12.5 mm SL. Its ossification center associated to the lateral margin of the anterior portion of the palatine process of the palatoquadrate cartilage, immediately anterior to the anterior extremity of the ectopterygoid. At 14.0 mm SL the autopalatine ossification has formed a ring around the mid-portion of the anterior region of the pterygoid process. At 20.7 the middle portion of the autopalatine is completely ossified, cartilage remains on its anterior tip that is associated to the maxilla anteriorly.

Opercular series. Most common sequence of ossification: opercle – subopercle – interopercle – preopercle.

Opercle: The opercle first appears and is consistently present as a dermic ossification from 2.9 mm NL. By 5.1 mm NL the opercle is fan-shaped, the posterior margin convex, the ossification falls just short of 90° between its dorsal and anteroventral margins, the dorsal margin is roughly horizontal. The socket associated to the condyle on the hyosymplectic cartilage is already well developed. The dorsal margin of the ossification stats to thicken at 6.1 mm NL, where the opercular ridge will develop. At 11.0 mm SL the ossification has advanced dorsally past the opercular ridge. By 14.0 mm SL the ossification has advanced dorsally almost reaching the horizontal through the dorsal tip of the cleithrum. At 20.7 mm SL the opercle has completely covered the branchial opening and has the shape similar to the observed in adults.

Subopercle: The subopercle first appears at 5.0 mm NL and is consistently present as a dermic ossification from 5.4 mm NL. At this size the subopercle is a crescent shaped dermal ossification just ventral to the opercle, not surpassing the opercle anteriorly. At 11.0 mm SL the subopercle surpassed the opercle anteriorly, laterally overlapping its ventral margin.

Interopercle: The interopercle first appears at 5.0 mm NL and is consistently present as a dermic ossification from 6.0 mm NL. At its earlier developmental stages the interopercle is a small dermal bone splint associated to the interopercle-mandibular ligament, just lateral to the region of the interhyal cartilage. at 11.0 mm SL the interopercle reaches half the length of the preopercle anteriorly.

Preopercle: The preopercle first appears and is consistently present as a dermic ossification from 8.1 mm SL. At 11.0 mm SL the preopercle extends from the vertical through the opercle-hyomandibular articulation until roughly half the length of the posterior arm of the quadrate, a conspicuous deep groove runs along the entire preopercle. At 14.0 mm SL the laterosensory canal running along the preopercle is mostly closed. At 20.7 mm SL the laterosensory canal is completely closed and the preopercle resembles the observed in adults.

Hyoid arch. Most common sequence of ossification: branchiostegal rays – anterior ceratohyal – urohyal – posterior ceratohyal – dorsal hypohyal and ventral hypohyal – basihyal – interhyal.

Branchiostegal rays: the branchiostegal rays fist appear at 3.5 mm NL and is consistently present as dermic ossifications from 4.0 mm NL. By 5.1 mm NL all four branchiostegal rays are ossified as curved dermal bone splints. The proximal tip of the two anteriormost branchiostegal rays are already associated to the perichondrally ossified anterior ceratohyal. By 5.8 mm NL the two posteriormost branchiostegal rays already have a flattened aspect. The posterior tip of the posteriormost branchiostegal ray surpasses half the length of the subopercle, whereas the posterior tip of the third posteriormost branchiostegal ray reaches the vertical through the anteriormost portion of the opercle. By 11.0 mm SL all four branchiostegal rays are curved and flattened, the anteriormost ray extends posteriorly until the vertical through the base of the third branchiostegal ray, the second rays extends posteriorly until the posterior margin of the interopercle. Both third and fourth rays reach the subopercle posteriorly, the third until one third and the fourth until half the length of the subopercle.

Anterior ceratohyal: the anterior ceratohyal fist appears at 3.6 mm NL and is consistently present as a perichondral ossification of the anterior region of the ceratohyal cartilage from 4.3 mm NL. The ossification center associated to the thinnest portion of the ceratohyal cartilage. By 5.1 mm NL the perichondral ossification has progressed both anteriorly and posteriorly, already with the same proportional size in relation to other hyoid arch elements observed in adults. At 11.0 mm SL there are deep notches on the ventral surface of the anterior ceratohyal, where the bases of the two anteriormost branchiostegal rays are associated to. The cartilage on the middle portion of the anterior ceratohyal has been entirely replaced by bone, cartilage still is visible on the anterior ceratohyal’s extremities. By 14.0 mm SL the ossification has advanced posteriorly, reaching the base of the third branchiostegal ray. At 20.7 mm SL cartilage is only visible at the anterior ceratohyal anterior and posterior margins.

Urohyal: the urohyal is a tendon bone that starts to ossify at 4.9 mm NL and is consistently present by 5.2 mm NL. The ossification center is associated to the bifurcation of the sternohyoideus tendons, at its earliest developmental stages the urohyal look like a small Y with the bifurcation turned anteriorly. By 6.1 mm NL the posterior portion of the ossification is twice as long as the two anterior projections. At 11.0 mm SL the urohyal has expanded on the sagittal plane. By 14.0 mm SL small bony flanges projecting laterally are visible at the anteroventral region of the urohyal.

Posterior ceratohyal: the posterior ceratohyal first appears at 5.0 mm NL and is consistently present by 5.4 mm NL. The perichondral ossification starts at the dorsoposterior margin of the ceratohyal cartilage, anterior to where the interhyal cartilage is associated to. At its earliest developmental stages the perichondral ossification spreads mainly anteriorly and posteriorly, not so much ventrally. At 11.0 mm SL the ossification has advanced anteroventrally reaching the base of the posteriormost branchiostegal ray. At 20.7 mm SL the posterior ceratohyal still is separated from the anterior ceratohyal by a thin strip of cartilage

Dorsal hypohyal: the dorsal hypohyal first appears at 5.2 mm SL and is consistently present from 6.8 mm SL. The ossification center is restricted to the dorsal tip of the dorsal projection on the anterior region of the ceratohyal cartilage. At 14.0 mm SL there is a notch on the postural ventral portion of the ossifying dorsal hypohyal, this notch forms a foramen with the anterior margin of the anterior ceratohyal. At 20.7 the dorsal hypohyal still does not contact the ventral hypohyal nor the anterior ceratohyal

Ventral hypohyal: the ventral hypohyal first appears as a perichondral ossification at 5.0 mm NL and is consistently present by 6.4 mm NL. The ossification center lies on two ventral protrusions that form a notch on the ventral surface of the anterior portion of the ceratohyal cartilage. By 5.8 mm NL the two ventral projections are connected by a bony bridge, this lamellar bone projections forms a foramen with the notch on the ventral surface of the ceratohyal cartilage. By 11.0 mm SL the foramen is entirely bordered by bone, the ossification advances dorsoposteriorly. At 20.7 mm SL the ventral hypohyal is still separated from the dorsal hypohyal dorsally and the anterior ceratohyal posteriorly by thin strips of cartilage.

Basihyal: the basihyal first appears as a perichondral ossification at 8.1 mm SL and is consistently present from 9.2 mm SL. At 11.0 mm SL the proximal portion of the basihyal is perichondrally ossified, where it articulates with the dorsal hypohyals and the basibranchial 1. At 14.0 mm SL the perichondral ossification has advanced anteriorly until roughly half the length of the basihyal cartilage. By 20.7 mm SL the basihyal is perichondrally ossified in its proximal three quarters, the cartilage has been completely replaced on its proximalmost region.

Interhyal: the interhyal first appears at 13.0 mm SL and is consistently present from 16.8 mm SL. The ossification of the interhyal cartilage is perichondral, starting at approximately the middle portion of the interhyal cartilage, slightly dislocated ventrally closer to the articulation with the hyoid arch. The ossification advances both dorsally and ventrally. Cartilage remains on the interhyal tips at 20.7 mm SL.

Branchial skeleton. Most common sequence of ossification: tooth plates associated with ceratobranchial 5 and pharyngobranchial 4 cartilages – ceratobranchial 5 and gill rakers – ceratobranchials 2, 3 and 4 – ceratobranchial 1 – epibranchial 4 – epibranchial 3 – epibranchials 1 and 2 – pharyngobranchial 3 – basibranchials 1 and 2 and pharyngobranchial 2 – basibranchial 3 and hypobranchial 3 – pharyngobranchial 1 – hypobranchial 2 – hypobranchial 1.

Pharyngeal jaws: The pharyngeal jaws first appear and are consistently present from 2.9 mm NL. The pharyngeal jaws of *A. lacustris* are composed of dermal tooth plates associated to pharyngobranchial 4 and the ceratobranchial 5. At this size only the teeth are clearly formed. By 5.1 mm NL the bony plate associated to the ceratobranchial 5 has two or three unicuspid teeth curved posteriorly, whereas the bony plate associated to pharyngobranchial 4 cartilage has four to five unicuspid teeth slightly smaller than those on the ceratobranchial 5 plate, but also curved posteriorly. The tooth plate on pharyngobranchial 3 was not fixed in the available series, the smallest specimen with this structure was 12.1 mm SL. The tooth plate was not consistently present on the larger specimens of the remainder of the series.

Ceratobranchials: All five ceratobranchials start as thin perichondral bone around the central portions of their respective cartilages, the ossification center is restricted to the middle portion of the cartilages of the ceratobranchials 1 through 4, the ossification of the ceratobranchial 5 lies just lateral to the tooth plate. The ossification spreads perichondrally towards the tips of the cartilage, only the extremities remain cartilaginous. The elements appear to ossify in a postero-anterior sequence, the first ceratobranchial to ossify is ceratobranchial 5 that first appears at 3.6 mm NL and is consistently present from 4.0 mm NL. Ceratobranchials 2-4 first appear at 3.8 mm NL and are consistently present from 4.4 mm NL, the ceratobranchial 1 is consistently present from 3.8 mm NL as well but is only consistently present from 4.9 mm NL. At 5.1 mm NL no ceratobranchial ossifications cover more than half the length of the cartilage. At 11.0 mm SL all ceratobranchials are perichondrally ossified along their entire length except the anterior and posterior tips. By 14.0 mm SL the middle section of all ceratobranchial had the cartilage replaced by bone. At 20.7 the ceratobranchials are entirely ossified except for their tips that remain cartilaginous.

Gill rakers: Gill rakers are first appear at 3.8 mm NL and are consistently present as dermal ossifications by 4.0 mm NL. At 5.1 mm NL there are around six gill rakers in all ceratobranchials, spread along the perichondrally ossified portions of the cartilages. By 11.0 mm SL gill rakers cover the dorsal surface of the perichondrally ossified portions of the ceratobranchials as well as the epibranchials. At 14.0 mm SL gill rakers are visible on all three hypobranchials

Epibranchials: Epibranchials start as thin perichondral bone around the central portions of their respective cartilages. The ossification spreads perichondrally towards the tips of the cartilage, only the extremities remain cartilaginous. As the ceratobranchials, the epibranchials appear to ossify in a postero-anterior orientation. The first epibranchial to ossify is the epibranchial 4 that first appears at 5.1 mm NL and is consistently preset at 5.9 mm NL. The epibranchial 3 first appears at 5.1 mm NL as well but is consistently present only at 6.1 mm NL. Epibranchial 2 first appears at 5.6 mm NL, while the epibranchial 1 first appears at 6.1 mm NL, both bones are consistently present by 6.5 mm SL. At 5.8 mm NL a ring of perichondral ossification is visible around the middle portion of the epibranchial cartilage 4, the same is observed for the epibranchial cartilage 3 at 6.1 mm NL. By 11.0 mm SL all four epibranchials are perichondrally ossified along their entire extension, except their anterior and posterior tips. By 14.0 mm SL the middle portion of all epibranchial had the cartilage replaced by bone. At 20.7 the epibranchials are entirely ossified except for their tips that remain cartilaginous

Pharyngobranchials: The pharyngobranchials as the ceratobranchials and epibranchials ossify perichondrally, the ossification center lies on the middle region of the cartilage forming a belt, the ossification advances towards the extremities, cartilage remains only on the tips. Also, as the ceratobranchials and epibranchials the pharyngobranchials ossify in a posterior-anterior orientation. The ossification of the pharyngobranchials is completely resolves, in contrast to the ceratobranchials and epibranchials that had ties between their elements. The first pharyngobranchial to ossify is the pharyngobranchial 3 that appears at 5.9 mm SL and is consistently present from 8.1 mm SL. Followed by pharyngobranchial 2 that appears at 7.1 mm SL and is consistently present from 9.2 mm SL, and by the pharyngobranchial 1 that appears at 8.4 mm SL and is consistently present at 10.0 mm SL. By 11.0 mm SL the pharyngobranchial 3 is mostly perichondrally ossified, except for its anterior and posterior tips, the ossification of the pharyngobranchial 2 is restricted to a ring around the middle section of the cartilage, whereas the pharyngobranchial 1 is in its early stages of ossification, with the ossification center at the cartilage middle region. At 20.7 mm SL cartilage is only visible at pharyngobranchial 1 extremities.

Basibranchials: the basibranchials ossify perichondrally at the anterior copula. All three basibranchials first appear at 8.1 mm SL, the basibranchials 1 and 2 are consistently present from 9.2 mm SL, while the basibranchial 3 is consistently present at 9.6 mm SL. By 11.0 mm SL all basibranchials have started ossifying, the ossification center of the basibranchial 1 is restricted to the anterior tip of the anterior copula, where it is associated to the ossifying basihyal, and then the ossification advances posteriorly. The ossification center of the basibranchial 2 lies between the horizontal through the posterior margin of the hypobranchial 1 and the anterior margin of the hypobranchial 2, the ossification then advances both anteriorly and posteriorly. The ossification of the basibranchial 3 lies between the pair of ossifying hypobranchial 3, the ossification then advances both anteriorly and posteriorly.

Hypobranchials: the paired hypobranchials ossify perichondrally, their ossification center at roughly the middle portion of their triangular shaped cartilages. The first element to ossify is the hypobranchial 3 that appears at 8.1 mm SL and is consistently present from 9.6 mm SL. The hypobranchials 2 first appears at 9.2 mm SL and is consistently present from 11.0 mm, whereas the hypobranchial 1 first appears at 11.0 mm SL and is consistently present at 12.0 mm SL. At 11.0 mm SL the perichondral ossification of the hypobranchial 3 is restricted to its anterior half, but not reaching its anterior tip. The ossification center of the hypobranchial 2 lies on the lateral surface of the cartilage, just anterior to its midpoint. By 14.0 mm SL the perichondral ossification of the hypobranchial 3 has reached its anterior tip. At 20.7 mm SL the hypobranchial cartilages have not been completely perichondrally ossified yet.

Weberian apparatus and associated centra. Most common sequence of ossification: centra 1, 2, 3 and 4 – neural arch 4 – intercalarium, neural arch 3 and scaphium – os suspensorium and tripus – neural spine 4 – supraneural 3 – claustrum.

Centra 1-4: The current series did not provide resolution for the sequence of ossification of the Weberian apparatus centra, all four first appear and are consistently present at 4.9 mm NL. The centra start to ossify dorsally and progress laterally and then ventrally. Despite the lack of resolution on the start of the ossification processes, different timings on the ossification are perceptible, at 5.1 mm NL the centra 1 and 2 are not entirely ossified around the circumference, centrum 1 is roughly half the way around whereas centrum 2 is falling just short of forming a complete ossified ring around the notochord. Both centra 3 and 4 are completely ossified and longer than centra 1 and 2, centrum 4 roughly twice as long as the dorsal portion of the ossifying centrum 2. At 11.0 mm SL all four centra are completely ossified, the centra are gradually longer posteriorly, the centrum 1 is the shortest of the four centra, centrum 4 being the longest.

Neural arches 3 and 4: The neural arch 4 first appears and is consistently present at 5.4 mm SL, followed by the neural arch 3 that first appears at 5.8 mm SL and is consistently present from 6.2 mm SL. At 5.6 mm NL the basidorsal of the centrum 4 is perichondrally ossified with small lamellar bone projections turned dorsally. At 11.0 mm

SL the neural arch three has laterally overlapped the ventral cartilaginous portion of the ossifying supraneural 3. The neural arch 4 is completely ossified and slightly tilted anteriorly, supporting a pair of supradorsal cartilages.

Intercalarium: the *intercalarium* is a perichondral ossification on the basidorsal 2 that first appears and is consistently present at 6.2 mm SL. At 11.0 mm SL the basidorsal cartilages are almost completely replaced by bone, except for the region where it articulates with centrum 2 which remains cartilaginous, the posterior tip of the intercalarium laterally overlaps the neural arch 3, at this size the intercalarium already has its curved shape, similar to the condition of adults.

Scaphium: the *scaphium* is a perichondral ossification of the basidorsal 1 that first appears and is consistently present from 6.2 mm SL. By 11.0 mm SL and anteriorly projected membrane bone is already fairly developed, close to the exoccipital anteriorly.

Os suspensorium: the os suspensorium first appears at 6.4 mm SL and is consistently present from 8.1 mm SL. At 11.0 mm SL both arms are well developed, the inner arm is turned anteriorly in *Astyanax* and at this size it already reaches the vertical through the posterior margin of centrum 2, the outer arm is membranous and projects laterally beyond the lateral margin of the tripus.

Tripus: the *tripus* is a perichondral ossification of the basiventral 3 that first appears and is consistently present from 6.5 mm SL. at 11.0 mm SL the tripus is well developed, its posterior projection, the tranformator process, already forms a semicircle and its posteriormost margin reaches the vertical through the midpoint of centrum 4, whereas its anterior tip surpasses the vertical through the posterior margin of the centrum 1.

Neural spine of vertebra 4: the neural spine 4 membrane bone extending dorsallu on the midline from the closed neural arch 4 that first appears and is consistently present at 6.4 mm SL. By 11.0 mm SL the neural spine 4 is well consolidated and shorter than is adjacent posterior neural spine.

Supraneural 3: the supraneural 3 first appears at 6.7 mm SL and is consistently present from 8.4 mm SL. Its ossification center lies on the anterior margin at roughly the middle portion of the cartilage. The perichondral ossification advances posteriotly forming a ring around the middle portion of the cartilage. By 11.0 mm SL the ossification has advanced both dorsally and ventrally, a posterior projection of lamellar bone is visible. At 20.7 mm SL the supraneural 3 has been completely ossified except for is ventral margin.

Claustrum: the *claustrum* is a dermal ossification first appears at 8.1 mm SL and is consistently present from 9.2 mm SL. It starts as an independent ossification dorsoanterior to the *concha scaphium*. At 11.0 mm SL the claustrum is V shaped in an almost straight angle, one arm turned anteriorly and the other ventrally

Axial skeleton. Most common sequence of ossification of the post-Weberian axial skeleton: vertebral centra – neural arches – ribs – neural spines – parapophyses – haemal arches – haemal spines – intermuscular bones – supraneurals.

Vertebral centra: the vertebral centra first appear and are consistently present from 4.9 mm NL. At 5.1 mm NL the five anteriormost post-Weberian centra are completely ossified forming a complete ring around the notochord. The following six post-Weberian centra still do not form a complete ring, the posteriormost with the ossification restricted to the ventral portion of the notochord. At 11.0 mm SL all centra are completely ossified with small triangular shaped zigapophyses.

Neural arches: Neural arches are formed anteroposteriorly, they first appear and are consistently present from 5.4 mm SL. At this size, the three anteriormost post-Weberian centra have their basidorsals perichondrally ossified with small portions of lamellar bone projecting dorsally.

Ribs: The ribs first appear at 5.6 mm SL and are consistently present by 5.8 mm SL, At this size only the ribs of the 5^{th} and 6^{th} vertebrae are present, they star to ossify proximally, close to their respective vertebral centrum, then the ossification advances distally. At 20.7 mm SL the ribs are fully formed and have small flanges projecting anteroventrally from their proximal portion.

Neural spines: Neural spines first 5.8 mm SL appear and are consistently present from 6.6 mm SL. The first neural spines to appear are the anteriormost, at 6.6mm SL the only formed neural spine is the one on the centrum 5. Neural arches are then visible on the vertebral centra just anterior to the cauda-fin supporting skeleton. By 11.0 mm SL all neural arches are present, slightly shorter at the region of the dorsal fin pterygiophores.

Parapophyses: the parapophyses first appear and are consistently present from 6.5 mm SL and are consistently present at 6,7 mm SL. The perichondral ossification on the basiventrals first appear at the anteriormost post-Weberian vertebra, the remaining parapophyses ossify in an anteroposteior sequence. By 11.0 mm SL all parapophyses are ossified with small triangular shapes processes turned anteroventraly.

Haemal arches: the haemal arches first appear at 6.5 mm SL and are consistently present by 6.8 mm SL. The first haemal arches to ossify are the posteriormost, just anterior to the caudal-fin supporting skeleton. The remaining haemal arches ossify in a postero-anterior sequence

Haemal spines: haemal spines are also formed postero anteriorly, they appear at 6.7 mm SL and are consistently present from 7.2 mm SL. At 8.1 mm SL, the spines are visible until 20th vertebra, and at 8.3 mm SL they are visible until the 18th vertebra. By 11.0 mm SL all haemal spines are formed, the anteriormost just anterior to the proximal tip of the anteriormost anal-fin pterygiophore.

Intermuscular bones: intermuscular bones are tendon bones that ossify in the myosepta along the epaxial and hypaxial musculature and first develop posteriorly on the body. They first appear at 7.2 mm SL and are consistently present from 9.2 mm SL. At 11.0 mm SL the intermuscular bones are restricted to the caudal region, series of epineurals and epipleurals both reaching 25th centrum anteriorly. At 20.7 mm SL, the epineurals reach the 7th vertebra, while the eplipleurals already reached the 15th vertebra.

Supraneurals: Supraneurals first appear as perichondral ossification on the supraneural cartilages at 8.9 mm SL and are consistently present at 9.6 mm SL. By 11.0 mm SL only the two anteriormost supraneurals have started to perichondrally ossify, the ossification center lies on the posterior margin of the cartilage where it is closest to the adjacent posterior neural spine. The ossification advances anteriorly and forms a ring around the cartilage slightly ventral to its mid-point, the ossification then advances both dorsally and ventrally. At 20.7 mm SL the supraneurals are Y shaped, the bifurcation pointing dorsally, their tips still cartilaginous at this size.

Pectoral girdle. Most common sequence of ossification: cleithrum – supracleithrum – posttemporal – postcleithrum 1 – pectoral-fin rays, postcleithra 2 and 3 – coracoid, mesocoracoid and scapula – extrascapular – pectoral-fin radials.

Cleithrum: the cleithrum is among the first elements to ossify. The dermal ossification first appears and is consistently present from 2.9 mm NL. At 5.1 mm NL the dorsal portion of the cleithrum, dorsal to the dorsal tip of the scapulocoracoid cartilage still is straight, whereas the ventral portion is curved anteromedially, falling just short of meeting its contralateral at the midline. A small posteriorly oriented flange is already visible projecting at the horizontal through the dorsalmost portion of the scapulocoracoid cartilage. At 6.2 mm NL the ventral portion of the cleithrum is flattened, approximately three time as wide as the dorsal portion. At 20.7 the pectoral girdle resembles the one observed in adults.

Supracleithrum: the supracleithrum first appears and is consistently present from 5.6 mm SL as a dermal bone splint oblique to the dorsal portion of the cleithrum, the dorsal tip of the developing supracleithrum points dorsoanteriorly. The ossification advances both dorsally and ventrally, reaching and articulating with the cleithrum. At 11.0 mm SL the supracleithrum has started to develop flanges projecting both anteriorly and posteriorly. At 20.7 mm SL a short stretch of a laterosensory canal is visible on the dorsalmost portion of the supracleithrum.

Posttemporal: the posttemporal first appears and is consistently present as a dermal bone from 6.8 mm SL. By 11.0 mm SL the posttemporal has both arms developed, the dorsal arm starts to develop lamellar projections from its main body. The bone grows ventrally reaching and articulating with the supracleithrum. At 20.7 mm SL has a short laterosensory canal associated to its lamellar portion between its arms.

Postcleithrum 1: the postcleithrum 1 ossifies as a dermal bone posterior to the articulation between the cleithrum and the supracleithrum. It first appears as a splint at 10.1 mm SL and is consistently present at 13.5 mm SL. at 11.0 mm SL the postcleithrum 1 starts to have a lamellar aspect.

Pectoral-fin rays: the pectoral-fin rays ossify as dermal bones, the ossification center is proximal to the pectoral radial plate, the dorsalmost ray is the first to ossify and is consistently present from 11.1 mm SL. By 14.0 mm SL the six dorsalmost pectoral fin rays are already ossified. At 20.7 mm SL there are nine total pectoral fin rays.

Postcleithrum 2: postcleithrum 2 first appears at 11.1 mm SL and is consistently present at 12.3 mm SL. By 14.0 mm SL the postcleithrum 2 is a small oval shaped dermal ossification just posterior to the cleithrum and lateral to the developing postcleithrum 3

Postcleithrum 3: postcleithrum 3 first appears at 9.4 mm SL and is consistently present from 12.3 mm SL the postcleithrum 3 is a rod-shaped dermal bone, at 14.0 mm SL it reaches ventrally almost as far as the ventral margin of the scapulocoracoid cartilage.

Coracoid: the coracoid is a perichondral ossification on the scapula coracoid cartilage that first appears at 12.5 mm SL and is consistently present at 13.6 mm SL. the ossification center, close to the foramen on the scapulocoracoid cartilage. By 14.0 mm SL the anterior arm of the scapulocoracoid cartilage is perichondrally ossified. At 20.7 mm SL the coracoid ossification had replaced the cartilage at the ventral portion of the scapulocoracoid plate and resembles to one observed in adults

Mesocoracoid: the mesocoracoid is a vertical ridge in the medial side of the scapulocoracoid cartilage that first appears and is consistently present at 13.6 mm SL. By 14.0 mm SL the mesocoracoid its ossification lies close to the connection between the scapulocoracoid cartilage and the cleithrum. By 20.7 mm SL no cartilage remains at the region of the mesocoracoid.

Scapula: the scapula is a perichondral ossification on the scapula coracoid cartilage that first appears at 12.5 and is consistently present from 13.6 mm SL. It ossifies perichondrally on the posterodorsal region of the scapulocoracoid cartilage, the center of ossification is associated to the foramen of the scapula. By 14.0 mm SL the margins of the scapular foramen are ossified. At 20.7 mm SL the scapula has completely ossified.

Extrascapular: the extrascapular first appears and is consistently present as a dermal bone from 13.6 mm SL. the dermal ossification appears just anterior to the bifurcation of the two arms of the posttemporal. At 14.0 mm SL the extrascapular has a small groove associated to a laterosensory canal, and partially copers the epiotic laterally. By 20.7 mm SL the extrascapular bears a laterosensory canal connecting the one oh the parietal dorsally to the one on the posttemporal ventrally.

Pectoral-fin radials: the pectoral-fin radials first appear and are consistently present from 15.7 mm SL. At 16.5 mm SL, the propterygium as well as the two dorsalmost pectoral-fin radials are ossified; at 17.4 mm SL the third dorsalmost radial shows an ossification center at its median region, somewhat distally dislocated. At 20.7 mm SL four distinct pectoral-fin radials are visible, including the propterygium, they all remain cartilaginous at their tips.

Pelvic girdle. Most common sequence of ossification: pelvic-fin rays – basipterygium – pelvic-fin medial radial – pelvic-fin lateral radial – pelvic-fin middle radial.

Pelvic-fin rays: the pelvic-fin rays first appear as dermal ossifications at 10.2 mm SL and are consistently present from 10.5 mm SL. At 11.0 mm SL four pelvic-fin rays are visible on both sides. At 20.7 mm SL a total of 8 pelvic-fin rays are visible, with up to seven segmentations.

Basipterygium: the basipterygium is a perichondral ossification on the basipterygial cartilage that first appears at 10.2 mm SL and is consistently present at 12.1 mm SL. The ossification center lies slightly dislocated distally from the middle portion of the rod-like anterior processes. At 20.7 mm SL the basipterygium has developed flanges projecting both laterally and medially from its rod-shaped portion. The basipterygium remains cartilaginous posteriorly at the region associated to the distal radials and at its anterior tip.

Pelvic-fin radials: the pelvic fin radials are perichondral ossification on the distal radial cartilages associated to the basipterygium. The first pelvic-fin radial to ossify is the medial radial, that first appears and is consistently present from 14.4 mm SL, followed by the lateral distal radial that first appears at 15.9 mm SL and is consistently present at 17.5 mm SL. the middle distal radial finally ossifies and is consistently present by 20.3 mm SL. The ossification center of the medial distal radial is associated to a medio-posterior projection of the cartilage, the ossification then advances laterally on the cartilage. Alternatively, the ossification center of the middle and lateral distal radials are located at the surface that articulates with the basipterygium. The current series did not include specimens with fully ossified pelvic-fin distal radials.

Dorsal fin. Most common sequence of ossification: dorsal-fin rays – proximo-middle radials – distal radials.

Dorsal-fin rays: the dorsal-fin rays first appear at 6.7 mm SL and are consistently present from 7.3 mm SL. By 11.0 mm SL all dorsal-fin rays are ossified, the larger segmented rays have up to four segmentations at this size. At 20.7 the dorsal fin profile resembles the one observed in adults.

Proximal-middle radials: the ossification of the proximal-middle radials cartilages start at the middle portion of the pterygiophores then expanding to the extremities. They first appear at 7.0 mm SL and are consistently present from 9.2 mm SL. At 10.6 mm SL only the proximal-middle radials 4, 5 and 6 are ossifying. By 11.0 mm SL the proximal-middle radials are perichondrally ossified at their distal half except for the distal tip, just the posteriormost proximal-middle radial is not yet ossified at this size. Small flanges are visible projecting both anteriorly and posteriorly on the second through fourth anteriormost proximal-middle radial. At 20.7 only the distal tips of the proximal middle radials are still cartilaginous. Flanges projecting both anteriorly and posteriorly are present on most proximal-middle radials.

Distal radials: the distal radials are perichondral ossifications on the distal radial cartilages that first appear at 8.7 mm SL and are consistently present from 9.6 mm SL. At 11.0 mm SL all distal radials have started ossifying except for the posteriormost. The ossification center is paired and lies on the lateral surface of the cartilage, slightly dislocated anteriorly. At this size the ossification is more evident on the anteriormost distal radial, which already have small triangular processes pointing anteriorly. At 20.3 mm SL, all the distal radials are already ossified.

Bony stay: an ossified bony stay was no observed in the current series.

Anal fin. Most common sequence of ossification: anal-fin rays – proximo-middle radials – distal radials.

Anal-fin rays: anal-fin rays first appear as dermal ossifications at 6.6 mm SL and are consistently present from 7.3 mm SL. The anal-fin rays develop anteroposteriorly. At 11.0 mm SL all anal rays are distinguishable, the anteriormost with up to four segments. At 14.0 mm SL the anal fin already has the profile observed in adult specimens.

Proximal-middle radials: the proximal-middle radials first appear at 6.7 and are consistently present from 8.1 mm SL. The ossification center slightly proximally dislocated from the middle portion of the rod-like projection of the cartilage. At 11.0 mm SL the 12 anteriormost proximal-middle radials are perichondrally ossified, ossification restricted to the distal half of the cartilage. By 20.7 mm SL the proximal-middle radials are completely ossified except for their distal tips.

Distal radials: the distal radials first appear at 8.9 mm SL and are consistently present from 11.0 mm SL. At 11.0 mm SL the nine anteriormost distal radials have their ossification center visible. The ossification center is paired and lies on the lateral surface of the cartilage, slightly dislocated anteriorly. At 20.3 mm SL, all the anal-fin distal radials are ossified.

Caudal fin and supporting skeleton. The caudal fin and its supporting skeleton is treated herein as comprising the four posteriormost vertebrae (ural, preural 1, 2 and 3), which include neural and haemal arches and spines of preural vertebrae 2 and 3, parhypural, six hypurals, two pairs of uroneurals, three epineurals, principal and procurrent caudal fin rays and ventral and dorsal caudal-fin bony stays. The most common sequence of ossification of these elements is: caudal-fin principal rays – haemal arch and spine of preural centrum 2, hypurals 1, 2 and 3, neural spine of preural centrum 2 and parhypural – caudal-fin ventral procurrent rays and haemal arch and spine of preural centrum 3, hypural 4, neural arch of preural centrum 2, neural arch and spine of preural centrum 3 and preural central 1, 2 and 3 – ural centrum 1 – hypural 5 – uroneural 1 – caudal-fin dorsal procurrent rays – hypural 6 and uroneural 2 – epurals 1 and 2. The caudal-fin skeletal elements are group and presented in alphabetical order as in Mattox et al. (2014) in order to facilitate the comparisons between the two series.

Epurals: the epurals ossify perichondrally around the two cartilaginous elements dorsal to the compound centra. The epural 1 first appears at 8.1 mm SL and is consistently present by 9.6 mm SL. The epural 2 first appears at 8.7 and is also consistently present from 9.6 mm SL. At 11.0 mm SL the two epurals entirely perichondrally ossified except for their distal tips. At 20.7 mm SL the epural are completely ossified, the epural 1 has a small flange projecting anteriorly from its proximal portion.

Haemal arches and spines of preural centra 2 and 3: the haemal arch and spine of the preural centrum 2 fist appear and are consistently present at 6.5 mm SL, whereas the haemal arch of the preural centrum 3 first appears at 6.5 mm SL and both haemal arch and spine of the preural centrum 3 are consistently present by 6.7 mm SL. Both haemal spines are completely perichondrally ossified except for their distal tips at 11.0 mm SL.

Hypurals 1-6: the six hypurals are preformed in cartilage, the ossification center are slightly dislocated proximally from the middle portion of the cartilage. Hypurals 1, 2 and 3 first appear at 5.9 mm SL and consistently present from 6.5 mm SL. Hypurals 4 first appears at 6.5 mm SL and is consistently present by 6.7 mm SL. The hypural 5 first appear at 6.7 mm SL and is consistently present by 7.2 mm SL. The hypural 6 is the last to ossify, first appearing at 7.3 mm SL and consistently present at 9.2 mm SL At 11.0 mm SL all hypurals are completely perichondrally ossified, bone and cartilage reabsorption is visible on the proximal region of hypurals 1 and 2.

Neural arches and spines of preural centra 2 and 3: the neural arches of the preural centra 2 and 3 first appear and are consistently present at 6.7 mm SL. The neural arches of the same centra first appear at 6.7 mm SL and are consistently present from 7.2 mm SL. Neural arches and spines are fully formed by 11.0 mm SL, some perichondrally ossified cartilage still is visible on the neural spine on preural centrum 2. At 20.7 mm SL a flange is visible projecting anteriorly from the base of the neural spine of the preural centrum 2.

Parhypural: the parhypural first appears and is consistently present from 6.5 mm SL mm SL. By 11.0 mm SL the parhypural is completely perichondrally ossified except for its distal tip, a lamellar bony flange is visible projecting from its anterior margin.

Preural centra 2 and 3: the preural centra 2 and 3 first appear at 6.5 mm SL and are consistently present from 6.7 mm SL. The ossification center lies on the ventral surface of the notochord, the ossification then advances laterally and then dorsally until a complete ossified ring is formed.

Principal caudal-fin rays: the principal caudal-fin rays first appear at 5.2 mm SL and are consistently present from 5.2 mm SL. the first caudal-fin rays to ossify are those associated to the hypural cartilages 2 and 3, the ossification of proceeds both dorally and ventrally. All principal caudal fin rays are visible at 11.0 mm SL with up to five segments, the caudal-fin profile already resembles the one of the adults.

Procurrent caudal-fin rays: the ventral procurrent caudal-fin rays are the first to ossify at 6.5 mm SL with a fixed presence from 6.7 mm SL. The dorsal procurrent cauda-fin rays first appear at 8.1 mm SL and are consistently present from 8.5 mm SL. At 11.0 mm SL there are eight dorsal procurrent rays, the anteriormost reaching the vertical through the distal tip of the neural spine of preural centrum 2. At this size there are 7 ventral procurrent rays, associated to the parhypural and haemal spine of the preural centrum 2. At 20.7 mm SL there are 11 dorsal procurrent rays and 12 ventral procurrent rays.

Ural and preural centra 1: ural centrum and preural centrum 1 are perichondral ossifications around the posterior portion of the notochord. Both elements first appear at 6.5 mm SL, the preural centrum 1 is consistently present by 6.7 mm SL, whereas the ural centrum 1 is consistently present by 7.0 mm SL. Both centra have fused together, forming the compound ural centrum at 11.0 mm SL

Uroneurals: the two pairs of uroneurals ossify as membrane bones without cartilaginous precursors. The first to appear is the uroneural 1at 6.5 mm SL and is consistently present from 8.4 mm SL. The uroneural 2 first appears at 8.5 and is consistently present from 9.2 mm SL. At 11.0 mm SL the uroneural 1 projects posteriorly from the compound centrum until the vertical through half the length of the hypural 6. The uroneural 2 just reaches the compound centrum anteriorly and the vertical through the distal ossified margin of the hypural 6. At 20.7 mm SL the uroneural 2 has a spine-shaped process projecting anteriorly from its distal third.

Ctenolucius hujeta

Neurocranium – olfactory region. Most common sequence of ossification: mesethmoid – vomer – lateral ethmoid – nasal.

Mesethmoid: The mesethmoid is an endochondral bone that first appears perichondrally at 7.1 mm SL and is consistently present at 8.1 mm SL. The ossification center lies on the anterior portion of the ethmoid plate, covering its dorsal surface. At 9.3 mm SL the ossification reaches the vertical through the anterior tip of the frontal posteriorly, just anterior to the orbitonasalis lamina. Shortly after, at 9.6 mm SL the ossification reaches the orbitonasalis lamina posteriorly. By 16.0 mm SL a lamellar projection of the ossification advances anteriorly beyond the anterior margin of the ethmoid plate. At 29.4 mm SL small lateral wings at the anterior portion of the mesethmoid are associated to the medial surface of the premaxillae laterally.

Vomer: The vomer is a dermal bone that ossifies ventral to the ethmoid plate and first appears at 8.5 mm SL and is consistently present at 9.4 mm SL. By 9.8 mm SL the vomer is a small V shaped dermal ossification with the vertex pointing anteriorly. At 10.1 mm, the posteriorly pointed projections border the anterior tip of the parasphenoid. At 29.4 mm SL the triangular shaped vomer has its anterior extremity lying on a v shaped slot on the mesethmoid.

Lateral ethmoid: The paired lateral ethmoid first appears perichondrally at 10.6 mm SL and is consistently present at 12.3 mm SL, its ossification center on the middle region of the *lamina orbitonasalis*. By 29.4 mm SL the lateral ethmoid reaches the ventral surface of the frontal dorsally. At this size, the lateral ethmoid is not directly visible laterally, covered by the supraorbital and the infraorbital 1.

Nasal: The nasal first appears as a dermal ossification at 15.4 mm SL and is consistently present at 16.4 mm SL just lateral to the lateral margin of the mesethmoid. At 19.2 mm SL a closed canal is already visible on the bone, a lamellar portion projecting medially, falling short of contacting the lateral margin of the mesethmoid. By 29.4 mm the nasal is triangular shaped with lamellar projections extending anteriorly and posteriorly, bearing a completely closed canal. The laterosensory canal contacts the frontal canal dorsoposteriorly.

Neurocranium – orbital region. Most common sequence of ossification: parasphenoid – frontal – pterosphenoid – orbitosphenoid.

Parasphenoid: The parasphenoid appears and is consistently present at 4.1 mm NL, its ossification center medial to the trabeculae. At 4.4 mm NL the anterior margin of the ossification already reaches the vertical through the center of the orbit. At 5,6 mm NL the anterior margin already surpasses the *lamina orbitonasalis* anteriorly, posterior region of the parasphenoid is bifurcated, posterior tips reaching the anterior margin of the ossified notochord. By 9.3 mm SL the dorsoposterior projections overlap the region of the otic capsule where the prootic will ossify. At 15.4 mm SL the lateral profile of the anterior portion is slightly curved dorsally, from the vertical through the posterior margin of the orbit until the anterior tip, concave ventrally.

Frontal: the frontal is a dermal ossification that first appears and is consistently present at 6.7 mm SL. Its ossification center is anterior to the epiphyseal bar, lateral to the *taenia marginalis*. At 7.6 mm SL the frontal is a splint without medial projections, falling just short of the *lamina orbitonasalis* anteriorly, covering the entire length of the taenia marginalis posterior to the epiphyseal bar. At 9.1 mm SL a closed laterosensory canal is already evident at the vertical through the epiphyseal bar. By 9.3 mm SL the anterior margin of the frontal already surpasses the anterior margin of the orbit, some ossification is already visible on the epiphyseal bar, but not reaching the contralateral frontal medially. Posteriorly, the developing frontal reaches the vertical through the hyomandibular foramen. At 10.1 mm SL the anterior margin of the frontal reaches the vertical through the anterior tip of the parasphenoid anteriorly and the posterior margin of the orbit posteriorly. Lateral projections are more developed than the medial ones. By 11.0 mm SL there are three to four foramina anterior to the vertical through the epiphyseal bar. At 18.5 mm SL the contralateral frontals meet each other medially, closing the fontanel at the region of the epiphyseal bar. By 21.2 mm SL the contact between the contralateral frontals at the midline is larger, closing roughly the entire anterior half of the posterior fontanel. At 29.4 mm SL the contralateral frontals overlap each other medially, closing the posterior fontanel, ornamentations on the surface of the bone are already visible. The frontal overlaps the parietal posteriorly and the anterior projection of the pterotic and sphenotic laterally. The laterosensory canal is evident on the lateral margin, from the anterior tip which is associated to the canal on the nasal at the vertical through the lateral ethmoid. The canal continues posteriorly until the vertical through the anterior tip of the pterotic.

Pterosphenoid: The pterosphenoid first appears and is consistently present at 11.4 mm SL. The ossification center appears perichondrally on the medial surface of the *taenia marginalis*, posterior to the epiphyseal bar. By 15.4 mm SL the pterosphenoid bears a foramen entirely circled by bone on the left side. At 15.6 mm SL the entire medial margin of the taenia marginalis is already ossified. By 19.2 mm SL the pterosphenoid contacts the frontal dorsally. At 29.4 mm SL the pteroshenoid is not yet in direct contact with the orbitosphenoid anteriorly and the sphenotic posteriorly, said bones are still separated by some cartilage, however, there is direct contact between the pterosphenoid and the prootic ventroposteriorly.

Orbitosphenoid: The orbitosphenoid first appears as a perichondral ossification at 12.3 mm SL, being consistently present by 13.0 mm SL. Its ossification center lies on the medial surface of the taenia marginalis anterior to the epiphyseal bar. The contralateral orbitosphenoids grow ventromedially in direction of each other. At 15.3 mm SL a lamellar projection of the orbitosphenoid is already in contact with the parasphenoid ventrally. By 29.4 mm SL the anterior and posterior margins of the orbitosphenoid are concave, anterior concave margin associated to a nerve. At this size the orbitosphenoid is in direct contact with the frontal dorsally and with the parasphenoid ventrally.

Neurocranium – otic region. Most common sequence of ossification: prootic – sphenotic – pterotic – parietal and epiotic – intercalar.

Prootic: the prootic first appears as a perichondral ossification at 6.8 mm SL and with fixed presence by 7.6 mm SL. The ossification center lies on the anterior region of the ear capsule bordering the *trigeminofacialis* foramen. At 9.3 mm SL this foramen has its entire circumference already ossified. By 12.4 mm SL an anterior lamellar projection of the prootic falls just short of the dorsolateral projections of the parasphenoid.

Sphenotic: The sphenotic first appears at 6.7 mm SL and is consistently present at 7.2 mm SL, the perichondral ossification center is associated to the ear capsule lateral projection that will develop into the sphenotic spine. At 9.3 mm SL the ossification still is restricted to the spine which is longitudinally elongated. By 16.3 mm SL the ossified spine projects lateroventrally. At 18.5 mm SL the sphenotic and the pterotic are in direct contact except for the portion of said bones that articulate with the hyomandibular, where some cartilage remains visible. By 29.4 mm SL there is no more cartilage between the sphenotic and the prootic, the ventral margin of the sphenotic forms the dorsal margin of a foramen which is delimited ventrally by the prootic. There still is some cartilage posterior to the sphenotic separating it from the pterotic.

Pterotic: The pterotic first appears as a perichondral ossification at 8.5 mm SL with fixed presence at 9.8 mm SL. The ossification center is at the lateral portion of the cartilage that forms the otic capsule posterior to the articulation with the hyosymplectic cartilage. At 11.9 mm SL anterior margin of the ossification reaches the vertical through the posterior portion of the ossifying hyomandibular. By 22.4 mm SL the posterior fourth of the articulation surface of the hyomandibular with the neurocranium is made of the ossified pterotic whereas the anterior three quarters of the articulation surface still is cartilaginous, the posterior tip of the pterotic is already ossified. At 29.4 mm SL a laterosensory canal and its associated foramina are visible along the ventral margin of the pterotic. The anterior margin of the ossification surpasses and overlaps laterally the sphenotic, the anterior margin of the pterotic reaches the vertical through roughly the midpoint of the sphenotic spine, the anterior portion of the pterotic is partially overlapped by the frontal medially.

Parietal: The parietal is a dermal ossification that first appears at 10.2 mm SL and has fixed presence by 11.4 mm SL. the ossification center is associated to the *taenia marginalis* posterior. By 11.9 mm SL the developing parietal is already overlapping with the frontal anteriorly. At 29.4 mm SL the parietal falls short of the pterotic laterally, partially covers the supraoccipital and epiotic posteriorly, the parietal has its anterior margin overlapped by the frontal and falls just short of meeting its counterpart medially. The posterior fontanel is restricted to the posteriormost portion of the skull, delimited by the parietals anteriorly and the anterior margin of the supraoccipital posteriorly. In slightly larger specimens (30.0 mm SL) the posterior fontanel is completely closed.

Epiotic: The epiotic fist appears at 10.2 mm SL as a perichondral ossification at the middle portion of the posterior vertical semicircular canal, where there is a slight anteromedial curvature, being consistently present at 11.4 mm SL. The ossification progresses both dorsally and ventrally. By 21.2 mm SL there is no more cartilage between the ventral margin of the epiotic and the dorsal margin of the pterotic. At 29.4 mm SL the intercalar is fused to the epiotic, there is still cartilage separating the medial portion of the epiotic to the lateral margin of the supraoccipital. There is still some cartilage between the ventral edge of the epiotic and pterotic. At this size a posterior projection of the epiotic associated to epaxial musculature.

Intercalar: The intercalar is small membrane bone that first appears at 14.6 mm SL as a small ossification visible on the right side of the animal on the proximal tip of the ligament that comes from the ventral arm of the posttemporal, between the ossifying exoccipital and epiotic. All specimens larger than 16.4 mm SL have an ossified intercalar. At 29.4 mm SL the intercalar is incorporated to the back of skull, more so to the ventral portion of the epiotic, near to the articulation to the posterior margin of the pterotic.

Neurocranium – occipital region. Most common sequence of ossification: basioccipital – exoccipital – supraoccipital.

Basioccipital: The basioccipital first appears and is consistently present as a perichondral ossification on the anterior tip of the notochord at 3.8 mm NL. At 7.0 mm SL lateral projections from the ossified portion of the notochord are already visible. In slightly larger specimens (7.6 mm SL) the lateral projections of the ossifying basioccipital reach the medial margin of the largest otolith capsule. At 12.4 mm SL the lateral projections are fairly evident, falling just short of the exoccipital posteriorly.

Exoccipital: The exoccipital first appears as a perichondral ossification of the occipital arch at 5.6 mm NL and is consistently present by 6.7 mm SL. The ossification center lies on the middle region of the occipital arch, slightly ventrally dislocated. At 7.6 mm SL the developing exoccipital already has evident posterior lamellar projections and is not yet in contact with the ossified notochord ventrally. By 9.1 mm SL half of the margins of the occipital foramen is ossified.

Supraoccipital: The supraoccipital appears as an ossification on the posterior margin of the parietal fontanel at 8.1 mm SL. the perichondral ossification center is not unpaired, there are two separate ossification centers really close to the median line. At 8.8 mm SL the ossification centers meet medially on the cartilaginous bridge that limits the parietal fontanel posteriorly, forming wide V-shaped ossification. At 12.4 mm SL the said cartilage bridge is fully ossified, from its anterior margin to its posterior margin. The ossification progresses laterally and posteriorly forming the supraoccipital spine. By 29.4 mm SL in a dorsal view the supraoccipital has a bow-tie shape and the cartilage on the supraoccipital spine has been fully replaced by bone.

Infraorbital series. Most common sequence of ossification: infraorbital 1 – supraorbital – infraorbital 2 – infraorbital 3 – infraorbitals 5 and 6. Adult ctenoluciids do not have an individualized antorbital, no evidence of a separate ossification equivalent to the antorbital was observed throughout the development of *Ctenolucius hujeta*. Similar condition was observed for the infraorbital 4, no evidence of a separate ossification equivalent to the infraorbital 4 was observed throughout the development of *Ctenolucius hujeta*, corroborating the loss of the infraorbital 4 in *Ctenolucius* proposed by Vari (1995), rather than the fusion of infraorbitals 3 and 4 as proposed by Roberts (1969).

Infraorbital 1: Infraorbital 1 appears as a dermal ossification at 18.5 mm SL. At 21.2 mm SL the infraorbital 1 is a triangular shaped ossification at the vertical through the lateral ethmoid. By 29.4 mm SL the laterosensory canal running through it is fairly evident, but still not contacting the infraorbital 2 posteriorly, the dorsal tip of the infraorbital 1 is associated to a notch on the ventral margin of the supraorbital.

Supraorbital: First appears as a dermal ossification at 19.0 mm SL and is consistently present at 19.9 mm SL. At 21.2 mm SL the supraorbital is a triangular shaped ossification, just posterior to the lateral ethmoid meeting the frontal dorsally. By 29.4 mm SL three to four foramina are visible along the ventroposterior margin that borders the orbit. There is a notch on the ventral portion associated to the dorsal tip of the infraorbital 1.

Infraorbital 2: the infraorbital 2 first appears as a dermal ossification at 18.5 mm SL and is consistently present at 21.1 mm SL. In a slightly larger specimen (21.2 mm SL) the infraorbital 2 is a thin ossification just posterior to the vertical through the posterior margin of the maxilla. At 29.4 mm SL the ossification has developed posteriorly until the vertical through the articulation of the quadrate and anguloarticular. At this size an incomplete laterosensory canal is visible at the dorsal margin of the bone.

Infraorbital 3: The infraorbital 3+4 first appears as a dermal ossification at 21.5 mm SL and is consistently present at 23 mm SL. By 29.4 mm SL it is largest ossification of the infraorbital series, appears to originate as one with no signs of fusion between two separate elements, at this size the still are no signs of a closed canal along the anterior margin of the bone. It is closest to the infraorbital 5 dorsally, when compared to the distance to the preopercle posteriorly and the infraorbital 2 anteriorly.

Infraorbital 5: the infraorbital 5 appears as a dermal ossification at 25.5 mm SL. At 29.4 mm SL it has a somewhat square shape, still with no clear signs of a closed canal on the anterior margin except for a foramen. By 30.0 mm SL a clear thickening on the margin of the orbit is visible.

Infraorbital 6: the infraorbital 6 appears as a dermal ossification at 25.5 mm SL. At 29.4 mm SL this bone is a triangular dermal ossification, a laterosensory canal is evident on the mid portion of its anteroventral margin, at this size the infraorbital 6 covers the anterior tip of the sphenotic spine laterally. By 30.0 mm SL an evident thickening on the margin of the orbit is visible.

Sclerotic bones

The available series did not encompass a specimen with ossified sclerotic bones.

Jaws. Most common sequence of ossification: dentary and maxilla – premaxilla – retroarticular – anguloarticular – coronomeckelian.

Dentary: The dentary is a dermal ossification that first appears at 3.8 mm NL along the anterodorsal portion of the Meckel's cartilage, at this size the dentary already has one conical tooth. At 4.7 mm NL there already are five posteriorly curved conical teeth. The dentary grows towards the posterior portion of the Meckel's cartilage and vertically resulting in a flattened aspect. By 9.3 mm SL the dentary has 14 teeth and there is evidence of tooth replacement (i. e. replacement teeth being formed in soft tissue, slanted in about 45° in relation to their respective functional teeth, cusp pointing lingually). In slightly larger specimens (10.9 mm SL) the dentary teeth are arranged in two rows which overlap at around the mid-point of the dorsal margin of the dentary. By 19.9 mm SL the two rows of dentary teeth are well defined, the inner row starts at half the length of the dentary, with conical teeth, smaller than those on the outer row. Outer row starts near the symphysis and goes slightly beyond the anterior portion of the inner row, slightly posterior to the midpoint of the dentary. The replacement teeth of the outer row are formed in bone cavities, laying down, cusps pointing posteriorly, while the replacement teeth of the inner row are formed in soft tissue, not as much posteriorly slanted. At 29.4 mm SL the outer row teeth resemble the ones of the adult, curved posteriorly, with a cutting edge anterodorsally. Inner row formed by conical teeth smaller than the ones of the outer row.

Maxilla: The maxilla first appears at 3.5 mm NL and is consistently present at 3.8 mm NL. At its early stages the maxilla is an edentulous splint of dermal bone. By 6.0 mm NL the posterior portion of the maxilla starts to differentiate into a flattened ossification. At 9.3 mm SL the maxilla bears four conical teeth. By 29.4 mm SL the maxilla has the same aspect and association to the premaxilla as the adult. At this size, there are ten conical teeth with no cutting edges, slightly smaller than the ones on the premaxilla and dentary.

Premaxilla: The premaxilla first appears at 4.7 mm NL as a splint of dermal bone lateral to the ethmoid plate. At this size the premaxilla already has one conical tooth on its medial region the two contralateral premaxillae are distant from each other at the midline. At 7.0 mm SL the premaxilla has five small conical teeth. By 9.3 mm SL the premaxilla has 10 small conical teeth, the contralaterals ossifications still do not meet at the midline. At 29.4 mm SL the teeth on the posterior portion of the premaxilla are curved posteriorly with cutting edge on their anteroventral margin, the anteriormost teeth are more conical in shape, with no cutting edges but also curved posteriorly. At 30.0 mm SL the fang like teeth on the anterior portion of the premaxilla are evident, similar to the condition in adults.

Retroarticular: the retroarticular first appears as a perichondral ossification at the posterior tip of the Meckel's cartilage where the interoperculo-mandibular ligament is attached at 5.1 mm NL. The ossification advances anterodorsally, at 11.0 mm SL a splint-shaped projection pointing anteriorly is already evident. By 29.4 mm SL there is still some cartilage between the dorsal margin of the retroarticular and the ventral portion of the anguloarticular, the anterior projection reaches the posterior tip of the ventral margin of the dentary anteriorly.

Anguloarticular: the anguloarticular is composed by the dermal angular and the endochondral articular, both appear as separate ossifications at 6.0 mm SL, at this size the angular is a triangular dermal ossification lateral to the posterior portion of the Meckel's cartilage, posterior to the dentary, but already overlapping it. The articular as a perichondral ossification on the articulation portion of the lower jaw, close to the posterior portion of the angular, more evident laterally. By 29.4 mm SL there is no more cartilage visible on the anguloarticular except for the articulation surface with the quadrate and the cartilage pad between the anguloarticular and retroarticular.

Coronomeckelian: The coronomeckelian is a small bone that ossifies on the lateral surface of posterior portion of the Meckel's cartilage, at the insertion of the *par stegalis* section of the *adductor mandibulae* on the lower jaw. This bone first appears at 10.2 mm SL and is consistently present at 16.1 mm SL. By 29.4mm SL the bone lies on the dorsal surface of the Meckel's cartilage, opposed to a more lateral position in smaller specimens.

Hyopalatine arch. Most common sequence of ossification: quadrate – symplectic – hyomandibular and metapterygoid – endopterygoid – ectopterygoid – autopalatine.

Quadrate: The quadrate first appears as a perichondral ossification at 4.1 mm NL and is consistently present at 4.7 mm NL. The ossification occurs at the posteroventral portion of the pars quadrata of the palatoquadrate cartilage. By 7.6 mm SL the perichondral ossification contacts the anguloarticular ventrally, the symplectic posteroventrally, and reaches the ventral margin of the quadrate-metapterygoid fenestra dorsally. At 9.1 mm SL both arms of the quadrate are perichondrally ossified, the ossification falls short of the metapterygoid dorsally and the endopterygoid anterodorsally. In a slightly larger specimen (9.3 mm SL) a ventroposterior lamellar projection contacting the symplectic is evident. By 15.4 mm SL the quadrate-metapterygoid fenestra is almost entirely bordered by bone. The cartilage on the region of the ossifying quadrate is almost entirely replaced by bone except of the dorsal tips of the dorsal arms of the quadrate and the articulation with the anguloarticular.

Symplectic: The symplectic first appears as a perichondral ossification at 5.6 mm NL. Its ossification center on the ventral portion of the hyosymplectic cartilage. The ossification advances both dorsally and ventrally. By 7.6 mm SL the perichondral ossification is restricted to the ventral part of the hyosymplectic cartilage, not reaching its anteroventral tip nor the region of the articulation with the interhyal cartilage dorsoposteriorly.

Hyomandibular: The hyomandibular first appears as a perichondral ossification at 6.5 mm NL an is consistently present at 7.1 mm SL. the ossification center lies at the horizontal through the hyomandibular foramen that by 7.6 mm SL already has its margins completely ossified. At this size, an anteroventral projection from of the ossifying hyomandibular already reaches the dorsalmost margin of the palatoquadrate cartilage, where the metapterygoid is ossifying. By 9.3 mm SL the anterior and posterior margins of the proximal portion of the ossifying hyomandibular, which is associated to the neurocranium, is already ossified, whereas the dorsal margin still cartilaginous. At 15.4 mm SL the cartilage has already been entirely replaced by bone except for the dorsal margin, the ventral tip and the posterior socket associated to the opercle. By 18.1 mm SL the ventral portion of the hyomandibular has become wider than the dorsal portion of the symplectic, resulting in a notch in the remaining portion of the hyosymplectic cartilage in that area, the ossifying interhyal is associated to this notch.

Metapterygoid: The metapterygoid first appears at 6.7 mm SL and is consistently present at 7.1 mm SL. Its ossification center lies on the dorsal margin of the dorsoposterior portion of the palatoquadrate cartilage. At 7.6 mm SL the perichondral ossification still is restricted to the anterodorsal margin of the cartilage, not reaching the quadrate-metapterygoid fenestra ventrally. In slightly larger specimens (9.1 mm SL) the perichondral ossification reaches the dorsal margin of the fenestra ventrally, the dorsal margin of the ossifying metapterygoid already in contact with the anteroventral lamellar projection of the hyomandibular. By 14.6 mm SL the dorsoposterior arm of the metapterygoid is well developed, forming a foramen along with the anterior margin of the hyomandibular and its lamellar projection.

Endopterygoid: The endopterygoid first appear as a thin splint of bone associated to the dorsal margin of the pterygoid process of the palatoquadrate cartilage, at its most arched portion, roughly at the vertical through the articulation quadrate-anguloarticular, at 6.7 mm SL with a fixed presence at 7.5 mm SL. At 9.3 mm SL the medial lamellar portion is already evident. By 16.6 mm SL a teeth row is present close to the ventrolateral edge of the ossification.

Ectopterygoid: The ectopterygoid first appears as a splint of bone lateroventrally to the posterior portion of the pterygoid process of the palatoquadrate cartilage only on the left side of a 7.1 mm SL specimen, by 8.1 mm SL, the ectopterygoid is consistently present on both sides. The ossification grows anteriorly towards the anterior portion of the pterygoid process and posteriorly towards the anterior arm of the quadrate, keeping the thin, splint-like aspect. At 12.3 mm SL there is one tooth on the left ectopterygoid and two teeth on the right. By 17.1 mm SL the ectopterygoid reaches and slightly overlaps the anterior arm of the quadrate. At 18.0 mm SL there are three conical teeth on the ventral surface of the ectopterygoid.

Autopalatine: The autopalatine first appears as a perichondral ossification at 16.4 mm SL. Its ossification center on the anterior portion of the pterygoid process of the palatoquadrate cartilage, just anterior to the anterior tips of the endo and ectopterygoid, the ossification is more evident on the lateral portion of said region of the cartilage. At 17.3 mm SL the perichondral ossification reaches the medial margin of the cartilage, forming an ossified belt around the middle portion of the anterior tip of the pterygoid process. By 29.4 mm SL the anterior tip still is cartilaginous. The endochondral portion has two dorsomedial projections, forming a concave margin, however, the extremities of the concavity are connected by a lamellar projection which renders the dorsomedial margin of the autopalatine straight.

Opercular series. Most common sequence of ossification: opercle – subopercle – interopecle and preopercle.

Opercle: The opercle is among the earliest ossifications to appear, at 3.5 mm NL as a small splint of dermal bone not yet connected to the hyomandibular anteriorly. At 4.4 mm NL the opercle has a fan-like aspect with a convex distal margin. By 7.6 mm SL a horizontal bony ridge is evident at the dorsal margin of the opercle. The ossification spreads anteroventrally for roughly 90°. At 9.1 mm SL the ossification surpasses the opercle ridge dorsally. By 29.4 mm SL the opercle covers almost the entire branchial opening, there is still some open space between the dorsal margin of the opercle and the ventral margin of the pterotic.

Subopercle: The subopercle first appears at 6.7 mm SL and is consistently present at 6.9 mm SL as a small dermal bone splint close to the anteroventral margin of the opercle. At 7.6 mm SL the ossifying subopercle surpasses the anterior margin of the opercle anteriorly, but not posteriorly. By 9.1 mm SL the subopercle is laterally overlapped by the opercle on its dorsal margin and by the interopercle anteriorly. At 29.4 mm SL the ossifying subopercle extends dorsoposteriorly beyond the horizontal through the opercle ridge.

Interopercle: The interopercle first appears at 6.7 mm SL and is consistently present at 7.1 mm SL as a dermal ossification anterior to the subopercle without contacting it, associated to the mandibular-hyoid ligament that connects the developing retroarticular to the hyoid arch. At 9.1 mm SL the interopercle is triangular shaped, its anterior tip extending anteriorly as much as the anterior tip of the preopercle at the vertical through the posterior margin of the ossifying anterior ceratohyal. By 29.4 mm SL the interopercle covers the posterior portion of the retracted branchiostegal rays, the dorsal half of the posterior ceratohyal and the ventral half of the interhyal.

Preopercle: The preopercle first appears at 6.7 mm SL and is consistently present by 7,1 mm SL as a thin dermal bone lamella laterally covering the region of the hyomandibular foramen dorsoposteriorly and almost the entire length of the symplectic anteroventrally. At 9.1 mm SL the anterior tip of the preopercle extends anteriorly as much as the anterior tip of the interopercle, at the vertical through the posterior margin of the ossifying anterior ceratohyal. The laterosensory canal is already evident at the region of the hyosymplectic cartilage between the ossifying symplectic and hyomandibular. In slightly larger specimens (9.3 mm SL) the preopercle extends from the horizontal through the hyomandibular foramen to the distal margin of the symplectic. At 15.4 mm SL the groove that bears the laterosensory canal runs along the entire length of the preopercle.

Hyoid arch. Most common sequence of ossification: anterior ceratohyal – branchiostegal rays and ventral hypohyal – posterior ceratohyal – urohyal – dorsal hypohyal – basihyal – interhyal.

Anterior ceratohyal: The anterior ceratohyal first appears as a perichondral ossification at 4.1 mm NL. The ossification center is restricted to the middle region of the ceratohyal cartilage, at its thinnest portion. The perichondral ossification advances both anterior and posteriorly. At 9.1 mm SL the cartilage has been entirely replaced by bone at the region of the ossification center. By 29.4 mm SL the ossifying anterior ceratohyal still is separate from the dorsal and ventral hypohyal anteriorly, and the posterior ceratohyal posteriorly, by thin portions of cartilage.

Branchiostegal rays: The branchiostegal rays first appear as dermal ossifications at 4,1 mm NL and are consistently present at 5.1 mm NL. The first branchiostegal ray to ossify is the posteriormost, associated to the posterior portion of the ceratohyal cartilage, at the vertical through the ossification center of the posterior ceratohyal. At 6.5 mm NL the two posteriormost branchiostegal rays are already present on both sides; By 7.6 mm SL only the anteriormost branchiostegal ray still is absent, the posteriormost already has a flattened aspect. At 9.3 mm SL the three posteriormost branchiostegal rays are well developed and flattened, the anteriormost ray is starting to develop but not yet in contact with the anterior ceratohyal. One 14.6 mm SL specimen has five branchiostegal rays on the left side, the extra branchiostegal ray is small bony splint curved ventroposteriorly, anterior to the others. By 15.4 mm SL the two anteriormost branchiostegal rays have their bases in direct contact with the anterior ceratohyal, whereas the third anteriormost branchiostegal ray has its base associated to the portion of the ceratohyal cartilage between the anterior and posterior ceratohyal, and the posteriormost branchiostegal ray has its base associated to the ossified posterior ceratohyal. At 29.4 mm SL all four branchiostegal rays are well developed, flattened and curved, gradually more so on the posterior ones. The anteriormost branchiostegal ray is shorter, originates on half the length of the anterior ceratohyal extending until the vertical through the anterior margin of the posterior ceratohyal. The second anteriormost branchiostegal ray originates halfway between the origin of the anteriormost branchiostegal ray and the posterior margin of the anterior ceratohyal extending posteriorly until roughly the vertical through the posterior margin of the interopercle. The third anteriormost branchiostegal ray originates on the anterior margin of the posterior ceratohyal and extending posteriorly until roughly the vertical through the anterior third of the length of the subopercle. The posteriormost branchiostegal ray originates at halfway the length of the posterior ceratohyal and extending posteriorly until the vertical through half the length of the subopercle.

Ventral hypohyal: The ventral hypohyal first appears as a perichondral ossification at 5.1 mm NL. The ossification center is restricted to a notch on the ventral surface of the anterior portion of the ceratohyal cartilage, both protrusions that delimit the notch are already ossified. At 5.6 mm NL a bony bridge is present connecting the two ossified dorsal projections forming a foramen. The perichondral ossification advances dorsoposteriorly. By 9.1 mm SL this ventral foramen already is entirely bordered by bone.

Posterior ceratohyal: The posterior ceratohyal first appears as a perichondral ossification at 5.6 mm NL. The ossification center is restricted to the dorsoposterior margin of the ceratohyal cartilage, near the articulation with the interhyal cartilage. The ossification advances posteroventrally. At 10.9 mm SL a small bony reinforcement starts to form on the lateral surface close to the dorsoposterior margin of the ossifying posterior ceratohyal. By 17.3 mm SL the perichondral ossification has advanced reaching the region of articulation with the interhyal posteriorly. At 22.4 mm SL there is a well-defined ridge on the lateral surface, running along the dorsoposterior margin of the posterior ceratohyal.

Urohyal: The urohyal is a tendon bone that starts to ossify at 5.6 mm NL and is consistently present at 6.5 mm NL as a thin bony splint, broader on its anterior portion, associated to the anterior portion of the sternohyoideus tendons. At 7.0 mm SL the ossifying urohyal is larger and bifurcated anteriorly. By 9.3 mm SL the urohyal starts to develop dorsal projections on the sagittal plane. At 16.6 mm SL the bone extends posteriorly beyond the vertical through the posterior margin of the hyoid arch. By 29.4 mm SL the urohyal has developed lateral projections on its posterior half, these lateral projections originate just dorsal to the ventral margin of the ossification.

Dorsal hypohyal: The dorsal hypohyal first appears a perichondral ossification at 5.6 mm NL and is consistently present at 6.6 mm NL. The ossification center is restricted to the dorsal projection on the anterior region of the ceratohyal cartilage. The perichondral ossification advances ventrally. At 14.6 mm SL the ossifying dorsal hypohyal has a ventral notch on its ventral surface that corresponds to the dorsal margin of a foramen, which is bordered by cartilage ventrally. By 29.4 mm SL this notch has become very deep forming an ovoid foramen.

Basihyal: The perichondrally ossified basihyal first appears at 8.5 mm SL and has fixed presence at 9.3 mm SL. the ossification center lies on the proximal region of the basihyal cartilage which is associated to the anterior copula. The perichondral ossification advances anteriorly in a slow pace. At 23.0 mm SL the ossified portion is restricted to the posterior third of the basihyal cartilage that have a diamond-shape profile in dorsal view. At this size a dermal bone plate is visible lying on the dorsal surface of both the ossified and cartilaginous portions.

Interhyal: The interhyal first appears as a perichondral ossification at 13.8 mm SL and is consistently present at 16.4 mm SL. The ossification center lies on the middle portion of the cylindrical cartilage, more evident on its posterior surface. The ring of perichondral bone spreads both dorsal and ventrally. By 19.0 mm SL the perichondral ossification has already spread along the entire circumference of the cartilage except for the tips.

Branchial skeleton. Most common sequence of ossification: tooth plates associated to the ceratobranchial 5 and pharyngobranchial 4 cartilages – ceratobranchial 5 – ceratobranchial 4 – epibranchial 4 – gill rakers – ceratobranchials 2 and 3 – ceratobranchial 1 – epibranchial 3 – basibranchial 1 – epibranchials 1 and 2 and basibranchial 2 – basibranchial 3 – hypobranchial 3 – pharyngobranchial 3 – hypobranchial 2 – hypobranchial 1 – pharyngobranchial 2 – pharyngobranchial 1.

Pharyngeal jaws: The pharyngeal jaws consist on toothed dermal bone plates associated to their respective cerato- and pharyngobranchial endoskeletal supporting elements. The first elements of this complex to ossify are the teeth and at 3.5 mm NL one large conical tooth is already visible, associated to ceratobranchial 5 cartilage and two smaller conical teeth are associated to pharyngobranchial 4 cartilage. By 4.4 mm NL the tooth plate associated to the pharyngobranchial 4 cartilage already has four teeth, whereas the ceratobranchial 5 tooth plate associated to the ceratobranchial 5 cartilage has two teeth, these being larger than the ones of the pharyngobranchial plate, the posteriormost tooth, which appeared first is curved posteriorly. The size of the dermal bone plates and the number of teeth increase during development, a slightly larger specimen (4.8 mm NL) has seven to eight teeth on the pharyngobranchial 4 tooth plate and three teeth on the ceratobranchial 5 tooth plate, the teeth on the ceratobranchial 5 being larger than the ones on the pharyngobranchial 4. The tooth plate of the ceratobranchial 5 has a posterior projection were the teeth are concentrated. At 18.5 mm SL the pharyngobranchial 3 has a dermal bone plate with a single small conical tooth. The tooth plate associated to the pharyngobranchial 3 did not have a fixed presence in the available series for this study

Ceratobranchials: All five ceratobranchials start as perichondral ossifications on their respective cartilaginous precursors, the ossification center is restricted to the middle portion of the cartilage. The ossification gradually advances towards the extremities replacing the cartilage that remain only on the medial and lateral tips of the ossified ceratobranchial. All five elements appear in a postero-anterior sequence, the first one to ossify is the ceratobranchial 5 that first appears at 3.8 mm NL. The ceratobranchial 4 first appears at 4.1 mm NL and is consistently present at 4.7 mm NL, the ceratobranchials 3 and 2 fist appear together at 4.7 mm NL and are consistently present at 6.1 mm SL, and finally the ceratobranchial 1that first appears at 4.7 mm NL and is consistently present at 6.3 mm NL. At 9.1 mm SL the cartilage has already been replaced by bone in the middle portion of all five ceratobranchials.

Epibranchials: The epibranchials 1-4 start to ossify perichondrally in their middle portion as do the ceratobranchials, another similarity is the posterior-anterior sequence in which both cerato- and epibranchial elements ossify. The epibranchial 4 first appears at 4.9 mm NL, the rest of the epibranchials lag behind in development, the epibranchial 3 first appears at 8.1 mm SL and is consistently present at 9.8 mm SL, the analyzed series did not bring resolution to the ossification of the epibranchials 1 and 2, both elements first appear at 8.5 mm SL and consistently present at 10.2 mm SL.

Gill rakers: The gill rakers appear at 5.6 mm NL on the posterior portion of the ceratobranchials 2, 3 and 4. At 7.6 mm SL more rakers are visible, being added anteriorly, however they are restricted to the ceratobranchials at this point. At 10.9 mm SL a difference in development of the gill rakers is evident, the ones more developed are the ones on the posterior portion of the ceratobranchials, already triangular in shape. In a slightly larger specimen (11.0 mm SL) gill rakers are visible on the lateral portion of the epibranchials.

Pharyngobranchials: The pharyngobranchials, in a similar way to the cerato- and epibranchials ossify perichondrally, the ossification center lies on the middle region of the cartilage forming a belt, the ossification advances towards the extremities, cartilage remains only on the tips. Also, as the cerato- and epibranchials the pharyngobranchials ossify in a posterior-anterior orientation. The first element to ossify is the pharyngobranchial 3 that first appears at 10.2 mm SL and is consistently present at 13.5 mm SL, followed by the pharyngobranchial 2 that first appears at 13.2 and is consistently present at 14.6 mm SL, and finally the pharyngobranchial 1 that appears at 17.1 mm SL.

Basibranchial: The basibranchials ossify perichondrally at the anterior copula, the ossification center of the basibranchial 1 is located on the anterior tip of the anterior copula, where it articulates with the ossifying basihyal. The ossification center of the basibranchial 2 lies posterior to the basibranchial 1, just anterior to the horizontal through the anterior tip of the hypobranchial 2 cartilages, the ossification center of the basibranchial 3 is the posteriormost, lying at the horizontal through the anterior tip of the hypobranchial 3 cartilages. The perichondral ossification of the basibranchial 1 advances posteriorly, whereas the ossification of the basibranchials 2 and 3 grow both anterior- and posteriorly. All three basibranchials first appear at 8.8 mm SL, the basibranchial 1 is consistently present at 10.1 mm SL, followed by the basibranchial 2 which is consistently present at 10.2 mm SL, the basibranchial 3 is the last to be consistently present, at 10.7 mm SL.

Hypobranchials: The paired hypobranchials ossify perichondrally, their ossification center lying on the anterior portion of their respective triangular shaped cartilages, all three of them more evident along the lateral margin of the cartilage. The perichondral ossification advances medially at first, forming a belt around the anterior portion of the cartilage, falling short of the anterior tip. From there, the ossification advances both anteriorly and posteriorly, the anterior tip of all three hypobranchials ossify earlier than their posterior margin. The hypobranchial 3 first appears at 8.8 mm SL and is consistently present at 11.4 mm SL, the hypobranchials 1 and 2 both first appear at 11.9 mm SL, the hypobranchial 2 is consistently present at 13.6 mm SL and the hypobranchial 1 is consistently present at 14.4 mm SL. At 12.4 mm SL the hypobranchial 3 is ossified on its anterior portion, but the ossification still falls short of the cartilage's anterior tip. By 16.6 mm SL the hypobranchials 1 and 2 still have cartilaginous portions on the anterior tip and the posterior margin, whereas the hypobranchial 3 has its anterior tip already ossified, posterior margin cartilaginous. At 17.1 mm SL the hypobranchial 2 has its anterior tip ossified.

Weberian apparatus and associated centra. Most common ossification center is: centra 1, 2, 3 and 4 – neural arch 4 – neural arch 3 – intercalarium and scaphium – neural spine 4 – os suspensorium, tripus and supraneural 3 - claustrum

Centra 1-4: the series did not provide resolution for the ossification sequence of the Weberian centra. As observed for other vertebral centra, the ossification starts at the ventral surface of the notochord advancing laterally and subsequently dorsally forming as ossified ring around the notochord. All four Weberian centra appear at 7.1 mm SL. Despite the lack of resolution on the start of the ossification processes, a difference in the centra development is perceptible, the development is faster for the posterior centra. At 7,6 mm SL the centra 3 and 4 already are already a closed ossified ring, whereas the centrum 2 fails to complete an ossified ring and centrum 1's ossification forms an arch that surrounds the ventral half of the notochord's circumference. By 11.0 mm SL the centrum 1 roughly half the length of the centrum 4.

Neural arches 3 and 4: The neural arches 3 and 4 are perichondral ossifications of the paired basidorsals of centra 3 and 4 respectively. The neural arch 4 is the first to appear at 8.1 mm SL followed by the neural arch 3 that first appears at 8.5 mm SL and is consistently present at 9.3 mm SL. At 7.1 mm SL the basidorsal cartilages associated to centrum 4 are already visible. By 9.1 mm SL the neural arch 4 already is ossified and in contact with the centrum ventrally, the supradorsal cartilages are evident on the dorsal tip of the arches. Neural arch 3 is ossified but does not reach the centrum ventrally.

Intercalarium: The intercalarium is a perichondral ossification of the basidorsal 2 that first appears at 8.5 mm SL and is consistently present at 10.1 mm SL. At 9.1 mm SL the intercalarium is mostly ossified but still not in contact with the centrum ventrally. At 17.1 mm SL the intercalarium is crescent shaped with a short anteriorly pointing projection near its base

Scaphium: The scaphium is a perichondral ossification of the basidorsal 1 that first appears at 8.5 mm SL and is consistently present at 10.1 mm SL. At 9.1 mm SL the scaphium is starting to ossify on the basidorsal cartilage, still with no lamellar projections. By 11.0 mm SL the anterior lamellar projection starts to develop. At 16.1 mm SL a foramen is formed on the anterior portion of the anterior lamellar projection.

Os suspensorium: The outer arm of the os suspensorium is a perichondral ossification of the basiventral 4, it first appears at 11.4 mm SL and is consistently present at 13.5 mm SL. At 11.9 mm SL the ossifying outer arm of the os suspensorium points posteroventrally. By 17.1 mm SL both arms have roughly the same length, extending posteriorly past the vertical through the parapophysis 5. The inner arm of the os suspensorium is a membrane bone that projects from the proximal portion of the developing outer arm at 13.8 mm SL. By 15,6 mm SL the ossification has advanced ventroposteriorly as the ossification of the outer arm, the outer arm being slightly longer. At 17.1 mm SL a connection of lamellar bone is visible between the two arms of the os suspensorium, only the distal tips of both arms are free from this connection

Tripus: The *tripus* is a perichondral ossification of the basiventral posterior to the lamellar process of the centrum 3 that first appears at 11.9 mm SL and is consistently present at 13.5 mm SL, at this size, the *tripus* is a curved splint projecting posteroventrally. At 17.1 mm SL the *tripus* has extended posteriorly reaching the vertical through the posterior margin of the centrum 5.

Supraneural 3: The supraneural 3 first appears 11.9 mm SL as a perichondral ossification of the supradorsal cartilage 3 and is consistently present at 13.5 mm SL. At the earlier stages the ossification is more evident on the middle portion of the longitudinal length of the cartilage. At 13,7 mm SL a lamellar projection on the anterior portion of the ossifying supraneural 3 is already visible. By 21.2 mm SL a slender spine like projection advancing anteriorly past the vertical through the skull's occiput.

Neural spine centrum 4: The neural spine 4 is a membrane bone extending dorsally on the midline from the closed neural arch. It first appears at 10.1 mm SL and is consistently present at 13.0 mm SL. At 17.1 the neural spine 4 is slightly shorter that the ones posterior to it.

Claustrum: The claustrum is a membrane bone that ossifies dorsal to the concha scaphium first appears at 16.4 mm SL.

Axial skeleton. Most common sequence of ossification of the post Weberian axial skeleton: vertebral centra – neural arches – haemal arches – haemal spines – neural spines – intermuscular bones – ribs – parapophyses – supraneurals.

Vertebral centra: The vertebral centra first appear at 7.1 mm SL. The ossification center lies on the ventral surface of the notochord, the ossification advances laterally and then dorsally forming an ossified ring around the notochord. At 9.1 mm SL 39 centra, except the preural centrum 1 and the ural centrum) are ossified and except for the preural centrum 2 forming an ossified ring.

Neural arches: The neural arches appear at 8.1 mm SL. At 9.1 mm SL every neural arch is ossifying, some with the supradorsal cartilages still visible.

Haemal arches: the haemal arches first appear at 8.5 mm SL and are consistently present at 9.3 mm SL. The first haemal arches to appear are the posteriormost, at 10.1 mm SL they are present from the preural centrum 2 until the vertical through the region of the dorsal fin. appear posteroanteriorly, at this size are present until the vertical through de dorsal fin region.

Haemal spines: The haemal spines first appear at 8.5 mm SL and are consistently present at 9.9 mm SL. As the haemal arches, the haemal spines first appear posteriorly. The first haemal spine to ossify is associate to the preural centrum 3. At 10.1 mm SL the haemal spines have advanced anteriorly until the preural centrum 6.

Neural spines: The neural spines first appear at 9.3 mm SL and are consistently present at 10.1 mm SL. At this size, the neural spines are present on the anteriormost and posteriormost regions of the axial skeleton, the ones in the middle are still not ossified. By 13,5 mm SL the 5th until the 25th centra have ossified neural spines.

Intermuscular bones: Intermuscular bones are tendon bones that ossify along the myosepta on the epaxial and hypaxial musculature. They first appear at 10.7 mm SL. At 13,6 mm SL both epipleurals and epineurals are already visible on the caudal peduncle, the epineurals slightly more developed. By 30.0 mm SL the four anteriormost epineurals are not forked anteriorly, same condition of the six posteriormost ones, the remaining are forked anteriorly, the more anterior ones with a longer forked portion than the more posterior, resulting in an apparently more dorsal position for the posteriormost.

Ribs: The ribs first appear at 9.3 mm SL and are consistently present at 11.0 mm SL. The first ribs to appear are associated to the 8th and 9th centra they start to ossify proximally, close to the respective centrum, the ossification subsequently grows distally. At 11.0 mm SL the 5th to 15th centra bear a pair of ribs. By 13,7 mm SL the ribs are present until the 22nd centrum. At 15.4 mm SL they are present until the 24th centra.

Parapophyses: The first parapophysis to appear is the one associated to the 5th vertebral centrum as a perichondral ossification at the distal portion of the basiventral at at 14.4 mm SL they are consistently present at 16.4 mm SL. The parapophyses ossify in an antero-posterior sequence at 15.4 mm SL they are ossified on the 5th to 17th centra. By 17.1 mm SL the perichondral ossification on the basiventral cartilages is more evident on the anterior portion of the distal region of the cartilage, where there is a small spiniform process pointing anteriorly, this process is gradually less evident on the posterior parapophyses.

Supraneurals: The first supraneural to perichondrally ossify is the supraneural 4 at 18.2 mm SL and is consistently present at 21.1 mm SL. At 22.4 mm SL there is total of 10 post Weberian supraneural cartilages, only the supraneural 4 is ossified and elongated, supraneural cartilages 5 and 6 are somewhat ovoid, the remaining supraneural cartilages are spherical. By 23.0 mm SL the supraneurals 4 through 8 are ossified, gradually less elongated posteriorly, remaining supraneural cartilages are spherical.

Pectoral girdle. Most common sequence of ossification: cleithrum – supracleithrum – posttemporal – postcleithrum 1 – coracoid – scapula – pectoral-fin rays and mesocoracoid – extrascapular – pectoral-fin radials. Adult ctenoluciids lack postcleithra 2 and 3, no individual ossifications equivalent to the postcleithra 2 and 3 were observed throughout the ontogeny of *Ctenolucius hujeta*

Cleithrum: The cleithrum is among the first ossifications to appear during the *Ctenolucius hujeta* development. The dermal ossification first appears at 3.5 mm NL. At 3.6 mm NL the yolk sack is still present on the specimen, that results in a ventroposterior rotation of the pectoral girdle. At 4.8 mm NL the pectoral girdle has assumed its regular position, the developing cleithrum is a splint almost entirely straight on lateral view. Slightly curved medially reaching the contralateral, also at this size, the posterior flange is starting to develop. By 9.1 mm SL the cleithrum is already articulating with the supracleithrum. A posterior bony flange is already evident as well as the anteroventral one.

Supracleithrum: The supracleithrum first appears at 6.7 mm SL as a dermal bone split only on the left side, almost parallel to the dorsal tip of the cleithrum. The supracleithrum has fixed presence at 7.1 mm SL. At 7.6 mm SL the supracleithrum still resembles a bony splint, parallel to the dorsal portion of the cleithrum. By 8.6 mm SL the supracleithrum already articulates with the cleithrum ventrally. At 9.1 mm SL the lamellar aspect beginning to be more evident, more so on the right side, where a small opening on the bone associated to the laterosensory canal is already visible.

Posttemporal: The posttemporal first appears as a dermal bone splint anterodorsally to the dorsal tip of the supracleithrum at 8.6 mm SL. At 9.1 mm SL the posttemporal is articulating ventrally with the supracleithrum. By 10.1 mm SL the dorsal arm of the posttemporal is much longer than the ventral but falling short from reaching the skull anteriorly. At 16.1 mm SL a flange is starting to develop at the posteriormost part of the bone. By 29.4 mm SL the dorsal arm of the posttemporal overlaps the epiotic and reaches the lateral margin of the supraoccipital dorsomedially.

Postcleithrum 1: The postcleithrum 1 is a dermal ossification that first appear as a splint posteroventrally to the region of articulation of the cleithrum and supracleithrum at 13.2 mm SL with fixed presence at 13.8 mm SL. At 17.1 mm SL the ossification expands posteriorly, resulting in a lamellar aspect. By 21.2 mm SL the postcleithrum 1 is roughly shaped as a semi-circle, anterior margin straight, posterior margin convex.

Coracoid: The coracoid first appears at 19.0 mm SL and is consistently present at 21.2 mm SL. At 22.4 mm SL the perichondral ossification lies just anterior to the foramen on the scapulocoracoid cartilage.

Scapula: The scapula first appears as a perichondral ossification on the scapulocoracoid cartilage at 21.5 mm SL being consistently present at 23.0 mm SL.

Pectoral-fin rays: The pectoral-fin rays first appear as dermal ossifications on the pectoral fin fold at 25.5 mm SL, at this size the two dorsalmost rays are already ossified.

Mesocoracoid: The mesocoracoid is a perichondral ossification on the dorsal portion of the scapulocoracoid cartilage that first appears at 25.5 mm SL. At 27.9 mm SL the bony bridge connecting the cleithrum to the scapulocoracoid cartilage entirely ossified but not yet reaching neither coracoid nor scapula ossifications.

Extrascapular: The extrascapular is a lamellar dermal bone anterior to the posttemporal, it first appears at 25.5 mm SL and is consistently present at 30.0 mm SL, at this size the extrascapular lies anterior to the forked portion of the posttemporal and posterior to the overlapping of the epiotic and pterotic, a foramen associated to the future laterosensory canal already evident on the ossification.

Pectoral-fin radials: the available series did not encompass a specimen with ossified pectoral-fin radials.

Pelvic girdle. Most common sequence of ossification: pelvic-fin rays – basipterygium – pelvic-fin radials. The lateral and middle pelvic-fin radials were not ossified in the largest available specimen in the series (35.5 mm SL).

Pelvic-fin rays: the pelvic-fin rays first appear at 13.2 mm SL and are consistently present by 16.3 mm SL. At 18.5 mm SL there are a total of eight pelvic-fin rays as in the adults, however, at this size the rays are not segmented yet

Basipterygium: The basipterygium first appear as a perichondral ossification along the middle portion of the basipterygial cartilage at 13.8 mm SL with fixed presence at 16.4 mm SL. The ossification advances both anterior- and posteriorly. At 18.5 mm SL most of the basipterygium is ossified except for the anterior tip and the posterior portion associated to the pelvic-fin radials.

Pelvic-fin radials: The first pelvic-fin radial to appear is the medial radial at 21.5 mm SL, its ossification center lying on the posteromedial projection. At 23.0 mm SL the ossification covers slightly over half the length of the cartilage.

Dorsal fin. Most common sequence of ossification: dorsal-fin rays – proximo-middle radials – distal radials.

Dorsal-fin rays: The dorsal-fin rays first appear as dermal ossifications along the dorsal fin fold at 9.8 mm SL and are consistently present at 11.4 mm SL. At 15.4 mm SL there is a total of 10 fin rays, none segmented distally.

Proximal-middle radials: The proximo-middle radials are perichondral ossifications of the proximo-middle cartilages. They first appear at 11.4 mm SL and are consistently present at 13.6 mm SL. The ossification center lies on the middle portion of the cartilage, once an ossified ring is formed it later advances both dorsal- and ventrally. At 15.4 mm SL there is a total of 9 ossified proximo-middle radials.

Distal radials: The distal radials are perichondral ossifications on the distal radial cartilages. The ossification center is restricted to lateral projections of the cartilage, close to their dorsal surface. The distal radials first appear at 21.5 mm SL and are consistently present at 23.0 mm SL. At 23.0 mm SL only the 2nd and 3rd cartilages have started ossifying.

Bony stay: an ossified bony stay was not observed on the current series.

Anal fin. Most common sequence of ossification: anal-fin rays – proximo-middle radials – distal radials.

Anal-fin rays: The anal-fin rays appear as dermal ossifications on the ventral fin fold. They first appear at 6.7 mm SL and are consistently present at 7.1 mm SL. At 9.1 mm SL there is a total of 9 rays, including the posteriormost, split at its base, none of them segmented yet. By 15.4 mm SL there are 11 rays, including the posteriormost split at its base, the 3rd to 9th rays are segmented distally.

Proximal-middle radials: The proximo-middle radials are perichondral ossifications of the proximo-middle cartilages. The ossification center is restricted to the central region of the cartilage, slightly dislocated proximally, once an ossified ring is formed around the cartilage the ossification advances both dorsal- and ventrally. They first appear at 8.5 mm SL and are consistently present at 9.3 mm SL. At 9.3 mm SL the 2nd to 6th proximo-middle radials are already ossifying,

Distal radials: The distal radials are perichondral ossifications on the distal radial cartilages that first appear at 19.0 mm SL and are consistently present at 21.2 mm SL. At 23.0 mm SL the 2nd to 6th distal radials are already ossified.

Caudal fin and supporting skeleton. The caudal fin and its supporting skeleton is treated herein as comprising the four posteriormost vertebrae (ural, preural 1, 2 and 3), which include neural and haemal arches and spines of preural vertebrae 2 and 3, parhypural, six hypurals, two pairs of uroneurals, three epineurals, principal and procurrent caudal fin rays and ventral and dorsal caudal-fin bony stays. The most common sequence of ossification of these elements is: caudal-fin principal rays – hypurals 1, 2 and 3 – parhypural – uroneural 1 – haemal arch and spine of preural centrum 2 and hypural 4 – haemal arch and spine of preural centrum 3 and caudal-fin ventral procurrent rays – preural centrum 1 – hypural 5 and ural centrum 1 – haemal arch and spine of preural centra 2 and 3 and preural centrum 2 – preural centrum 3 - caudal-fin dorsal procurrent rays – uroneural and hypural 6 – epural 2 – caudal-fin ventral bony stay - caudal-fin dorsal bony stay – epural 1*. The caudal-fin skeletal elements are group and presented in alphabetical order as in Mattox et al. (2014) in order to facilitate the comparisons between the two series

Epurals: The epurals ossify perichondrally at the middle portion of the median epural cartilages dorsal to the developing compound center. The ossification advances both dorsal- and ventrally on the cartilages reaching the proximal tip earlier than the distal tip. The epural 2 first appears at 10.2 mm SL and is consistently present at 13.6 mm SL. The epural 3 first appears at 11.9 mm SL and is consistently present at 16.4 mm SL. At 12.4 mm SL the epural cartilages 2 and 3 are well developed, whereas the epural cartilage 1 is starting to develop. By 18.5 mm SL the proximal tips of the epurals 2 and 3 are perichondrally ossified, their distal tips still are cartilaginous. One specimen (27.9 mm SL) had three epurals completely ossified except for their distal tips. Epural 1: the smallest specimen that had three ossified epurals was 14.6 mm SL, from the 34 analyzed specimens larger than the one mentioned only 13 had ossified epural 1 (around 39%). The epural 1 was never consistently present

Haemal arches and spines of preural centra 2 and 3: the haemal arch and spine of the preural centrum 2 first appear at 8.1 mm SL. The haemal arch and spine of the preural centrum 3 first appear at 8.4 mm SL

Hypurals 1-6: the six hypurals ossify perichondrally on their cartilaginous precursors that lie ventral to the notochord. The ossification centers lie roughly on the middle portion of the cartilage, slightly dislocated proximally, except for the hypural 6 which has its ossification center on the proximal tip of the cartilage. The ossification advances both proximally and distally, reaching the proximal extremity earlier, even the largest examined specimens still had the cartilaginous distal margins on all six hypurals. The hypurals 1, 2 and 3 first appear at 7.1 mm SL, followed by the hypural 4 that appears at 8.1 mm SL. The hypural 5 first appears at 8.5 mm SL and is consistently present at 9.8 mm SL. The hypural 6 first appear at 10.2 mm SL and is consistently present at 11.4 mm

SL. At 13,5 mm SL the hypural 1 is already disconnected from the preural centrum 1 due to the reabsorption of bone tissue, condition observed on the adults.

Neural arches and spines of preural centra 2 and 3: the neural arches and spines of preural centra 2 and 3 first appear at 8.8 mm SL and are consistently present at 10.1 mm SL

Parhypural: the parhypural first appears at 7.2 mm SL and is consistently present at 7.9 mm SL

Preural centra 2 and 3: Both preural centra first appears at 8.5 mm SL the preural centrum 2 is consistently present at 10.1 mm SL whereas the preural centrum 3 has fixed presence at 10.7 mm SL. The preural centrum 3. Both centra start to ossify perichondrally on the ventral surface of the notochord. As other centra the ossification advances dorsally until a ring of bone tissue is formed around the notochord. At 9.1 mm SL neither centra are entirely ossified dorsally.

Principal caudal-fin rays: Caudal-fin principal rays first appear at 6.5 mm NL and are consistently present at 7.0 mm SL. The first rays to ossify are associated to hypural cartilages 2 and 3. At 7.0 mm SL 16 rays are already ossified, the caudal fin has a convex profile at this size. By 8.5 mm SL all 19 principal caudal-fin rays are ossified, segmentations on the rays are visible distally. At 11.0 mm SL the forked distal profile of the caudal fin is already evident. By 19.2 mm SL the caudal-fin rays already have three to four segmentations.

Procurrent caudal-fin rays: the procurrent caudal-fin rays are the one anterior to the ventral- and dorsalmost unbranched caudal-fin rays. The ventral series of procurrent rays is the first to appear at 7.2 mm SL, with fixed presence at 8.4 mm SL, the first ray to ossify articulates proximally to the distal tip of the haemal spine of the preural centrum 2. The dorsal series of procurrent rays first appear at 8.5 mm SL and is consistently preset at 10.8 mm SL. the first caudal-fin procurrent ray to ossify does it just anterior to the tip of the notochord, more rays are added subsequently anterior to the mentioned ones both on the ventral and dorsal series of procurrent caudal-fin rays. At 14.6 mm SL there are 5 dorsal procurrent rays, the anteriormost anterior to the distal tip of the epural 2, at this size five procurrent rays are ossified in the ventral series as well, the anteriormost articulating with the anterior margin of the haemal spine of the preural centrum 3

Ural and preural centra 1: The preural centrum 1 first appears at 8.4 mm SL and is consistently present at 9.3 mm SL. The ural centrum first appears at 8.5 mm SL and is consistently present at 9.8 mm SL As other vertebral centra both start to ossify on the ventral surface of the notochord, the preural centrum 1 starting to ossify on the base of the developing parhypural whereas the ural centrum starts to ossify at the region of the base of the hypurals 2 and 3. By 10,2 mm SL both centra have formed a complete ring around the notochord, and are starting to fuse to each other starting from the ventral surface of the notochord. At 13,5 mm SL the two centra are practically entirely fused together.

Uroneurals: The two pairs of uroneurals appear as membrane bones. The uroneural 1 fist appears at 7.6 mm SL and is consistently present at 8.1 mm SL. At 9,2 mm SL the uroneural 1 extends from the anterior margin of the hypural 1 anteriorly, until the anterior margin of the hypural 4 posteriorly. The uroneural 2 starts to ossify at 8.5 mm SL and is consistently present at 11.4 mm SL. During its early developmental stages, the uroneural 2 is just a small splint lateral to the distal portion of the flexed notochord, anterior to the proximal tip of the hypural 5, slightly more developed on the right side. At 17.1 mm SL the anterior portion of uroneural 1 is firmly fused to the compound centrum and reaches the vertical through the anterior tip of the hypural 6 posteriorly, whereas the uroneural 2 stretches from just posterior the vertical through the anterior tip of the hypural 4 anteriorly until the vertical through the midpoint of the hypural 6 posteriorly.

Caudal-fin bony stays: the bony stays are membrane bones that ossify at the vertical septum. The ventral bony stay is the first to appear as a thin bony splint at 13.2 mm SL with fixed presence at 16.4 mm SL. The ossification grows anterodorsally resulting in a triangular profile. At 21.2 mm SL the anterior portion of the ventral bony stay is forked. The dorsal bony stay first appears as a thin bony splint at 14.6 and is consistently present at 16.4 mm SL. The ossification grows anteroventrally, resulting in a triangular shape. At 21.2 mm SL the dorsal bony stay has a small dorsal projection on its distal extremity.

For *Astyanax lacustris* a total of 143 skeletal elements were examined, four less than the 147 examined for *Salminus brasiliensis* (Mattox *et al*. 2014). Sclerotic bones and dorsal-fin bony stay were not observed in the available series of *A. lacustris*. The tooth plate associated to the pharyngobranchial 3 did not have a fixed presence in the available series. Adult *A. lacustris* lack a supraorbital.

For *Ctenolucius hujeta* a total of 140 elements were examined, compared to the 147 for *S. brasiliensis*. Sclerotic bones, dorsal-fin bony stay, pectoral-fin radials, lateral and middle pelvic-fin radials were not observed in the available series of *C. hujeta*. The tooth plate associated to the pharyngobranchial 3 did not have a fixed presence in the available series. Adult *C. hujeta* lack an antorbital, postcleithra 2 and 3. The dorsal and ventral caudal-fin bony stays were only observed in the series of *C. hujeta*.

The two proposed sequences show several differences among them and compared to the sequence of *S. brasiliensis*; these differences are detailed in the following section.

Comparative analyses

The two ossification sequences presented herein were compared to the complete ossification sequence of *Salminus brasiliensis* (Mattox *et al*. 2014), the only complete ossification sequence for a representative of the Characiformes in the literature. The comparison was made using only the skeletal elements common to all three sequences. The complete series for *S. brasiliensis* was the one with the most elements (147 independent elements, Mattox *et al*. 2014), followed by *Astyanax lacustris* (143 elements) and *Ctenolucius hujeta* (140 elements). The following structures were not included in the current comparative analysis: Sclerotic bones and dorsal-fin bony stay were not observed in the available series of *Ctenolucius hujeta* and *Astyanax lacustris*; tooth plate associated to the pharyngobranchial 3 did not have a fixed presence in the available series of *C. hujeta* and *A. lacustris*; ossified pelvic-fin lateral and middle radials were not observed in the available series of *C. hujeta*; antorbital, infraorbital 4 and postcleithra 2 and 3 are lacking in adults of *C. hujeta*; supraorbital is lacking in adults of *A. lacustris*; dorsal and ventral caudal-fin bony stays are only present in *C. hujeta* and were also excluded from the comparative analysis. A total of 136 skeletal elements were included in the comparative analysis (Table 1).

Due to the large number of structures that constitute the comparison (136 elements common to the three series used herein) the comparison between the three sequences were organized by anatomical complexes, following the same division used for the description of the development of the ossifications. The three sequences are compared for each anatomical complex in order to identify heterochronic changes in the relative order in which the elements ossify. For this comparison we present diagrams with the rank of each element for the three different sequences within that osteological complex (*i.e*. an osteological complex with four ossifications have rank values from 1 to 4). The sequences are also compared considering the entire sequence in order to identify relative acceleration or delay of a given skeletal element within the entire sequence. For this second comparison we present diagrams with the rank assigned to each ossification in relation to its order of appearance in the entire sequence (rank values vary from 1 to 136).

The rank values for the comparisons of the complete sequences are given in Table 1. The plateaus observed in the diagrams indicate two or more elements with the same ranks, a consequence of lack of resolution in the sequence of ossification. The term relative interval is used to describe the difference between the ranks of the last and first element to ossify regarding the complete sequence (*e. g.* the relative time interval for the elements of the olfactory region for *A. lacustris* is 30.5, difference between the ranks of the nasal and lateral ethmoid, 122.5-92)

Size of fixed presence and sequence of ossification of Salminus brasiliensis are those of Mattox *et al*. (2014).

A diagram comparing the complete sequence of ossification for *A. lacustris*, *C. hujeta* and *S. brasiliensis* is presented in the appendix (Fig. 38).

Neurocranium – Olfactory region.

In *A. lacustris* the first element to ossify is the lateral ethmoid and the last is the nasal (Fig. 7), with a relative interval of 30.5. In *C. hujeta* the first element to ossify is the mesethmoid and the last is the nasal with a relative interval of 64. The same sequence is observed in *S. brasiliensis,* with a relative interval of 51.5. Within the four elements of the olfactory region of the neurocranium only the nasal had the same rank across all three sequences, this bone is always the last to ossify (Fig.7). The lateral ethmoid had three different ranks in the three sequences, it is the first element of this complex to ossify in *A. lacustris*, the third in *C. hujeta* and the second in *S. brasiliensis* (Fig. 7) Considering the ranks for the entire sequence the highest variation in the ranks across the three species was observed for the vomer, which ossifies early in *C. hujeta* in comparison to *A. lacustris* and *S. brasiliensis* (ranks of 68 vs. 114.5 and 104 respectively), followed by the mesethmoid which ossifies comparatively earlier in *C. hujeta* (53.5) and later in *A. lacustris* (99), with *S. brasiliensis* having an intermediate rank (69.5). The lateral ethmoid along with the nasal had similar ranks across the three sequences (Fig. 8). The lateral ethmoid ranks for *S. brasiliensis* and *C. hujeta* is 94. *A. lacustris* was the species with the lowest difference between ranks of the first and last element to ossify in the olfactory region (30.5) indicating a fast development of these structures within the complete sequence. The entire anatomical complex starts to ossify relatively late regarding the complete sequence, the lowest rank is 53 for the mesethmoid in *C. hujeta*.

Neurocranium – Orbital region.

The three species had the same sequence of ossification of the elements of the orbital region in the neurocranium, parasphenoid followed by the frontal, pterosphenoid and finally the orbitosphenoid (Fig. 9). The relative interval for *A. lacustris* is 88.5, 80.5 for *C. hujeta* and 93.5 in *S. brasiliensis*. Considering the entire sequence only the rank for the frontal showed variation in the ranks with *C. hujeta* presenting the lowest rank (28.5), followed by *A. lacustris* (39) and *S. brasiliensis* (59). The remaining ossifications of the orbital region had similar ranks for the three species (Fig. 10).

Neurocranium – Otic region.

In *A. lacustris* the first element to ossify is the prootic and the last is the epiotic with a relative interval of 50. In *C. hujeta* the first element to ossify is also the prootic and the last is the intercalar with a relative interval of 51. As in *A. lacustris* the first and last elements to ossify in the otic region are respectively the prootic and epiotic in *S. brasiliensis* with a relative interval of 48.5. The prootic and sphenotic had the same rank within the complex in the sequences of the three species, being the first and second bones to ossify, respectively. The third bone to ossify in *A. lacustris* is the intercalar, this bone is the last to ossify in *C. hujeta* and the fourth in *S. brasiliensis*. The fourth bone to ossify in *A. lacustris* is the pterotic, which is the third to ossify in *C. hujeta* and the fifth in *S. brasiliensis*. The parietal is the fifth bone to ossify in *A. lacustris* is the parietal, this bone has the same rank as the epiotic in *C. hujeta* and is the third to ossify in *S. brasiliensis*. The epiotic is the last bone to ossify in *A. lacustris* and *S. brasiliensis* (Fig. 11). Several differences in the sequence of the elements of the otic region were observed. Only the prootic and sphenotic had the same rank across all three species, the epiotic had the same ranks in *A. lacustris* and *S. brasiliensis*. Among the whole sequence *A. lacustris* and *S. brasiliensis* are the most similar among the three, the highest rank difference among the two is for the intercalar (117.5 in *A. lacustris* and 112 in *S. brasiliensis* and), the ossification of the intercalar appears to be accelerated in *A. lacustris* when compared to the other two species. The only bone with similar ranks for *A. lacustris* and *C. hujeta* is the prootic (rank 46.5). The relative acceleration of the pterotic (70.5 in *C. hujeta* vs. 113 in *S. brasiliensis* and 109.5 in *A. lacustris*) is noteworthy (Fig. 12).

Neurocranium – Occipital region.

The three species had the same sequence of ossification of the elements in the occipital region of the neurocranium: basioccipital, followed by the exoccipital and finally the supraorbital (Fig. 13). *A. lacustris* had a relative interval of 74, *C. hujeta* had a relative interval of 47 and *S. brasiliensis* 67.5. *C. hujeta* was the species with all elements of the supraoccipital region ossified earlier. Within the complete sequence the three species had similar ranks for the basioccipital and the exoccipital, but a relative acceleration of the ossification of the supraoccipital was observed in *C. hujeta* in comparison to the other two species (53.5 in *C. hujeta* vs. 80 in *A. lacustris* and 88 in *S. brasiliensis*) (Fig. 14).

Infraorbital series.

A complete infraorbital series: antorbital, infraorbitals 1 through 6 and supraorbital is not present in, *A. lacustris*, which lacks the supraorbital and in *C. hujeta* which lacks the antorbital and infraorbital 4. The comparison was restricted to infraorbitals 1, 2, 3, 5 and 6

In *A. lacustris* the first element to ossify is the infraorbital 2, infraorbital 5 and 6 are tied as the last to ossify, the relative interval for *A. lacustris* is 9.5. In *C. hujeta* the first element to ossify is he infraorbital 1 the infraorbitals 5 and 6 are also tied as the last to ossify in this species, the relative interval is 10.5. In *S. brasiliensis* the infraorbital is the first to ossify and the infraorbital 6 the last, with a relative interval of 12. The lack of complete resolution of the sequence for all three species and the not complete correspondence of elements among them make the comparison more difficult (Fig. 15). However, it is possible to identify a somewhat antero-posterior orientation of the ossification across the three species. When considering the complete sequence, the ossification of the entire infraorbital series is restricted to the end of the sequence, the lowest observed rank of an element of this complex 123 out of 136 (infraorbital 1 of *C. hujeta*) (Fig. 16).

Jaws.

The dentary, premaxilla and maxilla are among the first elements to ossify in all three species but the exact order in which this happens is not completely resolved for any of them. In *A. lacustris* the first element to ossify in the jaws is the dentary, followed by the premaxilla and maxilla (tied). In *C. hujeta* the dentary and the maxilla are tied as the first elements to ossify, followed by the premaxilla. In *S. brasiliensis* the dentary and premaxilla ossify first (tied), followed by the maxilla. Retroarticular and anguloarticular also are restricted the earliest third of the complete sequence. A differentiation in timing between the sequence of ossification of the angular and the articular, was unresolved in *C. hujeta* and *A. lacustris*. In *S. brasiliensis* the angular ossifies earlier than the articular. The coronomeckelian is the last element to ossify in all three species (Fig. 17). The relative interval in *A. lacustris* is 94, 105.5 in *C. hujeta* and 95 in *S. brasiliensis*. When considering the complete sequence, all ossifications of the jaws except the coronomeckelian appear, within the first third of the sequence. The coronomeckelian ossifies much later, particularly in *C. hujeta* (rank 112) (Fig. 18). In *A. lacustris* and *C. hujeta* all elements of the jaw are ossified rather early in the sequence (rank 24 for the angular and articular in *A. lacustris* and 21.5 for the same two ossification in *C. hujeta*) when compared to *S. brasiliensis* (rank 45 for the articular). The coronomeckelian, however ossifies later in both *A. lacustris* and *C. hujeta* (ranks 99 and 112 respectively) compared to *S. brasiliensis* (rank 80, Fig 18.).

Hyopalatine arch.

Considerable variation is observed in the ossification sequence of the elements of the hyopalatine arch (Fig. 19). The first element to ossify in *C. hujeta* is the quadrate, as in *S. brasiliensis*. In *A. lacustris*, the quadrate is tied with the symplectic as the first elements to ossify, the symplectic is the second element to ossify in *C. hujeta* and the fourth in *S. brasiliensis*. In *A. lacustris* and *S. brasiliensis* the endopterygoid is the third to ossify and the fifth in *C. hujeta*. The hyomandibular in *A. lacustris* is the fourth element to ossify, in *C. hujeta* the hyomandibular and the metapterygoid are tied as the fourth to ossify, in *S. brasiliensis* the hyomandibular is the second bone to appear. The metapterygoid is the fifth element to ossify in *A. lacustris*, in *S. brasiliensis* the metapterygoid and the ectopterygoid are tied as the fifth bone to appear. The ectopterygoid is the sixth element to ossify in *A. lacustris* and *C. hujeta*. In all three species the autopalatine is the last element to ossify. The relative interval in *A. lacustris* is 109.5, 106 in *C. hujeta* and 123 in *S. brasiliensis*. Despite the several differences in the sequences within the hyopalatine arch among the three species, when the complete sequence is considered the three species are very similar except for the delay in the ossification of the hyomandibular in *A. lacustris* and *C. hujeta* (ranks 30 and 38 respectively vs 13.5 in *S. brasiliensis*) and the endopterygoid which is slightly delayed in *C. hujeta*. (46.5 vs. 24 in *A. lacustris* and 20.5 in *S. brasiliensis*) (Fig. 20).

Opercular series.

Complete resolution in the ossification sequence was only observed in *A. lacustris*, in this species the ossification sequence of the elements of the opercular series is opercle, subopercle, interopercle and preopercle. In *C. hujeta* the subopercle is also the second element to ossify, in *S. brasiliensis* the subopercle and the interopercle are tied as the second to appear. In *C. hujeta* the interopercle is tied to the preopercle as the third to ossify. In *S. brasiliensis* the preopercle is also the last to ossify. The relative interval for *A. lacustris* is 77.5, 36 for *C. hujeta* and 23 for *S. brasiliensis*. Considering the complete sequence (Fig. 22) the opercle is among the five first elements to ossify in all three species, some variation was observed in the interopercle that seems to be relatively delayed in *A. lacustris* and *C. hujeta* (41.5 in *A. lacustris* and 38.5 in *C. hujeta* vs 25 in *S. brasiliensis*), . The preopercle however, lags in relation to the rest of the series in *A. lacustris* when compared to the other two species (80 in *A. lacustris* vs. 28 in *S. brasiliensis* and 38.5 in *C. hujeta*).

Hyoid arch.

S. brasiliensis and *A. lacustris* are more similar to each other in relation to *C. hujeta* considering the ossification sequence within the hyoid arch (Fig. 23). The branchiostegal rays, anterior ceratohyal and urohyal are the three first elements to ossify in *A. lacustris* and *S. brasiliensis*. The anterior ceratohyal is the first element to ossify in *C. hujeta*, followed by the tied branchiostegal rays and ventral hypohyal in second, the urohyal is only the fifth ossification to appear in *C. hujeta*. The ventral hypohyal and the dorsal hypohyal are tied as the fifth element to ossify in *A. lacustris*, the ventral hypohyal is the fourth element to ossify in *S. brasiliensis*. The dorsal hypohyal is the sixth element to ossify in *C. hujeta* and *S. brasiliensis*. The basihyal and interhyal are, respectively, the seventh and eighth elements to ossify in all three species. The relative interval for *A. lacustris* is 123.5, for *C. hujeta* 101.5 and *S. brasiliensis* 118.5.

Considering the complete sequence (Fig. 24), the three species share similar ranks for all elements of the hyoid arch except for the ventral hypohyal that is comparatively delayed in *A. lacustris* (46.5 vs. 20.5 in *S. brasiliensis* and 16 in *C. hujeta*). A comparative acceleration is observed in *C. hujeta* for the basihyal (65 vs. 92.5 in *S. brasiliensis* and 99 in *A. lacustris*) and for the dorsal hypohyal (27 in *C. hujeta* vs. 52.5 in *S. brasiliensis* and 46.5 in *A. lacustris*).

Branchial skeleton.

The tooth plates associated to pharyngobranchial 4 and ceratobranchial 5 are the first elements to ossify in the branchial skeleton of all three species, and also within the entire skeleton (together with the cleithrum and opercle in *A. lacustris* and *C. hujeta*, and only cleithrum in *S. brasiliensis*) (Fig. 25). The last branchial skeleton element to ossify in *A. lacustris* and *S. brasiliensis* is the hypobranchial 1 whereas in *C. hujeta* the last element to ossify is the pharyngobranchial 1. The relative interval for *A. lacustris* is 118.5, *C. hujeta* has a relative interval of 107.5 and *S. brasiliensis* has an relative interval of 112.

In *A. lacustris* and *C. hujeta* the ceratobranchials ossify in a postero-anterior direction with ceratobranchial 5 ossifying first, followed by the ceratobranchial 4, ceratobranchials 2 and 3 are tied in both species, the ceratobranchial 1 is the last to ossify among the ceratobranchials. In *S. brasiliensis* the ceratobranchials ossify in an almost complete antero-posterior direction ceratobranchial 1 is the first to ossify among the ceratobranchials, followed by the ceratobranchials 2, 3, 5 and finally 4 (Fig. 25).

The ossification sequence of epibranchials is completely resolved for *C. hujeta*, a postero-anterior direction was observed with epibranchial 4 as the first bone to appear followed by epibranchials 3, 2 and 1. In addition, epibranchial 4 in *C. hujeta* appears to be comparatively accelerated (Fig. 25). In *A. lacustris* the first epibranchial to ossify is epibranchial 4, followed by epibranchial 3 and finally epibranchials 1 and 2 (in an unresolved sequence). The epibranchials ossify in the following order in *S. brasiliensis* epibranchials 2 and 3 tied in first, epibranchial 4 in third and finally the epibranchial 1 in fourth.

The pharyngobranchials showed a postero-anterior direction of ossification in all three species, regardless of the differences in their ranks. The ossification of the pharyngobranchials appear to be comparatively delayed in *C. hujeta*, with pharyngobranchials 2 and 1 being the last two elements to ossify in the branchial skeleton. In *A. lacustris*, pharyngobranchials 2 and 3 had similar ranks to those of *S. brasiliensis*, and pharyngobranchial 1 had a rank comparatively closer to the rank for the same structure in *C. hujeta* (Fig. 25).

The basibranchials also showed differences in the direction of the ossification sequence across the three species In *C. hujeta*, the basibranchials ossify in an antero-posterior direction, with basibranchial 1 appearing first, followed by basibranchial 2 (tied to epibranchials 1 and 2) and finally by the basibranchial 3. In *A. lacustris*, basibranchials 1 and 2 ossify first (both tied with pharyngobranchial 2). In *S. brasiliensis* the two posteriormost elements, basibranchial 2 and 3, ossify first (Fig. 24).

The hypobranchials ossify in a postero-anterior direction in all three species. In *A. lacustris*, hypobranchial 2 and 1 are the two last elements to ossify in the branchial skeleton and in *C. hujeta* the ossification of those two elements is followed by pharyngobranchials 2 and 1 (Fig. 24). In *S. brasiliensis* the ossification of hypobranchial 1 is only followed by pharyngobranchial 3 tooth plate (Mattox *et al*. Fig. 1).

For the entire branchial skeleton *A. lacustris* had a relative interval of 118.5, *C. hujeta* 107.5 and *S. brasiliensis* 116.

Considering the complete sequence, the ossification of the ceratobranchials, tooth plates and gill rakers occur within the first third of the sequence in all three species, despite the observed differences in the direction of ossification (Fig. 26). The clearest differences are associated to the pharyngobranchials, which are comparatively delayed in *A. lacustris* and *C. hujeta* when compared to *S. brasiliensis*. Other differences include the epibranchials in *C. hujeta* with epibranchial 4 comparatively accelerated (rank 14 vs. 39 in *A. lacustris* and 45 in *S. brasiliensis*), and the remaining epibranchials comparatively delayed, with epibranchial 3 with a rank of 70.5 (vs. 43 in *A. lacustris* and 41.5 in *S. brasiliensis*); epibranchial 2 with a rank of 84 (vs. 55.5 in *A. lacustris* and 41.5 in *S. brasiliensis*) and epibranchial 1, also with a rank of 84 (55.5 in *A. lacustris* vs. 53.5 in *S. brasiliensis*) (Fig. 26).

Differences in the ranks of the basibranchials are also noteworthy, since regardless of the antero-posterior direction of their ossification, *A. lacustris* is relatively delayed in the onset of the ossification of these elements relative to *C. hujeta*, with basibranchials 2 and 3 with rank 99 in *A. lacustris* (vs. 84 in *C. hujeta* and 80 in *S. brasiliensis* for the basibranchial 2); 109.5 vs. 87 in *C. hujeta* and 80 in *S. brasiliensis*, for the basibranchial 3), whereas the basibranchial 1 is comparatively accelerated in *C. hujeta* (78 vs. 99 in *A. lacustris* and 96 in *S. brasiliensis*) (Fig. 26).

Weberian apparatus.

The sequences of ossification of *A. lacustris* and *C. hujeta* are fairly similar to that of *S. brasiliensis*. The several ties observed might influence in the identification of heterochronic events in this complex (Fig. 27). The first elements to ossify in *A. lacustris* and *C. hujeta* are the centra 1 through 4 (not resolved in the sequence) in *S. brasiliensis* the resolution for the four centra was higher, but the first elements to ossified are the tied centra 3 and 4. The last element to ossify across the three species was the claustrum. The relative interval for *A. lacustris* is 75, 79 for *C. hujeta* and 80.5 for *S. brasiliensis*.

Regardless the similar relative interval of the three species, every element of Weberian apparatus in *A. lacustris* is comparatively accelerated in relation to *C. hujeta* and *S. brasiliensis* (Fig. 28). The lowest difference ranks observed was between *A. lacustris* and *S. brasiliensis*, 11.5 for the centra 1 and 2, while the highest was between *A. lacustris* and *C. hujeta*, 47.5 for the tripus.

Axial skeleton.

The first element to ossify in all three species were the vertebral centra. The last element of the axial skeleton to ossify in *A. lacustris* and *C. hujeta* are the supraneurals and in *S. brasiliensis* the last elements to ossify are the intermuscular bones. The relative interval for *A. lacustris* was 85.5, 86 in *C. hujeta* and 86.5 in *S. brasiliensis*. Several differences were observed in the sequences of the three species. The only elements that had the same ranks across the three sequences were the vertebral centra and the neural arches, the first and second elements to ossify. The third ossification to appear in *C. hujeta* and *S. brasiliensis* are the haemal arches, these elements are only the sixth to ossify in *A. lacustris*. The fourth element to ossify in *C. hujeta* and *S. brasiliensis* are the haemal spines, which are the seventh bones to appear in *A. lacustris*. The only other element that shared some similarity between the three species were the supraneurals, which are the last elements to ossify in *A. lacustris* and *C. hujeta*, the supraneurals are the eight in the *S. brasiliensis* sequence. The ribs appear earliest in *A. lacustris* (3^{rd}), they are the seventh in *C. hujeta* and the fifth to ossify in *S. brasiliensis*. The neural spines appear earliest *C. hujeta* (5^{th}), the seventh in *A. lacustris* and sixth in *S. brasiliensis* and. The parapophyses are comparatively accelerated in *A. lacustris* (5^{th}), they are the seventh to appear in *S. brasiliensis* and the eighth in *C. hujeta*. The intermuscular bones are comparatively accelerated in *C. hujeta* (6th), the eight in *A. lacustris* and the last element to ossify in *S. brasiliensis* (Fig. 29).

Despite the several differences in the sequence of ossification within this complex, when compared within the complete sequences they do not show as much variation. The ranks for the vertebral centra, neural arches, the haemal arches and spine and the supraneurals are relatively similar (Fig. 30). Two elements appear to be comparatively accelerated in *A. lacustris*, the ribs (37 vs. 90 in *C. hujeta* and 89.5 in *S. brasiliensis*) and the parapophyses (69 vs. 117.5 in *C. hujeta* and 100 in *S. brasiliensis*). The intermuscular bones are comparatively accelerated in *A. lacustris* and *C. hujeta* (99 in *A. lacustris* and 87 in C, hujeta vs. 122 in *S. brasiliensis*). The neural spines had an interesting behavior, they appear the earliest in *A. lacustris* (62.5), and latest in *S. brasiliensis* (92.5), *C. hujeta* had the almost exact intermediate rank for the neural spines (78) (Fig. 30).

Pectoral girdle.

The cleithrum, supracleithrum and posttemporal are tied for the first three elements to ossify consecutively in all three sequences. The fourth element to ossify in *S. brasiliensis* are the pectoral-fin rays, these elements are the sixth to ossify in *A. lacustris* and are tied with the mesocoracoid for the seventh in *C. hujeta*. From this point forward in the sequence, both *S. brasiliensis* and *A. lacustris* have several ties, what makes the comparisons more difficult. *C. hujeta* was the species with highest resolution in this complex with only the pectoral-fin rays and the mesocoracoid tied for the seventh element to ossify (Fig. 31). The extrascapular is the last element to ossify in *A. lacustris* and *C. hujeta*. In *S. brasiliensis* the extrascapular and mesocoracoid are tied as the last elements to ossify. The relative interval in *A. lacustris* is 128, 133.5 in *C. hujeta* and 131.5 in *S. brasiliensis*.

The cleithrum is observed in the smallest examined specimens of the three species. Despite the ties among elements and differences between sequences the three species had the pectoral girdle elements with similar ranks for the complete sequence (Fig. 32). The highest differences were observed for the posttemporal (75.5 in *A. lacustris*, 62 in *C. hujeta* and 52.5 in *S. brasiliensis*,) and the pectoral-fin rays (124 in *A. lacustris*, 134.5 in *C. hujeta* and 116 in *S. brasiliensis*,).

Pelvic girdle.

The pelvic-fin middle and lateral radials were excluded from this comparison since their ossification was not observed in the sequence of *C. hujeta*. The pelvic-fin lateral radial is the second to last to ossify and the pelvic-fin middle radial is the last within the pectoral girdle elements both in *S. brasiliensis* and *A. lacustris*. The three shared elements had the same order of appearance across the three sequences, the pelvic-fin rays being the first, followed by the basipterygium and finally the pelvic-fin middle radial. The relative interval in *A. lacustris* is 13.5, 15 in *C. hujeta* and 15.5 in *S. brasiliensis*.

Considering the complete sequence, the pelvic girdle elements ossify with similar timings across the three species, within the last quarter of the complete sequence (Fig. 33).

Dorsal and anal fins.

The ossification sequence of the three elements that constitute the dorsal and anal fin supporting skeleton did not vary among the sequences of the three species. The rays are the first to ossify, followed by the proximal-middle radials and finally by the distal radials. The relative interval for the dorsal fin in *A. lacustris* is 25.5, 36.5 in *C. hujeta* and 67 in *S. brasiliensis*. The relative interval for the anal fin in *A. lacustris* is 20.5, 88 in *C. hujeta* and 80 in *S. brasiliensis*.

Considering the complete sequence, the dorsal-fin rays are considerably delayed in *A. lacustris* and *C. hujeta* (84 in *A. lacustris* and 94 in *C. hujeta* vs. 41.5 in *S. brasiliensis*). The dorsal proximal-middle radials are also comparatively delayed in *A. lacustris* and *C. hujeta*, but not as markedly as the dorsal-fin rays (99 in *A. lacustris* and 107 in *C. hujeta* vs. 86.5 in *S. brasiliensis*). Whereas the dorsal distal radials are comparatively delayed in *C. hujeta* in relation to the other two species that had very similar ranks (130.5 vs. 109.5 in *A. lacustris* and 108.5 in *S. brasiliensis*) (Fig. 34).

The anal-fin rays are considerably delayed in *A. lacustris* (84 vs. 38.5 in *C. hujeta* and 35.5 in *S. brasiliensis*). The proximal-middle radials appear earliest in *C. hujeta*, while the other two species had similar ranks for this element (65 vs. 86.5 in *A. lacustris* and 80 in *S. brasiliensis*). Alternatively, when comparing the ranks of the distal radials the order is comparatively reversed, *C. hujeta* has the distal radials ossifying the latest (126.5 vs. 109.5 in *A. lacustris* and 116 in *S. brasiliensis*) (Fig. 35).

In *A. lacustris* the dorsal and anal fins have their elements ossifying with similar timings, 84 for the tied dorsal and anal-fin rays; 99 and 86.5 for the dorsal and anal-fin proximal-middle radials, respectively; and 109.5 for the tied dorsal and anal-fin distal radials (Figs. 34 and 35). Similar variation was observed for *S. brasiliensis*, dorsal and anal fins have similar ossification ranks for their elements. Moreover, both fins in *A. lacustris* have comparatively short intervals between the ossification of the first and last elements (84 and 109.5 for both fins), in contrast to both fins in *S. brasiliensis* (41.5 and 108.5 for the dorsal fin and 35.5 and 116 for the anal fin) and the anal fin in *C. hujeta* (38.5 and 126.5).

The dorsal fin starts to develop much later than the anal fin in *C. hujeta*, in contrast to the similar ranks described above for *S. brasiliensis* and *A. lacustris*. The anal-fin rays ossify relatively early (38.5), similar to *S. brasiliensis*, while the dorsal-fin rays will only ossify much later (94), even later than *A. lacustris* (Figs. 34 and 35).

Caudal-fin skeleton.

The first element of the caudal-fin skeleton to ossify are the principal caudal-fin rays in all three species. The last element to ossify in *C. hujeta* is the epural 2, in *A. lacustris* the epural 2 is tied to the epural 1 as the last element to ossify whereas in *S. brasiliensis* the epural 2 and the dorsal procurrent caudal-fin rays are tied as the last to ossify. The relative interval for *A. lacustris* is 70.5, 76.5 in *C. hujeta* and 91 in *S. brasiliensis*. The large number of elements and the lack of resolution in the sequence of ossification of the caudal skeleton for all three species the several ties render the comparison among the sequence in the three species difficult (Fig. 36). However, some differences are evident. The ossification of uroneural 1 is comparatively delayed in *A. lacustris* (rank 21 vs. 5 in *S. brasiliensis* and 7.5 in *C. hujeta*). The ossification of neural spine of preural centrum 2 is comparatively accelerated in *A. lacustris* (rank 5 vs. 13.5 in *S. brasiliensis* and 18 in *C. hujeta*).

Considering the complete sequence, the three species apparently have the caudal-fin skeleton elements ossifying with similar timings. Uroneural 1 and the neural spine of preural centrum 2 of *A. lacustris* still have diverging ranks from the other two species (88.5 in *A. lacustris* vs. 52.5 in *S. brasiliensis* and 53.5 in *C. hujeta* for the uroneural 1 and 55.5 in *A. lacustris* vs. 80 in *S. brasiliensis* and 78.5 in *C. hujeta*). The dorsal procurrent rays are comparatively accelerated in *A. lacustris* and *C. hujeta* (90.5 in *A. lacustris* and 89 in *C. hujeta* vs. 108.5 in *S. brasiliensis*) (Fig. 37). The caudal-fin skeleton starts to ossify later in *A. lacustris* and *C. hujeta* when compared to *S. brasiliensis* (Fig. 37), however the difference between the ranks of the first and last elements to ossify in *A. lacustris* and *C. hujeta* is smaller (70.5 and 76.5 respectively vs. 91 in *S. brasiliensis*).

Discussion

Trends of the skeletogenesis of *Salminus brasiliensis*, *Astyanax lacustris* and *Ctenolucius hujeta*.

Several differences were observed among the three sequences of ossification compared in the current study. Differences in the complete sequence as well as differences in sequence of ossification within a particular osteological complex. We did not identify a higher global similarity among two particular sequences as it would be expected to the more closely related *A. lacustris* and *S. brasiliensis* in relation to *C. hujeta* or the two smaller sized *A. lacustris* and *C. hujeta* in relation to the large sized *S. brasiliensis*.

The first elements to ossify in the skeleton of all three species are the tooth plates of ceratobranchial 5 and pharyngobranchial 4 and the cleithrum (with no resolution in their order of ossification). In *A. lacustris* and *C. hujeta* the onset of the ossification of the opercle is also tied with that of those ossifications. The dentary, maxilla and premaxilla also appear early in the sequence of all three species, despite some differences in the order in which they appear in each taxon. The three species showed less similarities regarding the last element to ossify In *A. lacustris* the last three ossifications to appear are the interhyal and infraorbitals 5 and 6 tied as the last element to ossify. In *C. hujeta* the last elements to ossify are the pectoral-fin rays, mesocoracoid and infraorbitals 5 and 6 tied as the second to last to ossify followed by the extrascapular. In *S. brasiliensis* the last elements to ossify are the tied autopalatine and extrascapular followed by the pelvic-fin medial radial and finally the infraorbital 6.

The complexes that showed the most differences between the three species were the olfactory region of the neurocranium, with the lateral ethmoid with three distinct ranks within the complex, and the hyopalatine arch that showed a considerable amount of variation specially for the hyomandibular and metapterygoid.

In some instances, the sequence within a complex is relatively conserved across the three species, but the ossification of the entire osteological complex was shifted in the complete sequence when compared to the other species. This was the case for the Weberian apparatus, with similar sequences among the three species (Fig. 21). However, a clear comparative acceleration is observed in *A. lacustris* that had all elements of the Weberian apparatus ossifying earlier in the complete sequence when compared to *S. brasiliensis* and *C. hujeta* (Fig. 22).

Another type of variation observed across the three species was differences in the sequence within an anatomical complex (*e. g.* the hyopalatine arch, Fig. 13). However, the observed differences within said complex were not translated in drastic differenced in the context of the complete sequence. When compared among the complete sequence the elements of the anatomical complex showed similar ranks (*e. g.* the hyopalatine arch, Fig. 14). This indicates that changes can occur in the ossification sequence within a complex with no drastic effects on the ossification timing of the entire complex within the complete sequence.

A noteworthy observed difference is related to the sequence of ossification of metameric structures such as the ceratobranchials and epibranchials that ossify posteroanteriorly in *A. lacustris* and *C. hujeta* and anteroposteriorly in *S. brasiliensis*. Difference in the sequence of the basibranchials were also observed, alternatively these structures ossify anteroposteriorly in *A. lacustris* and *C. hujeta* and posteroanteriorly in *S. brasiliensis*.

The dorsal and anal fins had the same sequence within the complex across the three species but, showed some interesting differences when compared within the complete sequence. In *A. lacustris* the anal fin start to develop rather late, but this delay does not result in a delay of the formation of the entire fin, *A. lacustris* is the species in which the anal-fin distal radial, the last element of the anal fin to ossify, ossified earlier than in A. brasiliensis and *C. hujeta*. This indicated that specific elements of a given anatomical complex can be accelerated or delayed with no effects on the timing of ossification of the remaining elements.

The relative interval of ossification of all elements within an osteological complex was similar across the three species for most of the osteological complexes. Differences of the relative interval were observed in the olfactory and occipital regions the neurocranium, for the opercular series and dorsal and anal fins. For the olfactory region of the neurocranium *A. lacustris* was the species with the lowest relative interval (30 vs. 64 in *C. hujeta* and 51,5 in *S. brasiliensis*) indicating that the elements of this osteological complex are relatively closer together in the context of the complete sequence when compared to the other two species. Alternatively, for the opercle series *A. lacustris* had the highest relative interval (77.5 vs. 36 in *C. hujeta* and 23 in *S. brasiliensis*), indicating that these elements are more spread apart in the context of the entire sequence when compared to the other two species.

Conclusions

The comparative analysis of complete ossification sequences for representatives of Characiformes presented herein showed that there is a considerable amount of variation among the sequence of ossification of *Astyanax lacustris, Ctenolucius hujeta* and *Salminus brasiliensis,* anatomical complexes with the same ossification sequence across the three species were a minority. The observed variation includes: (i) different sequence of ossification within an osteological complex, in these cases the differences within a complex can be coupled with alterations in the timing of the ossification of the complex in the context of the entire sequence (*e. g.* observed for the olfactory region of the neurocranium) or not (*e. g.* hyopalatine arch); (ii) different relative intervals between the ossification of the first and last element in an osteological complex, despite identical sequences within the complex (*e. g.* relative interval of the elements of the occipital region of the neurocranium in *C. hujeta*); (iii) shift of an entire osteological complex in the complete sequence, despite similar sequences and relative intervals across the three species (*e. g.* Weberian apparatus).

The observed degree variation indicates that the ossification sequences are a promising source of information. Comparative studies employing ossification sequences of the entire skeleton could point to heterochronic changes between taxa that could be explored in a functional anatomy perspective, as well as in developmental genetic approach. Moreover, the complete ossification sequences could be used in a phylogenetics systematics framework in a similar way as nucleotides and amino acids sequences are used.

References

Adriaens, D. & Verraes, W. 1998. Ontogeny of the osteocranium in the African catfish, *Clarias gariepinus* Burchell (1822) (Siluriformes: Clariidae): ossification sequence as a response to functional demands. *Journal of Morphology*, 235: 183-237.

Adriaens, D., Verraes, W. & Taverne, L. 1997. The cranial lateral-line system in *Clarias gariepinus* (Burchell, 1822) (Siluroidei: Clariidae). Morphology and development of canal related bones. *European Journal of Morphology,* 35: 181-208.

Arratia, G. & Bagarinao, T. 2010. Early ossification and development of the cranium and paired girdles of *Chanos chanos* (Teleostei, Gonorynchiformes). Pp. 73-106 in: Grande, T., Poyato-Ariza, F. J. & Diogo, R. (eds.), Gonorynchiformes and ostariophysan relationships – a comprehensive review. Science Publishers, Enfield.

Arratia, G. & Schultze, H-P. 1992. Reevaluation of the caudal skeleton of certain actinopterygian fishes: III Salmonidae. Homologization of caudal skeleton structures. *Journal of Morphology*. 214: 187-249

de Beer, G. R. 1927. The early development of the chondrocranium of *Salmo fario*. *Quarterly Journal of Microscopic Sciences*, 71: 259-312.

de Beer, G. R. 1937. The development of the vertebrate skull. Claredon Press, Oxford.

Bertmar, G. 1959. On the ontogeny of the chondral skull in Characidae, with a discussion on the chondrocranial base and the visceral chondrocranium in fishes. *Acta Zoologica* (Stockholm), 40: 203-364.

Bird, N. C. & Mabee, P. M. 2003. Developmental morphology of the axial skeleton of the zebrafish, *Danio rerio* (Ostariophysi: Cyprinidae). *Developmental Dynamics*, 228: 337-357.

Britz. R. & Conway, K.W. 2009. Osteology of *Paedocypris*, a miniature and highly developmentally truncated fish (Teleostei: Ostariophysi: Cyprinidae). *Journal of Morphology*. 270: 389–412.

Britz, R., Conway, K. W. & Rüber, L. 2009. Spectacular morphological novelty in a miniature cyprinid fish, *Danionella dracula* n. sp. *Proceedings of the Royal Society B*, 276, 2179–2186.

Britz, R. & Hoffmann, M. 2006. Ontogeny and homology of the claustra in otophysan Ostariophysi (Teleostei). *Journal of Morphology*, 267: 909-923.

Britz, R. & Johnson, G. D. 2002. “Paradox lost”: skeletal ontogeny of the paradox fish, *Indostomus paradoxus*, and its significance for the phylogenetic relationships of Indostomidae (Teleostei: Gasterosteiformes). *American Museum Novotates*. 3383: 1-36.

Britz, R. & Johnson, G. D. 2005. Leis’s Conundrum: homology of the clavus in Ocean Sunfishes. 1. Ontogeny of the median fins and axial skeleton of *Monotrete leiurus* (Teleostei, Tetraodontiformes, Tetraodontidae). *Journal of Morphology*. 266: 1-10.

Carvalho, M. & Vari, R. P. 2015. Development of the splanchnocranium in *Prochilodus aregenteus* (Teleostei: Characiformes) with a discussion of the basal developmental patterns in the Otophysi. *Zoology* 118. 34-50.

Conway, K. W., Kubicek, K. M & Britz, R. 2017. Morphological novelty and modest developmental truncation in *Barboides*, Africa’s smallest vertebrates (Teleostei: Cyprinidae). *Journal of Morphology* 278 (6): 750-767.

Cubbage, C. C. &. Mabee, P. M. 1996. Development of the cranium and paired fins in the zebrafish *Danio rerio* (Ostariophysi: Cyprinidae). *Journal of Morphology*, 229: 121-160.

Datovo, A. & Vari, R. P. 2013. The jaw adductor muscle complex in teleostean fishes: evolution, homologies and revised nomenclature (Osteichthyes: Actinopterygii). *PLoS ONE*, 8:e60846.

Engeman, J. M., Aspinwall, N. & Mabee, P. M. 2009. Development of the pharyngeal arch skeleton in *Catostomus commersonii* (Teleostei: Cypriniformes). *Journal of Morphology*, 270: 291-305.

Fraser, G. J., Britz, R., Hall, A., Johanson, Z. & Smith, M. M. 2012. Replacing the first-generation dentition in pufferfish with a unique beak. *Proceedings of the National Academy* of Sciences, USA, 109: 8179-8184.

Geerinckx, T., Brunain, M. & Adriaens, D. 2007. Development of the osteocranium in the suckermouth armored catfish *Ancistrus* cf. *triradiatus* (Loricariidae, Siluriformes). Journal of Morphology, 268: 254-274.

Hoffmann, M. & Britz, R. 2006. Ontogeny and homology of the neural complex of otophysan Ostariophysi. *Zoological Journal of the Linnean Society*, 147: 301-330.

Kohno, H., Ordonio-Aguilar, R., Ohno, A. & Taki, Y. 1996. Morphological aspects of feeding and improvement in feeding ability in early stage larvae of the milkfish, *Chanos chanos*. *Ichthyological Research*, 43: 133-140.

Mabee, P. M., Crotwell, P. L., Bird, N. C. & Burke A. C. 2002. Evolution of median fins modules in the axial skeleton of fishes. *Journal of Experimental Zoology Part B: Molecular and Developmental Evolution*, 294: 77-90.

Mattox, G. M. T., Britz, R. & Toledo-Piza, M. 2014. Skeletal development and ossification sequence of the characiform *Salminus brasiliensis* (Ostariophysi: Characidae). *Ichthyological Explorations of Freshwaters*. 25(2): 103-158.

Mattox, G. M., Britz, R., & Toledo-Piza, M. 2016. Osteology of *Priocharax* and remarkable developmental truncation in a miniature Amazonian fish (Teleostei: Characiformes: Characidae). *Journal of Morphology*, 277, 65–85.

Mirande, J. M. 2018. Morphology, molecules and the phylogeny of Characidae (Teleostei, Characiformes). *Cladistics*. 35: 282-300.

Nelson, G. 1978. Ontogeny, Phylogeny, Paleontology and the Biogenetic Law. *Systematic Zoology*. 27 (3): 324.345

Nelson, G. 1985. Outgroups and Ontogeny. *Cladistics*.1 (1): 29-45.

Nunn, C. L. & Smith, K. K. 1998. Statistical analyses of developmental sequences: the craniofacial region in marsupial and placental mammals. *The American Naturalist.* 152(1): 82-101.

Powers, A. K., Davis, E. M., Kaplan, S.A. & Gross, J. B. 2017 Cranial asymmetry arises later in the life history of the blind Mexican cavefish, *Astyanax mexicanus*. *PLoS ONE* 12(5): e0177419.

Powers, A. K., Kaplan, S. A., Boggs, T. E. & Gross, J. B. 2018. Facial bone fragmentation in blind cavefish arises through two unusual ossification processes. *Scientific Reports*. (2018) 8: 7015. 1-10.

Roberts, T. 1969. Osteology and relationships of characoid fishes, particularly the genera *Hepsetus*, *Salminus*, *Hoplias*, *Ctenolucius*, and *Acestrorhynchus*. *Proceeding of the California Academy of Sciences*, 36: 391-500.

Taki, Y., Kohno, H & Hara, S. 1986. Early development of fin-supports and fin-rays in the milk fish *Chanos chanos*. *Japanese Journal of Ichthyology*. 32: 413-420.

Taylor, W. R. & van Dyke, G. C. 1985. Revised procedures for staining and clearing small fishes and other vertebrates for bone and cartilage study. *Cybium*, 9: 107-119.

Vandewalle, P., Focant, B., Huriaux, F. & Chardon, M. 1992. Early development of the cephalic skeleton of *Barbus barbus* (Teleotei, Cyprinidae). *Journal of Fish Biology*, 41: 43-62.

Vari, R. P. 1995. The Neotropical fish family Ctenoluciidae (Teleostei: Ostariophysi: Characiformes): supra and intrafamilial Phylogenetic Relationships, with a revisionary study. *Smithsonian Contributions to Zoology*. 564: 1-97.

Walter, B. E. 2013. Cranial skeletogenesis and osteology of the redeye tetra *Moenkhausia sanctaefilomenae*. *Journal of Fish Biology*, 82: 69-95.

Weitzman, S. H. 1962. The osteology of *Brycon meeki*, a generalized characid fish, with an osteological definition of the family. *Stanford Ichthyological Bulletin*, 8: 1-77.

Tables

Table 1. Rank values for the complete sequence of ossification of the shared elements among *Salminus brasiliensis*, *Astyanax lacustris* and *Ctenolucius hujeta*.

	Rank SB	**Rank AL**	**Rank CH**
Cleithrum	2	2.5	2.5
Tooth plate cb5	2	2.5	2.5
Tooth plate pb5	2	2.5	2.5
Dentary	5	5	6.5
Opercle	5	2.5	2.5
Premaxilla	5	7.5	11.5
Maxilla	7	7.5	6.5
Branchiostegal rays	8	10.5	16
Anterior ceratohyal	10.5	15.5	11.5
Basioccipital	10.5	6	6.5

Parasphenoid	10.5	10.5	9
Quadrate	10.5	15.5	11.5
Hyomandibular	13.5	30	38.5
Urohyal	13.5	31	26
Ceratobranchial 1	15.5	24	25
Retroarticular	15.5	24	16
Caudal-fin principal rays	17.5	39	31
Ceratobranchial 2	17.5	15.5	23.5
Ceratobranchial 3	20.5	15.5	23.5
Endopterygoid	20.5	24	46.5
Exoccipital	20.5	24	28.5
Ventral hypohyal	20.5	46.5	16
Ceratobranchial 5	25	10.5	6.5
Gill rakers	25	10.5	19
Interopercle	25	41.5	38.5
Subopercle	25	33.5	30
Symplectic	25	15.5	19
Preopercle	28	80	38.5
Posterior ceratohyal	29	33.5	19
Angular	30.5	24	21.5
Supracleithrum	30.5	36	38.5
Anal-fin rays	35.5	84	38.5
Centrum 3	35.5	24	38.5
Centrum 4	35.5	24	38.5
Ceratobranchial 4	35.5	15.5	11.5
Hypural 1	35.5	55.5	38.5
Hypural 2	35.5	55.5	38.5
Parhypural	35.5	55.5	48
Post-Weberian vertebral centra	35.5	24	38.5
Centrum 2	41.5	24	38.5
Dorsal-fin rays	41.5	84	94
Epibranchial 2	41.5	55.5	84
Epibranchial 3	41.5	43	70.5
Articular	45	24	21.5
Epibranchial 4	45	39	14
Post-Weberian neural arches	45	33.5	53.5
Centrum 1	52.5	24	38.5
Dorsal hypohyal	52.5	46.5	27
Ectopterygoid	52.5	62.5	53.5
Epibranchial 1	52.5	55.5	84
Haemal arch pu2	52.5	55.5	53.5
Haemal spine pu2	52.5	55.5	53.5
Hypural 3	52.5	55.5	38.5
Metapterygoid	52.5	41.5	38.5
Neural arch 4	52.5	33.5	53.5

Pharyngobranchial 3	52.5	86.5	103
Posttemporal	52.5	75.5	62
Uroneural 1	52.5	88.5	53.5
Frontal	59	39	28.5
Haemal spine pu3	61.5	69	60
Neural arch pu2	61.5	69	78
Neural arch pu3	61.5	69	78
Post-Weberian haemal arches	61.5	75.5	65
Pharyngobranchial 2	64	99	111
Caudal-fin ventral preocurrent rays	69.5	69	60
Haemal arch pu3	69.5	69	60
Hypural 4	69.5	69	53.5
Hypural 5	69.5	80	70.5
Intercalarium	69.5	46.5	78
Mesethmoid	69.5	99	53.5
Neural arch 3	69.5	46.5	65
Pharyngobranchial 1	69.5	118	122
Prootic	69.5	46.5	46.5
Scaphium	69.5	46.5	78
Anal-fin proximal-middle radials	80	86.5	65
Basibranchial 2	80	99	84
Basibranchial 3	80	109.5	87
Coronomeckelian	80	99	112
Neural spine pu2	80	55.5	78
Neural spine pu3	80	69	78
Post-Weberian haemal spines	80	80	73
Preural centrum 1	80	69	65
Preural centrum 2	80	69	78
Preural centrum 3	80	69	87
Sphenotic	80	80	53.5
Dorsal-fin proximal-middle radials	86.5	99	107
Ural centrum 1	86.5	77	70.5
Supraoccipital	88	80	53.5
Os suspensorium inner arm	89.5	55.5	103
Post-Weberian ribs	89.5	37	90
Basihyal	92.5	99	65
Hypobranchial 3	92.5	109.5	94
Post-Weberian neural spines	92.5	62.5	78
Os suspensorium outer arm	92.5	55.5	103
Basibranchial 1	96	99	78
Hypobranchial 2	96	120	107
Pterosphenoid	96	90.5	94
Lateral ethmoid	98	92	98
Hypural 6	99	99	94
Parapophyses	100	69	117.5

Tripus	101	55.5	103
Epural 1	104	109.5	107
Neural spine 4	104	84	99.5
Orbitosphenoid	104	99	99.5
Uroneural 2	104	99	94
Vomer	104	114.5	68
Caudal-fin dorsal procurrent rays	108.5	90.5	89
Dorsal-fin distal radials	108.5	109.5	130
Epural 2	108.5	109.5	117.5
Supraneural 3	108.5	88.5	103
Parietal	111	114.5	94
Intercalar	112	99	117.5
Pterotic	113	109.5	70.5
Hypobranchial 1	114	121	110
Anal-fin distal radials	116	109.5	126.5
Claustrum	116	99	117.5
Pectoral-fin rays	116	124	133.5
Epiotic	118	116.5	94
Pelvic-fin rays	119.5	119	113
Post-Weberian supraneurals	119.5	109.5	124.5
Nasal	121	122.5	117.5
Intermuscular bones	122	99	87
Basipterygium	124	122.5	117.5
Postcleithrum 1	124	116.5	109
Scapula	124	128	130
Coracoid	126.5	128	126.5
Interhyal	126.5	134	117.5
Infraorbital 1	128	130.5	123
Infraorbital 2	129.5	126	124.5
Mesocoracoid	129.5	128	133.5
Infraorbital 3	131.5	132.5	130
Infraorbital 5	131.5	135.5	133.5
Autopalatine	133.5	125	117.5
Extrascapular	133.5	130.5	136
Pelvic-fin medial radial	135	132.5	128
Infraorbital 6	136	135.5	133.5

Figures

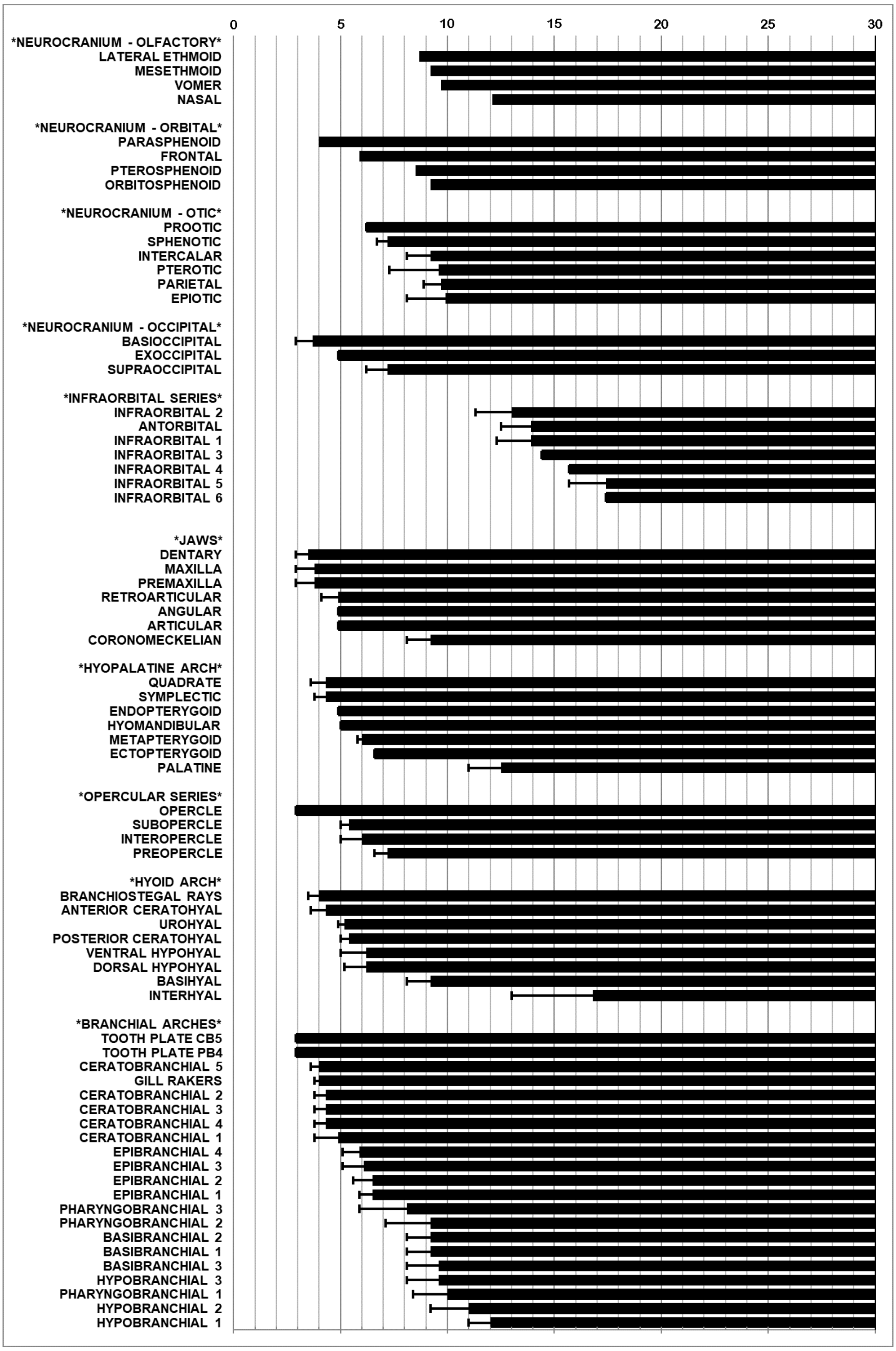


Figure 1. Diagram of sequence of ossification of *Astyanax lacustris* organized by anatomical complexes of the head. First appearance of ossifications shown as thin vertical lines, fixed presence of ossifications shown as thick horizontal line. Thin horizontal line represents lengths at which ossification may be present or absent. Lengths given in mm NL/SL.

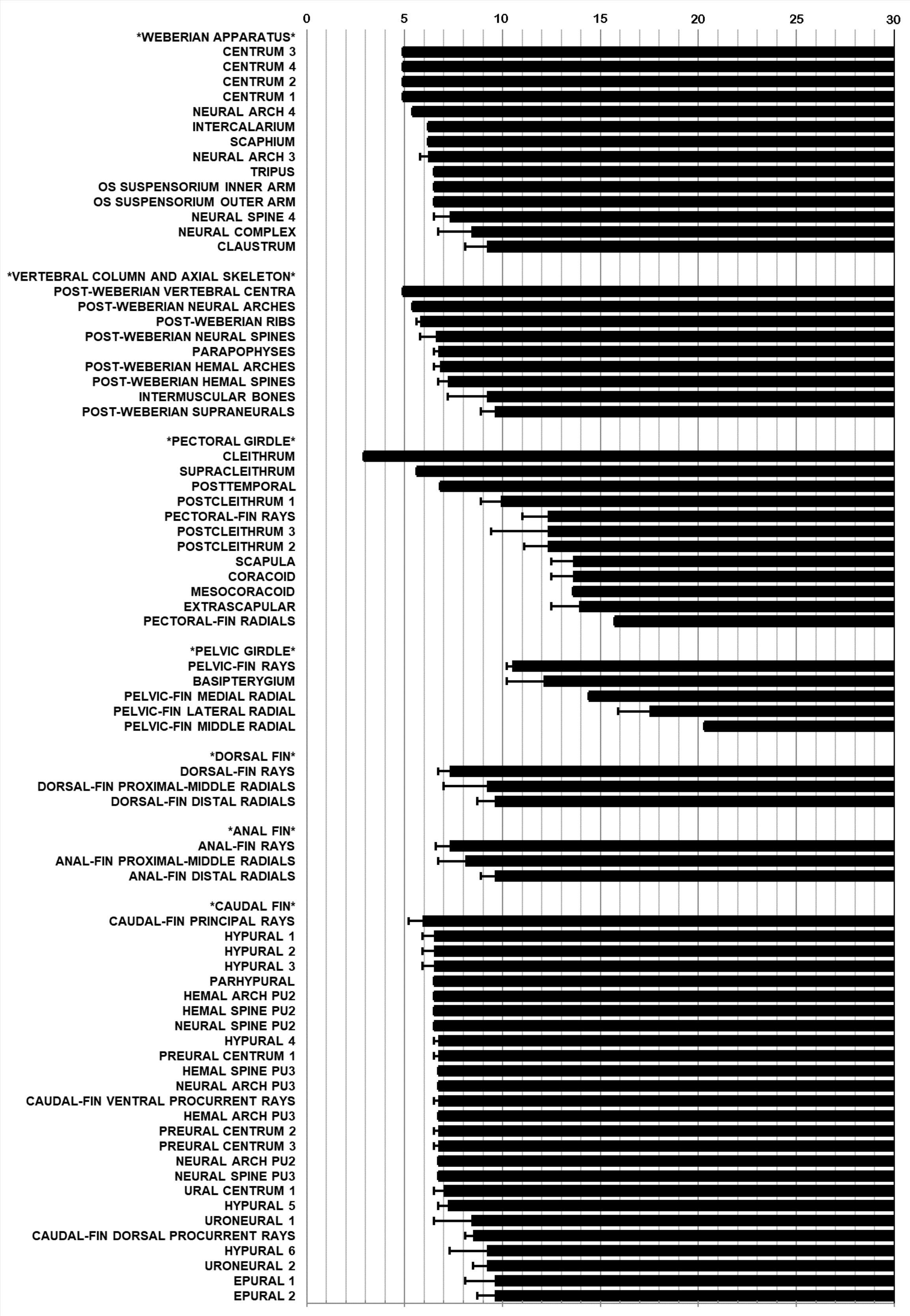


Figure 2. Diagram of sequence of ossification of *Astyanax lacustris*, organized by anatomical complexes of the post-cranial skeleton. First appearance of ossifications shown as thin vertical lines, fixed presence of ossifications shown as thick horizontal line. Thin horizontal line represents lengths in which ossification may be present or absent. Lengths given in mm NL/SL.

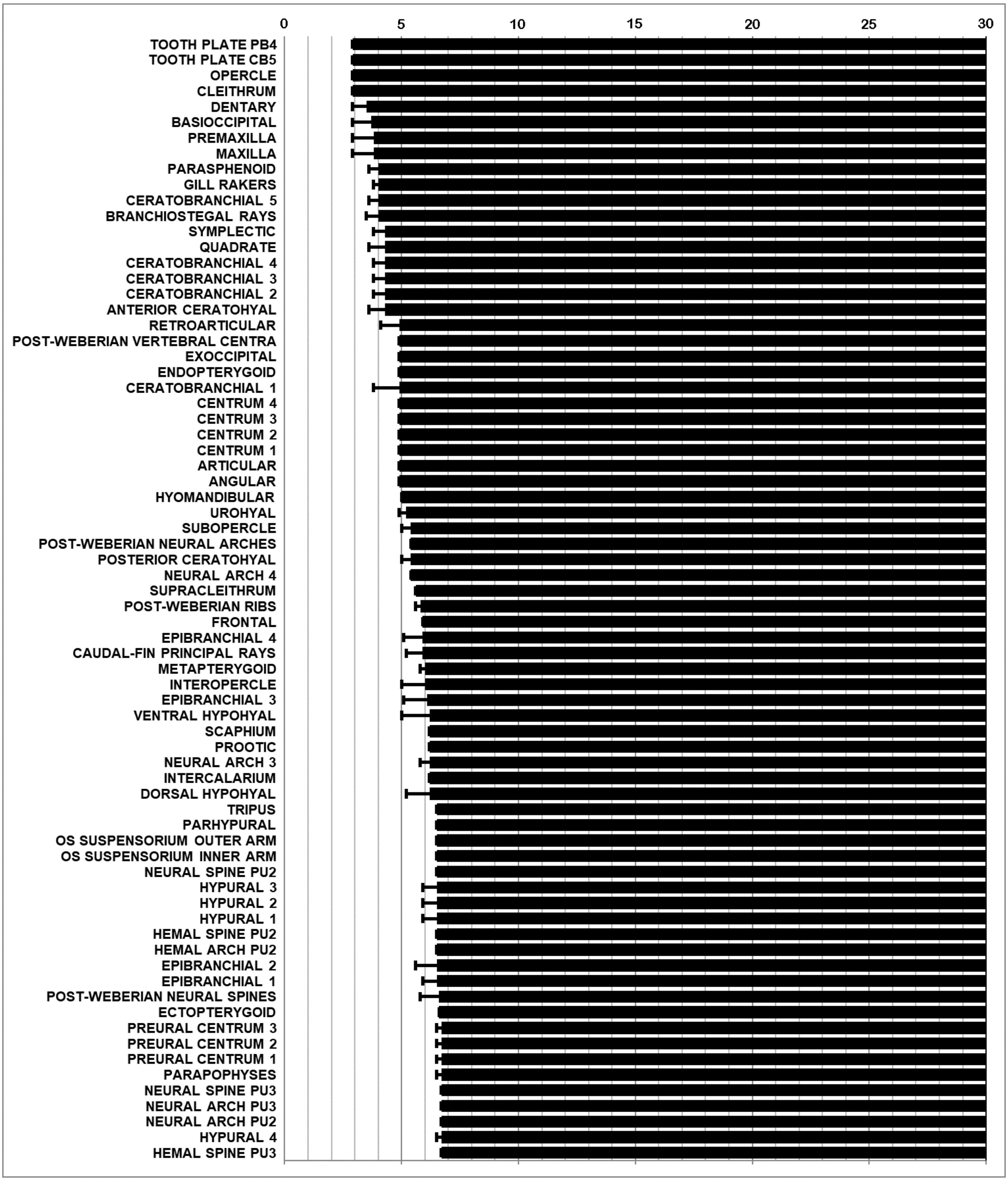


Figure 3. Diagram of sequence of ossification for the complete skeleton of *Astyanax lacustris*. First appearance of ossifications shown as thin vertical line, fixed presence of ossifications shown as thick horizontal line. Thin horizontal line represents lengths in which ossification may be present or absent. Lengths given in mm NL/SL.

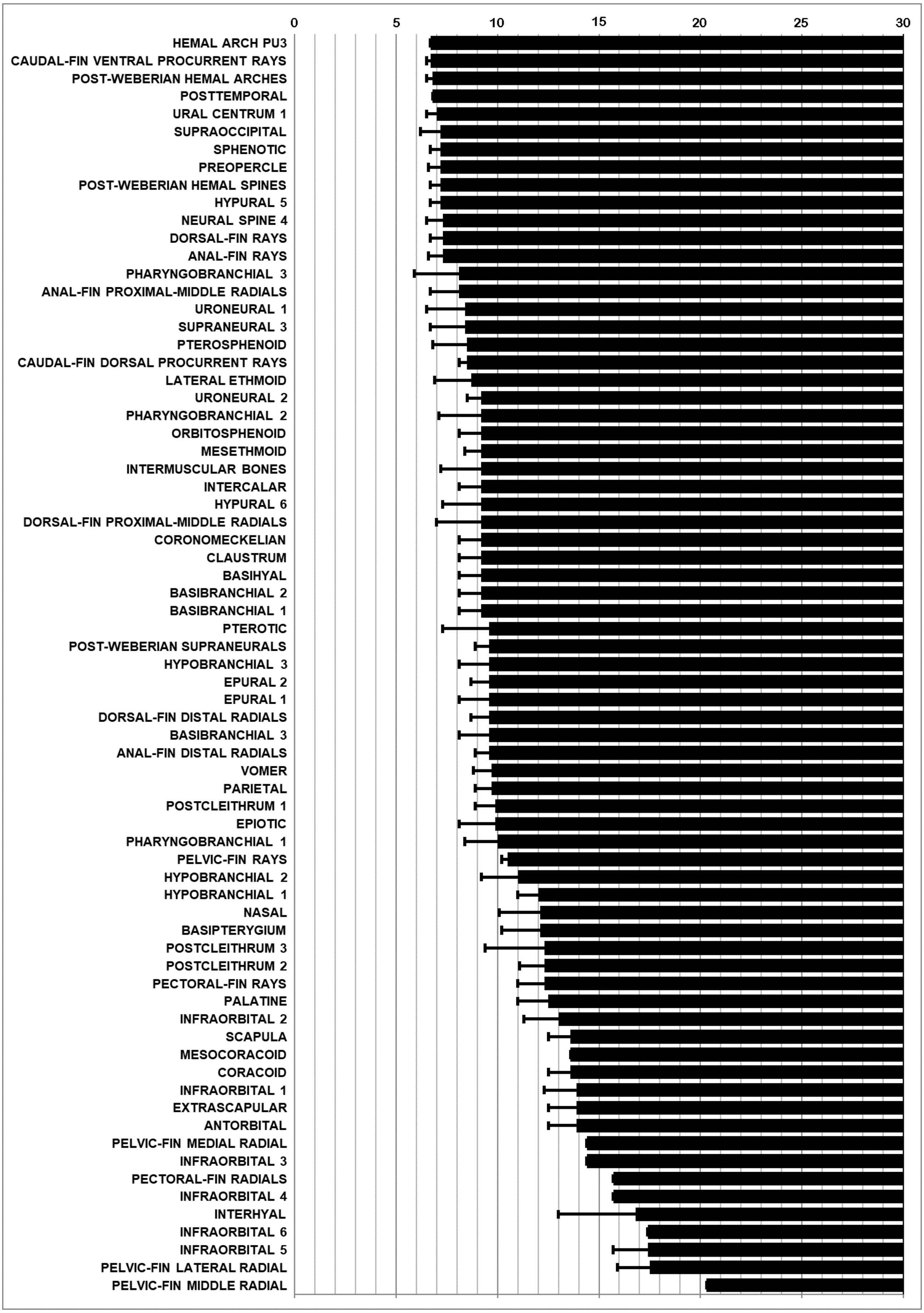


Figure 3. (continued).

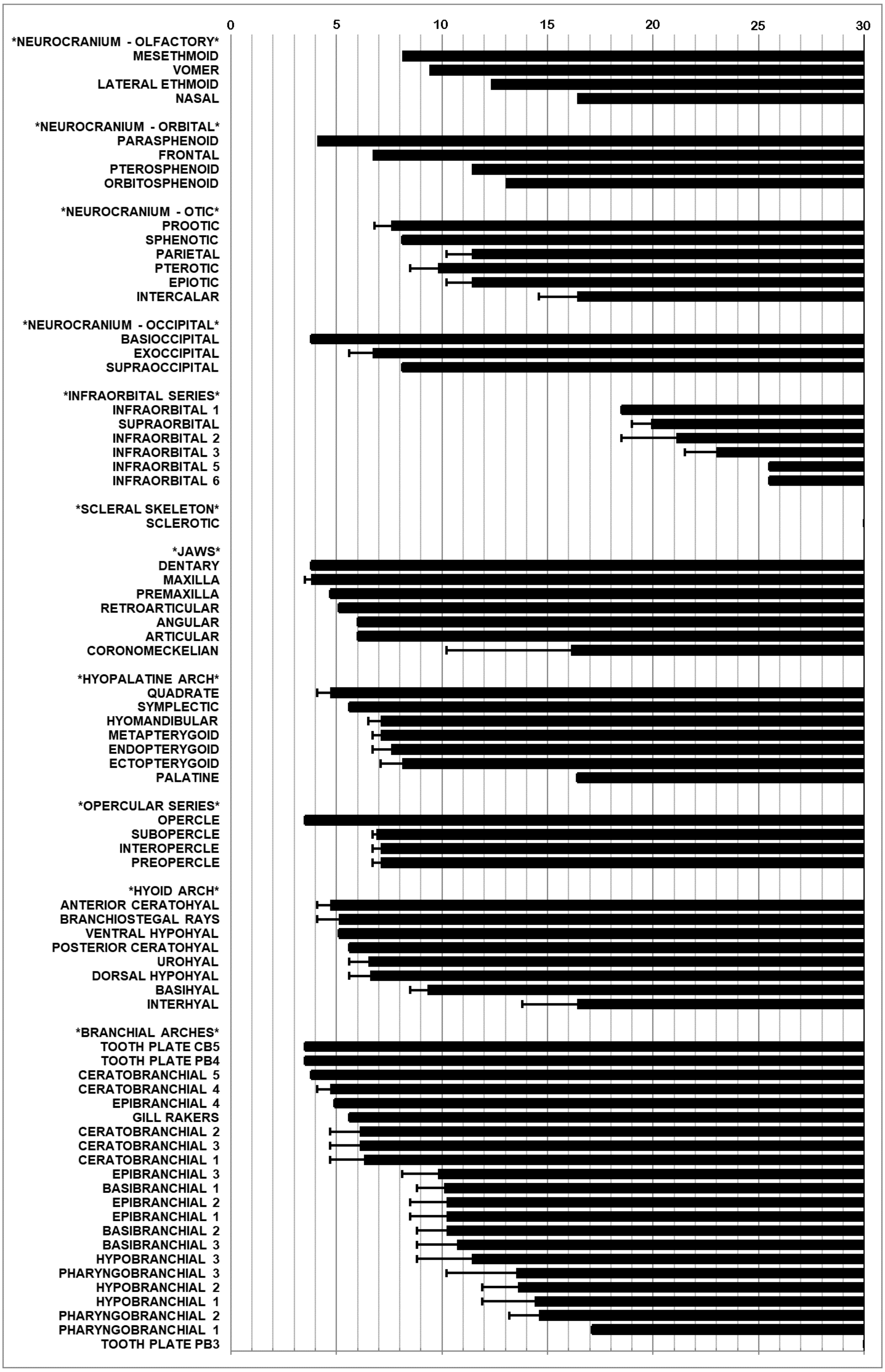


Figure 4. Diagram of sequence of ossification of *Ctenolucius hujeta* organized by anatomical complexes of the head. First appearance of ossifications shown as thin vertical lines, fixed presence of ossifications shown as thick horizontal line. Thin horizontal line represents lengths at which ossification may be present or absent. Lengths given in mm NL/SL.

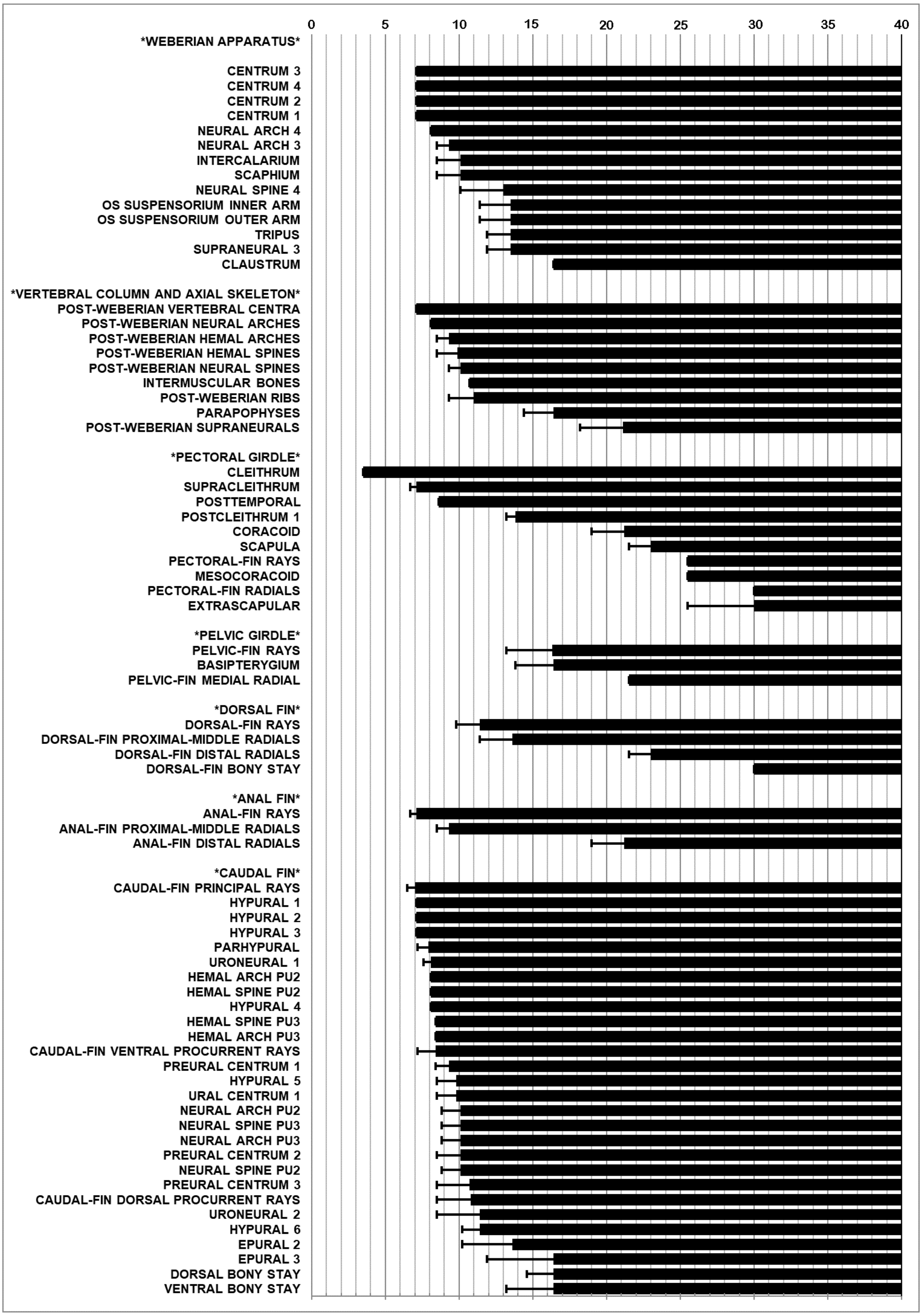


Figure 5. Diagram of sequence of ossification of *Ctenolucius hujeta*, organized by anatomical complexes of the post-cranial skeleton. First appearance of ossifications shown as thin vertical lines, fixed presence of ossifications shown as thick horizontal line. Thin horizontal line represents lengths in which ossification may be present or absent. Lengths given in mm NL/SL.

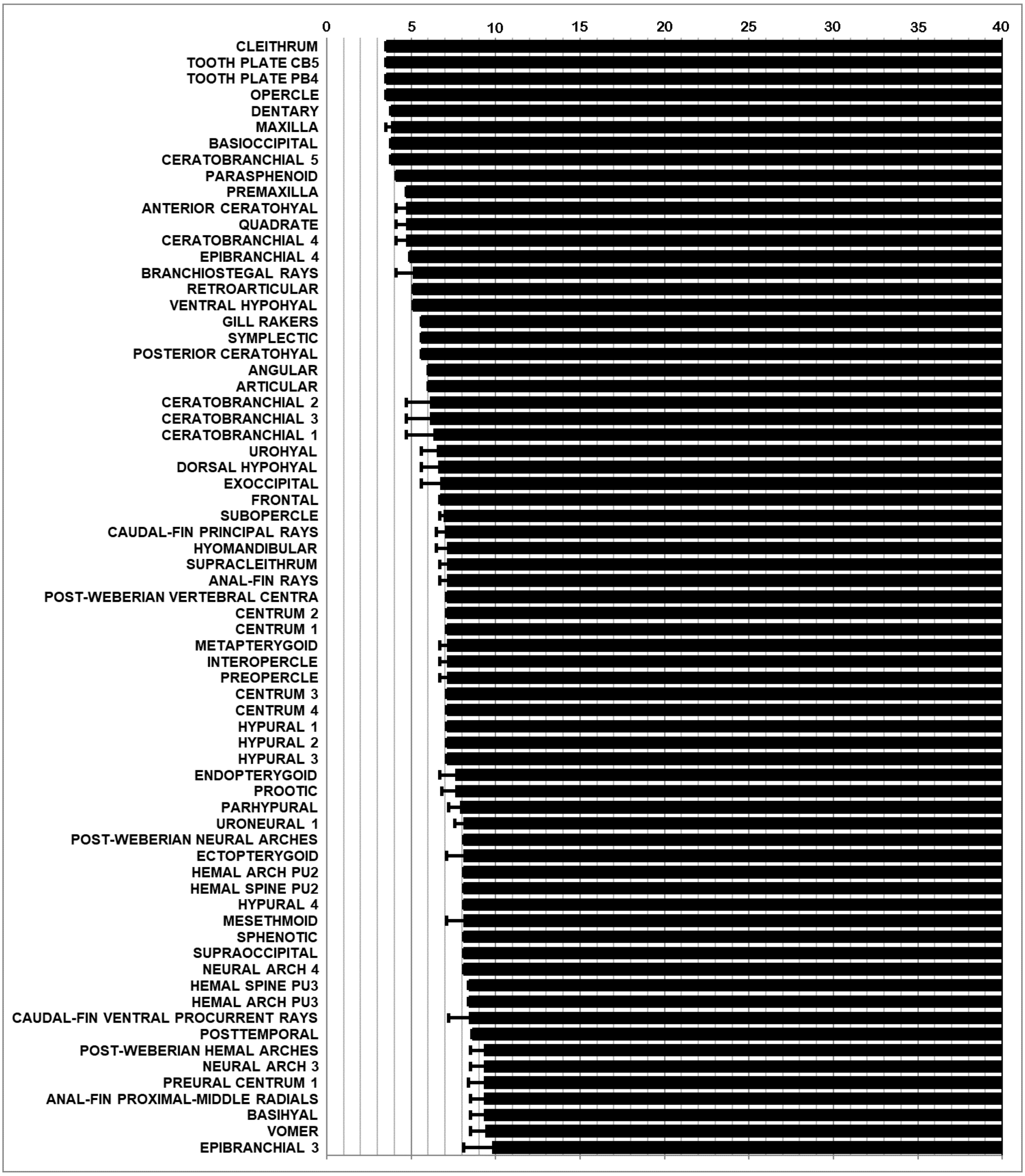


Figure 6. Diagram of sequence of ossification for the complete skeleton of *Ctenolucius hujeta*. First appearance of ossifications shown as thin vertical line, fixed presence of ossifications shown as thick horizontal line. Thin horizontal line represents lengths in which ossification may be present or absent. Lengths given in mm NL/SL.

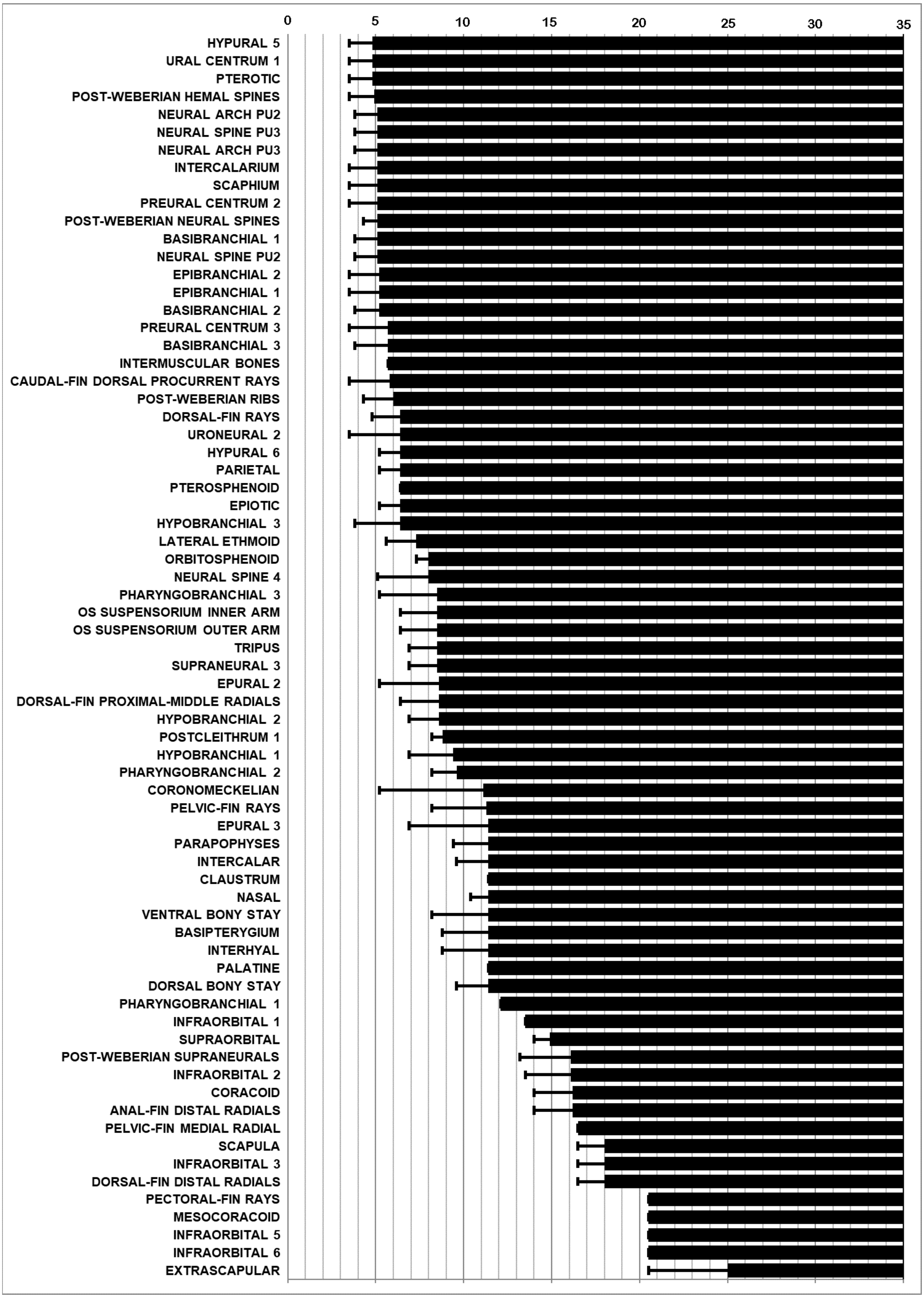


Figure 6. (continued).

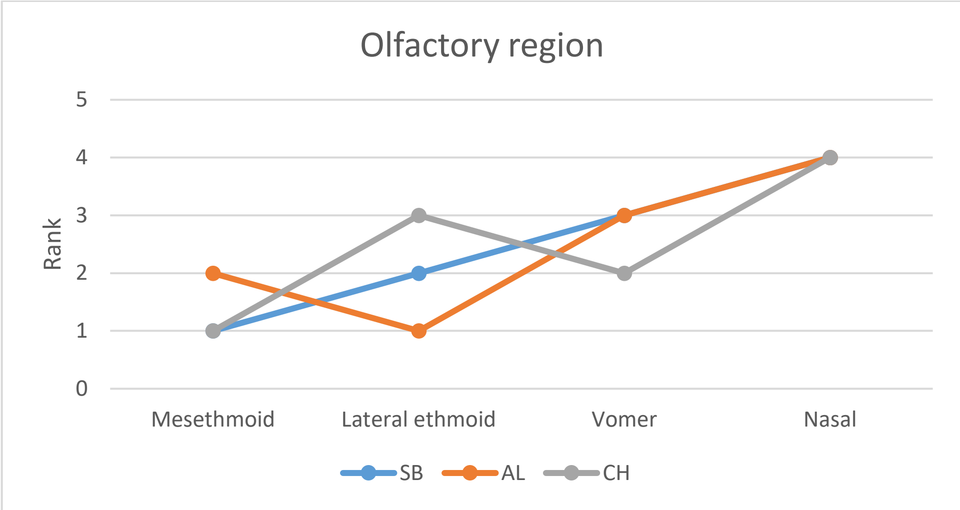


Figure 7. Diagram of the ranks within the respective osteological complex for the ossifications of the olfactory region.

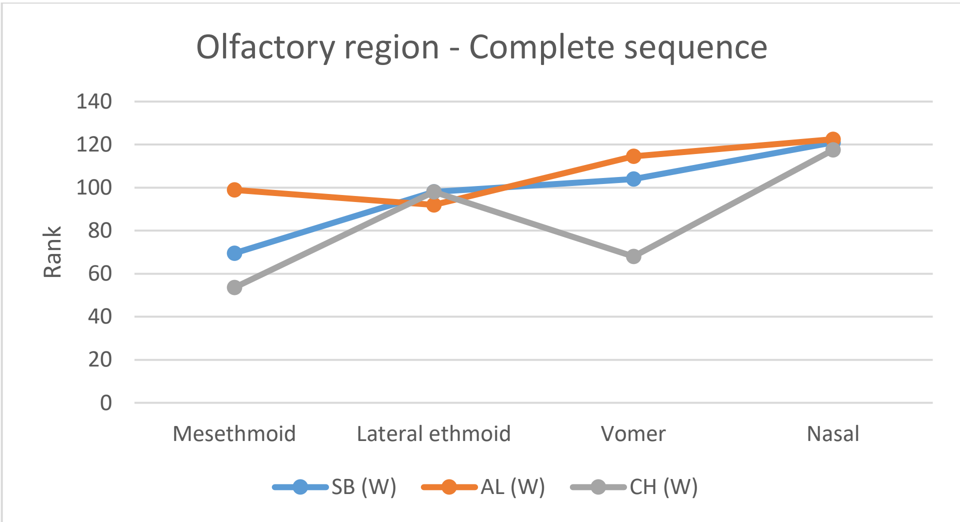


Figure 8. Diagram of the ranks in the complete sequence for the ossifications of the olfactory region.

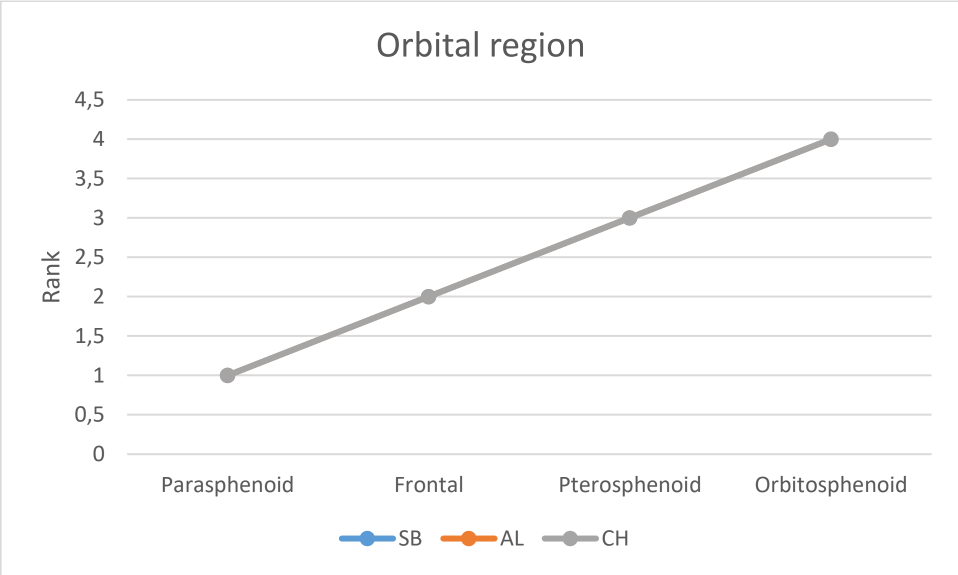


Figure 9. Diagram of the ranks within the respective osteological complex for the ossifications of the orbital region.

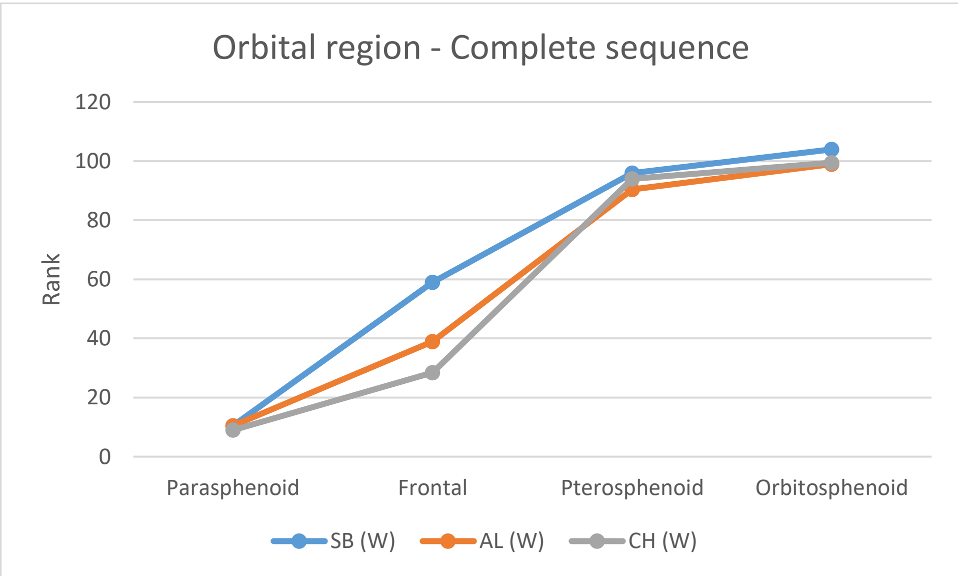


Figure 10. Diagram of the ranks in the complete sequence for the ossifications of the orbital region.

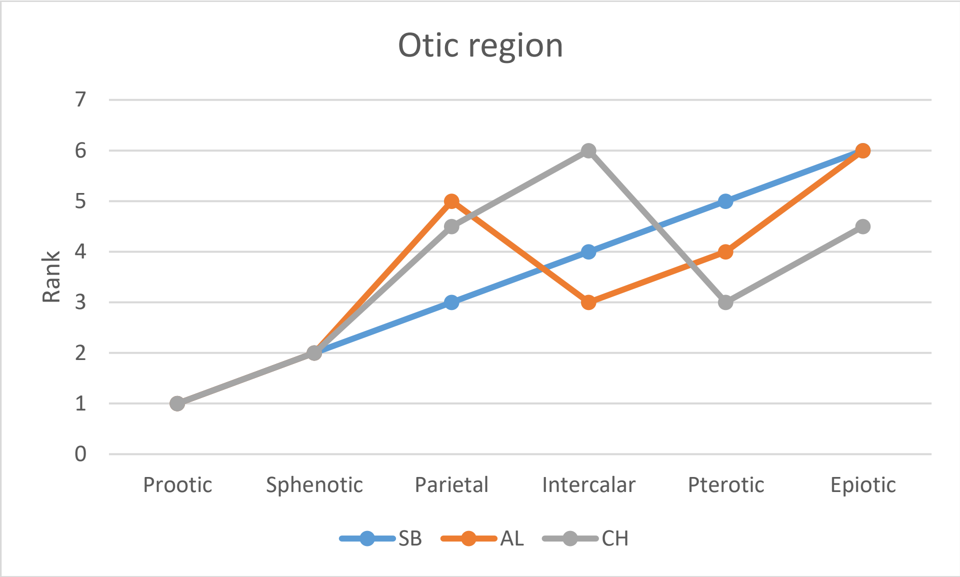


Figure 11. Diagram of the ranks within the respective osteological complex for the ossifications of the otic region.

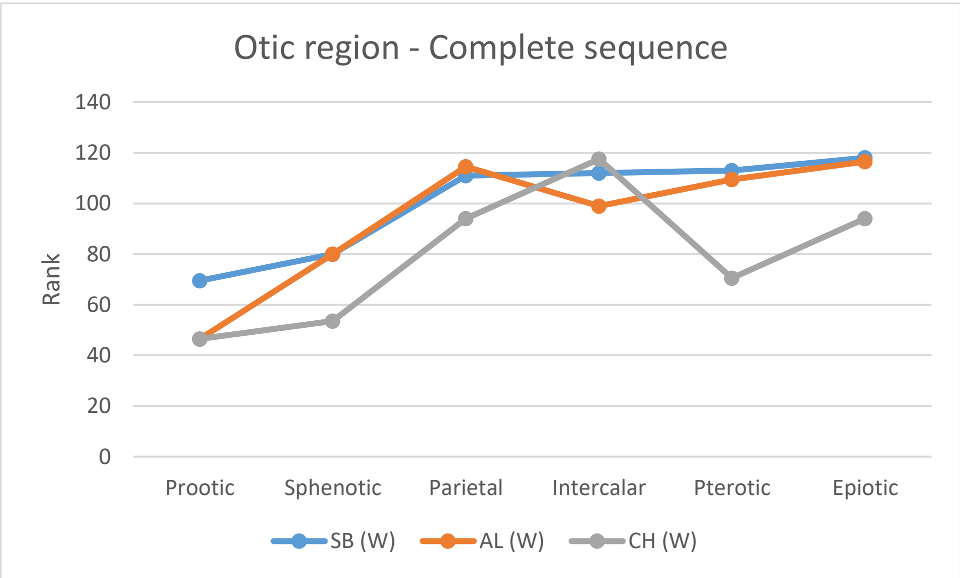


Figure 12. Diagram of the ranks in the complete sequence for the ossifications of the otic region.

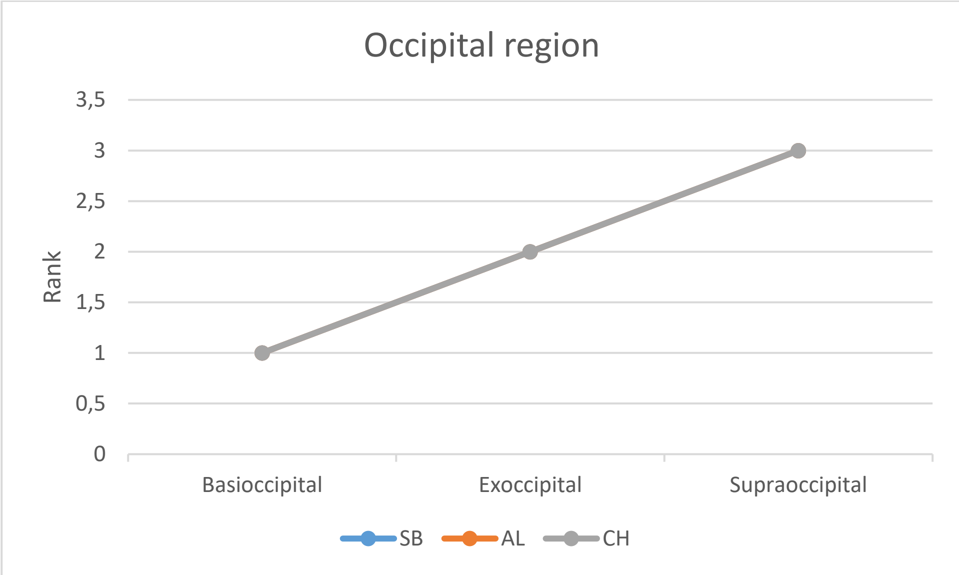


Figure 13. Diagram of the ranks within the respective osteological complex for the ossifications of the occipital region.

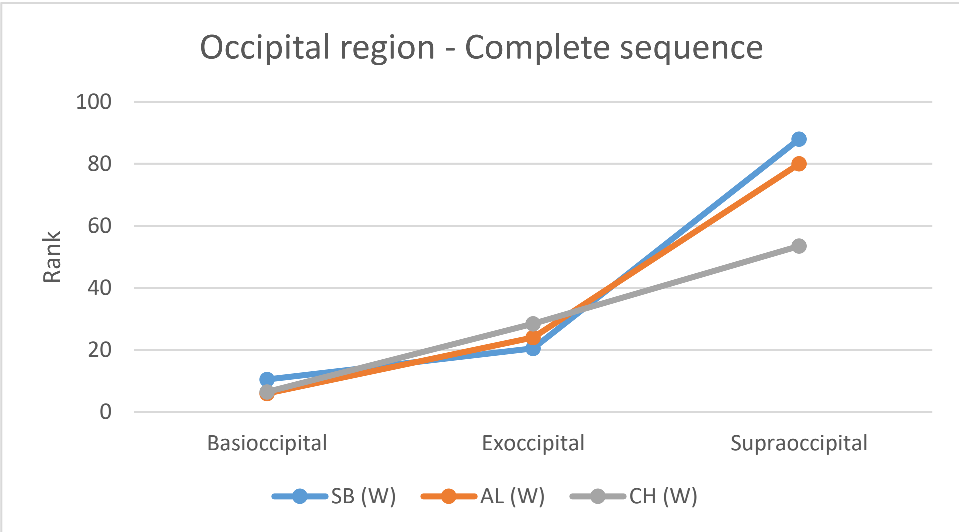


Figure 14. Diagram of the ranks in the complete sequence for the ossifications of the occipital region.

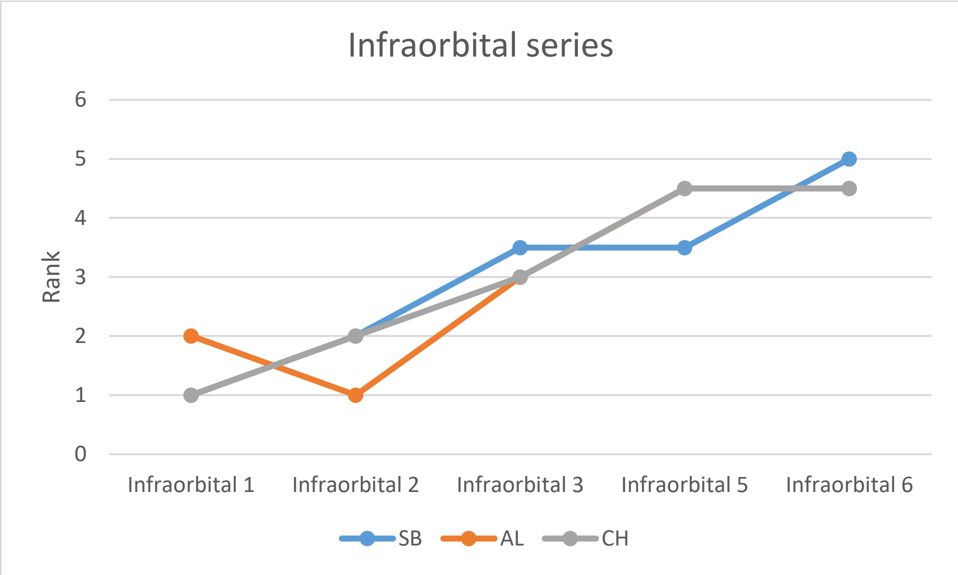


Figure 15. Diagram of the ranks within the respective osteological complex for the ossifications of the infraorbital series.

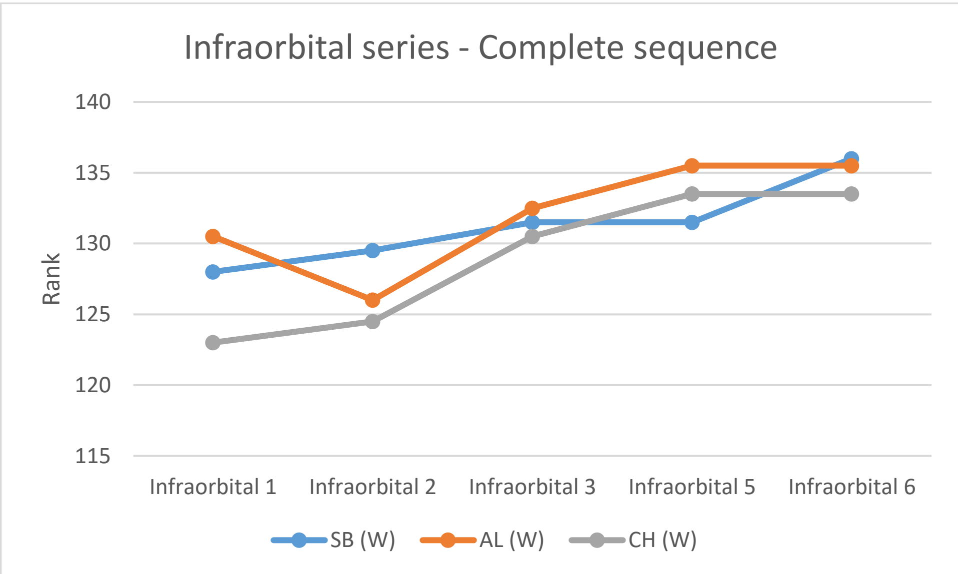


Figure 16. Diagram of the ranks in the complete sequence for the ossifications of the infraorbital series.

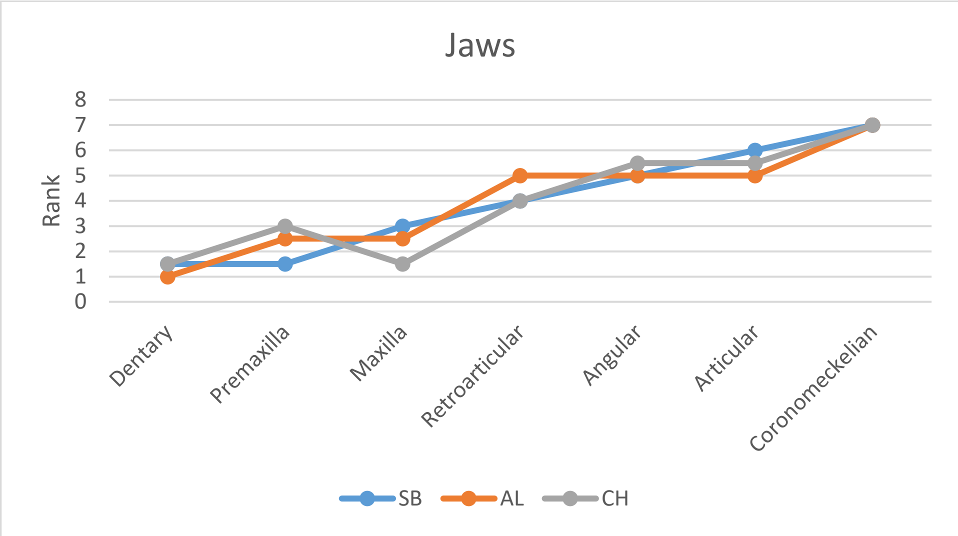


Figure 17. Diagram of the ranks within the respective osteological complex for the ossifications of the jaws.

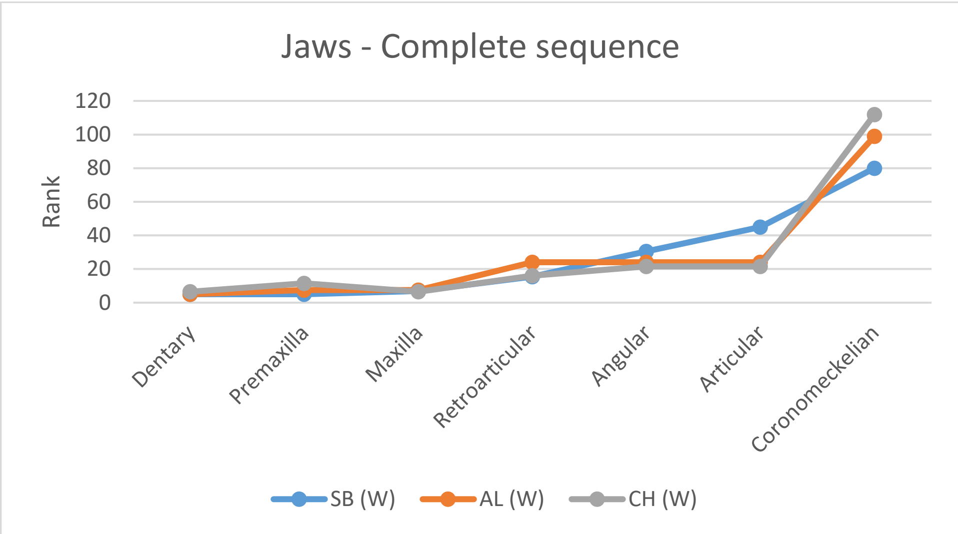


Figure 18. Diagram of the ranks in the complete sequence for the ossifications of the jaws.

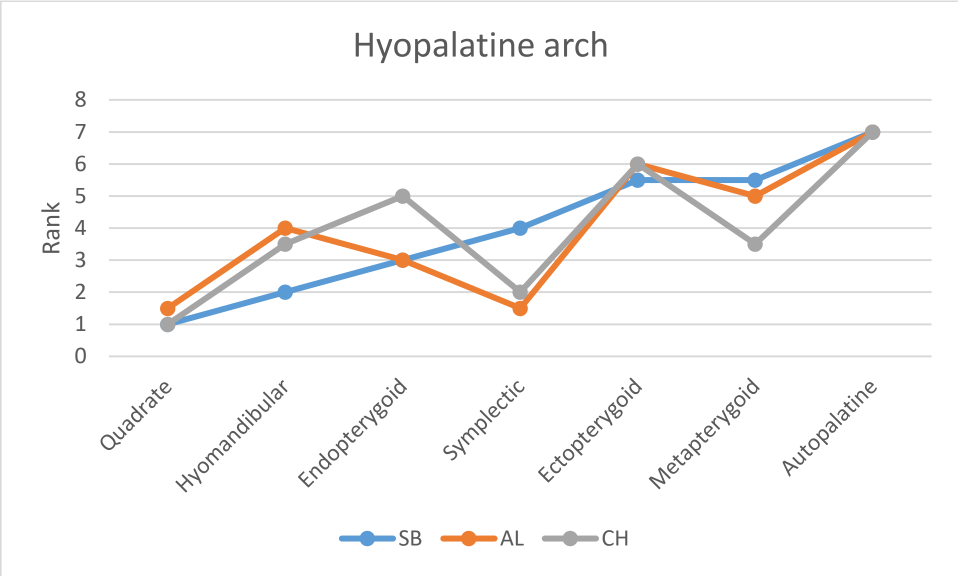


Figure 19. Diagram of the ranks within the respective osteological complex for the ossifications of the hyopalatine arch.

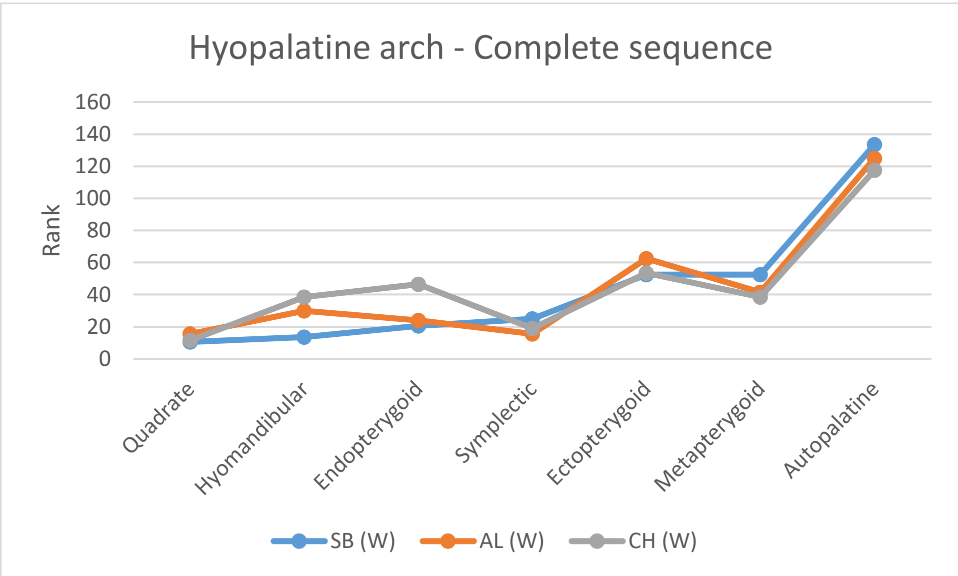


Figure 20. Diagram of the ranks in the complete sequence for the ossifications of the hyopalatine arch.

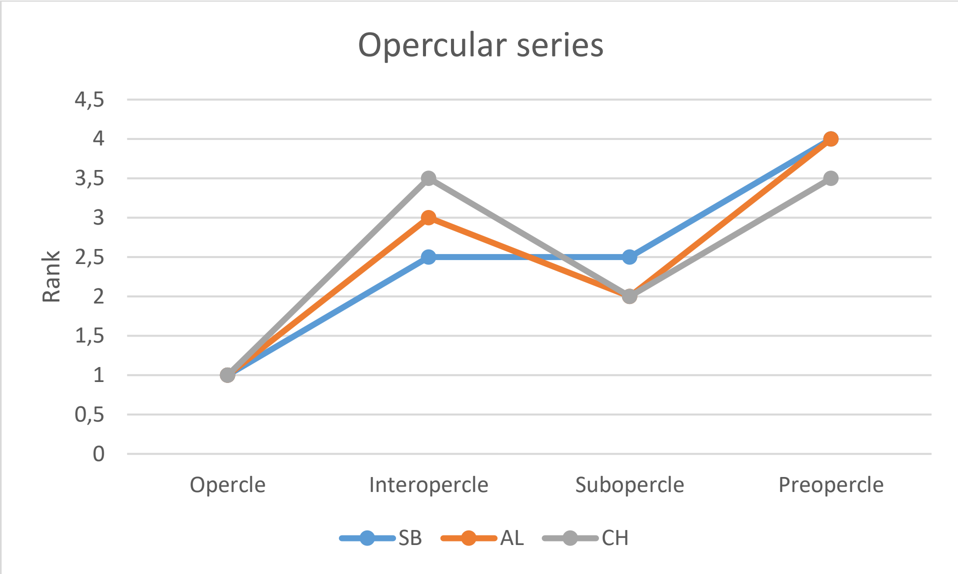


Figure 21. Diagram of the ranks within the respective osteological complex for the ossifications of the opercular series.

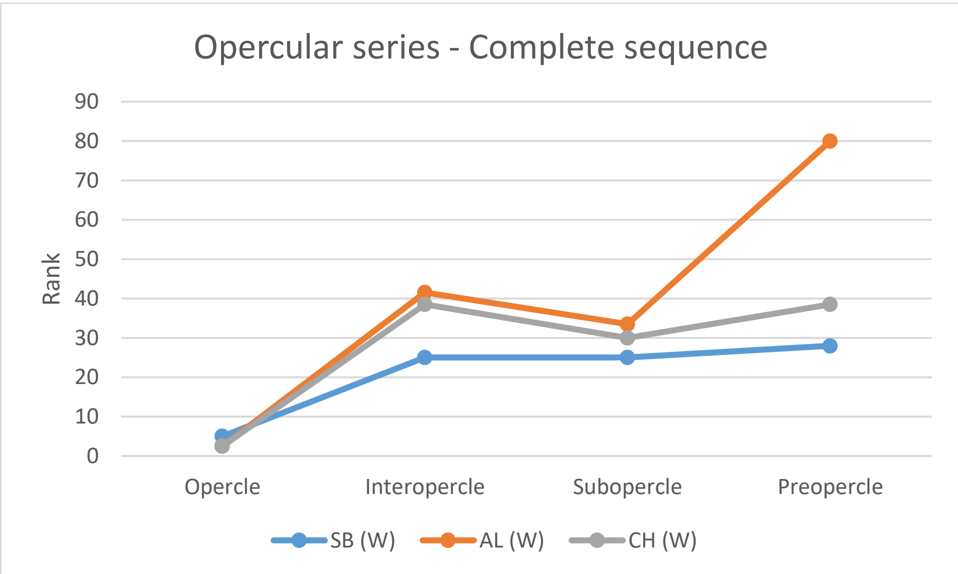


Figure 22. Diagram of the ranks in the complete sequence for the ossifications of the opercular series.

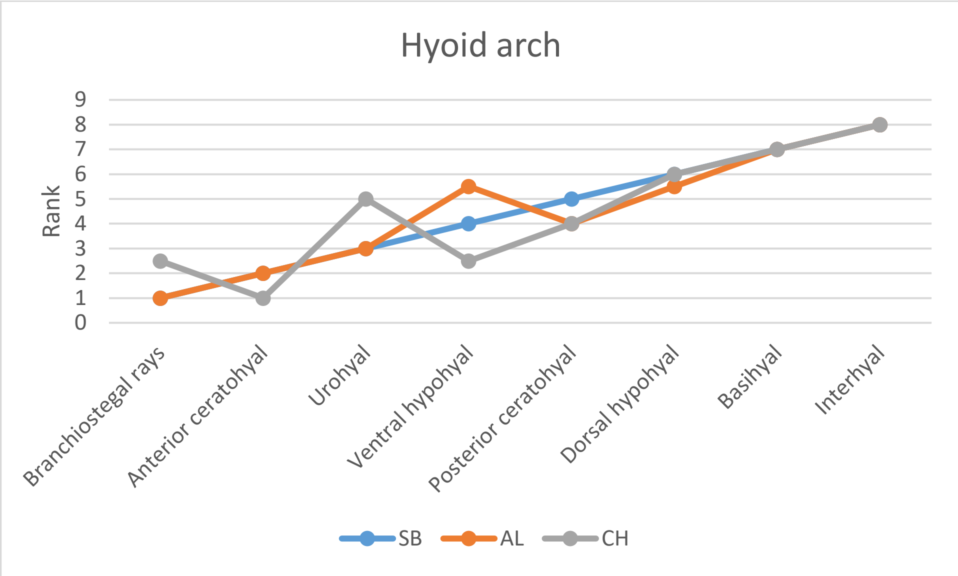


Figure 23. Diagram of the ranks within the respective osteological complex for the ossifications of the hyoid arch.

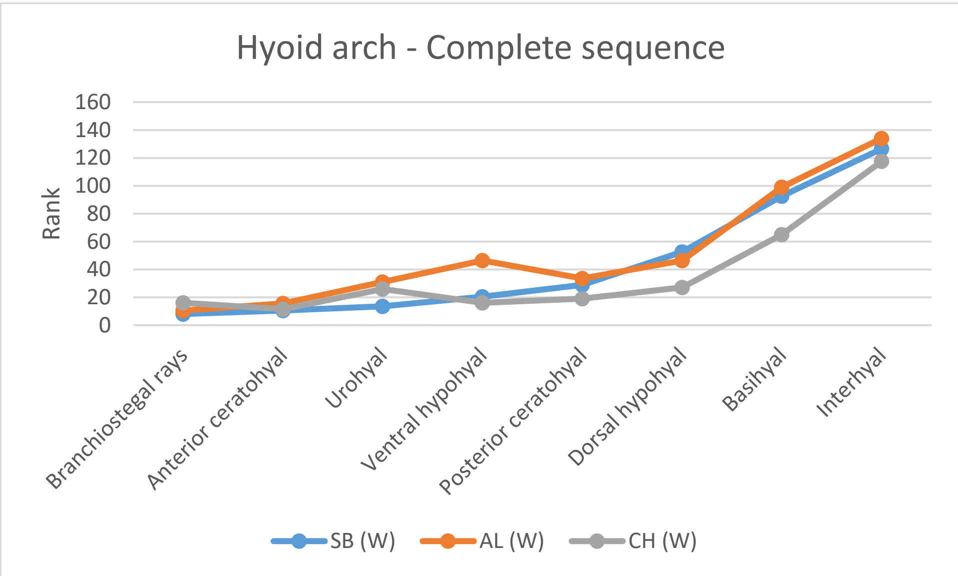


Figure 24. Diagram of the ranks in the complete sequence for the ossifications of the opercular series.

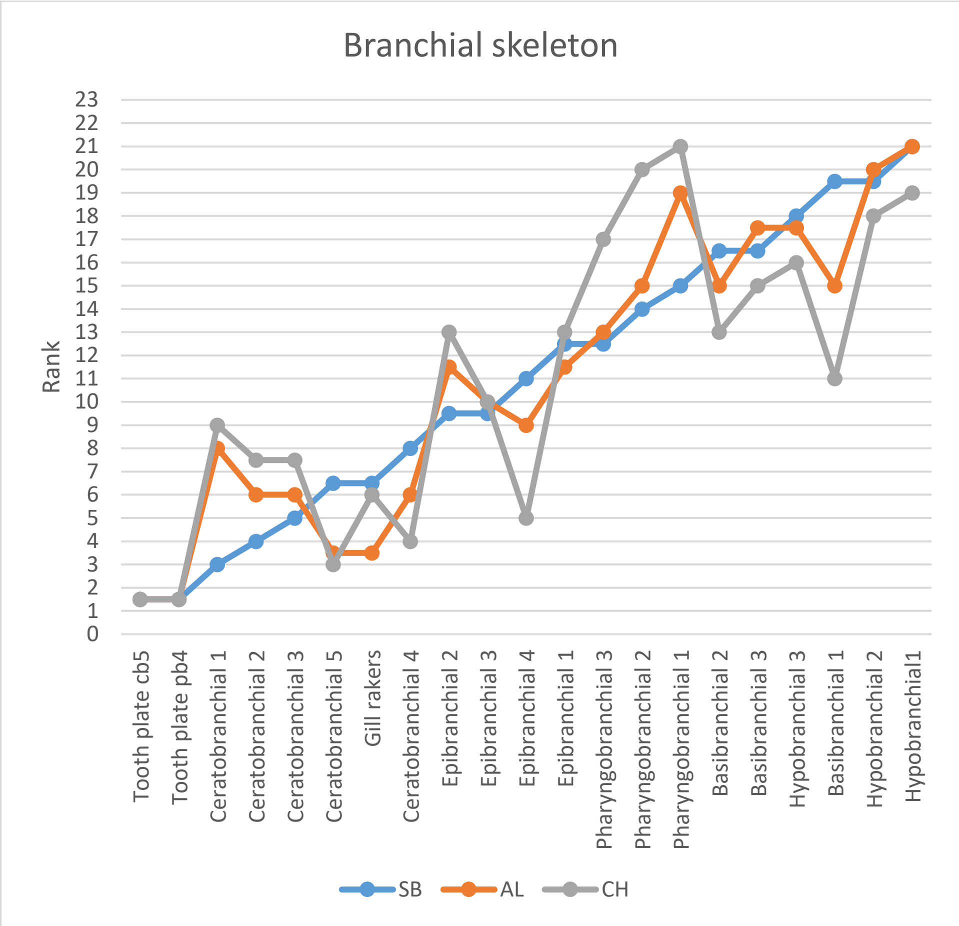


Figure 25. Diagram of the ranks within the respective osteological complex for the ossifications of the branchial skeleton.

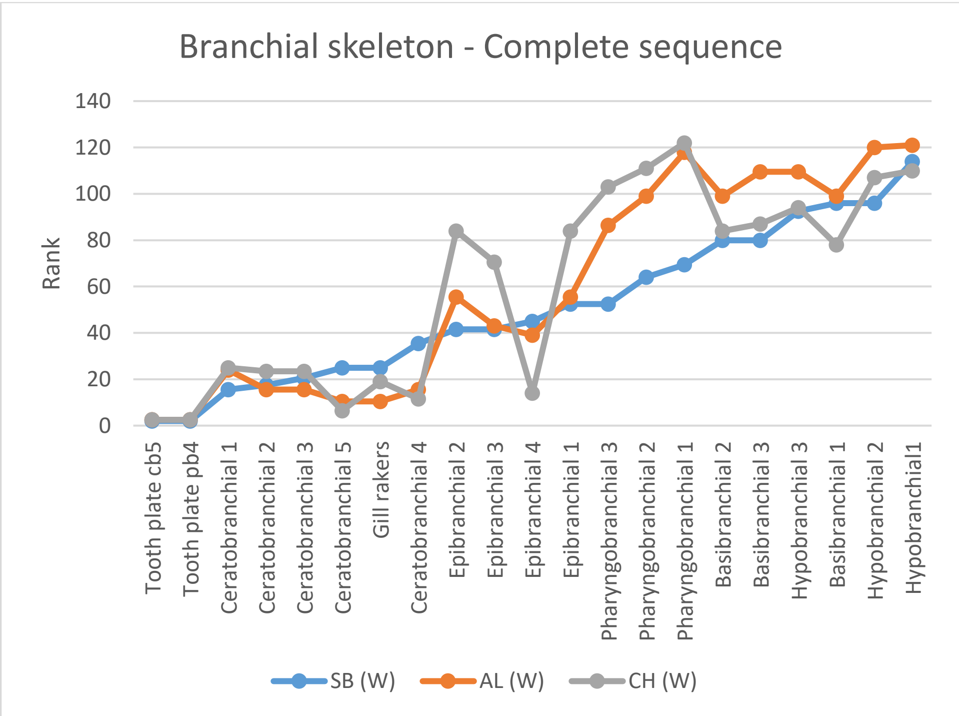


Figure 26. Diagram of the ranks in the complete sequence for the ossifications of the branchial skeleton.

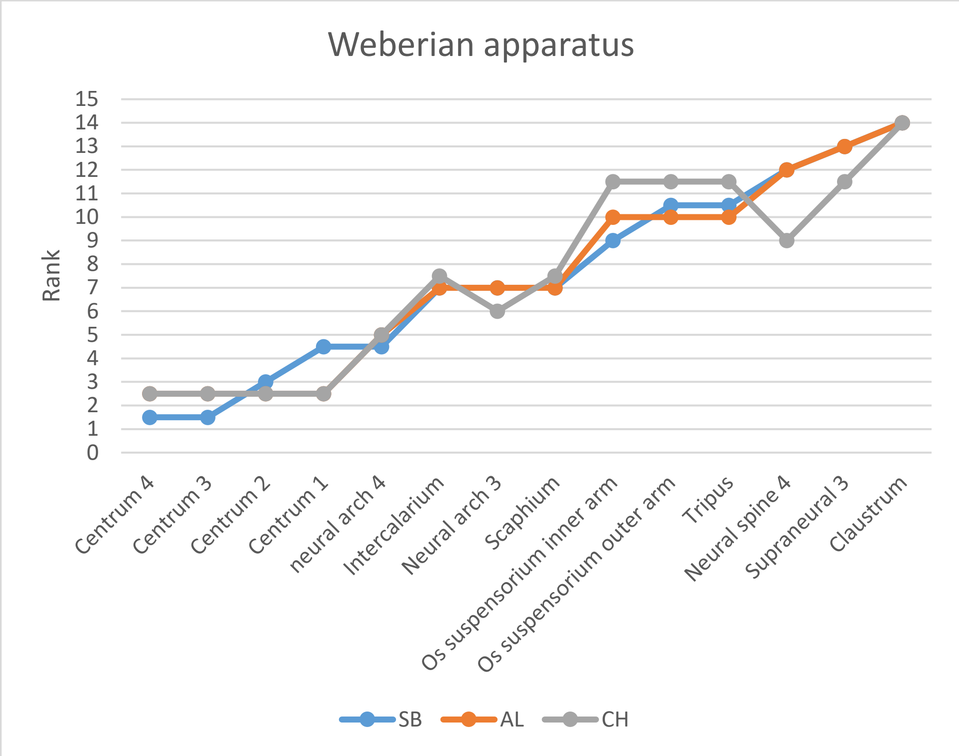


Figure 27. Diagram of the ranks within the respective osteological complex for the ossifications of the Weberian apparatus.

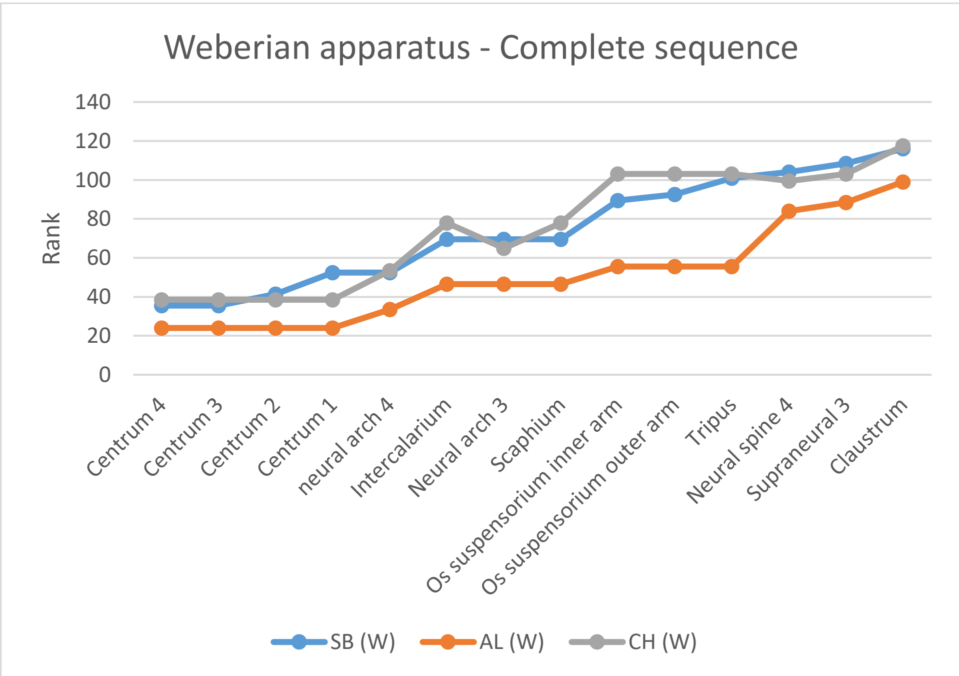


Figure 28. Diagram of the ranks in the complete sequence for the ossifications of the Weberian apparatus.

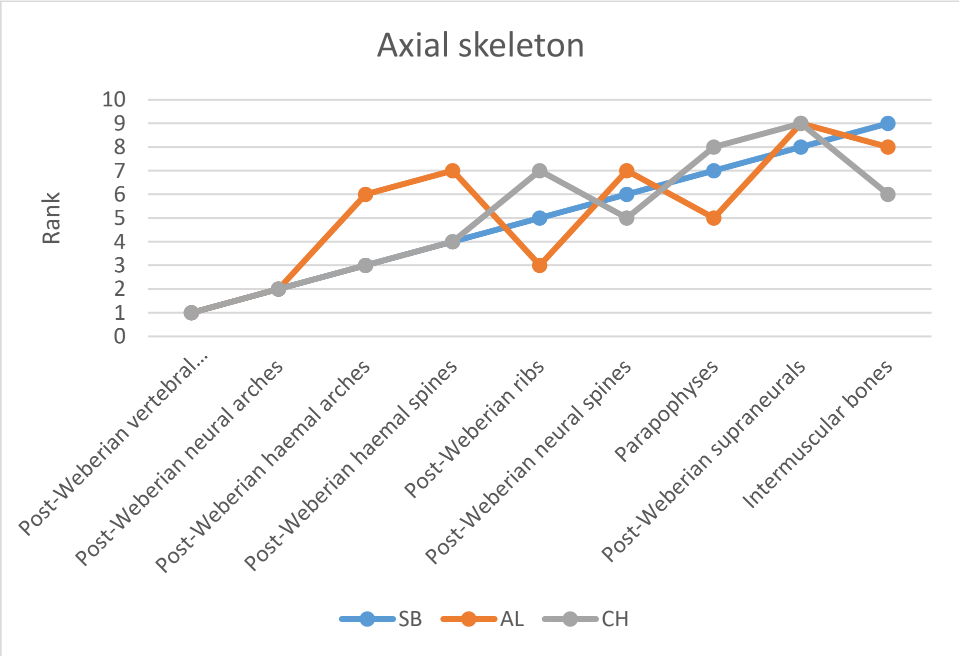


Figure 29. Diagram of the ranks within the respective osteological complex for the ossifications of the axial skeleton.

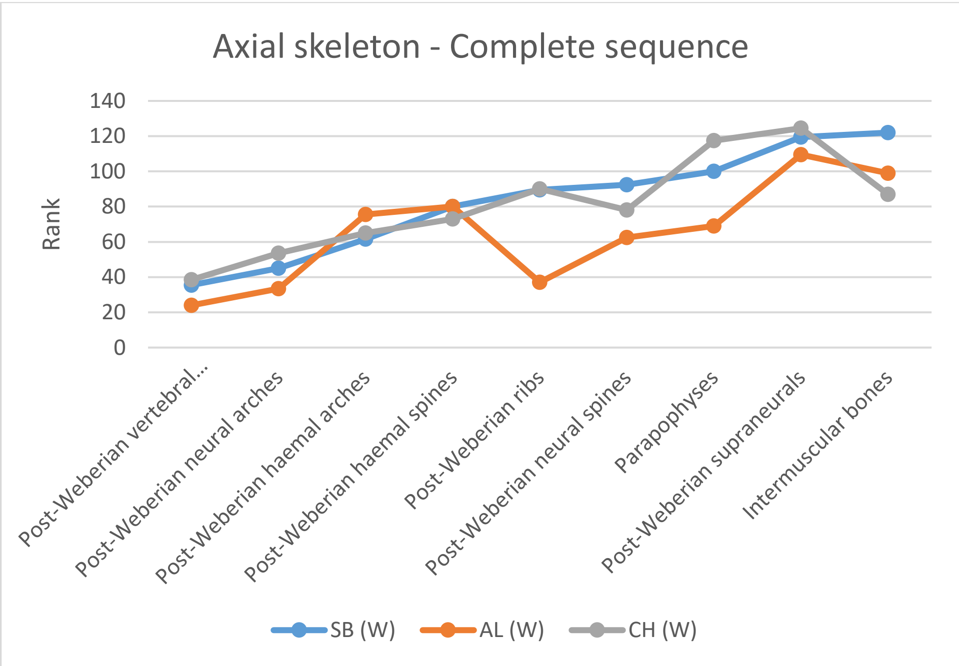


Figure 30. Diagram of the ranks in the complete sequence for the ossifications of the axial skeleton.

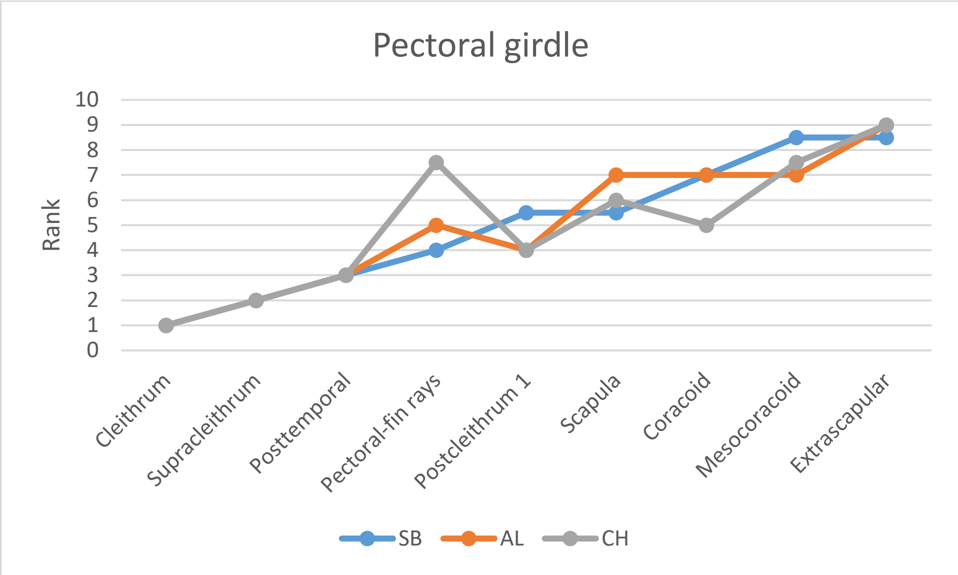


Figure 31. Diagram of the ranks within the respective osteological complex for the ossifications of the pectoral girdle.

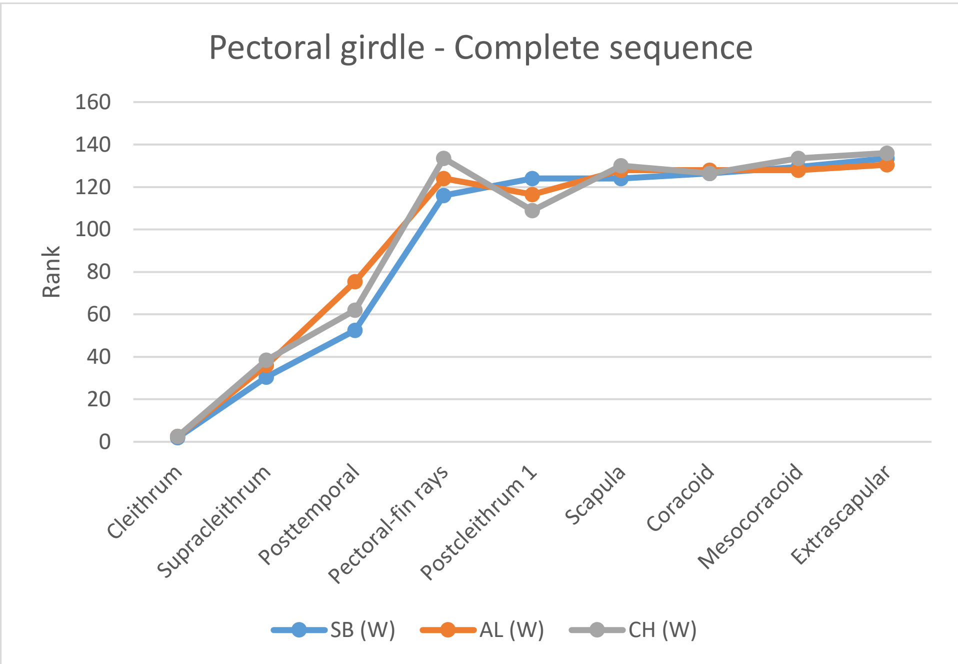


Figure 32. Diagram of the ranks in the complete sequence for the ossifications of the pectoral girdle.

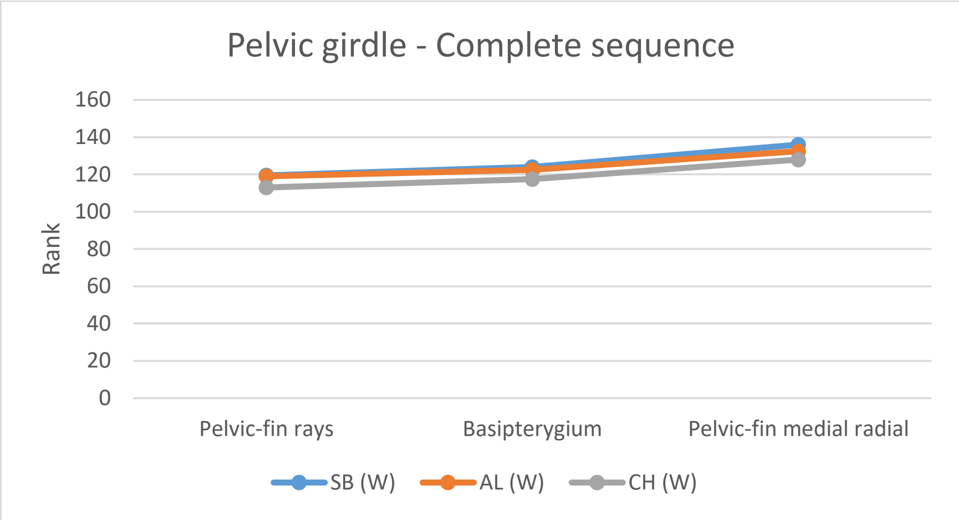


Figure 33. Diagram of the rankings in the complete sequence for the ossifications of the pelvic girdle.

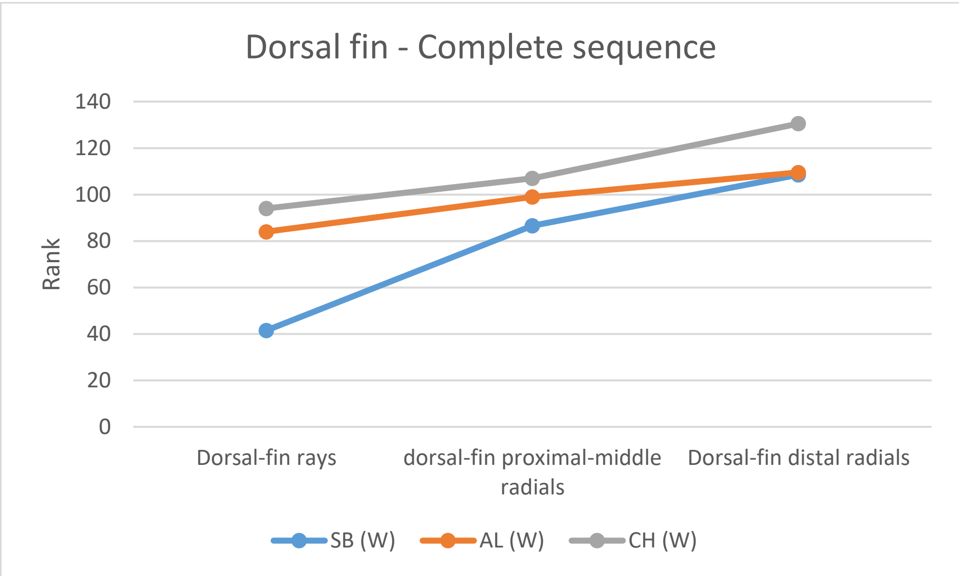


Figure 34. Diagram of the rankings in the complete sequence for the ossifications of the dorsal fin.

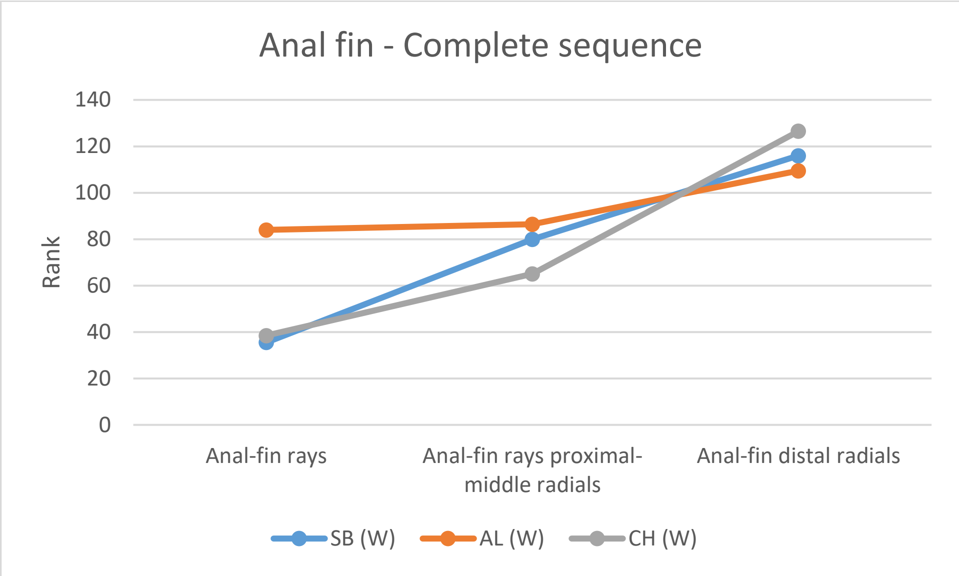


Figure 35. Diagram of the rankings in the complete sequence for the ossifications of the anal fin.

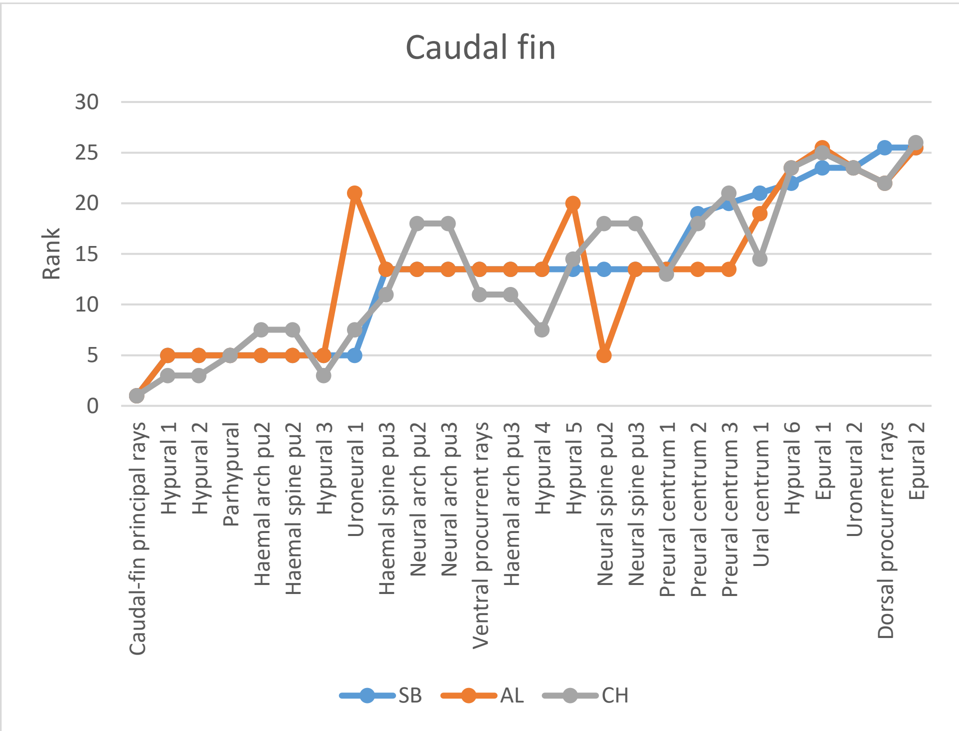


Figure 36. Diagram of the rankings within the respective osteological complex for the ossifications of the caudal fin.

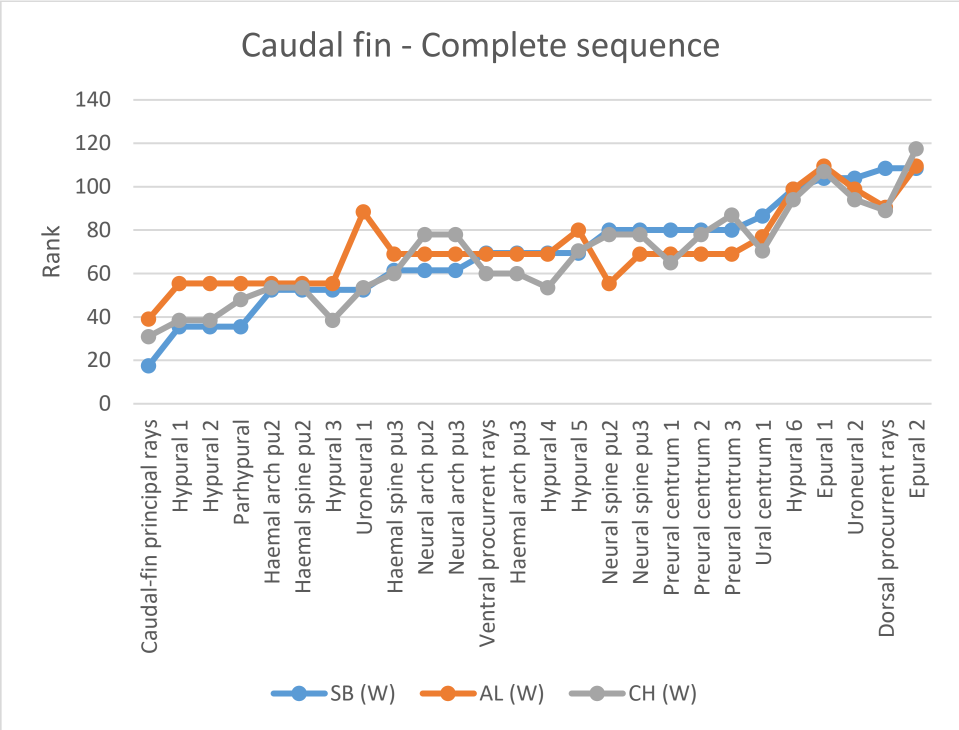


Figure 37. Diagram of the rankings in the complete sequence for the ossifications of the caudal fin.

Appendix

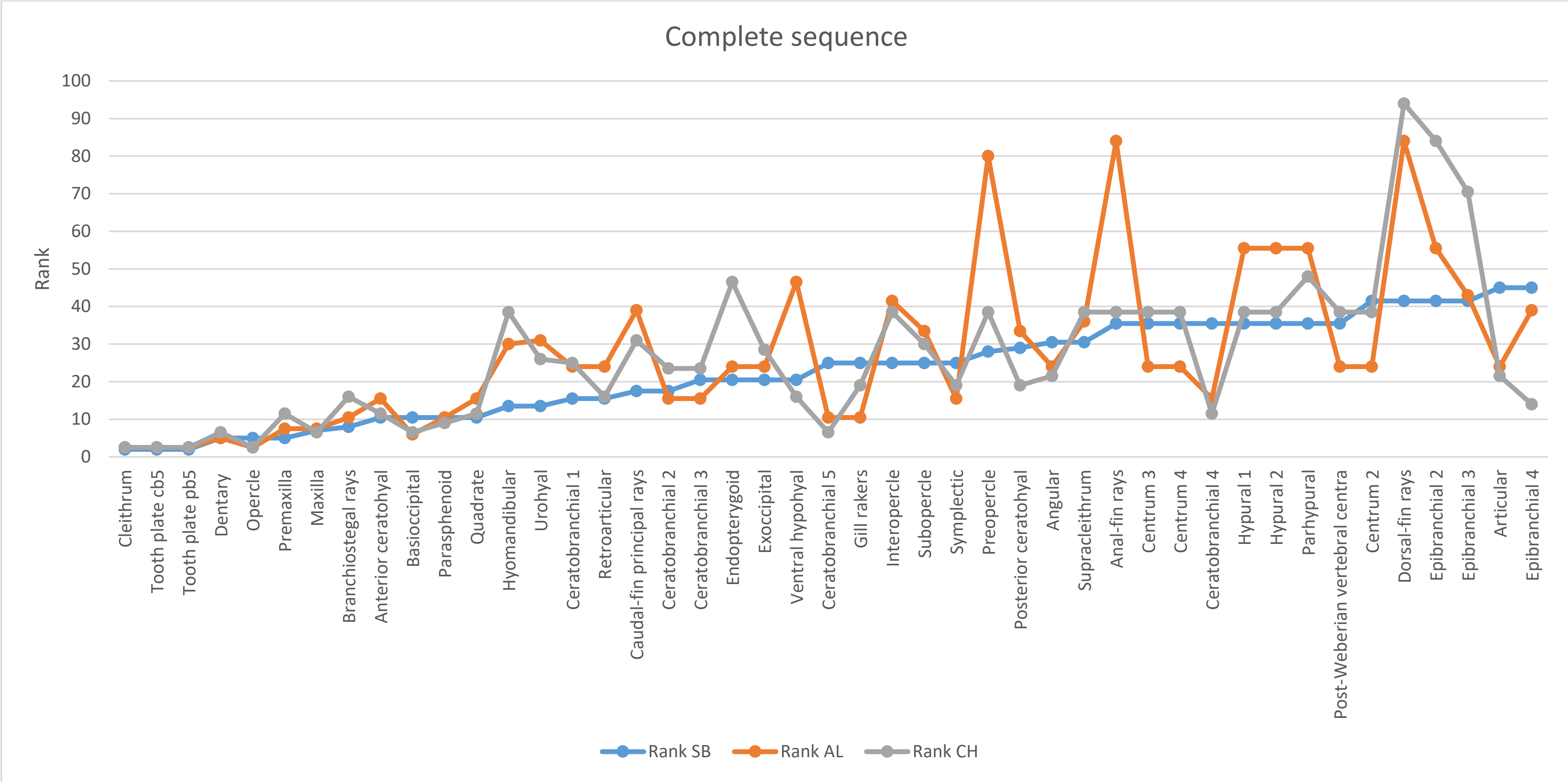


Figure 38. Diagram of the rankings of the complete sequence of ossification for *Astyanax lacustris*, *Ctenolucius hujeta* and *Salminus brasiliensis*.

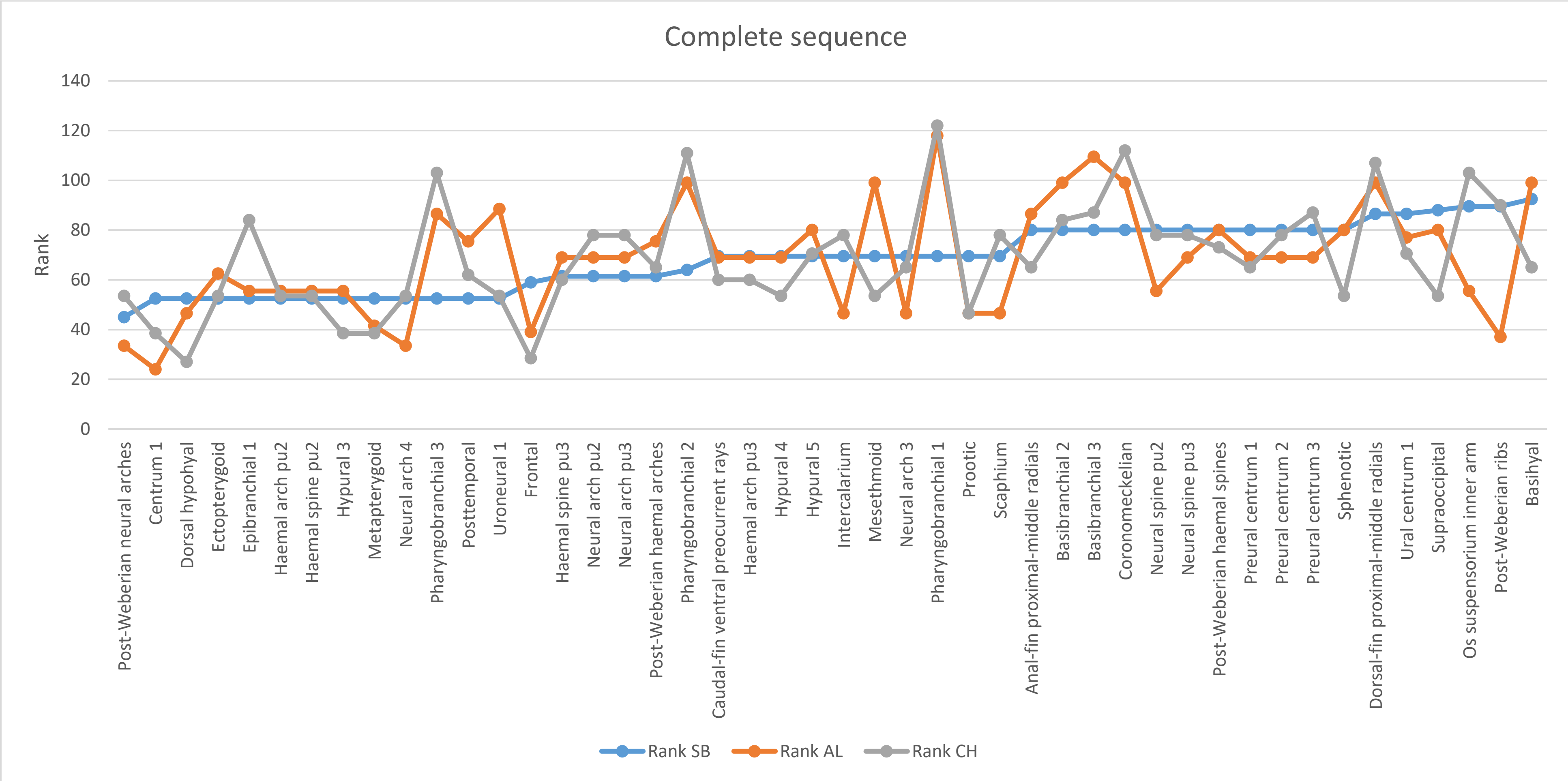


Figure 38. continued.

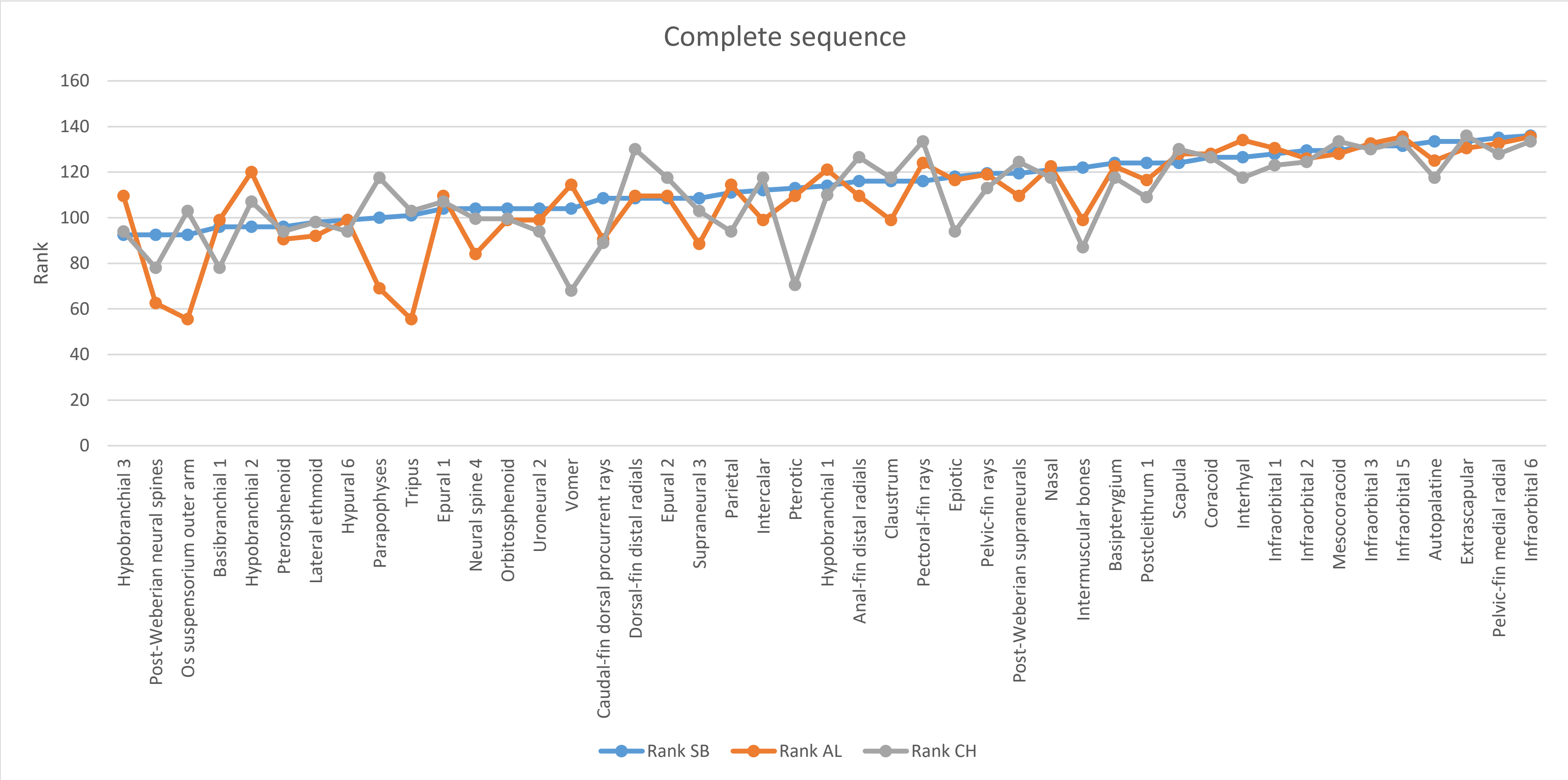


Figure 38. continued.

Conclusions

Detailed examination of the dentition, an already vastly explored character complex, resulted in the refinement of characters related to dentition and resulted in the proposition of possible additional synapomorphies for the Heterocharacinae (unicuspid teeth with abruptly tapering cusp), Serrasalminae (replacement teeth of the dentary formed in completely enclosed bony cavities) and Anostomidae (pleurodont implantation on premaxilla and maxilla).

Unilateral replacement patterns were observed in several taxa with multicuspid dentition including representatives of the Characidae, Chalceidae, Alestidae, Serrasalmidae, Iguanodectidae, Bryconidae and Agoniatidae. Furthermore, two distinct patterns within the unilateral pattern were identified the simultaneous unilateral replacement pattern observed in *Serrasalmus* and *Astyanax* and the sequential unilateral pattern observed in *Brycon* and *Chalceus*.

Based on differences in the modes of formation of replacement teeth we propose (i) an alternative interpretation of the identity and homology of the three premaxillary tooth rows observed in *Brycon*, *Triportheus* and *Chalceus*; (ii) the identification of two tooth rows for taxa in which this differentiation is problematic such as *Mimagoniates* and *Bryconamericus lethostigmus*; (iii) a proposition of homology between the single row of teeth present in taxa within the Characoidei and the inner row of taxa with two or three tooth rows on the premaxilla; (iv) the proposition of homology of the single row of teeth present in taxa within the Citharinoidei with the outer row of *Xenocharax spilurus*.

The comparative analysis of complete ossification sequences for representatives of Characiformes presented herein showed that there is a considerable amount of variation among the sequence of ossification of *Astyanax lacustris*, *Ctenolucius hujeta* and *Salminus brasiliensis*, anatomical complexes with the same ossification sequence across the three species were a minority. The observed variation includes: (i) different sequence of ossification within an osteological complex. In those cases the differences within a complex can be coupled with alterations in the timing of the ossification of the complex in the context of the entire sequence (*e. g.* observed for the olfactory region of the neurocranium) or not (*e. g.* hyopalatine arch); (ii) different relative intervals between the ossification of the first and last element in an osteological complex, despite identical sequences within the complex (*e. g.* relative interval of the elements of the occipital region of the neurocranium in *C. hujeta*); (iii) shift of an entire osteological complex in the complete sequence, despite similar sequences and relative intervals across the three species (*e. g.* Weberian apparatus).

The observed degree of variation suggests that the study of ossification sequences is a promising source of information to be explored in a phylogenetic context. Comparative studies employing ossification sequences of the entire skeleton could point to heterochronic changes between taxa that could be explored in a functional anatomy perspective, as well as in a developmental genetic approach. In addition, information from complete ossification sequences could be used as characters in a phylogenetics systematics framework in a similar way other character complexes are used.

Abstract

The dentition is a character complex recognized for being highly informative for systematic studies for the order Characiformes, hence the dentition was widely explored in systematic studies of several lineages within the order. However, detailed systematic studies that discuss the observed variation in the context of the order as a whole are still scarce. In a similar manner the despite the wide knowledge produced about the adult skeleton of the representatives of the Characiformes, detailed information about the development of this anatomical complex, as well as about the sequence of ossification of the complete skeleton of representatives of the Characiformes are still scarce and to this date there is only one complete sequence of ossification available in the literature. We herein present a detailed study on the dentition of the Characiformes contemplating tooth morphology, tooth implantation mode and implantation position, arrangement of teeth on each bone, formation mode of replacement teeth and the chronological pattern of the replacement. Detailed descriptions are provided for 78 species of Characiformes. with representatives from all recognized families, except for the recently described Tarumaniidae. Fifty-nine characters are proposed, including reinterpreted characters previously proposed in the literature, along with original characters. The variation and distribution of the proposed characters in the Characiformes is discussed along with the proposal of new interpretations of the identity and homology of tooth rows in the premaxilla in representatives of the order. Descriptions of ontogenetic variation of dentition in selected characiform species are provided. Possible additional synapomorphies related to the dentition are proposed for the Anostomidae, Heterocharacinae and Serrasalminae. Two patterns of replacement within the Characoidei are identified and described in detail. Alternative interpretation for the identity and homology of the three tooth rows on the premaxilla present in *Brycon*, *Triportheus* and *Chalceus* is presented along with a proposal of homology of the single premaxillary tooth row present within the Characoidei and Citharinoidei. Also, we herein studied the skeletal development of the small sized characid *Astyanax lacustris* and the ctenoluciid *Ctenolucius hujeta* presenting the ossification sequence of the complete skeleton for both species. This study was based on 111 specimens of *A. lacustris* (2.9 mm NL to 27.6 mm SL) and 100 specimens of *C. hujeta* (3.5 mm NL to 35.5 mm SL). Specimens were cleared and double stained and the presence of an ossification was scored whenever mineralization was detected. For both species the first ossifications to appear were the

tooth plates associated to ceratobranchial 4 and pharyngobranchial 4, the cleithrum and the opercle at 2.9 mm NL for *A. lacustris* and 3.5 mm NL for *C. hujeta*. Comparative analyses were conducted for the sequences of *A. lacustris, C. hujeta* and the already published sequence of *S. brasiliensis*. The sequences are compared within osteological complexes for the sequence within that complex and in the context of the entire sequence. Differences were observed regarding the sequence of ossification within an osteological complex; the relative intervals between the ossification of the first and last element in an osteological complex, as well as shift of an entire osteological complex in the complete sequence.

Resumo

A dentição é um complexo de caracteres reconhecido por ser altamente informativo em estudos sistemáticos para a ordem Characiformes, como consequência a dentição foi amplamente explorada em estudos sistemáticos das linhagens que compõem a ordem. No entanto, estudos sistemáticos detalhados que discutam a variação observada na dentição em um contexto da ordem como um todo são escassos. De maneira semelhante, apesar do amplo conhecimento existente sobre o esqueleto dos representantes adultos dos Characiformes, informações detalhadas sobre o desenvolvimento deste complexo anatômico assim como sobre a sequência de ossificação completa para representantes de Characiformes ainda são incipientes e, até hoje, existe apenas uma sequência completa de ossificação disponível na literatura. Apresentamos aqui um estudo detalhado sobre a dentição dos Characiformes contemplando a morfologia dentária, o modo de implantação e a posição da implantação, disposição dos dentes em cada osso, modo de formação dos dentes de substituição e padrão cronológico da substituição. Descrições detalhadas são fornecidas para 78 espécies de Characiformes. com representantes de todas as famílias reconhecidas, exceto para a família Tarumaniidae recentemente descrita. Cinquenta e nove caracteres são propostos, incluindo caracteres reinterpretados já propostos na literatura, juntamente com caracteres originais. A variação e distribuição dos caracteres propostos em Characiformes é discutida juntamente com a proposta de novas interpretações da identidade e homologia das fileiras de dente no pré-maxilar em representantes da ordem. São fornecidas descrições de variações ontogenéticas da dentição em espécies de Characiformes selecionadas. Possíveis sinapomorfias adicionais relacionadas à dentição são propostas para os Anostomidae, Heterocharacinae e Serrasalminae. Dois padrões de substituição dentro dos Characoidei foram identificados e descritos em detalhes. Interpretação alternativa para a identidade e homologia das três fileiras de dentes na pré-maxila presentes em *Brycon*, *Triportheus* e *Chalceus* é apresentada juntamente com uma proposta de homologia da única fileira de dentes pré-maxilares presentes nos Characoidei e Citharinoidei. Também estudamos aqui o desenvolvimento esquelético do caracídeo *Astyanax lacustris* e do ctenoluciídeo *Ctenolucius hujeta*, apresentando a sequência de ossificação do esqueleto completo para ambas as espécies. O estudo foi baseado em 111 exemplares de *A. lacustris* (2,9 mm NL a 27,6 mm SL) e 100 exemplares de *C. hujeta* (3,5 mm NL a 35,5 mm SL). Espécimes foram diafanizados e corados, a presença de uma ossificação foi pontuada sempre que a mineralização foi detectada. Para ambas as espécies, as primeiras ossificações a aparecer foram as placas dentárias associadas ao ceratobranquial 4 e faringobranquial 4, o cleitro e o opérculo em 2,9 mm NL para *A. lacustris* e 3,5 mm NL para *C. hujeta*. Análises comparativas foram realizadas para as sequências de *A. lacustris*, *C. hujeta* e a sequência já publicada de *S. brasiliensis*. As sequências são comparadas dentro de complexos osteológicos para a sequência dentro desse complexo, bem como no contexto de toda a sequência. Observaram-se diferenças entre as três sequências quanto à sequência de ossificação dentro de um complexo osteológico; os intervalos relativos entre a ossificação do primeiro e do último elemento em um complexo osteológico, bem como o deslocamento de todo um complexo osteológico na sequência completa.