Online Supplementary Material

**The oldest species of *Peltoperleidus* (Louwoichthyiformes, Neopterygii) from the Middle Triassic (Anisian) of China, with phylogenetic and biogeographic implications**

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   1. **Taxa and principal sources of data**

FMNH, Field Museum of Natural History, Chicago, USA

IVPP, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Beijing, China

LPV, Luoping County Vertebrates, Chengdu Institute of Geology and Mineral Resources, Chengdu, China

NHMUK, Natural History Museum, London, UK

PIMUZ, Paläontologisches Institut und Museum, Universität Zürich, Zürich, Switzerland

*Moythomasia durgaringa*: Gardiner, 1984

*Australosomus kochi*: Nielsen, 1949; NHMUK P17141–17143, 17156, 17157, 17160, 17161, 20940–20945

*Acipenser brevirostrum*:Hilton et al., 2011

*Amia calva*: Grande and Bemis, 1998

*Boreosomus piveteaui*: Nielsen, 1942

*Brookvalia gracilis*: Hutchinson, 1973b

*Caturus furcatus:* FMNH UC2057; Patterson, 1975; Grande and Bemis, 1998

*Chondrosteus acipenseroides*: Hilton and Forey, 2009

*Cleithrolepidina minor*: Hutchinson, 1973b

*Cleithrolepis* *granulate*: Wade, 1935; Hutchinson, 1973b

*Colobodus baii*:Sun et al., 2008; IVPP V19974

*Colobodus bassanii*: Mutter, 2002, 2004

*Colobodus giganteus*: Cartanyà et al., 2015

*Crenilepis sandbergeri*: Mutter, 2002, 2004

*Ctenognathichthys bellottii*: Bürgin, 1992

*Daedalichthys higginsi*: Hutchinson, 1973b

*Dipteronotus olgiatii*: Tintori, 1990

*Elops hawaiensis*:Forey, 1973

*Feroxichthys panzhouensis* Ma et al., 2021

*Feroxichthys yunnanensis* Xu, 2020

*Fuyuanperleidus dengi*: Geng et al., 2012; Sun et al., 2012

*Gigantopterus teller*: Griffith, 1977

*Habroichthys broughi*: Lin et al., 2011; IVPP V19373–19380

*Helichthys browni*: Hutchinson, 1973b

*Helmolepis cyphognathus*: Neuman & Mutter, 2005

*Kyphosichthys grandei*: Xu & Wu, 2012

*Lepisosteus osseus*: Grande, 2010

*Leptolepis coryphaenoides*: Patterson, 1975; Arratia, 1999, 2013

*Luganoia lepidosteoides*: Bürgin, 1992

*Luganoia* *fortuna*: Xu, 2020b

*Luopingichthys bergi*: Sun et al., 2009

*Louwoichthys pusillus*: Xu, 2021

*Meidiichthys browni*: Brough, 1931; Hutchinson, 1973b

*Perleidus altolepis*: Lombardo, 2001

*Peipiaosteus pani*: Zhou, 1992

*Peltopleurus rugosus*: Bürgin, 1992; PIMUZ T2904

*Peltopleurus nitidus*: Xu and Zhao, 2016

*Peltopleurus tyrannos*: Xu et al., 2018

*Peltoperleidus* *ducanensis*: Bürgin et al., 1991

*Peltoperleidus macrodontus*:Bürgin, 1992

*Peltoperleidus obristi*: Herzog, 2001

*Peripeltopleurus hypsisomus*:Bürgin, 1992; PIMUZ T1211, 2150, 2869

*Pseudobeaconia elegans*: Hutchinson, 1973a; López-Arbarello and Zavattieri, 2008

*Platysiagum* *sinensis*: Wen et al., 2019

*Plesiofuro mingshuica*: Xu et al., 2015a

*Polzbergia brochatus*: Griffith, 1977

*Potanichthys xingyiensis*: Xu et al., 2012

*Pteronisculus stensioi*:Nielsen, 1942; NHMUK P16282, 16283, 16300, 163001, 16307–16308

*Redifieldius gracilis*: Schaeffer and McDonald, 1978

*Semionotus elegans*: Olsen and McCune, 1991; Cavin, 2010; Grande, 2010; López-Arbarello, 2012

*Teffichthys* (*‘Perleidus’*) *madagascariensis*: NHMUK P16247, 16248, 19580–19584, 19587–19592, 19595–19599, 19603–19620, 19622, 19623; Lehman, 1952; Patterson, 1975; Marramà et al., 2017

*Thoracopterus niederristi*: Griffith, 1977; Lehman, 1979; NHMUK P1098

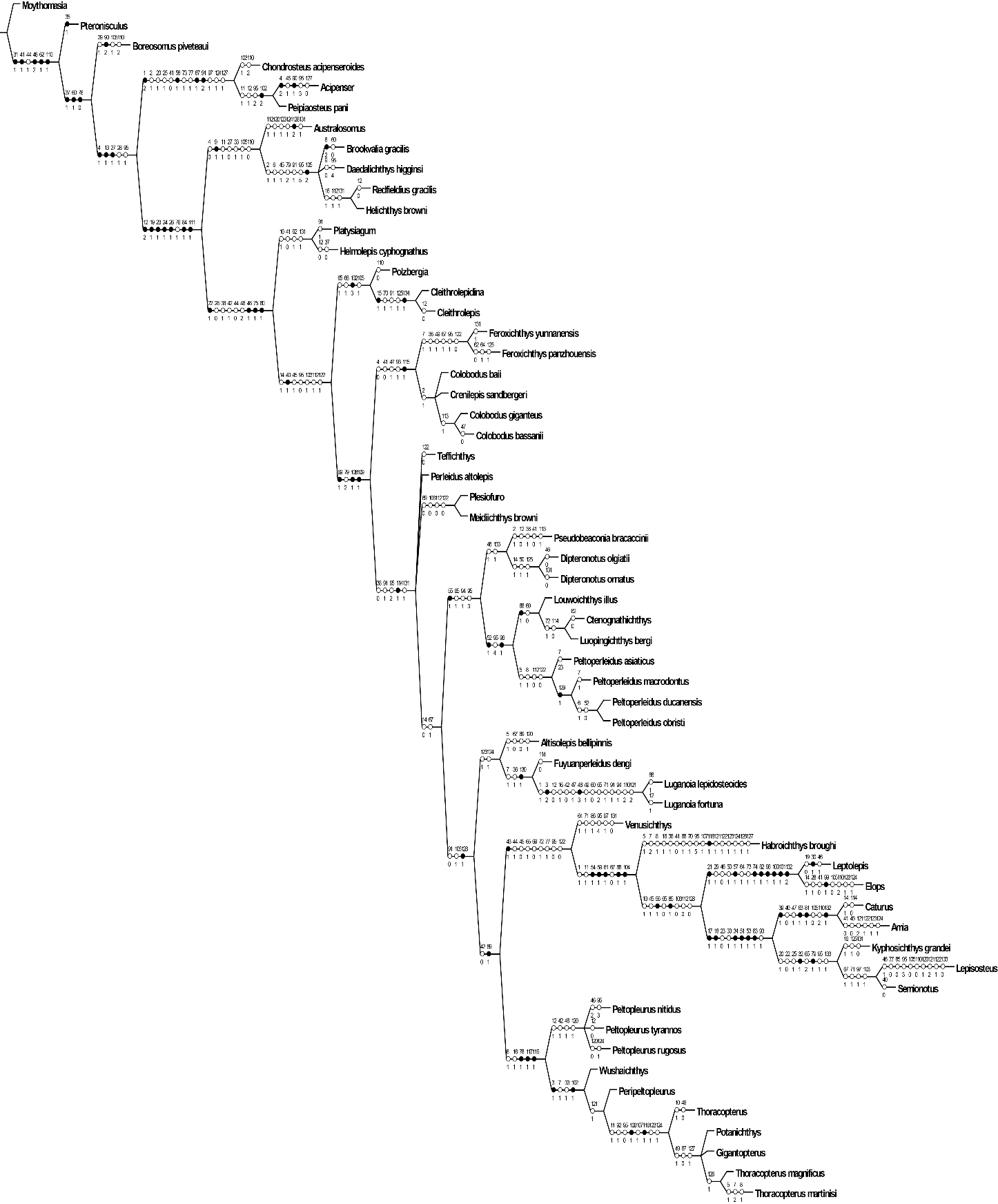
*‘Thoracopterus’ magnificus*: Tintori and Sassi, 1992

*‘Thoracopterus’ martinisi*: Tintori and Sassi, 1992

*Venusichthys comptus*: Xu and Zhao, 2016

*Wushaichthys exquisitus*: Xu et al., 2015b

1. **Supplementary Figure**



Supplementary Figure S1. Strict consensus of 120 most parsimonious trees (tree length = 384 steps, consistency index = 0.4505, retention index = 0.7719), illustrating the phylogenetic position of *Peltoperleidus asiaticus* sp. nov. within the Neopterygii. Character changes indicated with solid circles are unique.

**Character list**

**Skull Roof**

1. Rostral: large, shield-like or cap-like (0); small, much reduced or lost by fusion with other elements (1); irregularly shaped and anamestic (2). (Modified from Gardiner et al., 1996; Xu & Wu, 2012; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
2. Postrostral: absent (0); present (1). (Xu, 2020, 2021; Ma et al., 2021)
3. Frontal(s): elongate (0); laterally expanded (1); well constricted above orbit (2). (Xu et al., 2012, 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
4. Contact relationships of frontals: anterior portions of frontals partly separated by median rostral bone (0); fully contact each other medially (1); paired, completely separated by rostral bones (2). (Xu, 2020; Ma et al., 2021)
5. Suture between frontals: present, paired frontals (0); absent, fusion of frontals into single element (1).
6. Supraorbital sensory canal: ending in parietal (0); ending in frontal (1); ending in dermopterotic (2). (Modified from Xu et al., 2012, 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
7. Distinct parietal: present (0); absent, fused with dermopterotic (1); absent, fused with frontal and dermopterotic (2); absent, fused with frontal (3). (Modified from Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
8. Suture between parietals: present (0); absent (1).
9. Number of parietals: one pair or single (0); three or more (1). (Modified from Xu, 2020, 2021; Ma et al., 2021)
10. Nasal bones: completely separated from each other by median rostral or rostral bones (0); joined or nearly joined in midline (1). (Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
11. Nasal bone forming part of orbital margin: present (0); absent (1). (Xu & Zhao, 2016; Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
12. Number of extrascapulars: two pairs or more (0); three (1); one pair (2). (Modified from Xu et al., 2012, 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
13. Intertemporal: present (0); absent (1). (Modified from Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
14. Ratio of dermopterotic length to parietal length: less than two (0); two or more (1). (Xu, 2020; Ma et al., 2021)
15. Accessory dermopterotic: absent (0); present (1). (Xu et al., 2015; Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
16. Dermopterotic/preopercle contact: present (0); absent (1). (Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)

**Neurocranium**

1. Sphenotic with small dermal component: absent (0); present (1). (Grande, 2010; Xu & Wu, 2012; Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
2. Pterotic: present (0); absent (1). (Gardiner et al., 1996; Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
3. Opisthotic: present (0); absent (1). (Grande, 2010; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
4. Intercalar: present (0); absent (1). (Gardiner et al., 1996; Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
5. Supraoccipital: absent (0); present (1). (Grande, 2010; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
6. Post-temporal fossa: absent (0); present (1). (Gardiner & Schaeffer, 1989; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
7. Sub-temporal fossa: absent (0); present (1). (Gardiner & Schaeffer, 1989; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
8. Dilatator fossa: absent (0); present (1). (Gardiner & Schaeffer, 1989; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
9. Posterior myodome: present (0); absent (1). (Modified from Gardiner & Schaeffer, 1989; Gardiner et al., 2005; Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
10. Anterodorsal myodome: present (0); absent (1). (Xu et al., 2014, 2018; Xu & Zhao, 2016; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
11. Parasphenoid: short, terminates at otic fissure (0); long, extends across otic fissure (1). (Modified from Gardiner et al., 2005; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
12. Basipterygoid process: present (0); absent (1). (Gardiner et al., 2005; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
13. Internal carotid foramen on parasphenoid: absent (0); present (1). (Gardiner et al., 1996; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
14. Efferent pseudobranchial foramen on parasphenoid: absent (0); present (1). (Gardiner et al., 1996; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
15. Pineal foramen: present (0); absent (1). (Xu et al., 2014; Xu, 2020, 2021; Ma et al., 2021)

**Circumorbital Bones**

1. Anterior infraorbital bone(s): absent (0); present (1). (Modified from Grande, 2010; Xu & Wu, 2012; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
2. Antorbital (when it is not fused with premaxilla): small, shorter than nasal (0); enlarged, nearly equal to or deeper than nasal (1). (Modified from Xu, 2020, 2021; Ma et al., 2021)
3. Tube-like canal bearing anterior arm of antorbital: absent (0); present (1). (Grande, 2010; Xu & Wu, 2012; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
4. Anterior part of lacrimal bearing teeth: absent (0); present (1). (Modified from Xu, 2020, 2021; Ma et al., 2021)
5. Lacrimal: independent (0); fused with maxilla (1). (Xu, 2020; Ma et al., 2021)

Remarks: Based on personal observation on the holotype (IVPP V16517), the lacrimal is fused with the maxilla in *Fuyuanperleidus dengi* from the Middle Triassic (Anisian) of Luoping, Yunnan.

1. Dermosphenotic/nasal contact: present (0); absent (1). (Modified from Gardiner & Schaeffer, 1989; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)

Remarks: In *Helmolepis cyphognathus*, the triangular ‘supraorbital’ is better interpreted as a dermosphenotic according to its shape and position (Neuman & Mutter, 2005).

1. Dermosphenotic/preopercle contact: absent (0); present (1). (Xu, 2020, 2021; Ma et al., 2021)
2. Dermosphenotic attachment to skull roof in adult-sized individuals: loosely attached on the skull roof or hinged to the side of skull roof (0); firmly sutured into skull roof, forming part of it (1). (Grande & Bemis, 1998; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
3. Position of dermosphenotic relative to dermopterotic (intertemporal plus supratemporal): located at nearly same horizontal level of dermopterotic (0); located below dermopterotic (1). (Ma et al., 2021)
4. Suborbital(s): absent (0); present (1). (Modified from Gardiner & Schaeffer, 1989; Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)

Remarks: The coding (1) for *Australosomus* is based on personal observation on NHMUK 17157.

1. Positions of suborbital(s): extending below dermosphenotic (0); located posterior to dermosphenotic only (1). (Modified from Xu, 2020, 2021; Ma et al., 2021)
2. Number of infraorbitals between antorbital and dermosphenotic: three or less (0); four or more (1). (Modified from Gardiner & Schaeffer, 1989; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
3. Postinfraorbital(s): absent (0); present (1). (Xu, 2020, 2021; Ma et al., 2021)
4. Supraorbital: absent (0); present (1). (Modified from Gardiner & Schaeffer, 1989; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
5. Number of supraorbital bones: single (0); two (1); three or more (2). (Modified from Gardiner & Schaeffer, 1989; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)

Remarks: Based on personal observation (IVPP V25666), four supraorbital bones are present in *Luopingichthys bergi* from the Middle Triassic (Anisian) of Luoping, Yunnan.

1. Multiple supraorbital bones arranged in more than one horizontal rows: absent (0); present (1). (Xu, 2020; Ma et al., 2021)

**Jaws and dentation**

1. Premaxilla: fused with antorbital, bearing sensory canal (0); present as distinct elements, lacking sensory canal (1); lost (2); fused with rostral, bearing sensory canal (3). (Modified from Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)

Remarks: Personal reexaminations on the type specimens (LPV-11014 and LPV-11797) confirm that a pair of small, toothed premaxillae lacking sensory canal is present in *Platysiagum sinensis*.

1. Premaxilla(e): present as a pair of elements (0); fused as a median element (1). (Modified from Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
2. Mobile premaxilla: absent (0); present (1). (Modified from Gardiner & Schaeffer, 1989; Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
3. Premaxilla immovably attached to braincase by means of a deep nasal process tightly sutured to frontals: absent (0); present (1). (Grande, 2010; Xu & Wu, 2012; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
4. Number of marginal teeth on premaxilla: three or more (0); one or two (1). (Xu, 2020, 2021; Ma et al., 2021)
5. Foramen for olfactory nerve on premaxilla: absent (0); present (1). (Modified from Grande, 2010; Xu & Wu, 2012; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
6. Maxilla/preopercle contact: present (0); absent (1). (Coates, 1999; Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
7. Ventral portion of preopercle anteriorly extended, contacting maxilla anteriorly: absent (0); present (1). (Modified from Xu, 2020, 2021; Ma et al., 2021)
8. Supramaxilla: absent (0); present (1). (Modified from Gardiner & Schaeffer, 1989; Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
9. Number of supramaxilla: single (0); two (1). (Xu & Zhao, 2016; Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
10. Maxilla: present (0); absent (1). (Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
11. Mobile maxilla in cheek: absent (0); present (1). (Coates, 1999; Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
12. Suborbital/maxilla contact: present (0); absent (1). (Modified from Cloutier & Arratia, 2004; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
13. Expanded dorsal lamina of maxilla: present (0); absent (1). (Modified from Cloutier & Arratia, 2004; Xu, 2020, 2021; Ma et al., 2021)
14. Depth of dorsal lamina of maxilla: no smaller than orbital length (0); smaller than orbital length (1). (Xu, 2020, 2021; Ma et al., 2021)
15. Posterior margin of maxilla: slightly convex or straight (0); concave with a posterior maxillary notch (1). (Grande & Bemis, 1998; Xu & Wu, 2012; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
16. Oral margin of maxilla: concave or nearly straight (0); convex (1). (Xu, 2020, 2021; Ma et al., 2021)
17. Posterior end of maxilla relative to orbit: well behind orbit (0); ending below (or nearly below) posterior orbital margin (1); ending nearly below orbital center or even anteriorly located (2). (Xu, 2020, 2021; Ma et al., 2021)
18. Teeth on maxilla: present (0); much reduced or lost (1). (Modified from López-Arbarello & Zavattieri, 2008; Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
19. Distribution of teeth on maxilla: most of oral margin of maxilla (0); only anterior portion of oral margin of maxilla (1). (Xu, 2020, 2021; Ma et al., 2021)
20. Extraordinarily long, fang-like teeth on both jaws: absent (0); present (1). (Xu, 2020, 2021; Ma et al., 2021)
21. Molariform teeth on coronoid(s), prearticular and palatine bones: absent (0); present (1). (Xu, 2020; Ma et al., 2021)
22. Teeth on dentary: present (0); absent (1). (Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
23. Quadratomandibular articulation: well behind orbit or below posterior orbit margin (0); nearly below the orbital center or even anteriorly located (1). (Modified from López-Arbarello & Zavattieri, 20082; Xu et al., 2012, 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
24. Coronoid process: absent (0); present (1). (Gardiner & Schaeffer, 1989; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
25. Supra-angular bone in lower jaw: present (0); absent (1). (Arratia, 2013; Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)

**Palatoquadrate, Hyoid Arch, and Operculo-gular Series**

1. Vomers in adults: paired (0); fused (1). (Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
2. Suspensorium angle: acute (0); nearly vertical (1). (Modified from Gardiner et al., 2005; Xu et al., 2015; Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
3. Hyomandibula with canal for hyoid branch of nerve VII: absent (0); present (1). (Modified from Coates, 1999; Xu et al., 2015; Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
4. Dermohyal: present (0); absent (1). (Modified from Gardiner et al., 2005; Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
5. Postspiracle: absent (0); present (1). (Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
6. Quadratojugal: plate-like (0); splint-like (1); much reduced or lost (2). (Modified from Gardiner et al., 2005; Coates, 1999; Xu et al., 2015; Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
7. Symplectic: absent (0); present (1). (Modified Gardiner et al., 2005; Xu et al., 2015; Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
8. Symplectic involvement of jaw joint: absent (0); present (1). (Grande & Bemis, 1998; Grande, 2010; Xu & Wu, 2012; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
9. Elongated posteroventral process of quadrate: absent (0); present (1). (Modified from Gardiner et al., 1996; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
10. Number of hypobranchials: three (0); four (1). (Grande, 2010; Xu & Wu, 2012; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
11. Uncinate processes on epibranchials: absent (0); present (1). (Coates, 1999; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
12. Interopercle: absent (0); present (1). (Gardiner & Schaeffer, 1989; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
13. Two or more preopercular elements on each side of skull: absent (0), present (1). (Xu & Zhao, 2016; Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
14. Preopercle: present (0); absent (1). (Xu, 2020, 2021; Ma et al., 2021)
15. Shape of preopercle: boomerang-shaped or irregular (0); crescent-shaped or L-shaped (1). (Modified from Xu & Zhao, 2016; Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
16. Ventral end of preopercle located well above posterior end of oral margin of maxilla (when the ventral part of preopercle contacts maxilla): present (0); absent (1). (Modified from Xu, 2020, 2021)
17. Opercle: present (0); absent (1). (Xu, 2020, 2021; Ma et al., 2021)
18. Size of opercle: significantly larger than subopercle (0); nearly equal to or smaller than subopercle (1); much reduced (2). (Modified from Xu & Wu, 2012; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
19. Suture between opercle and subopercle: slightly inclined or horizontal (0); greatly inclined (1). (Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
20. Prominent anterodorsal process of subopercle: absent (0); present (1). (Xu, 2020; Ma et al., 2021)
21. Prominent anteroventral extension of subopercle: absent (0); present (1). (Xu, 2020, 2021; Ma et al., 2021)
22. Number of branchiostegal rays: ten or more (0); seven to nine (1); four to six (2); three (3); two (4); single (5). (Modified from Xu, 2020, 2021; Ma et al., 2021)
23. Posterior-most branchiostegal ray: elongate, plate-like or rod-like (0); triangular, much expanded posteriorly (1).
24. Gular bone(s): present (0); absent (1). (Modified from Coates, 1999; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)

**Vertebrate and Caudal Skeleton**

1. Solid vertebral centra of adult-sized individuals: absent (0); present (1). (Modified from Grande & Bemis, 1998; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
2. Epipleural intermuscular bones: absent (0); present (1). (Arratia, 2013; Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
3. Uroneural: absent (0); present (1). (Xu & Wu, 2012; Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021)
4. Division of hypurals into dorsal and ventral groups (a gap between hypurals 2 and 3): absent (0); present (1). (Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)

**Girdles and Fins**

1. Posttemporal: contacting extrascapular posteriorly (0); contacting extrascapular posterolaterally and separating this bone from contact with its counterpart (1); contacting extrascapular medially, and being incorporated into the skull roof (2); lost (3). (Modified from Xu et al., 2012, 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
2. Width of posttemporals: broad, nearly as wide as extrascapular (0); relatively narrow, about half width of extrascapular series (1). (Xu, 2020, 2021; Ma et al., 2021)
3. Clavicle: present as a broad plate (0); much reduced or lost (1). (Modified from Gardiner et al., 1996; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
4. Supracleithrum relative to posterior margin of opercle in depth: supracleithrum nearly as deep as posterior margin of opercle (0); supracleithrum shorter than posterior margin of opercle (1); supracleithrum well deeper than posterior margin of opercle (2). (Ma et al., 2021)
5. Pectoral fins enlarged as wings: absent (0); present (1). (Xu et al., 2012, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
6. Pelvic fins enlarged as auxiliary wings: absent (0); present (1). (Xu et al., 2012, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
7. Number of dorsal and anal fin rays relative to radials: rays more numerous than radials (0); rays and radials nearly equal in number (1). (Gardiner et al., 2005; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)

Remarks: In *Cleithrolepis granulate*, the rays are more numerous than the radials in both the dorsal (19 radials corresponding to 27 rays) and anal (9 radials corresponding to 19 rays) fins (Wade, 1935). The similar condition is also present in *Polzbergia brochatus*, in which, the rays are also more numerous than the radials in the dorsal fin (Griffith, 1977).

1. Dorsal and anal fin rays: segmented throughout the length (0); segmented distally (1). (Xu & Gao, 2011; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
2. Origin of dorsal fin: nearly opposite to the origin of anal fin, well posterior to the origins of pelvic fins (0); between origins of anal and pelvic fins (1); anterior to origins of pelvic fins (2). (Xu, 2020, 2021; Ma et al., 2021)
3. Caudal fin rays: terminate at caudal extremity of body axis (0); extend beyond termination of body axis (1). (Modified from Gardiner et al., 2005; Xu et al., 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
4. Epaxial procurrent rays in caudal fin: absent (0); present (1). (Modified from López-Arbarello & Zavattieri, 2008; Xu, 2020, 2021; Ma et al., 2021)
5. Number of epaxial procurrent rays in caudal fin: four or more (0); one to three (1). (Xu, 2020; Ma et al., 2021)
6. Number of principal caudal fin rays: 25 or more (0); 24 or less (1). (Xu, 2020, 2021; Ma et al., 2021)
7. Principal rays of caudal fin ornamented with rounded ganoid tubercles: absent (0); present (1). (Xu, 2020)
8. Dense lepidotrichial segments of pectoral fin rays between innermost principal pectoral fin ray and body: absent (0); present (1). (Xu et al., 2012, 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
9. Dense brush-like rays proximally articulating several stout segments at posterior portion of male anal fin: absent (0); present (1). (Modified from Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
10. Modification of male anal fin into unsegmented rays with tiny hooklets along anterior margin of longest leading ray: absent (0); present (1). (Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
11. Enlarged and posteriorly extended lateral scutes associate with anal fin: absent (0); present (1). (Modified from Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
12. Anal fin relative to dorsal fin in size: anal fin smaller than or equal to dorsal fin (0); anal fin larger than dorsal fin (1). (Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
13. Caudal fin: forked, lower lobe slightly shorter than or largely equal to upper lobe (0); forked, lower lobe longer than upper lobe (1); unforked (2). (Modified from Xu et al., 2012, 2015, 2018; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
14. Number of epiaxial basal fulcra associated with caudal fin: six or more (0); five or less (1).
15. Fringing fulcra on caudal fin: present (0); absent (1). (Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
16. Fringing fulcra on pectoral fins: present (0); absent (1). (Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)

**Body shape and scales**

1. An apparent dorsal hump between head and dorsal fin: absent (0); present (1). (Xu & Wu, 2012; Xu, 2020, 2021; Ma et al., 2021)
2. Scales: present (0); absent (1). (Modified from Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
3. Anterior flank scales: present (0); much reduced or absent (1). (Modified from Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
4. Lateral line scales: the lateral line scales as deep as or slightly deeper than those scales above and below (0); greatly deepened, 30% or more of the greatest depth of the body (1). (Modified from Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
5. Two horizontal rows of scales notably deepened in anterior flank region (lateral line scales notably deepened and nearly equal to the scales ventral to them): absent (0); present (1). (Xu, 2020; Ma et al., 2021)
6. Greatly deepened anterior flank scales corresponding to two or three horizontal rows of relatively shorter scales posteriorly: absent (0); present (1). (Xu, 2020; Ma et al., 2021)
7. Rhomboidal scales in anterior flank region: ornamented with ganoid ridges and tubercles (0); nearly smooth (1). (Xu, 2020; Ma et al., 2021)
8. Type of scales: ganoid of lepisosteoid type (0); elasmoid of amioid type (1); elasmoid of cycloid type (2). (Xu et al., 2012, 2015, 2018; Arratia, 2013; Xu & Ma, 2016; Xu, 2020, 2021; Ma et al., 2021)
9. A posteriorly directed spine on dorsal ridge scale anterior to dorsal fin: absent (0); present (1). (GML36; López-Arbarello & Zavattieri, 2008; Xu & Wu, 2012; Xu, 2020, 2021; Ma et al., 2021)
10. Posteriorly inclined scales in pectoral region: absent (0); present (1). (López-Arbarello & Zavattieri, 2008; Xu & Ma, 2016; Xu et al., 2018; Xu, 2020, 2021; Ma et al., 2021)
11. **Data matrix**

Moythomasia

0000000000000-0-0----00000000000-00000000-000--000000000-00-0000000000000001000000000000000000000000000000000000-000000000000000000000

Pteronisculus

0000000000000-0-0----000000000100010000010010--2-00-0000-0000100000000000001000000000000000000000000000000000100-000000000000000000000

Boreosomus\_piveteaui

0000000000000-0-0----000000010100000100010010--2-00-0000-001010000000000000000?000000000020000000000000010000200-000000000000000000000

Acipenser

2102000000111-0-0001000010110010?0?-10000---1002-00----0-1----------0-001-0010000000001--1--003010000200-0000100-00000000001000----000

Chondrosteus\_acipenseroides

2?01000000001-0-0???0?????1?0?1????-10000---0--2-00----0-1----------0-001-00100000??001--02000101000001000000200-00000000001001----000

Peipiaosteus\_pani

2?010?00001?1-0-0???0?????1????????-10000---0--2-00----0-1----------0-001-00100000??001--0200020100002?000000100-00000000001001----000

Australosomus

00000000101210000???001101010010??00?0-010010--???0?0000-00101000000000000010000000100000000001000000000100000110000000100110002001000

Brookvalia\_gracilis

01000200101210000???0?????????101000100010011002-00--000-000010000000000??0?002?????000000100050?????00020000010-000000000000000000000

Daedalichthys\_higginsi

01000100001210000???0?????????101000100010011002-00--000-00?010000000000??0?002?????000000100040?????00020000010-000000000000000000000

Redfieldius\_gracilis

0100010-101010010???0?????????101000100010011002-00--000-001010000000000??0?002?????000000100050?????000200000110000000000000000001000

Helichthys\_browni

01000100101210010???0?????????101000100010011002-00--000-001010000000000??0?002?????000000100050?????000200000110000000000000000001000

Platysiagum

00010000010210000???0?????????10000011000-000--10?000000-001010000000000??1?00??????00000011001000???00000000110-00000000000000000(01)000

Helmolepis\_cyphognathus

00010000010010000???0?????????10000001000-000--??????000-001010000000000??1?00??????00000001001000???00000000110-000000000000000001000

Cleithrolepidina

00010000000211100???0?????????100000110111?0120??00-0000-001010011000100??1?000?????0000001000???0???3-?100?011??000000001001000000001

Cleithrolepis

000?0000000011100???0?????????100000110111001201000-0000-001010011000(01)00??1?000?????000000100000?0???3-??000011100000000010?1000000001

Polzbergia

?00?00000??21?000???0?????????1???001101????1201000000?0-001010?1100000???1?00??????0?00?0000????????3-01000001100000000010?0000000000

Plesiofuro

00010000000211000???0?????????10000010011100120100000000-0010100000000000?1?002?????00000010002000???00?00011110-100000000000000001000

Teffichthys

00010000000211000---01110?100010000010011100120100000000-001010000001000??11002??00?00000010002000???01?000111110100000000000000001000

Meidiichthys\_browni

00010000000211000???0?????????10000010011100120100000000-00101000000?000??1?002??00?0000001000200????00000011110-100000000000000001000

Perleidus\_altolepis

00010000000211000???0?????????10000010011100120100000000-001010000001000??1?002?????0000001000200????01?000111110100000001000000001000

Peltoperleidus\_ducanensis

000111010?0210000???0?????????100000100111001?0100000010-00101001010?000??1?002?????0000001001410????01?00011110-100000000000000101000

Peltoperleidus\_macrodontus

00011011-00?1-000???0?????????10000010011100120100010010-00101001010100???1?002?????000000100141?????01?00011110-100000000000000101000

Peltoperleidus\_obristi

00011101000210000???0?????????10000010011100120100000010-00101001010?000??1?002?????0000001001410????01?000?1110-100000000000000101000

Peltoperleidus\_asiaticus

00011-(23)1-0021-000???0?????????10000010011100120100010010-001010010101000??1?002?????0000001001410????010000?1110-100000000000000001000

Pseudobeaconia\_bracaccinii

01010000000010000???0?????????10000011010-00110100000010-001010010101000??1?002?????0000001001300????0100001111111000000010?0000001010

Dipteronotus\_olgiatii

00010000000211000???0?????????10000010011100100??????010-00101001010?000??1???2?????0000?01001???????0??000?111101000000010?1000001010

Dipteronotus\_ornatus

0001000000?211000???0?????????1000001001??001101010?0010-001010010101000??1???2?????0000?0100130????????000?1111??0000000?0?1000000010

Louwoichthys\_illus

0001(01)0(02)(01)000210000???0?????????10000010011100120100010010-0010100101100000?1?002?????00000010014100???010000111110100000001000000001000

Ctenognathichthys

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Luopingichthys\_bergi

00010000000210000???0?????????10000010011100120100010010-0010100101100010?1?002?????00000010014100???010000111110000000001000000001000

Colobodus\_giganteus

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Colobodus\_bassanii

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Colobodus\_baii

01000000000211000???0?????????1000001?0?0-001?1100000000-00-0100000010000?11002?????00000000?0?0?????01?000?11110010000001000000000000

Crenilepis\_sandbergeri

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Feroxichthys\_yunnanensis

0000001000021-000???0?????????1000-111010-00121110000000-00-010000101000??1?002?????0000000010100????01?000?11110?10000000000000001000

Feroxichthys\_panzhouensis

??????????????????????????????????-111010-00121??????000-00-0001001010000?1?002?????0000000010100???????000?11110010000?00001000000000

Luganoia\_lepidosteoides

1021001000001-010???0?????????1000-110011000121310000000-000010020101010??11002?????0100-01001?0?????01?100112110100000021110001011000

Luganoia\_fortuna

1021001000011-010???0?????????1000-1100110001??310000000-00001002010?010??1?002?????0000-01001???????01?100112110100000021110001011000

Fuyuanperleidus\_dengi

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Altisolepis\_bellipinnis

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Peltopleurus\_nitidus

0001(01)1(02)(01)000110010???0?????????10000010011100120100000000-00101000010?000??1?012?????0000100000300????010100111110100101101000001001000

Peltopleurus\_tyrannos

0001(01)1(02)(01)000010010???0?????????10000010011100110100000000-001010000101000??1?012?????0000100000200????0??100?11110100101101000001001000

Peltopleurus\_rugosus

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Wushaichthys

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Peripeltopleurus

0011(01)11(01)-0021-010???0?????????10100010011000120100000000-001010000101000??1?012?????00001000002000???11?100111110100101011000001001000

Thoracopterus

00110110-1121-010???0?????????10100010011???100100000000-00101000010?000??1?????????00001001000000??011?111111110101???011110001001000

Potanichthys

00110110-0121-010???0?????1?0010100010011000120110000000-001010000001000??1??12?000?0000100100?000?0011?11111111010110101111001----000

Gigantopterus

00110110-??21-0?0???0?????????10?0001?01??00120?????0000-001010?00?0?000??11????????0000?00100?0?0??01??111111110?01?0??1111001----000

Thoracopterus\_magnificus

00110110-01?1-010???0?????????10?00010011?00???110000000-00101000000?000??1???2?00??00001001000000?0011?111111110101?0?01111011-----00

Thoracopterus\_martinisi

00111-21-01?1-010???0?????????10100010011?00???110?0?000-00101000000?000??1??12?00??0000100100???0?0011?111111110?01?0?01?11011-----00

Venusichthys

00010000000210000???0?????????100000100110110--100000000-001010110100011??1?102?????01001000004010???010100111110100000000000001000000

Habroichthys\_broughi

10011-21-0?21-010???0?????????10????11010-??0--??????1-0-0111-0011-0010???1?102??0??0001-0000050?0???01?101111110100010011110111001000

Caturus

100100000112110011100?????1?00101100101010111211001011-100111-100000000100111021101?1001-00010000000000?00011210-00000000000000000-100

Amia

10010000011210001110010101100010110010100-110--1001011-100111-10000000010011102110111001-00010000000000100011210-10000002111000000-100

Lepisosteus

100100000112100011110001111000111100100110111101001011-100---------000110011001100110001-00010301000001100011010-100000121000000001000

Semionotus

100100000112100011110?????1?00111100100010111201001011-100111-00201000110011101100111001-00010101000001110011110-100000000000000001010

Kyphosichthys\_grandei

10010000011210011???0?????????1111001001101112010010?1-100111-00200000010?1?101?????1001-000101000???00110011110-100000000001000000010

Leptolepis

100100000112100000001111011011100000100110111101010001-110111-01000000011111102101011001-00000000101100110011110-10000000000000000-200

Elops

1001000001121100001011?101111010000010010-111001010001-110111-01000000011111102101011001-00000000111100100011210-10000000011000000-200

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