

Supplementary Material:

A New Sinamiin Fish (Actinopterygii) from the Early Cretaceous of Thailand: Implications on the Evolutionary History of the Amiid Lineage

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This document contains:

Phylogenetic analysis including character lists and taxa scoring.

List of characters

Characters Selection from Xu (2019). Xu's original character numbering in parentheses.

Neurocranium

1. Membranous outgrowth of intercalary (5)

(Gardiner et al., 1996; Hurley et al., 2007; Giles et al., 2017; López-Arbarello and Sferco, 2018; Xu et al., 2018, 2019. This character can only be coded when separate braincase ossifications can be identified.)

0. Absent

1. Present

2. Opisthotic (7)

(Grande and Bemis, 1998; Cavin and Suteethorn, 2006; Hurley et al., 2007; Grande, 2010; López-Arbarello, 2012; Cavin et al., 2013; Deesri et al., 2014, 2016; Xu et al., 2014b, 2018, 2019; Giles et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018; López-Arbarello and Sferco, 2018. This character can only be coded when separate braincase ossifications can be identified.)

0. Present

1. Absent

3. Pterotic (8)

(Grande and Bemis, 1998; Xu and Wu, 2012; Brito and Alvarado-Ortega, 2013; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Giles et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018. This character can only be coded when separate braincase ossifications can be identified.)

0. Present

1. Absent Regarded as absent in sinamiidae, i.e. *Ichekaoamia* and *Sinamia* (Grande & Bemis, 1998: char. 52, p. 584)

4. Intercalar/parasphenoid contact (13)

(Gardiner et al., 1996; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Xu and Ma, 2018. This character can only be coded when separate braincase ossifications can be identified.)

0. Absent

1. Present

5. Sphenotic with small dermal component (17)

(Grande, 2010; Xu and Wu, 2012; Xu et al., 2012, 2014b, 2015, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Giles et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018; López-Arbarello and Sferco, 2018)

0. Absent

1. Present

6. Posterior extent of exoccipitals in adult-sized individuals (20)

(Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018; Ebert, 2018)

0. Reaches posterior margin of occiput

1. Does not reach posterior margin of occiput

Snout and skull roof

7. Rostral bone (23)

(Gardiner et al., 1996; Grande and Bemis, 1998; Xu and Wu, 2012; Xu et al., 2012, 2014a,b, 2018, 2019; Brito and Alvarado-Ortega, 2013; Xu and Shen, 2015; Sun et al., 2017; Giles et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

0. A deep cap on tip of snout

1. Of moderate size, sub-circular

2. Much reduced, sub-triangular, elongate, V-shaped or tube-like

3. Lost as an autogenous bone

8. Parietal length (25)

(Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018; Ebert, 2018; López-Arbarello and Sferco, 2018)

0. Short, with a width-to-length ratio range well exceeding 0.90

1. Relatively long, with a width-to-length ratio range not exceeding 0.90

9. Number of parietal bones (26)

(Grande and Bemis, 1998; Xu et al., 2014; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

0. Paired parietals normally present

1. Only a single median parietal

10. Ratio of frontal/parietal length (28)

(Modified from López-Arbarello, 2012; Cavin et al., 2013; Deesri et al., 2016; López-Arbarello and Wencker, 2016; Sun et al., 2017; López-Arbarello and Sferco, 2018; Xu et al., 2018, 2019)

- 0. 1.5 or more
- 1. Less than 1.5

11. Frontal width in adult-sized individuals (29)

(Modified from Grande and Bemis, 1998; López-Arbarello, 2012; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; López-Arbarello and Wencker, 2016; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018; López-Arbarello and Sferco, 2018)

- 0. Relatively wide, with a width-to-length ratio of 0.22 to 0.65
- 1. Relatively narrow, with a width-to-length ratio of no more than 0.21

12. Pre-orbital length equal to or longer than orbital length (30)

(Xu et al., 2019)

- 0. Absent
- 1. Present

13. Shape of dermopterotic (=supratemporal+intertemporal) (31)

(Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

- 0. Greatly widened posteriorly and tapered anteriorly
- 1. Subrectangular, not substantially tapered anteriorly or widened posteriorly

14. Dermopterotic length to parietal length (32)

(Modified from Gardiner et al., 1996; Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; López-Arbarello and Wencker, 2016; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

- 0. Dermopterotic significantly longer
- 1. Lengths about equivalent
- 2. Dermopterotic shorter than parietal

15. Number of extrascapular bones (33)

(Grande and Bemis, 1998; Xu et al., 2014b, 2018; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018; López-Arbarello and Sferco, 2018)

- 0. One pair
- 1. Two pairs
- 2. More than two pairs

16. Rostral/frontal contact (37)

(Grande and Bemis, 1998; Xu et al., 2014a,b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

- 0. Present
- 1. Absent

17. Contact relationships of nasals (38)

(Arratia, 2013; Ma and Xu, 2017; Giles et al., 2017; Xu and Ma, 2018; López-Arbarello and Sferco, 2018; Xu et al., 2018, 2019)

0. Separated by rostral

1. Contacting medially or close to contact medially (not separated by other bones)

2. Separated by frontals

3. Separated by mesethmoid

18. Nasal contributing to orbital margin (39)

(Xu and Wu, 2012; Xu et al., 2014a, 2018, 2019; Xu and Zhao, 2016; Giles et al., 2017; López-Arbarello and Sferco, 2018)

0. Present

1. Absent

19. Frontal contributing to orbital margin (40)

(Xu et al., 2018, 2019)

0. Absent

1. Present

20. Parietal portion of the supraorbital sensory canal (42)

(Cavin, 2010; López-Arbarello, 2012; Cavin et al., 2013; Deesri et al., 2016; Ma and Xu, 2017; Sun et al., 2017; Xu and Ma, 2018; Xu et al., 2018, 2019)

0. Present

1. Absent

Circumorbital bones

21. Tube-like canal bearing anterior arm on the antorbital bone. (45)

(Grande, 2010; Xu and Wu, 2012; Brito and Alvarado-Ortega, 2013; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Ma and Xu, 2017; Sun et al., 2017; Giles et al., 2017; Xu and Ma, 2018; López-Arbarello and Sferco, 2018)

0. Absent

1. Present

22. Supraorbital (46)

(Modified from Grande and Bemis, 1998; Brito and Alvarado-Ortega, 2013; Xu et al., 2014a,b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Giles et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018; López-Arbarello and Sferco, 2018)

0. Absent

1. Present

23. Number of supraorbital bones (47)

(Modified from Grande and Bemis, 1998; Brito and Alvarado-Ortega, 2013; Xu et al., 2014a,b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Giles et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018; Ebert, 2018; López-Arbarello and Sferco, 2018.)

0. Three or more

1. Two

2. Single

24. Supraorbital/antorbital contact (49)

(Xu et al., 2018, 2019)

0. Absent

1. Present

25. Antorbital/frontal contact (50)

(Xu et al., 2018, 2019)

0. Absent

1. Present

26. Infraorbital/dermopterotic contact (51)

(Xu et al., 2018, 2019)

0. Absent

1. Present

27. Contact relationships of infraorbital bone at posteroventral corner of orbit with preopercle (57)

(Modified from López-Arbarello, 2012; Xu and Ma, 2018; López-Arbarello and Sferco, 2018; Xu et al., 2018, 2019)

0. Absent

1. Present

28. Posterior notch of second infraorbital for supramaxilla (58)

(Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017)

0. Absent

1. Present

29. Antorbital contributing to orbital margin (59)

(Xu et al., 2012, 2014b, 2018, 2019; Xu and Shen, 2015; Xu and Zhao, 2016; Sun et al., 2017; López-Arbarello and Sferco, 2018)

0. Present

1. Absent

30. Lower margin of last infraorbital inclined posterodorsally (60)

(Gardiner et al., 1996; Alvarado-Ortega and Espinosa-Arrubarrena, 2008; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Ma and Xu, 2017; Xu and Ma, 2018)

0. Absent

1. Present

31. Size of last infraorbital (61)

(Modified from Grande and Bemis, 1998; Xu et al., 2018, 2019)

0. Small, relatively narrow

1. Large, posteriorly expanded

32. Number of infraorbitals between antorbital and dermosphenotic (62)

(Gardiner and Schaeffer, 1989; Xu et al., 2012, 2014b, 2018; Xu and Shen, 2015; Ma and Xu, 2017; Xu and Ma, 2018)

0. Two or three

1. Four or five

2. Six or more

33. Number of the infraorbital bones between the Lacrimal and the infraorbital at the posteroventral corner of the orbit (63)

(Modified from Gardiner et al., 1996; Xu et al., 2018, 2019)

- 0. Zero
- 1. One
- 2. Two to four

34. Number of postinfraorbital bones (64)

- 0. Two
- 1. Three or more

35. Depth of infraorbital bones at middle portion of the orbit (65)

(Xu et al., 2019)

- 0. Dorsoventrally short
- 1. Deeper than the orbital radius

36. Lacrimal (66)

(Modified from Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

- 0. Longer than deep
- 1. Deeper than long

37. Lacrimal relative to orbit in size (67)

(Modified from Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

- 0. Significantly smaller than orbit
- 1. Nearly equal to orbit in size

38. Contact relationships of lacrimal with supraorbital (68)

(Xu et al., 2019)

- 0. Well separated
- 1. Closely related or firmly contact

39. Inner orbital flange of dermosphenotic (69)

(Grande and Bemis, 1998; Brito and Alvarado-Ortega, 2013; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

- 0. Smooth, without sensory canal
- 1. Bearing sensory canal tube

40. Dermosphenotic participation in orbital margin (70)

(Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018; López-Arbarello and Sferco, 2018)

- 0. Dermosphenotic reaches orbital margin
- 1. Dermosphenotic does not reach orbital margin

41. Sphenotic with a relatively large exposed dermal component nearly reaching the orbital margin (71)

(Xu et al., 2018, 2019)

- 0. Absent
- 1. Present

42. Dermosphenotic bone attachment to skull roof in adult-sized individuals (72)

(Grande and Bemis, 1998; Brito and Alvarado-Ortega, 2013; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018; López-Arbarelo and Sferco, 2018. The states of *Subortichthys*, *Asialepidotus*, *Panxianichthys* and *Robustichthys* were changed from “1” to “0” in the data matrix.)

- 0. Loosely attached on the skull roof or hinged to the side of skull roof
- 1. Firmly sutured into skull roof, forming part of it

43. Position of dermosphenotic (74)

- 0. Dermosphenotic extending well below dermopterotic
- 1. Dermosphenotic located at same horizontal level of dermopterotic

44. Sclerotic ring ossification (75)

(Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018; Ebert, 2018; López-Arbarelo and Sferco, 2018)

- 0. Present
- 1. Absent

45. Suborbital bones (76)

(Grande and Bemis, 1998; Xu and Wu, 2012; Xu et al., 2014a,b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Giles et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018; Ebert, 2018; López-Arbarelo and Sferco, 2018)

- 0. Present
- 1. Absent

46. Number of suborbital bones (77)

(Modified from Xu and Gao, 2011; Xu et al., 2014b, 2018, 2019; López-Arbarelo and Wencker, 2016; Giles et al., 2017; López-Arbarelo and Sferco, 2018)

- 0. One
- 1. Two to six
- 2. Seven or more

47. Dermohyal (78)

(Grande and Bemis, 1998; Xu and Gao, 2011; Xu et al., 2014a,b, 2015, 2019)

- 0. Present
- 1. Absent

Palatoquadrate, hyoid and branchial arches

48. Quadrate (92)

(Modified from Cavin, 2010; Cavin et al., 2013; Deesri et al., 2014, 2016; López-Arbarelo and Sferco, 2018; Xu et al., 2018, 2019)

- 0. Not exposed (except condyle)
- 1. Partly or fully exposed

49. Quadrate partly or almost fully covered by maxilla (94)

- 0. Absent
- 1. Present

50. Quadratojugal (98)

(Modified from Grande, 2010; Cavin, 2010; Brito and Alvarado-Ortega, 2013; López-Arbarello, 2012; Cavin et al., 2013; Deesri et al., 2014, 2016; Xu and Zhao, 2016; Xu and Ma, 2016; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018, 2019; López-Arbarello and Sferco, 2018; Xu et al., 2018)

- 0. Present
- 1. Absent or fused to quadrate

51. Shape of quadratojugal (99)

(Gardiner et al., 1996; Hurley et al., 2007; López-Arbarello and Wencker, 2016; Xu et al., 2018, 2019)

- 0. Plate-like
- 1. Splint-like
- 2. Reduced to a small flange of bone on quadrate

52. Symplectic involvement in jaw joint (101)

(Grande and Bemis, 1998; Grande 2010; Xu and Wu, 2012; Brito and Alvarado-Ortega, 2013; Xu et al., 2014b, 2015, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Giles et al., 2017; Xu and Ma, 2018)

- 0. Absent
- 1. Present

53. Elongation of opercular process of hyomandibula (102)

(Grande and Bemis, 1998; Xu et al., 2014; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

- 0. Absent
- 1. Present

Jaws

54. Olfactory nerve pierces premaxilla (105)

(Grande, 2010; Xu and Wu, 2012; Cavin et al., 2013; Xu et al., 2014a,b, 2015, 2018, 2019; Xu and Shen, 2015; Xu and Zhao, 2016; Deesri et al., 2016; Sun et al., 2017; Giles et al., 2017; Xu and Ma, 2018)

- 0. Absent
- 1. Present

55. Nasal process of premaxilla (106)

(Gardiner and Schaeffer, 1989; Gardiner et al., 1996; Gardiner et al., 2005; Cavin and Suteethorn, 2006; Hurley et al., 2007; Grande, 2010; López-Arbarello, 2011; Xu and Wu, 2012; Cavin et al., 2013; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Xu and Zhao, 2016; Deesri et al., 2016; Giles et al., 2017; Xu and Ma, 2018)

- 0. Absent
- 1. Present

56. Mobile maxilla in cheek (111)

(Coates, 1999; Grande, 2010; Brito and Alvarado-Ortega, 2013; Xu et al., 2012, 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Giles et al., 2017)

- 0. Absent
- 1. Present

57. Maxilla extremely slender and rod-like (112)

(Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018, 2019)

- 0. Absent
- 1. Present

58. Peg-like anterior process of maxilla (113)

(Grande, 2010; Xu and Wu, 2012; Cavin et al., 2013; Xu et al., 2014b, 2018, 2019; Deesri et al., 2016; Giles et al., 2017)

- 0. Absent
- 1. Present

59. Lateral line canal in maxilla (114)

(Gardiner et al., 1996; Grande and Bemis, 1998; Brito and Alvarado-Ortega, 2013; Xu et al., 2014b, 2018; Xu and Shen, 2015; Sun et al., 2017; Xu and Ma, 2018; López-Arbarello and Sferco, 2018)

- 0. Absent
- 1. Present

60. Posterior margin of maxilla (115)

(Grande and Bemis, 1998; Xu and Wu, 2012; Xu et al., 2014b, 2015, 2018, 2019; Brito and Alvarado-Ortega, 2013; Arratia, 2013; Xu and Zhao, 2016; Giles et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

- 0. Convexly rounded or straight
- 1. Excavated

61. Size of postmaxillary process under postmaxillary notch (116)

(Grande and Bemis, 1998; Xu et al., 2014; Xu and Shen, 2015; Ma and Xu, 2017; Xu and Ma, 2018; López-Arbarello and Sferco, 2018)

- 0. Relatively small and short
- 1. Thick and elongate

62. Coronoid process (117)

(Gardiner and Schaeffer, 1989; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Giles et al., 2017; Xu and Ma, 2018; López-Arbarello and Sferco, 2018)

- 0. Absent
- 1. Present

63. Posterior end of maxilla relative to orbit (121)

(Modified from Gardiner et al., 1996; López-Arbarello and Sferco, 2018; Xu et al., 2018, 2019)

- 0. Posterior to the orbit
- 1. Below the orbit
- 2. Anterior to the orbit

64. Suborbital/maxilla contact (124)

(Xu et al., 2012, 2014b, 2015, 2018, 2019; Xu and Ma, 2016)

- 0. Present
- 1. Absent

65. Supramaxilla (125)

(Gardiner and Schaeffer, 1989; Grande and Bemis, 1998; Xu and Wu, 2012; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Xu and Ma, 2016; Sun et al., 2017)

- 0. Absent
- 1. Present

66. Dorsal process of maxilla for single supramaxilla (127)

(Modified from Xu et al., 2018, 2019)

- 0. Well developed
- 1. Much reduced or absent

67. Maxilla/preopercle contact (129)

- 0. Present
- 1. Absent

68. Number of tooth rows on coronoids (134)

(Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

- 0. Two or more rows for at least part of one or more coronoids
- 1. One row

69. Arrangement of vomerine teeth (135)

(Grande and Bemis, 1998; Xu et al., 2014b, 2018; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

- 0. Tooth patch with two to several rows of teeth
- 1. Tooth patch with only a single anterior marginal row, plus one or more teeth in a longitudinal series perpendicular to the anterior marginal row

70. Articular ossification of lower jaw (145)

(Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018; López-Arbarello and Sferco, 2018)

- 0. A single element, or two elements tightly sutured to each other
- 1. Two separate elements not in contact with each other

71. Well-developed posteroventral process of the dentary (148)

(Cavin, 2010; López-Arbarello and Wencker, 2016; López-Arbarello and Sferco, 2018; Xu et al., 2018, 2019)

- 0. Absent
- 1. Present

72. Morphology of caps of the jaw teeth in adult-sized individuals (149)

(Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

- 0. Round in cross-section, not sharply carinate
- 1. Labiolingually compressed, sharply carinate (keeled)

Opercular series, branchiostegals and gular

73. Shape of preopercle (151)

(Grande and Bemis, 1998; Brito and Alvarado-Ortega, 2013; Xu et al., 2014b, 2018; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018; López-Arbarello and Sferco, 2018)

- 0. Dorsally expanded, without anteroventral arm
- 1. Crescent-shaped
- 2. L-shaped
- 3. Ovoid

74. Peculiar ornamentation pattern of strongly defined, converging lines on opercle in adult-sized individuals (152)

(Grande and Bemis, 1998; Xu et al., 2014; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

- 0. Absent
- 1. Present

75. Width of opercle (153)

(Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

- 0. Narrow, with width-to-height ratio of 0.56 to 1.06
- 1. Wide, with width-to-height ratio in range of 1.07 to 1.39

76. Preopercle/dermopterotic contact (155)

(Xu and Ma, 2016; López-Arbarello and Sferco, 2018; Xu et al., 2018, 2019)

- 0. Present
- 1. Absent

77. Subopercle with well-developed anterodorsal process (157)

(López-Arbarello, 2012; Giles et al., 2017; Xu et al., 2018, 2019)

- 0. Absent
- 1. Present

78. Interopercle (159)

(Gardiner and Schaeffer, 1989; Xu and Gao, 2011; Xu et al., 2014b, 2015, 2018; Gardiner and Schaeffer, 1989; Olsen and McCune, 1991; Gardiner et al., 1996; Gardiner et al., 2005; Cavin and Suteethorn, 2006; Hurley et al., 2007; López-Arbarello, 2012; Xu and Zhao, 2016; Giles et al., 2017)

- 0. Absent
- 1. Present

79. Lateral gulars (162)

(Xu et al., 2014a,b, 2018; Giles et al., 2017. The anterior most 'fifth branchiostegal ray' of the 'Perleidus' species from Madagascar is reinterpreted as the lateral gular because it has pit-lines.)

- 0. Present
- 1. Absent

80. Number of branchiostegal rays (166)

(Modified from Grande and Bemis, 1998; Xu et al., 2014a,b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018; López-Arbarello and Sferco, 2018)

- 0. 10 to 20
- 1. 9 or fewer
- 2. 21 or more

Vertebrate and caudal skeleton

81. Solid, perichordally ossified, diplospondylous centra in adult-sized individuals (167)

(Grande and Bemis, 1998; Grande, 2010; Cavin et al., 2013; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Deesri et al., 2016; Ma and Xu, 2017; Xu and Ma, 2018; Ebert, 2018)

- 0. Absent
- 1. Present

82. Anteriorly projecting spine-like processes on neural and/or haemal arches (168)

(Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

- 0. Absent
- 1. Present

83. Solid vertebral centra of adult-sized individuals (169)

(Modified from Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018; Ebert, 2018)

- 0. Absent
- 1. Present

84. Surface of solid vertebral centra (170)

(Modified from Grande and Bemis, 1998; Ma and Xu, 2017; Xu and Ma, 2018; Xu et al., 2018, 2019)

- 0. Smooth
- 1. Two or more lateral fossae on each side of most centra

85. Number of supraneurals (171)

(Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

- 0. 13 or more
- 1. 5 to 11

86. Hypural-ural centra fusion in adult-sized individuals (173)

(Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

- 0. All hypurals autogenous (separate) from the ural centra
- 1. All but first hypural fused to corresponding centra

87. Large parapophyses fused to most of the abdominal centra (174)

(Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018; López-Arbarello and Sferco, 2018)

0. Absent

1. Present

88. Number of ural centra (175)

(Grande and Bemis, 1998; Xu et al., 2014; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

0. 10 or fewer

1. 11 to 22

89. Number of preural vertebral centra (176)

(Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

0. 40 to 73

1. 75 to 82

90. Morphology of pleural ribs (177)

(Grande and Bemis, 1998; Xu et al., 2014; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018; López-Arbarello and Sferco, 2018)

0. Distal ends pointed or with rounded points

1. Distal ends flatly truncated, even in large adults

91. One-to-one arrangement of hypurals and caudal fin rays (178)

(Grande and Bemis, 1998; Brito and Alvarado-Ortega, 2013; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018; López-Arbarello and Sferco, 2018)

0. Last few hypurals each articulate with bases of several caudal fin rays

1. Each hypural normally bears a single caudal ray

92. Number of ossified ural neural arches in adult-sized individuals (179)

(Grande and Bemis, 1998; Brito and Alvarado-Ortega, 2013; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018; López-Arbarello and Sferco, 2018)

0. Normally four or more

1. Normally 2 or fewer

93. Shape of haemal spines (183)

(Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018; López-Arbarello and Sferco, 2018)

0. Spine-like or rod-like

1. Broadly spatulate in the transverse plane

94. Orientation of preural haemal and neural spines near caudal peduncle (184)

(Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

0. Positioned at about 25° to 45° from the horizontal

1. Strongly inclined to nearly horizontal

95. Number of epurals (187)

(Grande and Bemis, 1998; Xu et al., 2014; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018; López-Arbarello and Sferco, 2018)

0. 2-8

1. 10-15

Girdles

96. Anteroventral process of posttemporal bone (188)

(Grande, 2010; Cavin et al., 2013; Deesri et al., 2016; Xu et al., 2018, 2019)

0. Absent

1. Weakly developed

2. Well developed as a ventral rod-like process

97. Lateral edge of posttemporal in adult-sized individuals (190)

(Grande and Bemis, 1998; Xu et al., 2014; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

0. Shorter than length of anterior edge

1. Elongate, about equal to or greater than width of anterior edge

98. Posttemporal (191)

(Modified from López-Arbarello and Sferco, 2018; Xu et al., 2018, 2019)

0. Broad (reaching the midline), not contacting parietal

1. Broad, contacting parietal

2. Relatively narrow, not reaching the midline (separated by scales)

3. Much narrow, narrower than the dermopterotic

99. Supracleithrum with a concave articular facet for articulation with the posttemporal (193)

(Grande, 2010; López-Arbarello and Sferco, 2018; Xu et al., 2018, 2019)

0. Absent

1. Present

100. Length of anterior arm of cleithrum relative to depth of its dorsal arm (194)

(Xu and Ma, 2018; Xu et al., 2018, 2019)

0. Anterior arm shorter than or nearly equal to dorsal arm

1. Anterior arm notably longer than dorsal arm

101. Substantial scapulocoracoid ossification in adult-sized individuals (195)

(Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

0. One or more elements present in the shoulder girdle

1. Absent

102. Clavicle anterior to cleithrum (197)

(Grande, 2010; Cavin et al., 2013; Deesri et al., 2016; Xu and Ma, 2018; López-Arbarello and Sferco, 2018; Xu et al., 2018, 2019)

0. Present

1. Absent

103. Anterior and posterior 'clavicle elements' (198)

(Grande, 2010; Cavin et al., 2013; Deesri et al., 2016; Xu and Ma, 2018; López-Arbarelo and Sferco, 2018; Xu et al., 2018, 2019)

0. Absent

1. Present

104. Medial wing on cleithrum (199)

(Cavin and Suteethorn, 2006; Grande, 2010; Cavin et al., 2013; Deesri et al., 2016; Giles et al., 2017; Xu et al., 2018, 2019)

0. Present

1. Absent

105. Presupracleithrum (200)

(Gardiner et al., 2005; Xu et al., 2014b, 2018, 2019; Giles et al., 2017)

0. Present

1. Absent

106. Shape of basipterygium (201)

(Grande and Bemis, 1998; Xu et al., 2014; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

0. Proximal end flat and widened anteriorly

1. Proximal end long and rod-like, without significant widening anteriorly

Fins

107. Shape of posterior margin of caudal fin (203)

(Grande and Bemis, 1998; Brito and Alvarado-Ortega, 2013; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

0. Forked

1. Convexly rounded or nearly vertical

108. Fringing fulcra on pectoral fins (204)

(Xu et al., 2018, 2019)

0. Present

1. Absent

109. Fringing fulcra on pelvic fins (205)

(Xu et al., 2018, 2019)

0. Present

1. Absent

110. Fringing fulcra on median fins (206)

(Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

0. Present

1. Absent

111. Shape of (first) dorsal fin (208)

(Gardiner and Schaeffer, 1989; Xu et al., 2018, 2019)

- 0. Triangular
- 1. Bow-shaped

112. Origin of (first) dorsal fin (209)

(López-Arbarello, 2012; Xu et al., 2018, 2019)

- 0. Posterior to the origins of pelvic fins
- 1. Opposite or anterior to the origins of pelvic fins

113. Number of dorsal fin rays (210)

(López-Arbarello, 2012; Deesri et al., 2016; Xu et al., 2018, 2019)

- 0. 20 or more
- 1. Less than 20

114. Number of principal caudal fin rays below the lateral line in adults (212)

(López-Arbarello, 2012; López-Arbarello and Wencker, 2016; Xu et al., 2018, 2019)

- 0. Nine or more
- 1. Eight or seven
- 2. Six or less

115. Number of epaxial procurent caudal fin rays (215)

(Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

- 0. 0 to 11
- 1. 12 to 15

116. Lateral line ossicles extending onto caudal fin (216)

(Gardiner et al., 1996; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018; López-Arbarello and Sferco, 2018)

- 0. Absent
- 1. Present

Body shape and scales

117. Scales (218)

(Alvarado-Ortega and Espinosa-Arrubarrena, 2008; Brito and Alvarado-Ortega, 2013; Xu et al., 2012, 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018; Ebert, 2018)

- 0. Rhomboid
- 1. Amioid-type, subrectangular to elongate oval
- 2. Elasmoid or cycloid type

118. Dorsal peg of rhomboid scale (219)

(Modified from López-Arbarello, 2012; Deesri et al., 2016; Xu et al., 2018, 2019)

- 0. Present
- 1. Absent

119. Urodermals in the caudal (224)

(Grande and Bemis, 1998; Xu et al., 2014b, 2018, 2019; Xu and Shen, 2015; Sun et al., 2017; Ma and Xu, 2017; Xu and Ma, 2018)

- 0. Present
- 1. Absent

Datamatrix

[illegible]