

Supplementary Material

The phylogenetic intrarelations of spiny-rayed fishes (Acanthomorpha, Teleostei, Actinopterygii): fossil taxa increase the congruence of morphology with molecular data

Donald Davesne^{1,2,3*}, Cyril Gallut², Véronique Barriel¹, Philippe Janvier¹, Guillaume Lecointre², Olga Otero⁴

¹ Centre de Recherche sur la Paléobiodiversité et les Paléoenvironnements, UMR 7207 CNRS, MNHN, UPMC, SU, Muséum national d'Histoire naturelle, Paris, France

² Institut de Systématique, Évolution, Biodiversité, UMR 7205 CNRS, MNHN, UPMC, EPHE, SU, Muséum national d'Histoire naturelle, Paris, France

³ Department of Earth Sciences, University of Oxford, Oxford, United Kingdom

⁴ Institut de Paléoprimateologie, Paléontologie Humaine : Évolution et Paléoenvironnements, UMR 7262 CNRS, Université de Poitiers, Poitiers, France

* Correspondence:

Donald Davesne

donald.davesne@earth.ox.ac.uk

Appendix 1.

List of the specimens used for character coding.

Multiple types of specimens were used: fresh specimens (fs), preserved in fluid (fl), as dry skeletons (sk) or as fossils (fo). Some extant specimens were prepared with dissections (di), clearing and staining (cs) or X-ray computed tomography (ct). Some fossils specimens had been previously prepared with acid transfer (at).

Institutional abbreviations: AMNH, American Museum of Natural History, New York City, USA; AMS, Australian Museum, Sydney, Australia; HUI, Hebrew University of Jerusalem, Israel; MNHN, Muséum national d'Histoire naturelle, Paris, France; NHMUK, Natural History Museum, London, UK; PB, Philippe Béarez research collection, Muséum national d'Histoire naturelle, Paris, France; ZMUC, Zoological Museum, University of Copenhagen, Denmark.

Aulopiformes – Synodontidae: *Synodus intermedius*: ZMUC 92394016 (sk); *Synodus scituliceps*: PB-6475 (sk); *Synodus synodus*: MNHN.IC.0000-4106 (fl+ct). **Myctophiformes** – Myctophidae: *Gymnoscopelus* sp.: MNHN, uncatalogued (fs+ct); *Myctophum nidulum*: MNHN.IC.1993.2333 (fl+cs). †**Ctenothrissiformes** – †Ctenothrissidae: †*Ctenothrissa protodorsalis*: MNHN.F.HAK22 (fo+at); †*Ctenothrissa signifer*: NHMUK PV P47524 (fo); †*Ctenothrissa radians*: NHMUK PV P11233 (fo+at), NHMUK PV P47912 (fo+at); †*Ctenothrissa vexillifer*: MNHN.F.HAK39 (fo+at), MNHN.F.HAK104 (fo+at). **Late Cretaceous acanthomorphs** – 'Aipichthyidae': †*Aipichthys minor*: MNHN.F.HAK94 (fo+at), MNHN.F.HAK1938 (fo); †*Aipichthys velifer*: MNHN.F.HAK57 (fo+at), NHMUK PV P4743 (fo), NHMUK PV P4744 (fo); †Aipichthyoididae: †*Aipichthyoides galeatus*: HUI EY59a, b (fo+at), HUI EY61 (fo+at), HUI EY63 (fo+at); †*Aipichthyoides formosus*:

HUJ EY58 (fo+at), HUI EY60 (fo+at); †Pycnosteroididae: †*Pycnosteroides levispinosus*: MNHN.F.HDJ105 (fo+at), MNHN.F.HDJ106 (fo+at), NHMUK PV P13901 (fo); †Sphenocephalidae: †*Sphenocephalus fissicaudus*: NHMUK PV P8772 (fo), NHMUK PV P8774 (fo), NHMUK PV P9059 (fo); cf. Polymixiidae: †*Omosomopsis simum*: MNHN.F.DTS222 (fo); cf. Holocentridae: †*Stichocentrus liratus*: MNHN.F.HDJ97 (fo+at); †*Stichocentrus spinulosus*: MNHN.F.HDJ101 (fo+at). **Lampridiformes** – Veliferidae: *Velifer hypselopterus*: MNHN.IC.1982-0025 (fl+ct), AMS 21840020 (fl+cs); Lamprididae: *Lampris guttatus*: ZMUC 74 (sk), AMNH 79669 SD (sk), AMNH 21720 SD (sk), MNHN.ZA.1883-1795 (sk); *Lampris immaculatus*: MNHN, uncatalogued (fs+di); *Lampris* sp.: AMNH 21766 SD (sk); Regalecidae: *Regalecus glesne*: AMNH 093518 SD (sk). **Order incertae sedis** – Stylephoridae: *Stylephorus chordates*: MNHN.IC.2004-1316 (fl+ct), MNHN.IC.2004-1317 (fl+ct). **Polymixiiformes** – Polymixiidae: *Polymixia* sp.: MNHN.IC.2006-1740 (fl+ct); *Polymixia nobilis*: NHMUK 95.5.28.1 (sk). **Percopsiformes** – Aphredoderidae: *Aphredoderus sayanus*: MNHN.IC.1987-0864 (fl+ct); Percopsidae: *Percopsis omiscomaycus*: MNHN.IC.1904-0278 (fl+ct). **Gadiformes** – Merlucciidae: *Merluccius merluccius*: MNHN, uncatalogued (fs+di), ZMUC 215 (sk); *Merluccius gayi*: PB-5124 (sk); Gadidae: *Gadus morhua*: PB-A-16 (sk). **Ophidiiformes** – Ophidiidae: *Brotula clarkae*: MNHN.IC.2002-1026 (fl+ct), PB-6515 (sk); *Brotula multibarbata*: NHMUK 1891.2.9.30 (sk); *Genypterus maculatus*: PB-5232 (sk). **Batrachoidiformes** – Batrachoididae: *Halobatrachus didactylus*: MNHN.IC.2005-2431 (fl+ct), MNHN.ICOS.1979.26 (sk), MNHN, uncatalogued (fs+di). **Zeiformes** – Cyttidae: *Cyttus australis*: NHMUK 72.7.1.20 (sk); Zeidae: *Zeus faber*: ZMUC P42190 (sk), MNHN.ICOS.1888-587 (sk), MNHN, uncatalogued (fs+di). **Beryciformes** – Trachichthyidae: *Hoplostethus atlanticus*: NHMUK 26.810 (sk); *Hoplostethus cadenati*: MNHN.IC.1974-0091 (fl+ct); Holocentridae: *Sargocentron* sp.: MNHN, uncatalogued (fs+di); *Sargocentron rubrum*: MNHN.ICOS.00276 (sk). **Percomorpha** – Moronidae: *Dicentrarchus labrax*: MNHN, uncatalogued (fl+cs); MNHN, uncatalogued (fs+di).

Appendix 2.

List of morphological characters used in the study.

The characters that we used were mainly taken from published phylogenetic studies, sometimes recoded, and newly coded if the original study did not use a character matrix.

Jaws and circumorbital series

1. Ascending process of the premaxilla (Fig. 7A): 0 – shorter than the alveolar process; 1 – equal to or longer than the alveolar process (coded from Olney *et al.*, 1993)
2. Premaxilla postmaxillary process (Fig. 7A): 0 – absent; 1 – present (coded from Patterson & Rosen, 1989)
3. Posterior margin of the premaxilla postmaxillary process (Fig. 7A): 0 – straight; 1 – notched (coded from Patterson & Rosen, 1989)
4. Anterior supramaxilla: 0 – present; 1 – absent (from Otero & Gayet, 1996)
5. Posterior supramaxilla: 0 – present; 1 – absent (from Otero & Gayet, 1996)
6. Supraorbital: 0 – present; 1 – absent (coded from Gaudant, 1979)
7. Antorbital: 0 – present; 1 – absent (from Otero & Gayet, 1996)

Braincase and skull roof

8. Lateral ethmoid (Fig. 6C): 0 – not in contact with the vomer; 1 – in direct contact with the vomer (coded from Stiassny, 1986)

9. Mesethmoid (Fig. 6C): 0 – anterior to the lateral ethmoid; 1 – median or posterior to the lateral ethmoid (coded from Olney *et al.*, 1993)
10. Orbitosphenoid: 0 – present; 1 – absent (from Johnson & Patterson, 1993)
11. Basisphenoid: 0 – present; 1 – absent (from Otero & Gayet, 1996)
12. Intercalar: 0 – small and not containing the foramen for cranial nerve IX; 1 – large and containing the foramen for cranial nerve IX (coded from Patterson & Rosen, 1989)
13. Epioccipital (= epiotic): 0 – not firmly bound to the dorsal limb of the posttemporal; 1 – firmly bound to the dorsal limb of the posttemporal; 2 – epioccipital and posttemporal fused (recoded from Johnson & Patterson, 1993)
14. Frontal: 0 – not forming part of the sagittal crest; 1 – forming part of the sagittal crest (recoded from Otero & Gayet, 1996)
15. Frontal vault or cradle: 0 – absent; 1 – present (coded from Olney *et al.*, 1993)
16. Spina occipitalis: 0 – absent; 1 – present (from Johnson & Patterson, 1993)
Remarks: the spina occipitalis is a ventral expansion of the supraoccipital that separates the exoccipitals and reaches the foramen magnum. When it is absent, the exoccipitals are joined together and form exclusively the dorsal roof of the foramen magnum.

Suspensorium and hyoid arch

17. Cranio-hyomandibular articulation (Fig. 9A): 0 – two-headed; 1 – single-headed (coded from Grande *et al.*, 2013)
18. Metapterygoid: 0 – in contact (or close approximation) with the quadrate; 1 – small and not in contact with the quadrate (recoded from Tyler *et al.*, 2003)
19. Anterior palatine process: 0 – present, palatine articulates with the maxilla; 1 – absent, no palatine-maxillary connexion (coded from Olney *et al.*, 1993)
20. Palatine teeth: 0 – present; 1 – absent (from Tyler *et al.*, 2003)
21. Posterior and anterior ceratohyals: 0 – separated with cartilage; 1 – sutured (recoded from Johnson and Patterson, 1993)
Remark: the posterior ceratohyal is sometimes called 'epihyal', in reference to the epibranchial bones of the branchial arches. However, this structure is probably not homologous with epibranchials (Nelson, 1969), which led us to prefer the usage of 'posterior ceratohyal'.
22. Articulation between the anterior ceratohyal and the ventral hypohyal (Fig. 8): 0 – straight; 1 – condylar (new character)
23. Anterior branchiostegals: 0 – subequal in length to the posterior ones; 1 – smaller than the posterior ones (recoded from Otero & Gayet, 1996)

Vertebral skeleton

24. Median fusion of neural spines: 0 – at least one paired neural spine; 1 – all neural spines fused medially, unpaired (coded from Gaudant, 1979)
25. Proximal insertion of Baudelot's ligament: 0 – on abdominal vertebrae; 1 – on basioccipital; 2 – on exoccipitals; 3 – split between the first abdominal vertebra and the exoccipitals (recoded from Johnson & Patterson, 1993)
26. Insertion of epineurals: 0 – all on neural arches or spines; 1 – at least partly below neural arches; 2 – at least partly on ribs (recoded from Johnson & Patterson 1993)
27. Epipleurals: 0 – present; 1 – absent (from Johnson & Patterson, 1993)
28. First vertebral centrum: 0 – no facets; 1 – facets articulating with exoccipital condyles (from Johnson & Patterson, 1993)
29. First neural spine (Fig. 7B): 0 – separated from the neurocranium; 1 – closely associated or sutured with the neurocranium (coded from Patterson & Rosen, 1989)
30. Second vertebral centrum (Fig. 7B): 0 – subequal in length to the others; 1 – abbreviated in length (coded from Patterson & Rosen, 1989)

Dorsal and anal fins

31. Number of ossified supraneurals: 0 – three or more; 1 – two; 2 – one; 3 – none (coded from Patterson & Rosen, 1989; Olney *et al.*, 1993)
 Remark: in some extant taxa, such as the ophidiiform *Brotula*, supraneurals are observed but never ossify (Patterson & Rosen, 1989; Carnevale & Johnson, 2015). We chose to consider ossified supraneurals only, since in fossil taxa unossified bones would have been unlikely to fossilize, leading to potentially false assumptions of absence.
32. Position of supraneurals: 0 – at least one posterior to the first neural spine; 1 – all anterior to the first neural spine (from Davesne *et al.*, 2014)
33. Insertion of the first dorsal pterygiophore (Fig. 6A-B): 0 – posterior to the neural spine 4; 1 – between the neural spines 2 and 4; 2 – between the neural spines 1 and 2; 3 – anterior to the first neural spine (recoded from Johnson & Patterson, 1993; Olney *et al.*, 1993)
34. Distal end of the first dorsal pterygiophore: 0 – oriented posteriorly; 1 – oriented anteriorly (coded from Olney *et al.*, 1993)
35. Dorsal-fin spines (Fig. 6A-B): 0 – absent; 1 – present (recoded from Johnson & Patterson, 1993)
 Remark: a "spine" is here defined as a fin ray which is unpaired (with contralateral halves fused together) and unsegmented distally, in opposition to the so-called "soft" spines, or lepidotrichia.
36. "Chain-link" articulation of dorsal-fin spines: 0 – absent; 1 – present (from Johnson & Patterson, 1993)
37. Spinous anterior dorsal fin (Figs. 2I, L-N; 6B): 0 – absent; 1 – present (new character)
38. Elongated and unbranched first soft ray of the dorsal fin: 0 – absent; 1 – present (from Davesne *et al.*, 2014)
39. Adipose fin (Fig. 2A-B, F): 0 – present; 1 – absent (new character)
40. Anal-fin spines (Fig. 6A-B): 0 – absent; 1 – present (recoded from Johnson & Patterson, 1993)
41. Soft rays of the unpaired fins: 0 – at least some branched distally; 1 – all unbranched (recoded from Tyler *et al.*, 2003)

Caudal fin and skeleton

42. Second ural vertebral centrum: 0 – autogenous to the hypurals; 1 – fused to the upper hypurals (recoded from Johnson & Patterson, 1993; Grande *et al.*, 2013)
43. Second ural vertebral centrum: 0 – autogenous to the first ural centrum; 1 – fused to the first ural centrum/first preural centrum (recoded from Johnson & Patterson, 1993)
44. Neural spine of the second preural vertebra: 0 – short and leaf-shaped; 1 – long and spine-like (coded from Patterson & Rosen, 1989)
45. First uroneural: 0 – autogenous; 1 – fused to the terminal centrum (coded from Grande *et al.*, 2013)
46. Number of epurals: 0 – three; 1 – two; 2 – one; 3 – none (coded from Patterson & Rosen, 1989)
 Remark: as noted by recent studies (Hilton & Johnson, 2007; Dosey & Wiley, 2015), the reduction in number of epurals is potentially non-homologous from one taxon to another (with different modes of reduction being sometimes observed in closely related taxa). In the gadiform *Gadus morhua*, older studies seem to suggest that only two epurals are present in the earliest ontogenetic stages (Barrington, 1937). However, to our knowledge the ontogeny of the caudal skeleton has not been studied in the other taxa of our sampling that are concerned by this reduction (e.g. zeiforms, lampridiforms). Thus, in the absence of more data,

we treat the reduction in number of epurals as a primary statement of homology, put into test by the phylogenetic analysis (e.g., de Pinna, 1991)

47. 'Y' bone: 0 – absent; 1 – present (coded from Patterson & Rosen, 1989)
48. Parhypural: 0 – articulated or fused to the first preural centrum; 1 – truncated proximally by the loss of the haemal arch and separated from the first preural centrum (from Johnson & Patterson, 1993)
49. Number of discrete hypurals: 0 – six; 1 – fewer than six (from Johnson & Patterson, 1993)
50. Overlap of the caudal skeleton by the caudal-fin rays: 0 – little to no overlap; 1 – extensive overlap or hypurostegy (from Davesne *et al.*, 2014)
51. Number of principal caudal-fin rays: 0 – 19 or more; 1 – 18; 2 – 17 or fewer (from Johnson & Patterson, 1993)

Remark: within our sample, all acanthomorph taxa have a maximum of 19 principal caudal fin rays, and a substantial number of taxa show 18 principal caudal fin rays. However, numerous taxa have 17 principal caudal fin rays or less, with a high variety of states (almost different for every terminal taxon hereby coded). Thus, we decided to lump "17 or fewer" into a unique character state.

Appendicular skeleton and paired fins

52. Scapular foramen: 0 – in scapula; 1 – between scapula and coracoid (coded from Patterson & Rosen, 1989)
53. Postcleithra: 0 – two or more separated bones; 1 – only one bone (from Otero & Gayet, 1996)
54. Insertion of the pectoral fin: 0 – vertical or oblique; 1 – horizontal (coded from Oelschläger, 1983)
55. Number of autogenous pectoral radials: 0 – four; 1 – three (coded from Olney *et al.*, 1993)
56. Pectoral-fin soft rays: 0 – at least some branched distally; 1 – all unbranched (recoded from Tyler *et al.*, 2003)
57. Anterior tip of the pelvic girdle (Fig. 6A-B): 0 – posterior to the distal postcleithrum; 1 – anterior to the distal postcleithrum (new character)
58. Contact between pectoral and pelvic girdles (Fig. 6A-B): 0 – no contact, with pelvic girdle posterior to the pectoral girdle; 1 – contact at the level of the cleithrum; 2 – contact at the level of the coracoid; 3 – pelvic girdle anterior to the pectoral girdle (recoded from Stiassny & Moore, 1992)
59. Antero-median pelvic process: 0 – absent; 1 – present (recoded from Stiassny & Moore, 1992)
60. External dorsal pelvic wing: 0 – shorter than the external ventral wing; 1 – equal in size to the external ventral wing (recoded from Stiassny & Moore, 1992)
61. Internal wings of the pelvic bone: 0 – separated; 1 – joined medially (from Davesne *et al.*, 2014)
62. Median processes of the pelvic bones: 0 – non-overlapping; 1 – overlapping medially (recoded from Stiassny & Moore, 1992)
63. Autogenous pelvic radials: 0 – present; 1 – absent (from Stiassny & Moore, 1992)
64. Number of soft rays of the pelvic fin: 0 – six or more; 1 – five or fewer (recoded from Johnson & Patterson, 1993)
65. Pelvic-fin spine (Fig. 9B): 0 – absent; 1 – present (from Stiassny & Moore, 1992)
66. Base of the pelvic-fin spine (Fig. 9B): 0 – symmetrical; 1 – asymmetrical (recoded from Johnson & Patterson, 1993)

References:

- Barrington, E.J.W. (1937) The structure and development of the tail in the plaice (*Pleuronectes platessa*) and the cod (*Gadus morrhua*). *Quarterly Journal of Microscopical Science* **79**, 447–465.
- Carnevale, G. & Johnson, G.D. (2015) A Cretaceous cusk-eel (Teleostei, Ophidiiformes) from Italy and the Mesozoic diversification of percomorph fishes. *Copeia* **103**, 771–791.
- Davesne, D., Friedman, M., Barriel, V., Lecointre, G., Janvier, P., Gallut, C. & Otero, O. (2014) Early fossils illuminate character evolution and interrelationships of Lampridiformes (Teleostei, Acanthomorpha). *Zoological Journal of the Linnean Society* **172**, 475–498.
- Doosey, M.H. & Wiley, E.O. (2015) Epural bones in teleost fishes: a problem of phylogenetic homology. *Ichthyological Research* **62**, 131–144.
- Gaudant, M. (1979) Recherches sur les relations phylogénétiques de certains poissons Eurypterygii du Crétacé de la Mésogée occidentale. *Comptes rendus de l'Académie des sciences, Paris, Série D* **288**, 1047–1050.
- Grande, T., Borden, W.C. & Smith, W.L. (2013) Limits and relationships of Paracanthopterygii: A molecular framework for evaluating past morphological hypotheses. In *Mesozoic Fishes 5 - Global Diversity and Evolution* (eds G. Arratia, H.-P. Schultze & M.V.H. Wilson), pp. 385–418. Verlag Dr. Friedrich Pfeil, Munich.
- Hilton, E.J. & Johnson, G.D. (2007) When two equals three: developmental osteology and homology of the caudal skeleton in carangid fishes (Perciformes: Carangidae). *Evolution & Development* **9**, 178–189.
- Johnson, G.D. & Patterson, C. (1993) Percomorph phylogeny: a survey of acanthomorphs and a new proposal. *Bulletin of Marine Science* **52**, 554–626.
- Nelson, G.J. (1969) Gill arches and the phylogeny of fishes, with notes on the classification of vertebrates. *Bulletin of the American Museum of Natural History* **141**.
- Olney, J.E., Johnson, G.D. & Baldwin, C.C. (1993) Phylogeny of lampridiform fishes. *Bulletin of Marine Science* **52**, 137–169.
- Otero, O. & Gayet, M. (1996) Anatomy and phylogeny of the Aipichthyoidea nov. of the Cenomanian Tethys and their place in the Acanthomorpha (Teleostei). *Neues Jahrbuch für Geologie und Paläontologie-Abhandlungen* **202**, 313–344.
- Patterson, C. & Rosen, D.E. (1989) The Paracanthopterygii revisited: order and disorder. *Science Series of the Natural History Museum of Los Angeles County* **32**, 5–36.
- de Pinna, M.C.C. (1991) Concepts and tests of homology in the cladistic paradigm. *Cladistics* **7**, 367–394.
- Stiassny, M.L.J. (1986) The limits and relationships of the acanthomorph teleosts. *Journal of Zoology (B)* **1**, 411–460.
- Stiassny, M.L.J. & Moore, J.A. (1992) A review of the pelvic girdle of acanthomorph fishes, with comments on hypotheses of acanthomorph intrarelationships. *Zoological Journal of the Linnean Society* **104**, 209–242.
- 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*.

Supplementary table 1. Taxon-by-character matrix used in the phylogenetic analyses.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
<i>Synodus</i>	0	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Gymnoscopelus</i>	0	0	-	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
† <i>Ctenothrissa</i>	0	0	-	0	0	0	0	0	0	0	0	?	0	0	0	1	0	0	0	0	0	0	0	1	?	?	0	?	0	0	0	0	1
† <i>Pycnoasteroides</i>	0	?	?	0	0	1	1	?	0	0	0	?	?	0	0	?	1	0	?	0	?	0	0	1	?	1	0	?	0	?	1	0	2/3
† <i>'Aipichthys'</i>	0	0	-	1	0	1	1	?	0	0	0	0	1	0	0	?	1	0	0	0	?	0	0	1	?	0	0	?	0	?	0	1	2
† <i>Aipichthyoides</i>	0	0	-	0	0	1	1	?	1	0	0	?	1	1	0	?	1	0	?	?	?	0	0	1	?	?	0	?	0	?	0	1	2
<i>Velifer</i>	1	0	-	1	1	1	1	1	1	0	0	0	1	1	1	0	1	0	1	1	0	1	0	1	3	0	1	1	0	0	1	1	3
<i>Lampris</i>	1	0	-	1	1	1	1	1	1	0	0	0	1	1	1	0	1	0	1	1	0	1	0	1	0	2	1	1	0	0	2	1	3
<i>Regalecus</i>	1	0	-	1	1	1	1	1	1	0	0	-	1	-	1	0	1	0	1	1	0	1	0	1	?	?	?	1	0	1	3	-	3
<i>Stylephorus</i>	1	0	-	1	1	1	1	?	1	1	1	-	1	-	0	1	1	1	-	1	0	0	0	1	?	?	?	-	1	1	3	-	0
<i>Polymixia</i>	0	1	0	0	0	1	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	1	0	1	0	1	0	0	0	0	0
† <i>Omosomopsis</i>	0	1	0	1	0	1	1	?	?	0	1	?	1	0	0	?	1	0	?	0	?	?	1	1	?	1	0	?	0	?	0	0	1
† <i>Sphenocephalus</i>	0	1	1	1	0	1	0	?	?	?	?	?	1	0	0	1	1	0	?	0	0	0	0	1	?	?	?	1	0	0	2	0	0/1
<i>Aphredoderus</i>	0	0	-	1	1	1	1	0	0	1	1	1	1	0	0	1	0	0	0	0	1	0	0	1	0	2	1	1	0	0	2	0	0
<i>Percopsis</i>	0	0	-	1	1	1	0	0	0	1	1	1	1	0	0	1	0	0	0	0	1	0	0	1	0	2	1	1	0	0	2	0	0
<i>Bregmaceros</i>	0	1	1	1	1	1	1	1	0	1	1	1	1	0	0	1	1	0	?	1	0	0	0	1	?	?	?	?	1	1	3	-	1/2
<i>Merluccius</i>	0	1	1	1	1	1	1	1	0	1	1	1	1	0	0	1	1	0	0	1	1	0	0	1	0	2	1	1	1	1	3	-	1
<i>Halobatrachus</i>	1	1	0	1	1	1	1	1	-	1	1	0	1	0	0	1	0	0	0	0	1	0	0	1	1	2	1	1	1	0	3	-	1
<i>Brotula</i>	0	1	1	1	0	1	1	1	0	1	0	0	1	0	0	1	0	0	0	0	1	0	0	1	1	2	1	1	0	1	3	0	1
<i>Cyttus</i>	1	1	1	1	1	1	1	0	0	1	0	0	2	0	0	1	1	1	0	1	0	0	0	1	0	?	1	?	1	1	2	-	2
<i>Zeus</i>	1	1	1	1	1	1	1	0	0	1	1	0	2	0	0	1	1	1	0	1	0	0	0	1	2	2	1	1	1	1	3	-	2
<i>Hoplostethus</i>	0	1	1	0	0	1	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	1	?	1	1	0	0	1	0	1
<i>Sargocentron</i>	0	1	0	0	0	1	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	1	1	2	1	1	0	0	0	0	2
† <i>Stichocentrus</i>	0	1	?	0	0	1	0	?	0	0	0	?	0	0	0	?	0	0	?	0	?	0	0	1	?	?	?	?	0	?	1	0	2
<i>Dicentrarchus</i>	0	1	0	1	0	1	1	1	0	1	0	0	1	0	0	1	0	0	0	0	1	0	0	1	1	2	1	1	0	0	0	0	1
<i>Lates</i>	0	1	0	1	0	1	1	1	0	1	0	0	1	0	0	1	0	0	0	0	1	0	0	1	1	?	?	1	0	0	0	0	1

	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	
<i>Synodus</i>	0	0	-	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	
<i>Gymnoscopelus</i>	0	0	-	0	0	0	0	0	1	1	0	?	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	
† <i>Ctenothrissa</i>	0	0	-	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	?	?	?	?	?	0	0	-	
† <i>Pycnopteroides</i>	0	1	?	0	0	1	1	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	1	2	?	?	?	?	?	0	1	?	
†'Aipichthys'	0	1	?	0	1	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	2	?	?	?	0	?	0	0	-	
† <i>Aipichthyoides</i>	0	1	?	0	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	0	1	2	?	?	?	?	?	0	0	-	
<i>Velifer</i>	0	1	?	0	1	1	1	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	2	0	0	1	0	0	0	0	-	
<i>Lampris</i>	0	0	-	0	1	1	0	0	1	0	0	0	1	0	0	1	1	0	0	1	1	1	0	1	2	0	0	1	0	1	0	0	-	
<i>Regalecus</i>	1	0	-	0	1	1	-	1	1	0	-	-	3	0	0	1	-	2	-	1	1	1	0	1	2	0	?	1	0	1	1	0	-	
<i>Stylephorus</i>	1	0	-	0	1	1	0	1	1	0	-	-	3	0	1	1	-	2	0	1	1	0	1	1	1	0	?	?	?	1	1	0	-	
<i>Polymixia</i>	0	1	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	-	
† <i>Omosomopsis</i>	0	1	0	0	0	1	1	0	0	0	1	0	1	1	0	1	0	1	0	0	0	0	0	1	0	?	?	?	?	?	0	0	-	
† <i>Sphenocephalus</i>	0	1	?	0	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	1	?	0	1	0	
<i>Aphredoderus</i>	0	1	0	0	0	1	1	0	1	0	1	0	1	0	1	0	0	1	0	1	0	0	0	1	0	0	0	0	0	1	0	0	-	
<i>Percopsis</i>	0	1	0	0	0	0	1	0	1	0	1	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	-
<i>Bregmaceros</i>	1	0	-	0	1	1	0	0	1	0	1	1	1	1	1	1	0	2	1	1	0	1	0	1	1	?	0	?	?	?	0	0	-	
<i>Merluccius</i>	0	0	-	0	0	1	0	0	1	0	1	1	1	1	1	1	0	2	1	1	0	0	0	1	1	0	?	0	0	?	0	0	-	
<i>Halobatrachus</i>	0	1	-	1	0	1	0	0	1	0	1	-	1	0	0	1	0	2	0	1	0	0	0	1	1	1	-	0	0	1	1	1	1	
<i>Brotula</i>	0	0	-	0	0	1	0	0	1	0	1	-	1	0	1	1	0	2	0	0	0	0	0	1	3	?	-	-	-	1	1	1	1	
<i>Cyttus</i>	0	1	0	1	0	1	1	1	1	1	1	1	1	0	1	1	0	2	0	1	0	0	1	1	1	0	0	1	0	1	0	1	0	
<i>Zeus</i>	0	1	0	1	0	1	1	1	1	1	1	2	1	1	1	0	2	0	1	0	0	1	1	1	0	0	1	0	1	0	1	0		
<i>Hoplostethus</i>	0	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	0	0	1	1	
<i>Sargocentron</i>	0	1	1	1	0	1	1	0	1	1	0	1	0	0	0	1	0	0	0	0	0	0	0	1	1	1	0	1	0	0	0	1	1	
† <i>Stichocentrus</i>	0	1	?	0	0	1	1	0	0	0	0	0/1	0	0	0	?	0	0	0	0	0	0	0	1	1	?	?	?	?	?	0	1	?	
<i>Dicentrarchus</i>	0	1	1	1	0	1	1	0	1	1	0	0	0	0	0	1	0	2	0	0	0	0	0	1	1	1	1	1	0	1	1	1	1	
<i>Lates</i>	0	1	1	1	0	1	1	0	1	1	0	0	1	0	0	1	0	2	0	0	0	0	0	1	1	1	1	1	0	1	1	1	1	

Supplementary table 2.

Consistency (CI) and retention indexes (RI) of character states used in this study, after Analysis 1 (simultaneous analysis of extant and fossil taxa).

Character	CI	RI	Character	CI	RI	Character	CI	RI
1	0.333	0.667	23	0.500	0.000	45	0.667	0.750
2	0.333	0.800	24	1.000	N.A.	46	0.375	0.500
3	0.333	0.600	25	1.000	1.000	47	0.333	0.333
4	0.200	0.429	26	0.500	0.600	48	0.333	0.667
5	0.333	0.800	27	0.333	0.714	49	0.167	0.444
6	0.500	0.000	28	1.000	1.000	50	0.333	0.600
7	0.167	0.375	29	0.500	0.800	51	0.500	0.857
8	0.333	0.667	30	0.333	0.667	52	1.000	1.000
9	0.500	0.750	31	0.333	0.538	53	0.333	0.800
10	0.333	0.818	32	1.000	1.000	54	0.500	0.500
11	0.333	0.714	33	0.500	0.538	55	0.500	0.500
12	0.500	0.667	34	0.333	0.000	56	1.000	1.000
13	0.667	0.667	35	0.200	0.500	57	0.500	0.500
14	1.000	1.000	36	1.000	1.000	58	0.600	0.833
15	1.000	1.000	37	0.333	0.600	59	1.000	1.000
16	1.000	1.000	38	0.333	0.667	60	1.000	1.000
17	0.250	0.727	39	0.333	0.333	61	0.250	0.571
18	1.000	1.000	40	0.200	0.500	62	0.333	0.500
19	1.000	1.000	41	0.500	0.667	63	0.333	0.714
20	0.500	0.857	42	0.250	0.667	64	0.333	0.600
21	0.333	0.667	43	0.250	0.400	65	0.250	0.700
22	1.000	1.000	44	0.500	0.909	66	1.000	1.000