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Supplementary information

Elpistostege and the origin of the vertebrate hand

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Supplementary Information for

Elpistostege and the origin of the vertebrate hand

Richard Cloutier[1,2], Alice M. Clement[2], Michael S. Y. Lee[2,3], Roxanne Noël[1], Isabelle Béchard[1], Vincent Roy[1], John A. Long[2]

[1]Université du Québec à Rimouski, 300 allée des Ursulines, Rimouski, Québec G5L 3A1, Canada

[2]College of Science and Engineering, Flinders University, Adelaide, South Australia 5042, Australia

[3]Earth Sciences Section, South Australian Museum, North Terrace, Adelaide, South Australia 5000, Australia

SUPPLEMENTARY DATA: PHYLOGENETICS

MATERIALS AND METHODS

1. MORPHOLOGICAL AND STRATIGRAPHIC DATA

1a. Body proportions and sources of information

The body proportions [(**Head proportion**) head length over total length (in %) and (**Trunk proportion**) distance between paired appendages over total length (in %)] of *Elpistostege* have been compared with that of other tetrapodomorphs. Total length is measured between the tip of the snout to the most posterior limit of the caudal fin; head length is measured between the tip of the snout to the most posterior limit of the skull roof; trunk length is measured between the body insertion of the pectoral fins and the body insertion of the pelvic fins. Although more than 121 species of piscine tetrapodomorphs have been described (in addition to 32 piscine tetrapodomorph of uncertain taxonomic affinities), very few are known from complete or almost complete specimens. Among the 42 taxa analyzed in our phylogenetic analyses (see part 1.b) only 15 of them have complete specimens known; the remaining taxa are identified in the list as not applicable (NA). We added six other complete tetrapodomorphs to our dataset to take into account the species for which complete specimens (or accurate reconstructions) were known; as far as we are aware this represents an exhaustive list. Proportions were calculated mainly from published reconstructions or actual collection specimens (*Eusthenopteron, Elpistostege* and *Callistiopterus*). When possible, the distance between paired appendages was taken as the distance between proximal humerus and proximal femur.

Taxa	Sources	Head	Trunk
Dipnomorpha (6 outgroups) and 37 Tetrapodomorpha			
Youngolepis	NA		
Diabolepis	NA		
Powichthys	NA		
Porolepis	NA (SVD 2158, not complete enough)		
Glyptolepis	Ahlberg (1991; reconstruction)[1]	21.26	35.43
Tungsenia	NA		
Kenichthys	NA		
Gooloogongia	Johanson & Ahlberg (2001; reconstruction)[2]	20.61	44.27
Sauripterus	NA		
Barameda	NA		
Screbinodus	NA		
Rhizodus	NA		
Strepsodus	Andrews (1985; reconstruction)[3]	18.46	32.31
Gyroptychius	Jarvik (1985; reconstruction)[4]	22.31	40.77
Osteolepis	Jarvik (1948; reconstruction)[5]	21.37	34.35
Gogonasus	NA		
Medoevia	NA		
Claradosymblema	NA		
Megalichthys	NA		
Ectosteorhachis	NA		

Beelarongia	NA		
Canowindra	Thomson (1973; reconstruction)[6]	20	36
Koharolepis	NA		
Marsdenichthys	NA		
Spodichthys	NA		
Tristichopterus	various specimens	22.40	37.70
Eusthenopteron	MHNM specimens	21.37	38.17
Jarvikina	NA		
Platycephalichthys	NA		
Cabonnichthys	Ahlberg & Johanson (1997; reconstruction)[7]	20.23	46.56
Mandageria	Johanson & Ahlberg (1997; reconstruction)[8]	16.92	45.38
Eusthenodon	NA		
Hongyu	NA		
Bruehnopteron	NA		
Tinirau	Swartz (2012; estimated TL)[9]	19.75	37.65
Panderichthys	Vorobyeva & Schultze (1991; reconstruction)[10]	26.44	40.23
Elpistostege	MHNM 06-2067	14.44	41.16
Tiktaalik	Shubin et al. (2015; estimated TL)[11]	18.52	42.96
Ventastega	NA		
Acanthostega	Clack (2007; reconstruction)[12]	19.08	26.72
Ichthyostega	Pierce *et al*. (2012; CT reconstruction)[13]	26.15	40.00
Tulerpeton	NA		

Tetrapodomorpha not included in the phylogenetic analyses (6 taxa)

Glyptopomus	Jarvik (1985; reconstruction)[4]	22.90	49.62
Heddleichthys	Snitting (2009; reconstruction)[14]	26.92	36.92
Thursius	Jarvik (1985; reconstruction)[4]	20.61	35.11
Callistiopterus	MCZ 7196	23.97	30.82
Eusthenopteron kurshi	Zupins (2008; photo)[15]	22.46	39.86
Rhizodopsis hanbuchi	Schultze & Heidtze (1993; photo)[16]	24.00	25.93

1b. Taxonomic sampling, stratigraphic dates and sources of information

The list of 43 taxa included in our phylogenetic analyses provides anatomical and stratigraphical bibliographic references from the primary literature. Most taxa were coded for a single species with the exception of *Powichthys* (*P. thorsteinssoni*[17] and *P. spitsbergensis*[18]), *Barameda* (*B. decipiens*[19], *B. mitchelli*[20]), *Rhizodus* (*R. hibberti*, *R. ornatus*)[21], *Strepsodus* (primarily *S. sauroides*[21]), and *Platycephalichthys* (*P. bischoffi*, *P. skuenicus*). Bold-faced taxa correspond to taxa for which original material has been observed. The numerical age of stages is taken from the limits provided in the most recent version (2018) of the International Chronostratigraphic Chart[22]. The numerical age of stage subdivisions (early, middle, and late) is calculated as three equal subdivisions of the stage duration.

Dipnomorpha (6 outgroups)

Youngolepis [23-28]	middle-late Lochkovian[29]	415.7-410.8
Diabolepis [25,26,30-32]	middle-late Lochkovian[29]	415.7-410.8
Powichthys [18,33]	late Lochkovian-early Pragian[18]	413.6-409.7
Porolepis [34,35]	late Lochkovian-late Givetian[34,36,37]	413.6-382.7
Glyptolepis [34,35,38]	early Eifelian-middle Frasnian[39,40]	393.3-375.7

Tetrapodomorpha (37 ingroups)

Tungsenia [41,42]	Pragian[42]	410.8-407.6
Kenichthys [43,44]	late Emsian[29]	398.1-393.3
Gooloogongia [2,45]	late Frasnian[46,47]	375.7-372.2
Sauripterus [48-51]	late Famennian[21]	363.3-358.9
Barameda [19,20,52-54]	Tournaisian[20,53]	358.9-346.7
Screbinodus [3,52]	Brigantian[21]	336-326.4
Rhizodus [3,52,55,56]	early Viséan-Myachkovskian[21]	346.7-306.5
Strepsodus [3,21,52,55-58]	Ivorian-Myachkovskian[21]	348-307.2
Gyroptychius [5,59]	Middle Devonian[40]	393.3-382.7
Osteolepis [5,60,61]	Middle Devonian[40]	393.3-382.7
Gogonasus [62-65]	early Frasnian[66]	382.7-379.2
Medoevia [67]	late Famennian[67]	363.3-358.9
Cladarosymblema [68]	early Viséan-middle Viséan[68]	346.7-336.2
Megalichthys [69-71]	early Viséan-Westphalian D[72,73]	346.7-306.5
Ectosteorhachis [69,74-78]	Early Permian[75]	298.9-272.95
Beelarongia [79]	late Givetian[46]	384.4-382.7
Canowindra [6,80]	late Frasnian[47]	375.7-372.2
Koharalepis [81]	middle Givetian[82]	386.0-384.4
Marsdenichthys [83,84]	late Givetian[46]	384.4-382.7
Spodichthys [4,85]	Frasnian[86]	382.7-372.2
Tristichopterus [4,87]	Givetian[15]	387.7-382.7
Eusthenopteron [88-92]	middle Frasnian[93]	379.2-375.7
Bruehnopteron [94]	late Givetian[9,94]	384.4-382.7
Jarvikina [59,95]	middle Frasnian-late Famennian[96,97]	379.2-358.9
Platycephalichthys [59,98]	late Givetian-late Famennian[97]	384.4-358.9
Cabonnichthys [7]	late Frasnian[47]	375.7-372.2
Mandageria [8,99]	late Frasnian[47]	375.7-372.2
Eusthenodon [100,101]	late Famennian[86,97]	363.3-358.9
Hongyu [102]	Famennian[102]	372.2-358.9
Tinirau [9]	late Givetian[9]	384.4-382.7
Panderichthys [10,103-109]	late Givetian-early Frasnian[39,96]	384.4-379.2
Elpistostege [10,110-112]	middle Frasnian[93]	379.2-375.7
Tiktaalik [113-116]	early Frasnian-middle Frasnian[116]	382.7-375.7
Ventastega [103]	late Famennian[117]	363.3-358.9
Acanthostega [103,118-123]	late Famennian[86,124]	363.3-358.9
Tulerpeton [125]	late Famennian[125]	363.3-358.9
Ichthyostega [13,101,103,122,126-128]	late Famennian[86,124]	363.3-358.9

1c. Character descriptions and codings

In order to determine the phylogenetic position of *Elpistostege* among stem-tetrapods, we amended the most recent data matrix dealing with tetrapodomorph phylogeny published by Zhu et al. (2017)[102]. Zhu et al.'s (2017)[102] matrix included 169 morphological characters coded for 38 taxa; their matrix included characters that had been used previously in different phylogenetic analyses[40,43]. This matrix was primarily designed to address the phylogenetic position of *Hongyu chowi*; many postcranial morphological characters used in previous phylogenetic analyses were not included. Characters 29, 70 and 134 from Zhu et al. (2017)[102] were split into two binary characters (char. 170, 171 and 172, respectively). In addition, we included 13 characters from Daeschler et al. (2006)[116], our characters 173 to 186, one of which (char. 80) we divided into two characters (our characters 176 and 177); nine of these characters were also used subsequently by Swartz (2012)[9]. Finally, 11 characters from Swartz (2012)[9] were also included in our analysis [seven of which were also used by Chen et al. (2018)[129]]. In addition, we added five new characters (char. 198-202).

Some characters and character states were modified; changes are specified in the list of characters. Changes to actual scorings for individual taxa are discussed in Section 1c. We used MorphoBank[130] version 3.0 to code and document our matrix. The list of characters and character states provides the reference to character numbers used in previous publications: D, Daeschler et al. (2006)[116]; S, Swartz (2012)[9]; Z, Zhu et al. (2017)[102]; C, Clack et al. (2012)[131]; CH, Chen et al. (2018)[129].

As in Zhu et al. (2017)[102], the dipnomorph taxa *Youngolepis, Diabolepis, Powichthys, Porolepis* and *Glyptolepis* were designated as a monophyletic outgroup. Multistate characters were treated as unordered unless they formed clear morphoclines, in which case they were ordered (characters 7, 10, 20, 34, 42, 63, 73, 78, 84, 98, 100, 107, 130, 139, 162, 198, 199 and 201). All characters are weighted equally.

The full character-by-taxon matrix is available as Dataset 1, which is a zipped file containing both Nexus executable (e.g., PAUP, Mesquite) and Word formats.

1   **Position of orbits** [D45, S97, Z1]: lateral and widely separated (0); dorsal and close together (1)

2   **Proportion of skull roof** (measured as length from tip of snout to posterior margin of postparietals) **lying anterior to middle of orbits** [D75, Z2]: <50% (0); ≧50% (1)

3   **Facial lamina of premaxilla** [Z3]: vertical, indicating deep snout (0); curved posteriorly, indicating flattened snout (1)

4   **Facial lamina of premaxilla** [Z4]: height less than 50% of length of premaxilla (0); more than 50% of length of premaxilla (1)

5   **Orientation of anterior tectal and lateral rostral relative to anterior nostril** [D23, Z5]: dorsal/ventral (0); posterior/anterior (1)

6   **Postrostral** [D34 (in part), S86 (in part), Z6]: absent (0); postrostral mosaic of small variable bones (1); large median postrostral, with or without accessory bones (2)

7   **Number of nasals** [D35, S83, Z7 (in part)]: more than two (0); two (1); one (2)

8   **Position of anterior nostril** [S91, Z8]: facial (0); edge of mouth (1)

9   **Dermintermedial process** [Z9]: absent (0); present (1)

10 **Position of posterior nostril** [ordered; S89 (in part), Z10]: external, far from jaw margin (0); external, close to jaw margin (1); palatal (2)

11 **Number of supraorbitals** [Z11]: one (0); more than one (1)

12 **Posterior or posteriormost supraorbital (postfrontal) extends anterior of orbit** [D86, S109, Z12]: yes (0); no (1)

13 **Relative size of anterior (or anteriormost) supraorbital (prefrontal, posterior tectal of Jarvik) and posterior (or posteriormost) supraorbital (postfrontal)** [76 (rephrased), Z13]: similar (0); prefrontal much bigger (1)

14 **Shape of posterior supraorbital** [S110 (in part), Z14]: posterior process similar in length or shorter than orbital margin (0); posterior process much longer than orbital margin (1)

15 **Contact between parietal and supraorbital** [S112 (in part), Z15]: present (0); absent (1)

16 **Intertemporal** [D74, S118, Z16, C6, CH5]: present (0); absent (1)

17 **Contact between posterior supraorbital and intertemporal** [S111, Z17]: present (0); absent (1)

18 **Number of tectals** [Z18]: one (0); more than one (1)

19 **Paired frontal bones meeting in midline, anterior to parietals** [D36, S113, Z19, C5, CH4]: absent (0); present (1)

20 **Width of ethmoid relative to length from snout tip to posterior margin of parietals** [ordered; D24 (in part), S103 (in part), Z20]: more than 80% (0); 70 – 79% (1); 50 – 69% (2); less than 50% (3)

21 **Pineal foramen** [D27, S115, Z21]: present (0); absent (1)

22 **Shape of pineal series** [D30, S117, Z22]. Numerous taxa in Zhu et al. (2017)[102] were coded for this character, while they did not have a pineal series (or plate). The recoding takes into account solely those taxa that have pineal plates. The taxa having a pineal opening (char. 21) but not plates are coded as "-": round or oval (0); kite shaped with distinct posterior corner (1)

23 **Location of pineal foramen/eminence** [D28, S116, Z23]: level with, or anterior to posterior margin of orbits (0); posterior to orbits (1)

24 **Parietals surround pineal foramen/eminence** [D29, S114, Z24]: yes (0); no (1)

25 **Dermal intracranial joint** [D50, S119, Z25, CH83]: absent (0); present (1)

26 **Postparietals narrow to a point posteriorly** [D32, S120, Z26]: no (0), yes (1)

27 **Proportions of postparietal shield maximum width of postparietal shield versus skull width at level of anterior end of postparietal** [D31 (in part), S121 (in part), Z27]: maximum width of postparietal shield <3 skull width at level of anterior end of postparietal (0); maximum width of postparietal shield >=3 skull width at level of anterior end of postparietal (1)

28 **Spiracular notch** [D87 (in part), S140 (in part), Z28]: small hole or narrow slit (0); wide notch between skull roof and cheek (1)

29 **Extratemporal** [D37 (in part), D40 (in part), S124 (in part), Z29 (in part)]. Zhu et al. (2017)[102] created apomorphic state 2 in which the extratemporal separates the lateral extrascapular from the squamosal, suggesting homology between the extratemporal and the postspiracular. We divided character 29 of Zhu et al. (2017)[102] into two characters (29 and 170) because the homology between the extratemporal and spiracular is dubious: absent (0); present (1)

30 **Contact between extratemporal and supratemporal** [D38, S126, Z30]: absent (0); present (1)

31 **Extrascapulars** [D77, S143, Z31]: present (0); absent (1)

32 **Anterior margin of median extrascapular** [D49, S141, Z32]: long (0); very short (1)

33 **Median extrascapular overlap** [D48, S142, Z33]: median extrascapular overlapped by lateral extrascapulars (0); median extrascapular overlapping lateral extrascapulars (1)

34 **Internasal pits** [ordered; D19, S88, Z34]: undifferentiated or anterior palatal fossa (0); shallow paired pits with strong midline ridge (1); deep pear-shaped pits (2)

35 **Tectum orbitale** [S11, Z35]: narrow (0); extensive (1)

36 **Large median opening and several small dorsolateral openings in postnasal wall** [Z36]: absent (0); present (1)

37 **Position of exit of pituitary vein** [S5, Z37]: in front of basipterygoid process (0); dorsal to vertical portion of basipterygoid process (1)

38 **Descending process of sphenoid** (with its posterior extremity lacking periostegeal lining) [S9, Z38]: absent (0); present (1)

39 **Endoskeletal intracranial joint** [D51, S7, Z39]: absent (0); present (1)

40 **Proportion of neurocranium** [Z40]: ethmosphenoid shorter than or equal in length to otoccipital (0); ethmosphenoid longer than otoccipital (1)

41 **Dorsal element of hyoid arch** [Z41]: hyomandibula articulating with lateral commissure (0); stapes inserted into fenestra ovalis (1)

42 **Relative positions of hyomandibular facets** [ordered; S15 (morphocline changed), Z42 (morphocline changed)]. The original character states provided by Zhu et al. (2017)[102] have been reordered to form a morphocline: ventral anterior to dorsal (0); dorsal directly above ventral (1); dorsal anterior to ventral (2)

43 **Vestibular fontanelle** [Z43] : absent (0); present (1)

44 **Anterior margin of vestibular fontanelle anterior to posterior margin of basicranial fenestra** [Z44]: no (0); yes (1)

45 **Basicranial fenestra** [D52, S8, Z45]: absent (0); present (1)

46 **Posttemporal fossae** [Z46] : absent (0); present (1)

47 **Extent of crista parotica** [D25, S6, Z47]: does not reach posterior margin of tabular (0); reaches posterior margin of tabular (1)

48 **Otical process** [Z48]. Zhu et al. (2017)[102] defined the optical process as an outgrowth from the lateral wall of the braincase penetrated by the branches of the r. oticus lateralis: absent (0); present (1)

49 **Foramina** (similar to infradentary foramina) **on cheek bones** [S134, Z49]: absent (0); present (1)

50 **Postorbital** [S98, Z50]: contributes to orbital margin (0); excluded from orbital margin (1)

51 **Jugal extends anterior to middle of orbit** [D78, S95, Z51, C7, CH6]: no (0); yes (1)

52 **Relationship of jugal to orbit** [D43, Z52]: contributes to orbital margin (0); excluded from orbital margin (1)

53 **Lacrimal excluded from orbit** [D79, S92, Z53, C8, CH7]: no (0); yes (1)

54 **Contact between posterior supraorbital (postfrontal) and lacrimal** [D44, S93, Z54]: absent (0); present (1)

55 **Jugal-quadratojugal contact** [D42, S96, Z55]: absent (0); present (1)

56 **Number of cheek bones bearing preopercular canal posterior to jugal** [Z56]: one (0); two (1)

57 **Bone bearing both quadratojugal pit-line and preopercular canal** [Z57]: absent (0); present (1)

58 **Bar-like preopercular** [D88 (in part), S137, Z58, C17 (in part), CH16 (in part)]: absent (0); present (1)

59 **Subsquamosals** [D47, S101, Z59]: absent (0); present (1)

60 **Preoperculosubmandibular** [D46, S102, Z60]: absent (0); present (1)

61 **Vomer proportions** [D17, S57, Z61, C22 (in part), CH21 (in part)]: not much broader than long (0); much broader than long (1)

62 **Anteromedial process of vomer** [D16 (in part), S63 (in part), Z62 (in part)]: absent (0); present (1)

63 **Posterior process of vomers** [ordered; D15, S64, Z63]: absent (0); short (1); long (2)

64 **Articulation of vomers** [Z64]: vomers not articulating with each other (0); vomers articulating with each other (1)

65 **Parasphenoid** [Z65, C27 (in part)]: protruding forward into ethmoid region of endocranium (0); behind ethmoid region (1)

66 **Denticulated field of parasphenoid** [D20 (in part), S67, Z66]: without spiracular groove (0); with spiracular groove (1)

67 **Relationship of vomer to parasphenoid** [D18, S65 (in part), Z67, C20 (in part), CH19 (in part)]: no contact, or simple abutment (0); dorsal/ventral overlap anteriorly (1); side to side overlap between posterior processes of vomers and lateral sides of parasphenoid (2)

68 **Shape of parasphenoid** [Z68]: broad, splint-shaped (0); slender, splint-shaped (1)

69 **Lateral sides of parasphenoid** [Z69]: parallel or slightly diverging anteriorly (0); converging anteriorly (1)

70 **Posterior carotid opening in parasphenoid** [S10 (in part); Z70 (in part)]. Character 70 of Zhu et al. (2017)[102] has been divided into two binary characters (char. 70 and 171): present (0); absent (1)

71 **Articulation of pterygoids** [D14, S70, Z71, C18 (in part), CH17]: pterygoids not articulating with each other (0); pterygoids articulating with each other (1)

72 **Proportions of entopterygoid** [D13, S69, Z72]: anterior end level with processus ascendens (0); anterior end considerably anterior to processus ascendens (1)

73 **Number of fang pairs on ectopterygoid** [ordered; D12 (morphocline changed), S80 (in part) (morphocline changed), Z73 (morphocline changed), C30 (in part), CH29 (in part)]. The original character states provided by Zhu et al. (2017)[102] have been reordered to form a morphocline: two (0); one (1); none (2)

74 **Palatal fangs mesial to marginal tooth row** [D72, Z74]: yes (0); no (1)

75 **Subterminal mouth** [D73, S82, Z75]: absent (0); present (1)

76 **Enlarged anterior tooth on premaxilla** [D21, S53 (in part), Z76]: absent (0); present (1)

77 **Posterodorsal process of maxilla** [D41, S56, Z77]: present (0); very weak or absent (1)

78 **Meckelian ossification** [ordered; Z78, CH53 (in part)]: strong, complete from articular to symphysial region (0); incomplete (1); absent (2)

79 **Coronoids labiolingually flattened** [Z79]: no (0); yes (1)

80 **Protrusion of lower jaw in front of skull** [D75, Z80]: absent (0); present (1)

81 **Anteroventral lower jaw profile** [Z81]: rounded (0); squared off (1)

82 **Large ventromesially directed flange of symphysial region of mandible** [Z82]: absent (0); present (1)

83 **Dermal ornament on each infradentary** [Z83]: even (0); separate "starburst" on each bone (1)

84 **Infradentary foramina** [ordered; D11, Z84]: always present (0); variable (1); always absent (2)

85 **Dentary fang pair** [D8, S26 (in part), Z85]: absent (0); present (1)

86 **Teeth of dentary** [D7, S25, Z86]: reaching anterior end of dentary (0); not reaching anterior end (1)

87 **Accessory tooth rows on dentary** [D64, S24, Z87, CH74 (in part)]: present (0); absent (1)

88 **Splenial** [D28 (in part), S47 (in part), Z88]: not sutured to prearticular (0); sutured to prearticular (1); postsplenial obstructing splenial-prearticular contact (2)

89 **Suture between splenial and anterior coronoid** [D63, S40, Z89, CH44]: absent (0); present (1)

90 **Mesial lamina of splenial** [D62, Z90, CH67 (in part)]: absent (0); present (1)

91 **Angular and prearticular** [D3, S48, Z91, CH43 (in part)]: separated by ventral exposure of Meckelian bone (0); in contact (1)

92 **Parasymphysial tooth whorl** [D16 (in part), D17 (in part), D18, D19, Z92]: present (0); absent (1)

93 **Parasymphysial dental plate** [D1 (in part), S17 (in part), Z93, CH75]: absent (0); present (1)

94 **Parasymphysial dental plate** [D1 (in part), S16 (in part), Z94, CH76 (in part)]: long with posterior corner, sutured to anterior coronoid, denticulated or with tooth row (0); short, rounded, not sutured to anterior coronoid, denticulated (1)

95 **Tooth row on parasymphysial dental plate** [S17 (in part), Z95, CH78 (in part)]: absent (0); present (1)

96 **Mesial parasymphysial foramen** [D67, S21, Z96, CH57]: absent (0); present (1)

97 **Fangs of coronoids** (*sensu stricto*) [D70 (in part), S30 (in part), S44 (in part), Z97, CH68]: absent (0); present (1)

98 **Marginal denticle band on coronoids** [ordered; S38 (in part), Z98, CH72 (in part)]: broad band, at least posteriorly (0); narrow band with 2-4 denticle rows (1); single tooth row or absent (2)

99 **Coronoid proportions** [D6, S34 (in part), Z99]: posterior coronoid similar in length to, or shorter than middle coronoid (0); posterior coronoid significantly longer than middle coronoid (1)

100 **Number of fang pairs on posterior coronoid** [ordered; D9 (morphocline changed), Z100 (morphocline changed)]. The original character states of Zhu et al. (2017)[102] have been reordered to form a morphocline: two (0); one (1); none (2)

101 **Anterior end of prearticular** [D2, S46, Z101]: not forked (0); forked (1)

102 **Longitudinal dorsal ridge on prearticular** [Z102, CH63]: absent (0); present (1)

103 **Anterior mandibular (precoronoid) fossa** [Z103]: absent (0); present (1)

104 **Retroarticular process** [Z104]: absent (0); present (1)

105 **Foramen in hyomandibular** [Z105]: absent (0); present (1)

106 **Opercular process of hyomandibula** [Z106]: present (0); absent (1)

107 **Distal portion of hyomandibula** [ordered; Z107]: developed (0); reduced (1); absent (2)

108 **Contact between hyomandibula and palatoquadrate** [Z108]: present (0); absent (1)

109 **Position of distal exit of hyomandibular canal or sulcus on anterolateral face of hyomandibula** [Z109]: at a level of mid-shaft or obvious curvature (0); within proximal portion (1)

110 **'Urohyal' morphology** [Z110]: dorsoventrally compressed and rod-like, may bifurcate posteriorly (0); vertical plate (1)

111 **Shape of anterior basibranchial** [Z111]: rounded (0); rectangular, significantly longer than wide (1)

112 **Sublingual rod** [Z112]: absent (0); present (1)

113 **Opercular** [D111, S139, Z113, C14, CH13]: present (0); absent (1)

114 **Number of branchiostegal rays per side** [Z114]: more than one (0); one (1)

115 **Size of median gular** [D81 (in part), S136, Z115]: small (0); large (1)

116 **Course of ethmoid commissure** [S127 (in part), Z116]: canal penetrating the body of the premaxilla (0); sutural course (1)

117 **Direction of anterior pit-line on parietal shield** [Z117]: antero-posterior, reaching or almost reaching parietal-postparietal border (0); essentially transverse, anterior or almost anterior to pineal foramen/eminence (1)

118 **Middle and posterior pit-lines on postparietal** [Z118]: posteriorly situated (0); mesially situated (1)

119 **Course of supraorbital canal** [Z119]: straight (0); lyre-shaped (1)

120 **Posterior end of supraorbital canal** [Z120]: in postparietal (0); in parietal (1); in intertemporal (2)

121 **Contact between otic and supraorbital canals** [Z121]: not in contact (0); in contact (1)

122 **Otic (postotic) canal** [S129, Z122]: runs through skull roof (0); follows edge of skull roof (1)

123 **Otic (postotic) canal enters postparietal** [Z123]: no (0); yes (1)

124 **Supracleithrum and posttemporal** [S145 (in part), Z124, CH101]: present (0); absent (1)

125 **Curvature of dermal shoulder girdle** [Z125]: smoothly curving chain from cleithrum to posttemporal, paralleling the posterior margin of the skull (0); tall caudally-inclined cleithrum sloping away from the skull and forming sharp angle with anocleithrum-supracleithrum-posttemporal (if present) (1)

126 **Cleithral ornamentation** [D106, S197, Z126, CH88]: present (0); absent (1)

127 **Contact margin for clavicle on cleithrum** [D53, S150, Z127]: straight or faintly convex (0); strongly concave (1)

128 **Ventral or lower lamina of cleithrum** [Z128]: extensive without or with little scapulocoracoid lateral exposure (0); reduced, with large scapulocoracoid lateral exposure (1)

129 **Overlap relations of cleithrum and clavicle** [Z129]: normal (0); rhizodontid condition (1)

130 **Depressed posterior flange on cleithrum** [ordered; Z130]: absent (0); poorly developed (1); well developed (2)

131 **Narrow waist on cleithrum** [Z131]: no (0); yes (1)

132 **Ventral lamina of cleithrum much broader than dorsal lamina** [Z132]: no (0); yes (1)

133 **Clavicle ascending process** [Z133]: clavicle has rod-like ascending process (0); clavicle lacks rod-like ascending process (1)

134 **Interclavicle size** [D83 (in part), S158 (in part), Z134 (in part), CH98 (in part)]. Character 134 of Zhu et al. (2017)[102] has been divided into two characters: size (char. 134) and ornamentation (char. 172): small (0); large (1)

135 **Scapulocoracoid and cleithrum attachment** [D108 (in part), S82 (in part), Z135]: triradiate scapulocoracoid lying flush against internal surface of cleithrum, not separated by foramina (0); single large foramen piercing C-shaped scapulocoracoid close to contact face for cleithrum (1); scapulocoracoid attaching to cleithrum via three buttresses (2); scapulocoracoid attaching to cleithrum along its anterodorsal margin (3)

136 **Scapular process of scapulocoracoid** [S153, Z136, CH106 (in part)]: small (0); large, dorsally projecting (1)

137 **Subscapular fossa** [D109, Z137]: absent (0); present (1)

138 **Coracoid plate** [D103, S152, Z138]: absent (0); present and extends ventromedially (1)

139 **Pectoral fin radials** [ordered; Z139]. The term "radial" refers to endoskeletal elements located distally to the first row of proximal carpals (i.e., radiale, intermedium and tibiale). "Proximal radials" refer to the first proximo-distal row of elements (also referred to as "central carpals") located distally to the proximal carpals. Proximal radials include the A4 element. "Intermediate radials" refer to the second proximo-distal row of elements located distally to the proximal radials and including the A5 elements. All the elements located distally to the intermediate radials are referred to as "distal radials" (or phalanges). This terminology follows that used by Wagner & Chiu (2001)[132] and Johanson et al. (2007)[133]: only preaxial and terminal (0); preaxial and postaxial radials in distal part of fin, only preaxial radials in proximal part (1); symmetrical array of preaxial and postaxial radials (2)

140 **Shape of ectepicondyle** [Z140, CH91 (in part)]: rounded (0); elongate parallel-sided ridge (1)

141 **Entepicondyle size** [S161 (in part), Z141]: entepicondyle narrow relative to humerus shaft length (0); entepicondyle as broad as or broader than humerus is long (1)

142 **Body of humerus** [S162, Z142]: cylindrical (0); flattened rectangular (1)

143 **Caput humeri** [D112 (in part), S154 (in part), Z143]: almost flat (0); ball-shaped (1); elongate (2)

144 **Area proximal to radial facet** [D102, Z144]: short, cylindrical leading edge (0); enlarged, sharp leading edge (1)

145 **Shape of entepicondyle** [Z145]: narrow, finger-like (0); broad rectangular plate (1)

146 **Discrete pectoral process on ventral ridge of humerus** [Z146, CH92]: absent (0); present (1)

147 **Postaxial process on ulnare** [D91, S175, Z147]: present (0); absent (1)

148 **Pectoral fin radials** [D57 (in part), S177, Z148]: jointed (0); unjointed (1)

149 **Radial length** [D101, S170, Z149]: longer than humerus (0); equal to or shorter than humerus (1)

150 **Shape of radius** [D94, S169, Z150]: bladelike (0); subcylindrical (1)

151 **Termination of radius** [Z151]: radius and intermedium terminate at different levels (0); radius and intermedium terminate at same level (1)

152 **Digit** (parallel, segmented, non-branching endoskeletal elements relatively uniform in size and shape (radials or phalanges), and articulating one-to-one proximodistally, at the distal end of vertebrate paired appendages) [S178, Z152, CH90]. Owen (1849, p.

10)[134] was among the first anatomists to define the hand and its constituents: "the hand [of Man] or third segment is formed by a group of little thick bones, the "carpals" (56) and by five rays or digits; one (I) consisting of three segments, the rest (II-V) of four segments each; the five bones joining the carpus being called "metacarpals," and the others the "phalanges." Rather than defining the manus, Goodrich (1930)[135] defined digits as being composed of phalanges that are distinct from metacarpals (or metatarsals) and carpals (or tarsals). However, the first modern definition is that of Coates (1994)[136] where digits are defined as segmented postaxial radials, supporting no lepidotrichia or dermotrichia. Subsequently Coates et al. (2002)[137] identified a few characteristics of digits: they consist of two or more spool-shaped bones/cartilages articulating one-to-one proximodistally, they occur as an anteroposteriorly arranged set or series radiating from the distal end of the appendage. However, Boisvert et al. (2008)[106], based on the pectoral fin of *Panderichthys,* have asserted the homology between digits and radials with abstraction of the presence of fin rays. They identified the four radials located distally to the ulnare and intermedium of *Panderichthys* as digit homologues. By doing such identification (without using properly defined digits), Boisvert et al. (2008)[106] synonymized digits with autopodial elements distal to the proximal carpals. Finally, Stewart et al. (2017)[138] referring to Coates (1994)[136] re-defined digits as parallel, non-branching and segmented endoskeletal elements at the distal end of vertebrate paired pectoral and pelvic appendages.

A deep homology between digits and distal fin regions including radials and dermal fin rays has been repeatedly suggested (Tulenko et al., 2016, 2017)[139,140] based on the distal expression of *Hoxd13* gene in the distal region of the fin of *Polyodon*. Johanson et al. (2007)[133] suggested that fin radials are homologous to digits based on shared mechanism of *Hoxd13* expression, while Woltering et al. (2014)[141] concluded that although fish have the *Hox* regulatory toolkit to produce digits, this potential is not utilized as it is in tetrapods, and thus fin radials are not homologous to tetrapod digits. According to Thorogood (1991), the evolutionary origin of the autopod involved a loss of the fin-fold and associated dermal skeleton (scales and lepidotrichia) with a simultaneous elaboration of the distal endoskeleton to form a wrist and digits.

The four main issues dealing with the definition of digits are: (**1**) the presence of segmented and aligned elements, (**2**) the topographic (developmental) postaxial position, (**3**) the absence of branching elements and (**4**) the presence or absence of an exoskeletal component. (**1**) If one looks only at unequivocal digits, as those found in advanced tetrapods (even in Devonian forms such as *Acanthostega, Ichthyostega, Tulerpeton*), it is pertinent to talk about the segmentation and the alignment because numerous phalanges are composing each digit. However, if we assume a transitional condition in which there has not been a duplication of subunits (e.g., phalanges) we might expect a single element to be aligned with a terminal carpal or two elements characterized by a 1:1 relationship proximo-distally. In *Tulerpeton* (Lebedev & Coates, 1995)[125] and numerous lissamphibians (Fabrezi & Barg, 2001; Fröbisch & Shubin, 2001)[142,143], two digits (or metacarpals plus phalanges) articulate directly on a single carpal whether a proximal or a distal carpal. (**2**) The presence of postaxial elements is in reference to the posterior to anterior development of the digits, but this developmental pattern is found in amniotes and anurans, whereas a preaxial pattern

is known in salamanders (Wagner & Chiu, 2001; Wagner & Larsson, 2007; Johanson et al., 2007)[132,133,144]. (**3**) The absence of branching elements is primarily to distinguish central and distal radials (e.g., A4, A5) from phalanges. In numerous basal tetrapods, there is a one-to-one relationships between carpal and metacarpal (Carroll & Holmes, 2007)[145]. (**4**) Finally, we considered that a definition of digits should not take into account the presence or absence of fin rays; the endochondral and dermal components of the appendages should be considered as separate entities. The absence or presence of lepidotrichia associated with paired appendages is already taken into account in the phylogenetic analysis (Char. 194). We considered that the absence of lepidotrichia and the presence of digits should be taken into account if we were to define the manus (and pes).

We modified Coates' (1994)[136] and Stewart et al.'s (2017)[138] definitions to take into account digits in transitional fin to manus, thus we defined digits as parallel, segmented, non-branching endoskeletal elements relatively uniform in size and shape (radials or phalanges), and articulating one-to-one proximodistally, at the distal end of vertebrate paired appendages: absent (0); present (1)

153 **Dorsal and anal fins** [D58, S191, Z153]: present (0); absent (1)

154 **Caudal fin** [D59 (in part), S193 (in part), Z154]: heterocercal (0); triphycercal (1); diphycercal (2)

155 **Epichordal radials in caudal fin** [S194, Z155]: absent (0); present (1)

156 **Well-ossified ribs** [Z156]: absent (0); present (1)

157 **Expanded ribs** [D113, S181, Z157]: absent (0); present (1)

158 **Imbricate ribs** [D114, S182, Z158]: absent (0); present (1)

159 **Sacrum** [Z159]: absent (0); present (1)

160 **Intercentra fused to solid ring** [Z160]: no (0); yes (1)

161 **Ossified supraoccipital plug for the attachment of the supraneural ligament** [Z161]: present (0); absent (1)

162 **Scales** [ordered; D61 (in part), S199 (in part), Z162]. The original character states of Zhu et al. (2017)[102] have been reordered to form a morphocline: rhombic (0); intermediate between rhombic and round (1); round (2)

163 **Median boss on round scale** [Z163]: present (0); absent (1)

164 **Long basal segments of lepidotrichia in pectoral fin** [S180, Z164]: no (0); yes (1)

165 **Basal scutes** (on fins) [D60, S198, Z165]: absent (0); present (1)

166 **Pore-canal network** [Z166]: absent (0); present (1)

167 **Enamel lining of pore canals** [Z167]: absent (0); present (1)

168 **Rostral tubuli** [S2, Z168]: absent (0); present (1)

169 **Plicidentine** [D10, S201, Z169]: absent (0); simple or generalized polyplocodont (1); labyrinthodont (2)

170 **Postspiracular** [D37 (in part), D40 (in part), S124 (in part), Z29 (in part)]. This character is part of character 29 by Zhu et al. (2017)[102]. We divided the original character because we do not agree with the assumption that the extratemporal is homologous with the postspiracular: absent (0); present (1)

171 **Posterior carotid opening in parasphenoid** [S10 (in part), Z70 (in part)]. This character is linked with character 70 (Zhu et al. 2017)[102]: large (0); small (1)

172 **Interclavicle ornamentation** [D83 (in part), S158 (in part), Z134 (in part)]. This character corresponds in part of character 134 of Zhu et al. (2017)[102]: unornamented (0); ornamented (1)

173 **Choana** [D22]: absent (0); present (1)

174 **Anocleithrum** [D54]: exposed (0); subdermal (1)

175 **Archipterygial pectoral fin** [D55]: no (0); yes (1)

176 **Submandibulars** [D80 (in part), S135 (in part)]: present (0); absent (1)

177 **Gular** [D80 (in part), S135 (in part)]: present (0); absent (1)

178 **Contact between postorbital and lacrimal** [D84, S99]: absent (0); present (1)

179 **Contact between postfrontal and supratemporal** [D85]: no (0); yes (1)

180 **Transverse joint at the level of the ulnare, intermedium and radius** [D89, S173]: absent (0); present (1)

181 **Branched radials (A4) distal to the ulnare** [D93, S176]: absent (0); present (1)

182 **Olecranon process on ulna** [D95, S172]: absent (0); present (1)

183 **Radial facet** [D98, S167]: faces distally (0); has some ventrally directed component (1)

184 **Ulnar facet** [D99, S171]: faces distally (0); has some ventrally directed component (1)

185 **Glenoid position** [D104, S155]: elevated from plane formed by clavicles (0); offset ventrally to lie at same level as clavicular plane (1)

186 **Glenoid orientation** [D110, S156]: posterior orientation (0); lateral component to glenoid orientation (1)

187 **Premaxillary tooth proportions** [S53, CH35 (in part)]: all approximately same size (0); enlarged anterior tooth (1); posteriormost teeth at least twice height of anteriormost teeth (2)

188 **Anocleithrum** [S147, CH87]: oblong with distinct anterior overlap area (0); drop-shaped with no anterior overlap area (1); absent (2)

189 **Glenoid proportions** [S157]: height/width ratio 60% or greater (0); height/width ratio 40-50% 1)

190 **Interclavicle shape** [S159, CH99]: ovoid (0); kite-shaped (1); kite-shaped with posterior stalk (2)

191 **Deltoid and supinator process on humerus** [S163]: absent (0); present (1)

192 **Anterior termination of ventral ridge** [S164]: adjacent to the caput humeri (0); offset distally toward the proximodistal mid-region of anterior margin of humerus (1)

193 **Radius and ulna** [S166, CH102]: radius much longer than ulna (0); approximately equal length (1)

194 **Lepidotrichia in paired appendages** [S179, CH100]: present (0); absent (1)

195 **Ribs, trunk** [S183, CH103]: no longer than diameter of intercentrum (0); longer (1)

196 **Ribs, trunk** [S185, CH105]: all cylindrical (0); some or all bear flanges from posterior margin that narrow distally (1); some or all flare distally (2)

197 **Supraneural spines** [S186]: present (0); absent (1)

198 **Number of transverse flexion distal to ulnare** [ordered]: 1-2 rows (0); 3 rows (1); 4 rows (2)

199 **Number radials articulating on ulnare** [ordered; D90 (in part), S174 (in part)]: 0-2 radials (0); 3-4 radials (1); 5 radials (2)

200 **Number of digits**: five or less (0); more than five (1)

201 **Radiale**: absent (0); small (approximately one fifth the length of the radius) (1); large (approximately half the length of the radius) (2)

202 **Tabular horn**. A tabular horn is formed by an embayment in the posterior margin of the tabular: absent (0); present (1)

1d. Coding modifications from original matrices

List of character coding changes per taxon from original matrices of Zhu et al. (2017)[102], Swartz (2012)[9] and Daeschler et al. (2006)[116] with justifications. A total of 275 changes has been made to original matrices for 33 taxa (excluding new observations on *Elpistostege*). These changes correspond to either (1) original miscoding, (2) unused information published at the time the matrix was compiled, (3) newly published information, or (4) new observation on original material. In previous phylogenetic analyses, the percentage of characters coded for *Elpistostege* was low: 20% (23/115)[131], 20.6% (42/204)[9], 26.3% (30/114)[116], and 30.8% (52/169)[102]. In our matrix, 82.7% of the characters are coded for *Elpistostege* primarily owing to the morphological completeness of specimen MHNM 06-2067 (156 character states and 11 non-applicable); which brings the percentage of coding similar to *Panderichthys* (96.5%) and *Tiktaalik* (86.1%).

Tungsenia (9 coding differences)

Char. 27: The coding of *Tungsenia* is based on Lu et al. (2019, fig. 1-2)[41].

Char. 40: The coding of *Tungsenia* is based on Lu et al. (2019)[41].

Char. 41: Although the facets of hyomandibular articulations are not well-shown on the specimen (Lu et al. 2019)[41], they are present.

Char. 43: Based on Lu et al. (2019, fig. 1B, 2B)[41], a large vestibular fontanelle is present on the lateral braincase wall of *Tungsenia* at the same level with the ventral arcual plate.

Char. 44: Based on Lu et al. (2019, fig. 1B, 2B)[41], the anterior margin of the vestibular fontanelle is located posterior to the posterior margin of the basicranial fenestra.

Char. 45: The basicranial fenestra is coded as present based on Lu et al. (2019)[41].

Char. 46: The posttemporal fossa is present but poorly developed in *Tungsenia* (Lu et al. 2019)[41].

Char. 48: The coding of the optical process is based on Lu et al. (2019)[41].

Char. 122: The coding for the otic canal of *Tungsenia* is based on Lu et al. (2019)[41].

Kenichthys (1 coding difference)

Char. 61: Swartz (2012)[9] coded the condition of *Kenichthys* as unknown, however we agree with the coding provided by Zhu et al. (2017)[102].

Gooloogongia (1 coding difference)

Char. 7: Daeschler et al. (2006, char. 35)[116] and Swartz et al. (2012, char. 83)[9] coded *Gooloogongia* as having "one or two nasals". On the other hand, Zhu et al. (2017, char. 7)[102] coded *Gooloogongia* as having more than one nasal. However, Johanson & Ahlberg (1998, fig. 2f)[45] illustrated the right side of the snout with two nasals and the left side with three nasals. Thus, we are coding *Gooloogongia* as polymorphic.

Sauripterus (4 coding differences)

Char. 152: Davis et al. (2004, fig. 3-4, 7A, D; dr3 and dr4 are misidentified in fig. 7D)[51] illustrated a fairly complete pectoral fin of *Sauripterus*. Two relatively small, elongated elements articulate on a branched radial located distally to dr5. These two elements could be considered potentially as two one-segment digits. However, using a segmented 1:1 relationship, these elements do not respect this condition to be unambiguously recognized as digits, thus we are coding *Sauripterus* as "?".

Char. 163: Davis et al. (2004)[51] described the fusiform-shaped boss on the inner surface of scales of *Sauripterus taylori*.

Char. 174: The coding is based on Jeffery (2012, p. 507)[52].

Char. 181: Davis et al. (2004, figs 2-3)[51] illustrated a branched radials distal to the ulnare.

Barameda (25 coding differences)

Char. 33: Jeffery (2012, char. 20)[52] coded *Barameda* with the median extrascapular overlapped by the lateral extrascapulars. We do see an overlap area on the specimen of the skull (Long 1989)[19] and have re-examined the cast of the skull; it is code as "-" because we interpret the condition of the extrascapulars only as an abutment and not an overlap.

Char. 59: The subsquamosals are coded as "?" and not as "absent" because this region is not known for *Barameda*.

Char. 60: Preoperculosubmandibular is coded as "?" and not as "absent" because this region is not known in *Barameda*.

Char. 73: This character is scored for one pair of fangs on the ectopterygoid as seen in Long (1989, fig. 4C)[19].

Char. 77: The maxillary posterodorsal process is figured by Holland et al. (2007)[20]; so it is coded here as weakly developed.

Char.78: The lower jaw is well-known in *Barameda*, and there is no Meckelian ossification present on any of the material (Long, 1989, fig. 7A, B)[19].

Char. 98: Holland et al. (2007)[20] show a radiograph of the coronoid bones in *Barameda decipiens,* showing the row of large marginal teeth present with the large pair of fangs. No evidence exists of denticle bands associated with the coronoids, so this character is here scored as "-".

Char. 101: The anterior end of the prearticular is coded as "?" as this region is not known for the genus.

Char. 102: The condition of the longitudinal dorsal ridge on the prearticular is coded here as "?" as not known for this taxon.

Char. 105: The hyomandibula is figured by Holland et al. (2007, fig. 7C)[20] substantiated by direct comparison with other rhizodontid hyomandibulae figured in Brazeau & Jeffery (2008)[146]. There is no evidence for a canal present in *Barameda* so it is here coded as absent.

Char. 108: contact between hyomandibula and palatoquadrate. Here coded as "?" because this region is not known in this taxon.

Char. 115: Long (1989, p. 8)[19] clearly stated that there is room for one small median gular as indicated by the shape of lateral gulars (Long, 1989, fig. 4G)[19], so the character is here coded as present.

Char. 125: Curvature of dermal shoulder girdle. Long (1989, figs 7, 9)[19] shows the top of the cleithrum is tall and caudally inclined, so here coded as "1".

Char. 131: Long (1989, fig. 7)[19] shows several examples of the *Barameda* cleithrum, yet none of them show the cleithrum as narrow waisted, rather it is parallel sided all through its length.

Char. 134: The interclavicle is not known for *Barameda*, so here coded as "?".

Char. 135: Holland (2013, fig. 5)[147] figures the scapulocoracoid for *Barameda decipiens* and identified the supraglenoid foramen, and other morphological landmarks that suggest it attached to the cleithrum in the same way as the tri-radiate scapulocoracoid of *Gogonasus*. Although the three buttresses are not clear on Holland's figure, the overall shape of the scapulocoracoid is much the same as that of *Gogonasus* so this is why we coded this character as such.

Char. 136: Holland (2013, fig. 5)[147] figures the scapulocoracoid for *Barameda decipiens* so we score it accordingly as small.

Char. 138: Holland (2013, fig. 5)[147] figures the scapulocoracoid for *Barameda decipiens* so we score it accordingly as absent.

Char. 141: Both elongate and short entepicondyles are described for *Barameda* (Long 1989; Holland et al. 2007)[19,20] so coded for both short and long.

Char. 159: As we do not know this region on the specimens, it cannot be coded as "absent" but must be "?".

Char. 163: Long (1989, p. 12)[19] states the median boss is present on the basal surface of the scale, here coded as "present".

Char. 165: None of the fins are preserved in full articulation with the body, so the condition of basal scutes is unknown; this character must be scored as "?".

Char. 189: Deltoid and supinator processes of the humerus are described by Long (1989, p. 1, fig. 11A)[19].

Char. 196: The number of transverse flexion (distal to ulnare) is scored based on Garvey et al. (2005, fig. 2)[53] and Holland et al. (2007)[20].

Char. 197: The number of radials articulating with the ulnare is figured by Garvey et al. (2005)[53] and Holland et al. (2007)[20] as three elements.

Screbinodus (29 coding differences)

Char. 2 : Based on Jeffery's (2012, fig. 21)[52] reconstitution of the skull of *Screbinodus*, the proportion of the skull roof lying anterior to the middle of the orbits is unambiguously less than 50%.

Char. 21: Jeffery (2012)[52] tentatively interpreted the presence of a pineal opening in *Screbinodus* based on the presence of a notch on the median margin of the right parietal of SME 4714; we agree with this interpretation.

Char. 33: Jeffery (2012, fig. 10)[52] described and illustrated the overlap relationship among the extrascapulars for *Screbinodus*.

Char. 50: In contrast to Zhu et al. (2017)[102] coding, the postorbital is forming the posterior margin of the orbit of *Screbinodus* (Jeffery, 2012)[52].

Char. 51: In contrast to Zhu et al. (2017)[102] coding, the jugal extends anteriorly to the middle of the orbit, reaching almost the anterior level of the orbit of *Screbinodus* (Jeffery, 2012)[52].

Char. 63: The coding for the vomer of *Screbinodus* is based on Jeffery (2012, p. 507)[52].

Char. 74: Zhu et al. (2017)[102] coded *Screbinodus* as "?", the condition is based on Andrews (1985)[3] and Jeffery (2012)[52].

Char. 75: Zhu et al. (2017)[102] coded *Screbinodus* as "?", the condition is based on Andrews (1985)[3] and Jeffery (2012)[52].

Char. 78: Zhu et al. (2017)[102] coded *Screbinodus* as "?", the condition is based on Andrews (1985)[3] and Jeffery (2012)[52].

Char. 80: Zhu et al. (2017)[102] coded *Screbinodus* as "?", the condition is based on Andrews (1985)[3] and Jeffery (2012)[52].

Char. 81: Zhu et al. (2017)[102] coded *Screbinodus* as "?", the condition is based on Andrews (1985)[3] and Jeffery (2012)[52].

Char. 85: Zhu et al. (2017)[102] coded *Screbinodus* as "?", the condition is based on Jeffery (2012)[52].

Char. 86: Zhu et al. (2017)[102] coded *Screbinodus* as "?", the condition is based on Jeffery (2012)[52].

Char. 115: Zhu et al. (2017)[102] coded *Screbinodus* as "?", the condition is based on Jeffery (2012, p. 493)[52].

Char. 118: Zhu et al. (2017)[102] coded *Screbinodus* as "?", the condition of the postparietal is based on Jeffery (2012, fig. 8A, B)[52].

Char. 119: Zhu et al. (2017)[102] coded *Screbinodus* as "?", the condition of the postparietal is based on Jeffery (2012, fig. 21B)[52].

Char. 121: Zhu et al. (2017)[102] coded Screbinodus as "?", the condition of the postparietal is based on Jeffery (2012, fig. 21B)[52].

Char. 125: Zhu et al. (2017)[102] coded *Screbinodus* as "?", the condition of the cleithrum is based on Andrews (1985, fig. 13G)[3].

Char. 126: Zhu et al. (2017)[102] coded *Screbinodus* as "?", the condition of the cleithrum is based on Andrews (1985)[3].

Char. 127: Zhu et al. (2017)[102] coded *Screbinodus* as "?", the condition of the cleithrum and clavicle is based on Andrews (1985, fig. 13G)[3].

Char. 128: Zhu et al. (2017)[102] coded *Screbinodus* as "?", the condition of the cleithrum is based on Andrews (1985, fig. 13G).

Char. 133: Zhu et al. (2017)[102] coded *Screbinodus* as "?", the condition of the cleithrum is based on Andrews (1985, fig. 13G)[3].

Char. 134: Zhu et al. (2017)[102] coded *Screbinodus* as "?", the condition of the interclavicle is based on Andrews (1985, fig. 13G)[3].

Char. 135: Zhu et al. (2017)[102] coded *Screbinodus* as "?", the condition of the cleithrum is based on Andrews (1985, fig. 13G)[3].

Char. 138: Zhu et al. (2017)[102] coded *Screbinodus* as "?", the condition of the coracoid plate is based on Andrews (1985)[3].

Char. 152: Zhu et al. (2017)[102] coded *Screbinodus* as "?", however the sole pectoral fin present on the holotype does not show any indication of the presence of digits (Jeffery, 2001)[56].

Char. 162: Zhu et al. (2017)[102] coded *Screbinodus* as "?", however scales have been illustrated by Andrews (1985, fig. 16)[3].

Char. 162: Zhu et al. (2017)[102] coded *Screbinodus* as "?", however scales have been illustrated by Andrews (1985)[3].

Char. 174: The coding of the anocleithrum for *Screbinodus* is based on Jeffery (2012, p. 507)[52].

Rhizodus (18 coding differences)

Char. 63: Zhu et al. (2017)[102] coded *Rhizodus* as "?", the coding for the vomer of *Rhizodus* is based on Jeffery (2012, p. 507)[52].

Char. 126: Zhu et al. (2017)[102] coded *Rhizodus* as "?", our coding is based on Andrews & Westoll (1970, pl. 6)[148].

Char. 127: Zhu et al. (2017)[102] coded *Rhizodus* as "?", our coding is based on Andrews (1985, fig. 13 D-F)[3].

Char. 128: Zhu et al. (2017)[102] coded *Rhizodus* as "?", our coding is based on Andrews (1985, fig. 13 D-F)[3].

Char. 133: Zhu et al. (2017)[102] coded *Rhizodus* as "?", our coding is based on Andrews (1985, fig. 13 D-F)[3].

Char. 134: The interclavicle of *Rhizodus* is illustrated by Andrews (1985, fig. 5d)[3].

Char. 141: Zhu et al. (2017)[102] coded *Rhizodus* as "?", the condition of the humerus is described and illustrated by Jeffery (2001)[56].

Char. 142: Zhu et al. (2017)[102] coded *Rhizodus* as "?", the condition of the humerus is described and illustrated by Jeffery (2001)[56].

Char. 147: Zhu et al. (2017)[102] coded *Rhizodus* as "?", the condition of the ulnare is described and illustrated by Jeffery (2001)[56].

Char. 149: Zhu et al. (2017)[102] coded *Rhizodus* as "?", the condition of the pectoral endoskeleton is described and illustrated by Jeffery (2001)[56].

Char. 150: Zhu et al. (2017)[102] coded *Rhizodus* as "?", the condition of the pectoral endoskeleton is described and illustrated by Jeffery (2001)[56].

Char. 151: Zhu et al. (2017)[102] coded *Rhizodus* as "?", the condition of the pectoral endoskeleton is described and illustrated by Jeffery (2001)[56].

Char. 180: Swartz (2012)[9] coded *Rhizodus* as "?", the condition of the pectoral endoskeleton is described and illustrated by Jeffery (2001)[56].

Char. 182: Swartz (2012)[9] coded *Rhizodus* as "?", the condition of the pectoral endoskeleton is described and illustrated by Jeffery (2001)[56].

Char. 193: Swartz (2012)[9] coded *Rhizodus* as "?", the condition of the pectoral endoskeleton is described and illustrated by Jeffery (2001)[56]. The radius of *Rhizodus* is longer than the ulna; although the discrepancy is not as important as in *Cabonnichthys* and *Barameda*.

Char. 194: Swartz (2012)[9] coded *Rhizodus* as "?", the condition of the pectoral fin is described and illustrated by Jeffery (2001)[56].

Char. 199: Swartz (2012)[9] coded *Rhizodus* as "?", the condition of the ulnare suggests the presence of two radials (Jeffery 2001)[56].

Char. 201: Jeffery (2001)[56] reconstructed an endochondral element in a position distal to the radius of *Rhizodus hibberti* (fig. 6) based on disarticulated elements from one

specimen (fig. 2). Subsequently, *Rhizodus* has been illustrated has having a radiale; however, this reconstruction is too uncertain to allow us to code for the presence of a radiale.

Strepsodus (19 coding differences)

Char. 33: *Strepsodus* is coded based on the coding of Jeffery (2012, data matrix character 20)[52].

Char. 118: Zhu et al. (2017)[102] coded *Strepsodus* as "?", the condition of the postparietal is based on Jeffery (2012, fig. 8E, F)[52].

Char. 126: The cleithral ornamentation of *Strepsodus* is visible in Andrews & Westoll (1970, pl. 11H)[148].

Char. 127: The condition of the contact between the clavicle and cleithrum of *Strepsodus* is based on Andrews (1985, fig. 13H)[3].

Char. 128: The condition of the cleithrum of *Strepsodus* is based on Andrews (1985, fig. 13H)[3].

Char. 133: The condition of the clavicle of *Strepsodus* is based on Andrews (1985, fig. 13)[3].

Char. 141: Zhu et al. (2017)[102] coded *Strepsodus* as "?", the condition of the humerus is illustrated by Jeffery (2001, fig. 4E-H)[56].

Char. 142: Zhu et al. (2017)[102] coded *Strepsodus* as "?", the condition of the humerus is illustrated by Jeffery (2001, fig. 4E-H)[56].

Char. 147: Zhu et al. (2017)[102] coded *Strepsodus* as "?", the condition of the ulnare is illustrated by Jeffery (2001, fig. 1C)[56].

Char. 149: Although the precise length and shape of the radius is poorly known in *Strepsodus*, the radius is clearly shorter than the humerus based on Jeffery (2001, fig. 1C)[56].

Char. 155: Zhu et al. (2017)[102] coded *Strepsodus* as "?", the condition of the caudal fin is based on Andrews (1985, p. 71-74)[3].

Char. 156: Zhu et al. (2017)[102] coded *Strepsodus* as "?", the condition of the caudal fin is based on Andrews (1985, p. 71-74)[3].

Char. 173: Partial choanal details in *Strepsodus* have been described by Jeffery (2012)[52].

Char. 174: The coding is based on Jeffery (2012, p. 507)[52].

Char. 177: In contrast to Swartz (2012)[9], the gulars of *Strepsodus* are coded as present (Holland et al. 2007)[20].

Char. 181: The coding is based on Jeffery (2001, fig. 1C)[56].

Char. 185: The coding is based on the reconstruction of the shoulder girdle of *Strepsodus sauroides* by Andrews (1985, fig. 13)[3].

Char. 186: Based on the reconstruction of the shoulder girdle of *Strepsodus sauroides* by Andrews (1985, fig. 13)[3], the glenoid is oriented posterolaterally.

Char. 187: *Strepsodus* is coded with an enlarged anterior tooth based on Andrews (1985, fig. 9g)[3] and Jeffery (2012, fig. 3E, F)[52].

Gyroptychius (3 coding differences)

Char. 6: *Gyroptychius* is coded as "?" since the snout is covered by cosmine obliterating individual bones.

Char. 85: None of the specimens of *Gyroptychius* illustrated by Jarvik (1948)[5] shows a dentary with fang pair.

Char. 97: Jarvik (1948, pl. 35, fig. 9)[5] figured a lower jaw of *Gyroptychius milleri* in internal view showing coronoid fangs.

Osteolepis (1 coding difference)

Char. 190: The coding of the interclavicle is based on the condition illustrated and mentioned by Jarvik (1948)[5].

Gogonasus (19 new scorings)

Char. 26: Long (2006)[65] shows the postparietal ending in an angle (point) rather than levelled off; also see Long et al. (1997, figs 2C, 5D)[63]. Clearly the reconstructions are not as accurate.

Char. 61: Vomers are very broad on *Gogonasus* (1.64 times as broad as long), quite similar in shape and proportion to those of *Claradosymblema* which is coded as "2".

Char.68: The parasphenoid of *Medoevia* is coded as slender-splint shaped as for *Gogonasus* -exactly the same shape, but extending further anteriorly, so coding here changed to "1".

Char. 134: No evidence of an interclavicle present in any of the descriptions (Long et al. 1997; Holland 2013)[63,147], so it is coded as "-".

Char. 143. The humerus is very well preserved and described in Long et al. (2006)[65] and Holland & Long (2009)[64]. The caput humeri is flat to convex and not ball-shaped.

Char. 153: Redescribed tail shows posteriorly located dorsal and anal fins (Long & Trinasjtic 2018, fig. 3A)[66]; thus it is coded as present.

Char. 154: The caudal fin is described and figured in Long & Trinajstic (2018, fig. 3A, B)[66].

Char. 155: The caudal fin is described and figured in Long & Trinajstic (2018, fig. 3A, B)[66].

Char. 160: Based on synchrotron scan of new WAM specimen to be described, the intercentra remain separate.

Char. 171: Holland (2013, fig. 2)[147] confirm the anocleithrum shows an externally ornamented area.

Char. 177: Transverse joint at the level of the ulnare, intermedium and radius. Holland (2013, fig. 9)[147] show the condition here, as does Long et al. (2006)[65].

Char. 178: Long et al. (2006, fig. 2)[65] confirm that there is an articulation for more than two radials on the ulnare.

Char. 181: Swartz (2012, char. 176)[9] coded for the absence of A4 in *Gogonasus*. However, Long et al. (2006, fig. 2g, i)[65] identified A4 in *Gogonasus*.

Char. 183: In contrast to Swartz (2012)[9], Long et al. (2006)[65] show the facet for the radius is partially ventral in *Gogonasus*.

Char. 185: Holland (2013, fig. 9)[147] shows the glenoid position clearly.

Char. 187: Based on Holland (2013, fig. 4C)[147], glenoid width is almost exactly twice as long as high.

Char. 188: No interclavicle present, so coded as "-".

Char. 196: The number of transverse flexion is coded as 1-2 rows.

Char. 197: The number of radials articulating on ulnare is coded as 1-2 radials.

Medoevia (2 coding differences)

Char. 76: Zhu et al. (2017, char. 17)[102] and Johanson & Ahlberg (2001, char. 27)[2] coded for the absence of the enlarged anterior premaxillairy tooth, in contrast to Swartz (2012, char. 53)[9]. Lebedev (1995, p. 296)[67] mentioned that the medial tooth pair is slightly bigger than the others in *Medoevia*.

Char. 188: Swartz (2012)[9] coded *Medoevia* as "?". However, the anocleithrum condition of *Medoevia* is well illustrated in Lebedev (1995, fig. 1A-B, 30E-F)[67].

Claradosymblema (10 coding differences)

Char. 28: We have coded this as present, small, based on observation of the actual material held in the ANU collections. The spiracular notch was restored in Fox et al. (1995, fig. 14)[68], as it is clearly present.

Char. 34: The specimens clearly show differentiated shallow internasal pits [e.g., Fox et al. (1995, fig. 21)[68]] so we code this as state "1", not "0" as previously coded by Zhu et al. (2017)[102].

Char. 134: Fox et al. (1995, p. 183)[55] note the presence of a distinct overlap area on the anterior margin of the clavicle for the interclavicle. While the bone cannot be easily seen in the Holotype (fig. 6), we code it as present based on this evidence. Fox et al. (1995, p. 183)[55] claim it would have been "rather nondescript".

Char. 170: A choana is certainly present in *Claradosymblema* as shown by the presence of large ventrolateral fossae on the palate (Fox et al. 1995, fig. 21)[55] and typical palatal bones like the vomer present [Fox et al. (1995, fig. 5)[55] show pterygoids present but cannot be described]. We do not see it enclosed by the palate, as the palatal bones are not described, but there is enough evidence here to demonstrate it did possess a choana in the same way other megalichthyinids do.

Char. 171: Fox et al. (1995, fig. 59C,D)[68] show part of the anocleithrum, confirming it has an exposed dermal ornamented section.

Char. 172: Holland (2013, fig. 13)[147] shows a radiograph of the *Claradosymblema* Holotype pectoral fins, showing clearly it had a metapterygial style fin.

Char. 165: A large basal scute appears to be present on the inner side of the pectoral fin (Fox et al. 1995, fig. 64B)[68], as occurs in *Megalichthys* (Andrews & Westoll 1970, pl. IV, A)[148].

Char. 167: Fox et al. (1995, p. 196)[68] clearly state that "no downturned enamel edges are seen buried within the cosmine" referring to the scales.

Char. 187: Fox et al. (1995, fig. 63)[68] show the glenoid fossa as being very narrow.

Char. 191: Holland (2013, fig. 13)[147] clearly shows that the radius is longer than the ulna.

Megalichthys (2 coding differences)

Char. 175: This coding of *Megalichthys* is based on Andrews & Westoll (1970, fig. 3b)[148].

Char. 182: Daeschler et al. (2006, char. 95)[116] coded this character as "?", whereas Swartz (2012, char. 172)[9] coded *Megalichthys* as lacking an olecranon process on the ulna.

Beelarongia (16 coding differences)

Many of the characters of the humerus were uncoded, so these are now added in (it is figured in Long 1987)[79].

Char. 5: The orientation of the anterior tectal and lateral rostral is not clear from the material described by Long (1987)[79], so it is coded as "?".

Char. 14: Long (1987, pl. 91-1, text-fig. 5)[79] show the posterior supraorbital has a very small process.

Char. 17: The contact between the posterior supraorbital and intertemporal is not known (Long 1987)[79] so it is coded as "?".

Char. 133: Long (1987, text-fig. 4)[79] shows the clavicle.

Char. 135: The scapulocoracoid of *Beelarongia* is described by Long (1987, text-fig. 3B, C)[79]; it looks like a typical tri-radiate attachment.

Char. 136: The scapulocoracoid is described for *Beelarongia* by Long (1987, text-fig. 3 B, C)[79].

Char. 137: The scapulocoracoid is described for *Beelarongia* by Long (1987, text-fig. 3B, C)[149] but the subscapular fossa is absent (see Long's identification of ?f.sub).

Char. 138: The scapulocoracoid is described for *Beelarongia* by Long (1987, text-fig. 3 B, C)[149], but the subscapular fossa is absent (see Long's identification of ?f.sub).

Char. 140: The humerus of *Beelarongia* is described by Long (1987, text-fig. 3)[149] and coded accordingly.

Char. 141: The humerus of *Beelarongia* is described by Long (1987, text-fig. 3)[149] and coded accordingly.

Char. 142: The humerus of *Beelarongia* is described by Long (1987, text-fig. 3)[149] and coded accordingly.

Char. 143: The humerus of *Beelarongia* is described by Long (1987, text-fig. 3)[149] and coded accordingly.

Char. 144: The humerus of *Beelarongia* is described by Long (1987, text-fig. 3)[149] and coded accordingly.

Char. 145: The humerus of *Beelarongia* is described by Long (1987, text-fig. 3)[149] and coded accordingly.

Char. 153: The dorsal and anal fins are not known in *Beelarongia* (Long 1987)[149] so it is coded as "?".

Char. 189: The deltoid and supinator processes are present in *Beelarongia*.

Canowindra (2 coding differences)

Char. 52: Long (1985, fig. 2)[80] shows that the jugal did not contribute to the orbital margin.

Char. 171: Long (1985, fig. 4)[80] shows the externally ornamented area of the anocleithrum.

Koharalepis (27 coding differences)

New CT scans using the Australian synchrotron and Dingo neutron beam have given the authors a lot of new information about *Koharalepis*. Some of this was published in Long et al. (2018)[150].

Char. 5: The orientation of the anterior tectal-lateral rostral is shown by Long et al. (2018, fig. 7)[150].

Char. 10: Long et al. (2018, fig. 9B)[150] show possible choana in CT images.

Char. 11: Long et al. (2018, fig. 10)[150] show the presence of one supraorbital.

Char. 12: Long et al. (2018, fig. 10)[150] show the condition of the supraorbital.

Char. 13: This character is coded as "-" because only one supraorbital is present.

Char. 14: The shape of the posterior supraorbital is coded as "-" as only one supraorbital is present.

Char. 18: Long et al. (2018, fig. 9B)[150] show one tectal present.

Char. 35: Long et al. (2018, fig. 8B)[150] show the thickness of the braincase at orbit to be narrow.

Char. 41: Long et al. (2018, fig. 8A)[150] show braincase with hyomandibular attached.

Char. 65: Long et al. (2018, fig. 8B)[150] show the shape of the parasphenoid in CT imagery as normal for basal stem tetrapods.

Char. 67: Long et al. (2018, fig. 8B)[150] show the shape of the parasphenoid in CT imagery as normal for basal stem tetrapods.

Char. 73: The number of fang pairs on the ectopterygoid is determined based on unpublished CT data by Dingo neutron beam.

Char. 74: The presence of palatal fangs mesial to marginal tooth row is determined based on unpublished CT data by Dingo neutron beam.

Char. 79: Long et al. (2018, fig. 9A)[150] show coronoids.

Char. 85: Long et al. (2018, fig. 9B)[150] show dentary fangs.

Char. 86: Long et al. (2018, fig. 9A-B)[150] show dentary teeth.

Char. 92: Long et al. (2018, fig. 9A-B)[150] show dentary without parasymphysial tooth whorl.

Char. 93: Long et al. (2018, fig. 9A)[150] show dentary without parasymphysial plate area.

Char. 94: Long et al. (2018, fig. 9A)[150] show dentary without parasymphysial plate area.

Char. 95: Long et al. (2018, fig. 9A)[150] show dentary with parasymphysial plate area without a tooth row visible.

Char. 97: Long et al. (2018, fig. 9A-B)[150] show the presence of coronoid fangs.

Char. 98: Long et al. (2018, fig. 9A)[150] show coronoid details with small rows of teeth behind fangs.

Char. 99: Long et al. (2018, fig. 9A)[150] show coronoid details.

Char. 100: Long et al. (2018, fig. 9A)[150] show coronoid details.

Char. 104: Young et al. (1992, fig. 11A)[81] show the weakly developed retroarticular process.

Char. 153: The dorsal and anal fins are not known as only the skull and anterior part of the trunk are preserved; thus, it is coded as "?".

Char. 170: From new CT data, we can confirm the presence of a choana.

Marsdenichthys (8 coding differences)

Char. 62: In contrast to Zhu et al. (2017)[102] who coded *Marsdenichthys* as "?", the anteromedial process on vomer is present as shown in Holland et al. (2010, fig. 4)[83].

Char. 63: In contrast to Zhu et al. (2017)[102] who coded *Marsdenichthys* as "?", Posterior process on vomers. as shown in Holland et al. (2010, fig. 4)[83].

Char. 64: In contrast to Zhu et al. (2017)[102] who coded *Marsdenichthys* as "?", there is a clear articulation between the vomers as shown in Holland et al. (2010, fig. 4)[83].

Char. 65: In contrast to Zhu et al. (2017)[102] who coded *Marsdenichthys* as "?", the parasphenoid is protruding forward in the ethmoid region of the endocranium as shown in Holland et al. (2010, fig. 4)[83].

Char. 73: In contrast to Zhu et al. (2017)[102] who coded *Marsdenichthys* as "?", there is one fang pair present on the ectopterygoid as shown in Holland et al. (2010, fig. 4)[83].

Char. 76: In contrast to Zhu et al. (2017)[102] who coded *Marsdenichthys* as "?", there is no enlarged anterior teeth on the premaxilla as shown in Holland et al. (2010, fig. 2)[83].

Char. 120: In contrast to Zhu et al. (2017)[102] who coded *Marsdenichthys* as "?", the posterior end of the supraorbital canal is located in the intertemporal as shown by Long (1985)[84] and Holland et al. (2010)[83].

Char. 121: In contrast to Zhu et al. (2017)[102] who coded *Marsdenichthys* as "?", there is a contact between the otic and supraorbital canals as shown by Long (1985)[84] and Holland et al. (2010)[83].

Tristichopterus (16 coding differences)

Char. 30: Because the extratemporal and the postspiracular were considered to be homologous by Zhu et al. (2017)[102], they coded for the absence of contact between the extratemporal and supratemporal. Considering our redefinition of character 29 (limited to the presence of the extratemporal), character 30 is coded as inapplicable rather than the absence of contact.

Char. 61: Swartz (2012)[9] coded the condition of *Tristichopterus* as "?", while Zhu et al. (2017)[102] reported the plesiomorphic condition.

Char. 62: Zhu et al. (2017)[102] coded *Tristichopterus* as "?", however, Swartz (2012)[9] coded *Tristichopterus* with the absence of an anteromedial process of the vomers where the vomers are in close contact.

Char. 72: Swartz (2012)[9] coded *Tristichopterus* as "?", while Zhu et al. (2017)[102] coded the proportions of the entopterygoid in which the anterior end is considerable anterior to the processus ascendens.

Char. 114: The condition of the branchiostegal rays of *Tristichopterus* is visible on specimen AMF 143859.

Char. 130: Coding based on new specimen (Flinders University).

Char. 131: Coding based on new specimen (Flinders University).

Char. 132: Coding based on new specimen (Flinders University).

Char. 147: Coding based on new specimen (Flinders University).

Char. 149: Coding based on new specimen (Flinders University).

Char. 150: Coding based on new specimen (Flinders University).

Char. 151: Coding based on new specimen (Flinders University).

Char. 154: Zhu et al. (2017)[102] coded the caudal fin of *Tristichopterus* as heterocercal; however, the caudal fin of *Tristichopterus* is triphycercal with the middle part being less developed than in *Eusthenopteron*.

Char. 174: Coding based on new specimen (Flinders University).

Char. 175: The pectoral fin of *Tristichopterus* does not display an archipterygial pattern (specimen at Flinders University).

Char. 193: Coding based on new specimen (Flinders University).

Eusthenopteron (4 coding difference)

Char. 30: Because the extratemporal and the postspiracular were considered to be homologous by Zhu et al. (2017)[102], they coded for the absence of contact between the extratemporal and supratemporal. Considering our redefinition of character 29 (limited to the presence of the extratemporal), character 30 is coded as inapplicable rather than the absence of contact.

Char. 57: Based on new observations, Schultze & Reed (2012, fig. 10A)[94] illustrated *Eusthenopteron* with a quadratojugal bearing both the quadratojugal pitline and the preopercular canal.

Char. 114: The element identified by Schultze & Reed (2012, fig. 2)[94] as the posteriormost submandibular is identified herein as a branchiostegal ray.

Char. 197: Swartz (2012)[9] coded *Eusthenopteron* as lacking supraneurals; however, cervical supraneurals (1, 3, and 5) have been described by Hitchcock (1995)[91].

Platycephalichthys (1 coding difference)

Char. 76: Zhu et al. (2017, char. 76)[102] coded for the absence of enlarged anterior tooth on the premaxilla, whereas Swartz (2012, char. 53)[9] coded for the presence of such enlarged teeth. Vorobyeva (1977, fig. 44)[59] illustrated a specimen of *Platycephalichthys bischoffi* showing enlarged anterior teeth on the premaxilla.

Cabonnichthys (2 coding differences)

Char. 30: Because the extratemporal and the postspiracular were considered to be homologous by Zhu et al. (2017)[102], they coded for the absence of contact between the extratemporal and supratemporal. Considering our redefinition of character 29 (limited to the presence of the extratemporal), character 30 is coded as inapplicable rather than the absence of contact.

Char. 181: Swartz (2012, char. 176)[9] coded for the absence of A4 in *Cabonnichthys*. However, Ahlberg & Johanson (1997, fig. 13B)[7] illustrated and identified an element as A4.

Mandageria (1 coding difference)

Char. 30: Because the extratemporal and the postspiracular were considered to be homologous by Zhu et al. (2017)[102], they coded for the absence of contact between the extratemporal and supratemporal. Considering our redefinition of character 29 (limited to the presence of the extratemporal), character 30 is coded as inapplicable rather than the absence of contact.

Char. 181: Swartz (2012, char. 176)[9] coded for the absence of A4 in *Mandageria*. However, Johanson & Ahlberg (1997, fig. 16a)[8] illustrated and identified an element as A4.

Eusthenodon (2 coding difference)

Char. 30: Because the extratemporal and the postspiracular were considered to be homologous by Zhu et al. (2017)[102], they coded for the absence of contact between the extratemporal and supratemporal. Considering our redefinition of character 29 (limited to the presence of the extratemporal), character 30 is coded as inapplicable rather than the absence of contact.

Char. 194: A partial pectoral fin of *Eusthenodon* has been described by Clément (2002)[100].

Bruehnopteron (1 coding difference)

The coding of *Bruehnopteron murphyi* Schultze & Reed (2012)[94] is based on specimens KUVP 94040, UCMP 117884, 118283 and 123135. Specimens UCMP 117884, 118283 and 123135 were originally assigned to *Tinirau clackae* (Schultze & Reed, 2012)[94].

Char. 170: We identified as postspiracular the element that Schultze & Reed (2012, fig. 2)[94] referred to as the extratemporal.

Tinirau (11 coding differences)

The coding of *Tinirau clackae* Swartz (2012)[9] is based on specimens UCMP 118605, 190999 and 190998.

Char. 6: Swartz (2012, char. 86; Figure S3)[9] coded *Tinirau* as having a median postrostral. However, the only specimen (UCMP 118283) interpreted to share this condition is attributed to *Bruehnopteron*. Thus, *Tinirau* is coded as "?". Furthermore, it is unclear if a large median postrostral is present in this specimen (Schultze & Reed, 2012)[94].

Char. 33: Swartz (2012)[9] coded the condition of *Tinirau* as unknown. Reexamination of the holotype suggests that the median extrascapular is overlapped by the lateral extrascapulars. The overlapped condition is also clear on the right side of the extrascapular series of specimen UCMP 190999.

Char. 38: Swartz (2012)[9] coded for the absence of the descending process of the sphenoid. However, the state of preservation of specimen UMC 190999 does not allow for a clear observation.

Char. 42: Swartz (2012)[9] coded for the dorsal hyomandibular facet of *Tinirau* being directly above the ventral facet. However, the state of preservation of specimen UMC 190999 does not allow for a clear observation.

Char. 51: Swartz (2012, char. 95)[9] coded for the jugal not extending anteriorly to mid-orbit. However, a re-examination of the cheek condition of specimen UCMP 118605 of *Tinirau* does not show clearly the limit of the orbit, furthermore it is unclear if the line interpreted as the suture between the lacrimal and jugal might be a fracture.

Char. 61: Swartz (2012, char. 57)[9] coded *Tinirau* as having a vomer not much broader than long. This coding was most likely based on specimen UCMP 117884 which shows completely the vomers. However, this specimen has been reassigned to *Bruehnopteron* (Schultze & Reed, 2012)[94]. Therefore, the condition of the vomers has to be based on specimen UCMP 190999, for which the anterior margin of the vomers are poorly preserved. Although the condition seems to correspond to a vomer not much broader than long, we are coding *Tinirau* as "?" because of the incompleteness of the vomers.

Char. 62: Swartz (2012, char. 63)[9] coded *Tinirau* as having a vomer lacking anteromedial process. This coding was most likely based on specimen UCMP 117884. However, this specimen has been reassigned to *Bruehnopteron* (Schultze & Reed, 2012)[94]. Therefore, the condition of the vomers has to be based on specimen UCMP 190999, for which the anterior margin of the vomers are poorly preserved. Thus, we are coding *Tinirau* as "?".

Char. 76: Swartz (2012, char. 53)[9] reported that the premaxillary teeth of *Tinirau* are all of similar size based on specimen UCMP 117884; although the anterior teeth are larger than the remaining ones. Specimen UCMP 117884 has been reassigned to *Bruehnopteron* (Schultze & Reed, 2012)[94] leaving no specimen of *Tinirau* showing properly the premaxillary teeth. Thus, *Tinirau* is coded as "?".

Char. 117: Swartz (2012, fig. 3Ai-ii, S3)[9] illustrated an anterior pit-line essentially transverse located anteriorly to the pineal opening of *Tinirau*. This coding was based on specimen UCMP 117884 and 118283, both of which have been reassigned to *Bruehnopteron* (Schultze & Reed, 2012)[94]. Specimens UCMP 118605 and 190999 do not show the condition of the anterior pit-lines. Thus, *Tinirau* is coded as "?".

Char. 135: Swartz (2012, char. 151)[9] coded *Tinirau* as having a small and tripodal scapulocoracoid. However, the condition of attachment between the scapulocoracoid to the cleithrum is unclear, and therefore *Tinirau* is coded as "?".

Char. 143: Swartz (2012, char. 154)[9] coded *Tinirau* as having a caput humeri concave. However, the proximal part of the humerus is unknown in *Tinirau*, thus we are coding as "?".

Panderichthys (8 coding differences)

Char. 51: Zhu et al. (2017) coded the jugal of *Panderichthys* as not extending anterior to middle of orbit. Of the two specimens (PIN 3547/18 and PIN 3547/26) of *Panderichthys* illustrated by Vorobyeva & Schultze (1991, fig. 4-5), the anterior extent of the jugal varies between individuals and bilaterally. We are coding character 51 as polymorphic.

Char. 52: Of the two specimens of *Panderichthys* illustrated by Vorobyeva & Schultze (1991, fig. 4-5)[10], specimen PIN 3547/18 has the jugal forming part of the orbit on both sides, whereas in specimen PIN 3547/26, the jugal is excluded from the orbit on the left side. We are coding character 52 as polymorphic.

Char. 100: Zhu et al. (2017, char. 100)[102] coded *Panderichthys* for the presence of one fang on the posterior coronoid. However, Ahlberg & Clack (1998, fig. 1B-C, p. 14)[103] described and illustrated solely the presence of teeth and no tusk on the posterior coronoid.

Char. 101: Zhu et al. (2017)[102] coded the anterior end of the prearticular of *Panderichthys* as forked. However, figure 1C of Ahlberg & Clack (1998)[103] does not show a forked ending nor does the lower jaw of *Panderichthys* from the museum in Berlin. Thus, we are coding the condition of the anterior end of the prearticular as "0".

Char. 151: Swartz (2012)[9] coded that the intermedium and the radius terminated at the same level; that is considering that the distal element is a second intermedium. Taking into account only the intermedium (*senso stricto*) that is articulating with the ulna, the radius and intermedium do not terminate at the same level.

Char. 180: Daeschler et al. (2006)[116] coded the presence of this first joint in *Panderichthys*, while Swartz (2012)[9] coded the absence of this joint. We agree with Swartz (2012)[9].

Char. 187: Swartz (2012)[9] coded *Panderichthys* as having premaxillary teeth of the same size. However, examination of specimen PIN 3547/18 shows clearly that anterior teeth are slightly larger than posterior one.

Char. 190: In contrast to Swartz (2012)[9], we are coding the interclavicle of *Panderichthys* as ovoid based on Vorobyeva & Schultze (1991)[151]. Although the shape is not perfectly ovoid, it is clearly not kite-shaped and there is no stalk posteriorly.

Elpistostege (10 coding differences)

Char. 25: Clack et al. (2012)[131] coded *Elpistostege* has having a dermal intracranial joint; however, the fusion of elements as well as the digitated sutures show that there is no dermal joint on the skull roof.

Char. 79: Zhu et al. (2017)[102] coded this character on the coronoid condition; however, this was unknown in previous specimens.

Char. 101: The condition of the anterior end of the prearticular of *Elpistostege* is coded as "?". Although there is no obvious anterior forked ending, the CT-scan rendering is not obvious enough to assign the condition as unforked.

Char. 153: In *Elpistostege*, the dorsal fins are absent, whereas the anal fin is present.

Char. 162: According to Witzmann (2011)[112], among elpistostegalians, the scales of *Elpistostege* resemble most closely those of tetrapods in their increased length (more elongate in shape) and in their vermiculate dermal sculpture.

Char. 178: Daeschler et al. (2006)[116] and Swartz (2012)[9] coded for presence of a contact between the postorbital and the lacrimal of *Elpistostege*. We are coding this character as polymorphic because in both specimens (MHNM 06-358, 06-2067) it varies bilaterally.

Char. 179: Daeschler et al. (2006)[116] coded that there was a contact between the postfrontal and supratemporal of *Elpistostege*; however, specimen MHNM 06-2067 shows clearly that there is no contact between these two elements on both sides of the specimen.

Char. 187: Swartz (2012)[9] coded *Elpistostege* as having premaxillary teeth of same size; however, CT scan data from both specimens show clearly that posteriormost teeth are much larger than anterior ones.

Char. 188: The condition of the anocleithrum of *Elpistostege* is similar to that of *Eusthenopteron*.

Char. 202: The posterior margin of the tabular is emarginated forming a tabular horn. The tabular horn of *Elpistostege* is less developed than the condition observed in *Acanthostega*. In addition, the tabular horn of *Elpistostege* does not contributes to the spiracular notch, while it forms part of it in *Acanthostega*.

Tiktaalik (16 coding differences)

Char. 7: The recognition of individual bones anterior to the frontals in *Tiktaalik* is unclear since most elements seem to be fused. Therefore, we are coding this character as "?" as Daeschler et al. (2006, char. 35)[116] and Swartz (2012, char. 83)[9], but in contrast to Zhu et al. (2017, char. 7)[102] that coded for the presence of many nasals.

Char. 16: Although Swartz (2012)[9] and Zhu et al. (2017)[102] code *Tiktaalik* as "?", we are coding *Tiktaalik* as lacking an intertemporal as suggested by Daeschler et al. (2006)[116].

Char. 50: Zhu et al. (2017)[102] coded *Tiktaalik* as "?", however, the postorbital clearly forms the posterior margin of the orbit (Daeschler et al. 2006)[116].

Char. 52: Zhu et al. (2017, char. 52)[102] coded *Tiktaalik* as having the lacrimal contributing to the orbital margin. However, on the holotype (NUFC 108) the condition is polymorphic since the jugal contributes to the orbital margin on the left side, whereas the jugal is excluded from the orbit on the right side because of the contact between the postorbital and the lacrimal Daeschler et al. (2006, fig. 3)[116].

Char. 53: The condition of the lacrimal varies bilaterally on the holotype of *Tiktaalik* (Daeschler et al. 2006)[116].

Char. 60 : Zhu et al. (2017, char. 60)[102] and Daeschler et al. (2006, char. 46)[116] coded for the absence of the preoperculosubmandibular. However, in their description Daeschler et al. (2006, p. 761)[116] wrote that "the status of the preoperculosubmandibular is indeterminate." Thus, we are coding the condition of the preoperculosubmandibular of *Tiktaalik* as "?".

Char. 70: Zhu et al. (2017)[102] coded this character as "?". The posterior carotid opening of *Tiktaalik* does not pierce the parasphenoid (Down et al. 2008, fig. 3)[114].

Char. 75: Zhu et al. (2017)[102] and Swartz (2012)[9] coded *Tiktaalik* as not having a subterminal mouth, while Daeschler et al. (2006)[116] coded for a subterminal mouth as well as mentioned that *Panderichthys, Elpistostege* and *Tiktaalik* have such condition.

Char. 113: Character 113 is coded as absent by Zhu et al. (2017)[102] because the opercular was said to be absent in *Tiktaalik* by Daeschler et al. (2006)[116]. However, there is no direct evidence that this element is absent, since it might have been disarticulated prior to burial as the distal segmented parts of the lepidotrichia and a large part of the gular series.

Char. 134: The condition (size and ornamentation) of the interclavicle of *Tiktaalik* was coded as "?" by Zhu et al. (2017)[102]. Shubin et al. (2015)[11] described the interclavicle of *Tiktaalik* as a large, oval-shaped element. However, the asymmetry of the interclavicle in Shubin et al. (2015, fig. 4.6)[11] is unusual (the exact size needs to be confirmed). We are coding *Tiktaalik* with a large interclavicle although the shape is unclear.

Char. 152: Shubin et al. (2006, fig. 1c, 2a,b)[113] illustrated a fairly complete pectoral fin of *Tiktaalik*. Two small elements articulate distally with A5; one of the element is slightly represented in the reconstruction of the ventral view (Fig. 2b), whereas the other element is only figured with dotted lines in both ventral and dorsal views. These two elements could be considered potentially as two one-segment digits. However, using a segmented 1:1 relationship, these elements do not respect this condition to be unambiguously recognized as digits, thus we are coding *Tiktaalik* as "?".

Char. 172: The condition (size and ornamentation) of the interclavicle of *Tiktaalik* was coded as "?" by Zhu et al. (2017)[102]. Shubin et al. (2015, p. 83)[11] mentioned that the ventral surface of the interclavicle of *Tiktaalik* has "a rugose surface texture but does not have

ornamentation" as present on the ventral surface of the clavicles. Therefore, we decided to code *Tiktaalik* as "?".

Char. 178: Swartz (2012)[9] coded *Tiktaalik* as having a contact between the postorbital and lacrimal. We coded the condition as polymorphic because it varies bilaterally.

Char. 183: Daeschler et al. (2006, char. 98)[116] coded that the radial facet of the humerus of *Tiktaalik* was facing distally. On the other hand, Swartz (2012, char. 167)[9] coded that the radial facet has some ventrally directed component.

Char. 184: Daeschler et al. (2006)[116] coded *Tiktaalik* as the ulnar facet facing with some ventrally directed component. Swartz (2012)[9] coded the ulnar facet as facing distally. Although the difference between the conditions could be very subtle, we coded *Tiktaalik* as having the ulnar facet facing distally based on the reconstruction of the pectoral fin by Shubin et al. (2006)[113] and 3D printing of the original elements.

Char. 190: In contrast to Swartz (2012)[9], the interclavicle of *Tiktaalik* is coded as ovoid based on Shubin et al. (2015, fig. 4.6)[11] illustration and description.

Acanthostega (2 coding differences)

Char. 181: Daeschler et al. (2006)[116] and Swartz (2012)[9] coded for the absence of branched radials distal to the ulnare. We are coding this character as "?" because the space between the ulnare and the digits in *Acanthostega* (Coates 1996)[118] has a space, potentially for A4, but most likely this element was cartilaginous and thus we do not have its condition. Swartz (2012, char. 176)[9] did not specify A4 in the definition of the character.

Char. 182: Daeschler et al. (2006)[116] coded *Acanthostega* as lacking an olecranon process on the proximal corner of the posterior margin of the ulna (as suggested by Coates 1996[118]). Although the process is poorly developed in *Acanthostega*, compared to *Ichthyostega*, it is argued to be present by Ahlberg (2011)[152] and Pierce et al. (2013)[122]. The poorly developed state representing the plesiomorphic condition of the olecranon process.

Ichthyostega (1 coding difference)

Char. 162: Witzmann (2011)[112] reported the presence of rounded scales overlapping in an anterior to posterior direction that were described by Jarvik (1952)[101] in the tail of *Ichthyostega*. However, Witzmann (2011)[112] mentioned that these scales are too poorly preserved to be described in detail.

Ventastega (3 coding differences)

Char. 61: Chen et al. (2018)[129] coded the vomer of *Ventastega* as being not much broader than long. However, we coded this character as "?" because of the partial condition of the vomer (Ahlberg et al., 1994, fig. 10b)[153].

Char. 67: Chen et al. (2018, char. 19)[129] coded for a condition in which the vomers were not separated for more than half their length. We are coding *Ventastega* as "?" because only one disarticulated partial vomers is known (Ahlberg et al. 1994)[153] not providing enough information on the medial condition of this element.

Char. 113: Chen et al. (2018)[129] coded for the absence of an opercular in *Ventastega*. It is likely that the opercular is absent in *Ventastega*, however, we are coding this character as "?" because the described material is disarticulated and partial, thus we have no strict evidence that this element is absent.

Tulerpeton (1 coding difference)

Char. 162: Mondéjar-Fernández et al. (2014)[154] described in detail the scales of *Tulerpeton*. *Tulerpeton* possesses only two of the four known scale morphotypes (Lebedev & Coates, 1995)[125]: small rounded scales located on the limbs, resembling the putative scales on the tail of *Ichthyostega*; and ovoid scales covering the complete surface of the trunk (ventral region included), similar to those of the dorsal region of *Greererpeton* (Godfrey, 1989)[155].

2. PHYLOGENETIC ANALYSES

The character data above were analyzed using two methods: undated Bayesian approaches and maximum parsimony. Tip-dated Bayesian approaches were not employed as the taxon and character sampling did not satisfy the assumptions of these methods.

2a. Bayesian analyses

Bayesian analyses[156,157] using Markov-chain Monte Carlo (MCMC) approaches were performed using MrBayes 3.2[158]. The discrete morphological characters were analyzed using the Mk-model with correction for non-sampling of invariant characters[159], which has been well-tested[160]. Multistate characters, which formed clear morphoclines, were treated as ordered (see Section 1b). Polymorphic morphological data (e.g., 0&1 in a 3-state character) were treated exactly as coded (0 or 1, but *not* 2), not as total uncertainty (0 or 1 or 2).

The Bayesian MCMC analysis was run four times: each run employed four incrementally-heated chains (temperature 0.1) and being 50 million steps long with sampling every 5000th step (i.e., 1000 samples per run). The results were checked in MrBayes[158] and in Tracer[161] to confirm burnin and convergence/stationarity. A burnin of 20% was confirmed to be more than sufficient, after which all parameters and topologies the four runs were essentially indistinguishable. The post-burnin tree samples (last 80%) from all four runs were combined, and summarised using a majority-rule consensus tree in MrBayes[158] (Extended Data Fig. 4a, summarised in Fig. 6 in main text).

Files for the executable MrBayes script and resultant log and tree file are available in Dataset 3 (zipped file).

2b. Parsimony analyses

Parsimony analyses used PAUP* [162]. As before, discrete characters that formed clear morphoclines (see Section 1b) were treated as ordered. The most parsimonious tree(s) were inferred using a heuristic search with 100 random addition starting points, with a maximum of 10000 trees held during each search. 216 most-parsimonious trees of length 445 steps were found, and the strict consensus is shown in Extended Data Figure 4b (summarised in Figure 6 in main text).

Clade support was assessed using 200 replicates of non-parametric bootstrapping[163], with the above search settings, and those supports are shown in Extended Data Fig. 4b (summarized in Fig. 6 in main text). Apomorphies diagnosing each node were inferred by optimizing characters under both delayed transformation (DELTRAN, which places changes as late as possible on the phylogeny) and accelerated transformation (ACCTRAN, which places changes as early as possible). The main discussion clearly distinguishes changes which are optimization-unambiguous (i.e., occur at the same under both DELTRAN and ACCTRAN), and those which are optimization-ambiguous.

Files for the PAUP parsimony analysis including bootstrapping, along with the 216 MPTs, are available in Dataset 4 (zipped file).

LIST OF SUPPLEMENTARY DATA FILES

- Dataset 1: MrBayes executable file (including formatted data), screen log, and consensus tree in Nexus/FigTree format. Multiple files (zipped)

- Dataset 2: PAUP executable files, all 216 MPTs, and consensus tree in Nexus/FigTree tree. Multiple files (zipped)

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