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SUPPLEMENTARY ONLINE MATERIAL FOR

Osteology and phylogeny of Late Jurassic ichthyosaurs from the Slottsmøya Member Lagerstätte (Spitsbergen, Svalbard)

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Published in *Acta Palaeontologica Polonica* 2019 64 (4): 717-743.

https://doi.org/10.4202/app.00571.2018

Supplementary Online Material

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SOM 1. Phylogeny

1: Phylogenetic characters

New phylogenetic characters for the postcranium

The phylogenetic character dataset for ichthyosaurs is heavily skewed towards cranial characters, which might pose a challenge for inferring phylogenetic relationships (Maxwell et al. 2015). One aim of the present contribution was to add more postcranial data, and an additional 15 characters were incorporated into the full matrix (Supp. text 1). The SML specimens PMO 222.667, PMO 224.252 and PMO 222.670 (Delsett et al. 2017) show that the ribs in ophthalmosaurids are more morphologically variable than previously thought. While PMO 222.667 and PMO 224.252 possess ribs with a T-shaped cross section, those of PMO 222.670 have ribs with a rounded cross section and longitudinal striations in the distal portion. This variation is captured in a revised coding of character 48.

In this paper two phylogenetic characters relating to coracoid shape are added. One (char. 101) is new and is added to accommodate the presence of a process on the anterior margin of anteromedial notch, found in *Sveltonectes insolitus* and the SML taxon *Janusaurus lundi* (Fischer et al. 2011, Roberts et al. 2014).

There are few phylogenetic characters for the clavicle and interclavicle as they are vulnerable to preservation biases and possibly individual variation (Johnson 1979). A character concerning the clavicles in Moon (2017; char. 182) distinguishes between expanded and narrow medial portions of this element. This is based on an assumption that clavicles are medially expanded in basal ichthyosaurs and rod-like in derived taxa (Maisch and Matzke 2000), which is not correct as most ophthalmosaurids possess an expanded medial margin with several finger-like projections. However, there might be a phylogenetic signal in the medial outline of clavicles as two *Keilhauia* specimens have a single dorsoventrally narrow finger, a variation found in *Ophthalmosaurus icenicus* (Delsett

et al. 2017; OUMNH J48011; pers. obs. LLD). The only character for the interclavicle in Moon (2017; char. 181) is not suited to separate derived ichthyosaurs as all are T-shaped in ventral view. A new character (char. 102) is instead added here for the length of the median stem compared to the transverse bar. This relationship is characteristic on genus level for *Stenopterygius* and *Ophthalmosaurus* (Johnson 1979, Moon and Kirton 2016).

The acromion process on the scapula is taxonomically important, but problematic to score as its prominence results from a two factors: the amount of dorsal expansion anteriorly and the area of the dorsolateral (Delsett et al. 2018). In Fischer et al. (2016), one character covers the acromion process (char. 56), which is not sufficient to capture the variation in this trait, whereas the three characters in Moon (2017) are problematic as there is overlap between the character for prominence (char. 191; Moon 2017) of the process and the presence or absence of dorsal emargination (char. 193; Moon 2017) because these features depend on each other. Here, a combination of changed character 56 and new character 99 is used to accommodate the variation (Supp. text 1-2).

Based on previous work on pelvic girdle evolution (Delsett et al. 2017), two characters for this region are included here (chars. 107 and 108), which relate to the relationship between the length of the ilium, ischiopubis and femur, as this has been shown to be phylogenetically relevant for SML taxa because several pelvic girdles are known.

Character list

Character number 1-88 are taken from Fischer et al. 2016, character 89-110 are added for this analysis. References are given with the characters. New characters are marked with an asterisk. Character 48 and 56 are modified for this analysis.

Dentition

1. **Crown striations**: presence of deep axial ridges (0), crown enamel subtly ridged or smooth (1).
2. **Base of enamel layer on crown**: weakly defined, invisible (0), well defined, precise (1).
3. **Root cross-section in mid-jaw teeth of adults**: rounded (0), quadrangular (1).
4. **Deep apicobasal grooves in root**: present (0), absent (1).

Skull

5. **Overbite**: absent or slight (0), clearly present (1).
6. **Processus supranarialis of the premaxilla**: present (0), absent (1).
7. **Subnarialis process of the premaxilla**: ends anteriorly to posterior end of naris (0), reaches posterior end of naris (1).
8. **Processus postpalatinis of the pterygoid**: absent (0), present (1).
9. **External part of the anterior process of the maxilla, in lateral view**: extends anteriorly to the anterior border of the naris (including reduced anterior narial opening, if present) (0), don't (1).
10. **External exposure of the maxilla:** large, well visible (0), extremely reduced, nearly absent in external view by processes of the premaxilla and the lacrimal (1).
11. **Processus narialis of the maxilla in external view**: present (0), absent (1).
12. **Naris size**: large, ≥ ½ orbit diameter (0), small, << ½ orbit diameter (1).
13. **Naso-maxillary pillar dividing the naris in two (regardless of the reduction of the anterior portion)**: absent (0), present (1).
14. **Narialis process of the nasal**: absent (0), present (1).
15. **Processus narialis of prefrontal:** absent (0), present (1).
16. **Lacrimal-prefrontal suture in external view**: straight (0), strongly crenulated (1).
17. **Anterior margin of the jugal**: tapering, running between lacrimal and maxilla (0), broad and fan-like, covering large area of maxilla ventrolaterally (1).

18. **Anterior margin of the jugal II**: terminates prior to anterior end of lacrimal (0), reaches or surpasses anterior end of lacrimal (1).
19. **External prefrontal–parietal contact**: absent (0), present (1).
20. **Processus temporalis of the frontal**: absent (0), present (1).
21. **Anterior part of the postfrontal**: simple, unpaired (0), bifurcated in a medial and anterolateral processes (1).
22. **Supratemporal-postorbital contact**: absent (0), present (1).
23. **Broad postfrontal-postorbital contact**: absent (0), present (1).
24. **Anterolateral supratemporal process that connects to parietal**: absent (0), present (1).
25. **Sagittal eminence of the parietal**: present (0), absent (1).
26. **Supratemporal–stapes contact:** absent, the posteroventral process of the supratemporal does not extend up to the shaft of the stapes (0), present (1).
27. **Supratemporal fenestra reduction**: absent, the supratemporal fenestra is large, elongated and its anterior margin is set at the level of the parietal foramen or more anteriorly (0), reduced, the supratemporal fenestra is small, rounded, and its anterior margin is set posterior to the parietal foramen (1).
28. **Squamosal shape**: square (0), triangular (1), squamosal absent (2).
29. **Quadratojugal exposure**: extensive (0), small, largely covered by squamosal and postorbital (1).
30. **Lower temporal embayment between jugal and quadratojugal (=jugal– quadratojugal notch or incisura postjugalis)**: present (0), lost (1).
31. **Occipital lamella of the quadrate:** present, giving the lateral surface of the quadrate a Ushape in posterior view (0), reduced, the dorsal part of the quadrate is a simple transversely-compressed lamella (1).

32. **Basipterygoid processes**: short, giving basisphenoid a square outline in dorsal view (0), markedly expanded laterally, being wing-like, giving basisphenoid a marked pentagonal shape in dorsal view (1).
33. **Extracondylar area of basioccipital**: wide (0), reduced but still present ventrally and laterally (1); extremely reduced, being non-existent at least ventrally (2).
34. **Basioccipital condyle peripheral groove:** absent (0), present laterally (1), present laterally and ventrally (2).
35. **Basioccipital peg**: present (0), absent (1).
36. **Ventral notch in the extracondylar area of the basioccipital:** present (0), absent (1).
37. **Raised opisthotic facet of the basioccipital**: absent (0), present (1).
38. **Shape of the paroccipital process of the opisthotic:** short and robust (0), elongated and slender (1).
39. **Stapedial shaft in posterior view in adults**: thick (0), slender and gracile (1).
40. **Stapes proximal head**: slender, much smaller than opisthotic proximal head (0), massive, as large as or larger than opisthotic (1).
41. **Supraoccipital shape**: semioval with reduced ventral notch (0), squared and markedly U-shaped with a deep ventral notch (1).

Mandible

42. **Angular lateral exposure**: much smaller than surangular exposure (0), extensive (1)

Axial skeleton

43. **Posterior dorsal/anterior caudal centra**: 3.5 times or less as high as long (0), four times or more as high as long (1).
44. **Tail fin centra**: strongly laterally compressed (0), as wide as high (1).

45. **Neural spines of atlas-axis**: completely overlapping, may be fused (0), functionally separate, never fused (1)**.**
46. **Chevrons in apical region**: present (0), lost (1).
47. **Rib articulation in thoracic region**: predominantly unicapitate (0), exclusively bicapitate (1).
48. **Rib cross-section at mid-shaft**: rounded (oval or circular) (0), '8'-shaped (1), T-shape (2).[Modified]
49. **Ossified haemapophyses**: present (0), absent (1).
50. **Tail size**: as long as or longer than the rest of the body (0) distinctly shorter (1).
51. **Lunate tailfin**: no (0) well-developed (1).

Scapular girdle and forefin

52. **Coracoid shape in adults**: rounded (length to width ratio less than 1.3 and often close to 1) (0), anteroposteriorly elongated (length to width ratio greater or equal to 1.5) (1).
53. **Anteromedial process of the coracoid**: absent (0), present (1).
54. **Anterior notch of the coracoid**: present (0); absent (1).
55. **Glenoid contribution of the scapula**: extensive, being at least as large as the coracoid facet (0), reduced, being markedly smaller than the coracoid facet (1).
56. **Prominent acromion process of scapula:** Small dorsolateral flange (0) Large (1). [Modified].
57. **Plate-like dorsal ridge on humerus**: absent (0), present (1).
58. **Protruding triangular deltopectoral crest on humerus**: absent (0), present (1); present and very large, matching in height the trochanter dorsalis, and bordered by concave areas (2).
59. **Humerus distal and proximal ends in dorsal view (thus regardless of the size of the dorsal and ventral processes)**: distal end wider than proximal end (0), nearly equal or proximal end slightly wider than distal end (1).

60. **Anterior accessory epipodial element anterior to radius**: absent (0), present (1); present with associated facet on humerus (2).
61. **Humerus with posterodistally deflected ulnar facet and distally facing radial facet**: absent (0), present (1).
62. **Humerus/intermedium contact**: absent (0), present (1).
63. **Anterodistal extremity of the humerus**: prominent leading edge tuberosity (0), acute angle (1).
64. **Posterior accessory epipodial element posterior to ulna**: absent (0), present (1); present with associated facet on humerus (2).
65. **Shape of the posterior surface of the ulna**: rounded or straight and nearly as thick as the rest of the element (0), concave with a thin, blade-like margin (1)
66. **Spatium interosseum between radius and ulna**: present as a space or foramen (0), absent (1).
67. **Manual pisiform**: absent (0), present (1).
68. **Notching of anterior facet of leading edge elements of forefin in adults**: present (0), absent (1).
69. **Preaxial accessory digits on forefin**: absent (0), one (1); two or more (2)**.**
70. **Posterior enlargement of forefin**: number of postaxial accessory 'complete' digits: none (0), one (1), two or more (2).
71. **Longipinnate or latipinnate forefin architecture**: one (0), two (1) digit (s) directly supported by the intermedium.
72. **Zeugo- to autopodial elements**: flattened and plate-like (0), strongly thickened (1).
73. **Compact and tightly packed epi- and mesopodial rows:** absent, elements are loosely connected (0), present (1).
74. **Tightly packed rectangular phalanges**: absent, phalanges are mostly rounded (0), present (1).
75. **Digital bifurcation**: absent (0), frequently occurs in digit IV (1).
76. **Manual digit V**: lost or reduced to small floating elements (0), present (1).

77. **Forelimb–hind limb ratio**: nearly equal (0), forelimb longer twice as much as hind limb.

Pelvic girdle and hind fin

78. **Ischium-pubis fusion in adults**: absent or minute (0), present with an obturator foramen (1); present with no obturator foramen (2).
79. **Ischium or ischiopubis shape**: plate-like, flattened (0), rod-like (1).
80. **Iliac anteromedial prominence**: absent (0), present (1).
81. **Ilium proximal region:** expanded (0), narrow proximally and distally, rib-like (1).
82. **Prominent, ridge-like dorsal and ventral processes demarcated from the head of the femur and extending up to mid-shaft:** absent (0), present (1).
83. **Wide distal femoral blade**: present (0), absent, the distal extremity of the femur being smaller than the proximal one in dorsal view (1).
84. **Astragalus/femoral contact**: absent (0), present (1).
85. **Femur anterodistal facet for accessory zeugopodial element anterior to tibia**: absent (0), present (1).
86. **Spatium interosseum between tibia and fibula**: present (0), absent (1).
87. **Hind fin leading edge element in adults**: notched (0), straight (1).
88. **Postaxial accessory digit**: absent (0), present (1).

Characters added for this analysis

89. **Greatly enlarged parietal foramen:** Absent **(**0), present (1) *.
90. **Basioccipital – notochordal pit on the condylar surface:** (0) absent (1) present. Moon 2017 (char. 95).

91. **Basioccipital – contribution to the floor of the foramen magnum**: (0) absent, excluded by the exoccipitals (1) present, the portion contributing being flat, or concave, and covered in finished bone. Moon 2017 (char. 101).
92. **Basioccipital condyle: width and height** approximately equal (0); much wider than high (1). Maxwell et al. 2015 (char. 24).
93. **Basisphenoid, dorsal view**: dorsal plateau appears equal or wider than basioccipital facet, i.e. basioccipital facet oriented mostly posteriorly (0); basioccipital facet appears equal to or wider than dorsal plateau (1). Maxwell et al. 2015 (char. 20).
94. **Parabasisphenoid – location of the carotid foramen/foramina**: (0) ventral surface (1) posterior surface. Moon 2017 (char. 107).
95. **Basipterygoid processes on basisphenoid**: present (0), absent (1)*.
96. **Presacral vertebrae – number:** (0) $n < 30$ (1) $30 \leq n < 55$ (2) $55 \leq n$. Moon 2017 (char. 153).
97. **Anterodorsal centra – rib facet position:** (0) confluent with anterior face in at least some centra (1) not confluent in any. Moon 2017 (char. 162).
98. **Gastralia**: present (0) absent (1). Moon 2017 (char. 179).
99. **Scapula – shape of the anterodorsal margin**: fan-shaped (0) emarginated (1) Straight. (2). Moon 2017 (char. 193).
100. **Coracoid – medial facet for the scapula:** (0) absent (1) present. Moon 2017 (char. 190).
101. **Coracoid – anteromedial process anterior margin in ventral or dorsal view** is straight or concave (0), angled (1)*.
102. **Interclavicle** - Median stem is equal to or longer than the transverse bar (0), Transverse bar is longer than median stem (1)*.
103. **Humerus – relative size of radial and ulnar facets**: (0) radial facet is larger than the ulnar facet (1) radial and ulnar facets approximately equal size. Moon 2017 (char. 209).

104. **Humerus – separation of radial and ulnar facets**: (0) continuous (1) separated by notch. Moon 2017 (char. 210).

105. **Radius – proximodistal length to anteroposterior width**: (0) longer than wide (1) wider than long. Moon 2017 (char. 222).

106. **Ulna – anteroposterior width**: proximal end narrower than distal (0) about equal widths. (1). Moon 2017 (char. 224).

107. **Ilium- ischiopubis length ratio**: Ischiopubis (ischium) length <2 times ilium length (0), ischiopubis two times or more the length of the ilium*.

108. **Ischiopubis- femur length ratio**: Ischiopubis (ischium) longer than femur (0), equal to or shorter than femur (1).*

109. **Ischium and pubis – relative size**: (0) pubis larger than ischium (1) similar size or ischium larger. Moon 2017 (char. 259).

110. **Femur – ventral process size relative to dorsal process**: (0) smaller (1) same size or larger, more prominent. Moon 2017 (char. 268).

2: References for phylogenetic character scores

Mikadocephalus gracilirostris	Maisch & Matzke 1997; Fischer et al. 2016 ; Moon 2017
Hudsonelpidia brevirostris	McGowan 1995; Fischer et al. 2016; Moon 2017
Macgowania janiceps	McGowan 1996; Fischer et al. 2016; Moon 2017
Leptonectes tenuirostris	Personal inspection; Fischer et al. 2016; Moon 2017
Excalibosaurus costini	McGowan 2003; Fischer et al. 2016; Moon 2017
Eurhinosaurus longirostris	Personal inspection; Fischer et al. 2016; Moon 2017
Suevoleviathan disinteger	Personal inspection; McGowan & Motani 2003; Fischer et al. 2016; Moon 2017

Temnodontosaurus spp.	Personal inspection; Fischer et al. 2016; Moon 2017
Hauffiopteryx typicus	Personal inspection; Maisch 2008; Fischer et al. 2016 ; Moon 2017
Malawania anachronus	Fischer et al. 2013; Fischer et al. 2016; Moon 2017
Ichthyosaurus communis	Personal inspection, McGowan & Motani 2003; Maxwell et al. 2015; Fischer et al. 2016; Moon 2017
Stenopterygius quadriscissus	Personal inspection; Maxwell et al. 2015; Fischer et al. 2016; Moon 2017
Chacaicosaurus cayi	Fernandez 1994; Fischer et al. 2016; Moon 2017
Stenopterygius aaleniensis	Personal inspection; Maxwell et al. 2012; Fischer et al. 2016; Moon 2017
Ophthalmosaurus icenicus	Personal inspection; Maxwell et al. 2015; Fischer et al. 2016; Moon 2017; Moon & Kirton 2017
Baptanodon natans	Gilmore 1905; Maxwell et al. 2015; Fischer et al. 2016; Moon 2017
Mollesaurus periallus	Personal inspection; Fischer et al. 2016; Moon 2017
Acamptonectes densus	Fischer et al. 2012; Maxwell et al 2015; Fischer et al. 2016; Moon 2017
Leninia stellans	Fischer et al. 2013; Maxwell et al. 2015; Fischer et al. 2016; Moon 2017
Brachypterygius extremus	Personal inspection; Maxwell et al. 2015; Fischer et al. 2016; Moon 2017
Arthropterygius chrisorum	Maxwell 2010; Maxwell et al. 2015; Fischer et al. 2016; Moon 2017
Caypullisaurus bonapartei	Personal inspection; Maxwell et al. 2015; Fischer et al. 2016;

	Moon 2017
Aegirosaurus leptospondylus	Personal inspection; Bardet & Fernandez 2000; Maxwell et al. 2015; Fischer et al. 2016; Moon 2017
Athabascasaurus bitumineus	Druckenmiller & Maxwell 2010; Maxwell et al. 2015; Fischer et al. 2016; Moon 2017
Sveltonectes insolitus	Fischer et al. 2011; Maxwell et al. 2015; Fischer et al. 2016; Moon 2017
Simbirskiasaurus birjukovi	Fischer et al. 2014; Maxwell et al. 2015; Fischer et al. 2016; Moon 2017
Platypterygius australis	Zammit et al. 2010; Maxwell et al. 2015; Moon 2017 + Fischer et al. 2016
Pervushovisaurus bannovkensis	Fischer et al. 2014; Maxwell et al. 2015; Fischer et al. 2016; Moon 2017
Platypterygius hercynicus	Kolb & Sander 2009; Fischer 2012; Maxwell et al. 2015; Fischer et al. 2016; Moon 2017
Platypterygius americanus	Maxwell & Kear 2010; Maxwell et al. 2015; Fischer et al. 2016; Moon 2017
Platypterygius platydactylus	Broili 1907; Fischer et al. 2016; Moon 2017
Platypterygius sachicarum	Maxwell et al. 2015; Fischer et al. 2016; Moon 2017
Palvennia hoybergeti	Personal inspection
Cryopterygius kristiansenae	Personal inspection
Janusaurus lundi	Personal inspection
Sisteronia seeleyi	Fischer et al. 2014; Fischer et al. 2016; Moon 2017
Keilhauia nui	Personal inspection
Undorosaurus gorodischensis	Personal inspection; Efimov 1999; Moon 2017

Paraophthalmosaurus spp	Personal inspection; Arkhangelsky 1999; Efimov 1999; Moon 2017
Muiscasaurus catheti	Maxwell et al. 2015; Moon 2017
Gengasaurus nicosiai	Paparella et al. 2016; Moon 2017
PMO 222.667	Personal inspection
PMO 224.252	Personal inspection
PMO 222.670	Personal inspection
PMO 224.250	Personal inspection
PMO 222.658	Personal inspection

Modified scores compared to Fischer et al. 2016

- *Janusaurus lundi* Modified character 33, 40, 59.
- *Undorosaurus*: Modified character 26, 33, 34, 36, 39, 40 and 41 based on Efimov 1997 p. 121, pers. comm. Zverkov and personal observation. Scorings based on Zverkov & Arkhangelsky 2015: 38, 39, 43, 55, 56, 52, 61,62, 65,67,68,70, 69, 72 and 75. Modified from scorings in Zverkov & Arkhangelsky: char. 74, 78 and 79.
- *Paraophthalmosaurus* sp.. Scorings from Zverkov & Arkhangelsky 2015 and personal inspection. Characeter 69 scored as ? as no complete fin is known from the literature.
- *Gengasaurus nicosiai*: Scored as in Paparella et al. 2016 and based on description in the article. Scorings for 78 and 79 changed to ? as the article says nothing from the pelvic girdle or hindfin was preserved.

- *Muiscasaurus catheti*: Scored based on original description Maxwell et al. (2015) and description in the article.
- *Athabascasaurus bituineus*: Character 15, 22, 31, 33, 34 and 81 scored based on original description.
- *Ophthalmosaurus icenicus*: Character 4, 9 modified based on Moon and Kirton (2017). Character 41 and 79 based on personal inspection. There might be some uncertainty as to what rod-like means.
- *Eurhinosaurus longirostris*: Character 2 modified to {01} based on pers.obs. of intraspecific variation (SMNS 81718 and SMNS 81777 vs. SMNS 7580). Character 35 and 81 modified.
- *Stenopterygius quadriscissus*: Character 2 and 9 modified to {01} based on pers.obs. (char.2: Munich 1967 XVI 32 compard to SMNS55933) (char. 9: some have a long anterior process, e.g.SMNS 51948). Character 63 modified based on pers. obs.
- *Stenopterygius aaleniensis*: Modified character 63, based on pers. obs. of holotype.
- *Leptonectes tenuirostris*: Modified character 81, based on CAMSM J35279 (see also Delsett et al. 2017).
- *Aegirosaurus leptospondylus*: Modified compared to Fischer et al. 2016 based on pers.obs. of BSPHGM 1954 I 608: characters 47, 63, 83.
- *Mollesaurus periallus*: Modified based on AJR pers. obs: Character 8, 17 and 23.
- *Caypullisaurus bonapartei*: Character 17 modified based on AJR pers. obs.

Comments on Zverkov & Efimov 2019

- The scorings for *Undorosaurus gorodischensis* are based on the Russian material, as PMO 214.578 is run as a separate OUT.

- We have not included the two *Grendelius* species, nor *Plutoniosaurus bedegensis*, as observations on the latter are only pers. obs. The species has been synonymized with *Platypterygius* (Storrs et al. 2000, Kear 2005) and not redescribed after this (Delsett 2018)
- The characters added by Zverkov and Efimov (2019) in their phylogenetic analysis are not considered in this paper as a thorough review of these are beyond the scope of this paper

3: Character scores for phylogenetic analysis

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Mikadocephalus_gracilirostris 0???000?0?0000000000000???0000?????????00?????????0000?00000000?0?0????0???000000000000??????00?????????????????
Hudsonelpidia_brevirostris    ????0?????????????????????????????????????????????0???????000000000??000?00?10001000000000???????11?????00110110
Macgowania_janiceps           ?0?00???1?0000?0???????????100?????????????0?????????????????0000?000?0001?1001?????????????????????????10????10????
Leptonectes_tenuirostris      10010?0??000000000100000001110?0?????????0???001000100000000000000000?10001000100000000??????210200?10110?10
Excalibosaurus_costini        100?1????0??00?????????????1?????000?????????0?0?001100?000000000100000?1000?000?000000000??????1?0200?0011?1??
Eurhinosaurus_longirostris    1{01}0010011000000000?0000?0001111??0?000000?00?1000100000000?000000011000?1000000000000001?0????10020??10110011?
Suevoleviathan_disinteger     0??000001001000000?0?0{01}???0101???????????0?????101?10?00?00000001?1000010110001?00001000??????101200?00110011?
Temnodontosaurus_spp          000000000010000000?11000010{01}?000001000000000011000100000000000100000010000000100000000101?00101200?10110010
Hauffiopteryx_typicus         1???000?100100?0?0?0100000001111??0?0????1?00???11?11010000?0000?00100000?1001100??0000010001 0??0?100200?00110011
Malawania_anachronus          ??????????????????????????????????????????????????1??????00?110001001?0001?1001?????????????????????002???00111????
Ichthyosaurus_communis        00000{01}001011000?00100000000{12}10000000000000000011111000{01}00110001001{01}10110111110001000010001111001002000100110011
Stenopterygius_quadriscissus  1{01}010001{01}0110000001001000?011100000{01}000100111111111110100100000001100{01}001{01}1111001?000100010100010 0{12}00010110{01}0?
Chacaicosaurus_cayi           1???0????0???0?????????????????????0001?????????????1????????01?0?0?001100001100??????0????????100???????????11????1
Stenopterygius_aalensis       1??1010?10010000101000101?01?????????????00???1????110010?000000001100?011??1?????????????0??????1?1110000 1?????
Ophthalmosaurus_icenicus      0100010100110101100001101101110{01}11100101{01}11011111110100111{01}2101011111111100111101100011001100001101000 10110011
Baptanodon_natans                 10?101?11011010?00000110?10111 0?11?00111110?0??????01011?112101011?11?1?1001????1???????0110?00?10100?0011????
Mollesaurus_periallus         11???????01???011?????1????011?110101001??0?????0?????????????????????????????????????????111?00?????????????????
Acamptonectes_densus          1??1?????0???1?????????1?????0112110111010 0?1?0???010001{12}121010111?{12}???10?????????????????1100001?1100?10?0????
Leninia_stellans              ?????????01??10010000?01110{01}110?12?0??1??1?????????????????????????????????????????????????1?1?????????????????
Brachypterygius_extremus      011100??00110{01}?011????1???????1?120110????1???????????0?1??1001100111111111001?????????????110010????0??1111????
Arthropterygius_chrisorum     ?????????0?????????????????????????02001 0??1??11?1?????000??111210100 1?1?0110???????0100????110110?1??01?0011???1
Caypullisaurus_bonapartei     ????00??001101000{01}???0????0001???????????10???11????001102120011 0111{12}2011101121??110?111?????????010?11011??11
Aegirosaurus_leptospondylus   0001010?1111011010010{01}0???0111?????????????1????11?11???????1001000111111?110112 1?1?0001110??????100???011100011
Athabascasaurus_bitumineus    10?1?10?0001??011?00101?1000010?22??00?1?10?1?????????????????????????????????????21001 0?????0??????1???????????0011
Sveltonectes_insolitus        101101??111101101001 1?101?0??1002011 1??1?100?1?11??0101112110 01{01}?1?1111110110112 1??1101111??11?101??101?101?0011
Simbirskiasaurus_birjukovi    0?11?01?00?11101100?1?????0?????20110?????????????????????????????????????????????????????110???????????????????
Platypterygius_australis      011100000001110011011110000201012011?001110111??11?000011212001{12}011122011101121??1101111011001011?101?1011?011
Pervushovisaurus_bannovkensis 01110???00?111?????????????????????????????????1?????????????????????????????????????????????????1?????????????????????
Platypterygius_hercynicus     01110????01???0?1?0111?01?0{01}1?1?20?1100111??1?100?1?11??0101112100 1201120111?????111011?0011????11020??1011???1
Platypterygius_americanus     1???000?00110100?0???10????201???????????101?111??????011210001201 1???0111???????1100???0??????11?10??1011???1
Platypterygius_platydactylus  ????0?????????????????????????1120?1??01?101???1??100111?{12}100010011112011101?????????????1??1?11?20??1011????
Platypterygius_sachicarum     01110???0011110?????????????01?????????1?????????????????????????????????????????????????????????????????????????
Palvennia_hoybergeti          1111011100??0?1???00011?1102??0?221110111 1??0?1{12}???0101110020000111101100 0???????????1110?10?0020001011????
Undorosaurus_kristiansenae   011?011?000101011001??1????111?112?00001?1????1???01000111000000 1?1101111011110010001?01100001?0200110110011
Janusaurus_lundi              11?????0111??11001??11????21????2?1???1??1????11???110??1102100001011?11?00?12110110 0?1?0111?????0?01110111011
Sisteronia_seeleyi            0111?????????????????????????????0201?10011?0???1????????1?{12}??00?2?????????????????????????101000???2???00??????
Keilhauia_nui                    ?????????????????????????????????????????????????{01}1??11???0100010021000???1????????1210001?0?10?????????100100?00??0111
Undorosaurus_gorodischensis      0111?????????01?????????00?????1121 1[01]00011101??1????0101111121 00?0101111121 00{01}?11?1100102?0?101?1011?01?
Paraophthalmosaurus_spp  1????1????????1????0????0???????1??0?????1????1????110?1101110102???1?????0?????????????????????????1100?????0 1?
Muiscasaurus                     1?1??01?00?101??????0?????021???21?1?????1?????????????????????????????????????????????????0??0?????????????????
Gengasaurus_nicosiai             ??????????????????????????????????00111?11??1?0?1?11?????????0200100??11??1?0?????????????????????0?01??1???1011????
PMO222667                        1101?????????????????????????????0010111?1???????12???0?00010?2100?01?1???0?0?????????????????110011?00100?1011????
PMO224252                        1?110???????????0?01????1?0???0??????????1??1?12?????????????????????????1?????????????????0???????00????????????
PMO222670                        ??????????????????????????????????????????????00??1{01}?????????????????????????????2101110 0?????????????????????1011
PMO224250                        ??????????????????????????????????11?????????????????0101111021000 11?10?10000?????????????110??????10000011????
PMO222658                        ??????????????????????????????????????????????0????????1?0??101210000 1?11?????????????????????????0??1011????
Undorosaurus nessovi            0111?????????????????????????????11??????01?101??1????0101111121 0?10111100111 0?????????????????????????????????
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SOM 2.1 Complete phylogenetic trees

Phylogenetic trees for analysis 1 and 2, including all thunnosaurian taxa.
A, B and C correspond to figure 12 A, B and C respectively.

SOM 2.2

Phylogenetic trees, analysis 3 and 4

Analysis 3. Strict consensus tree. Number of trees retained: 6. Length of shortest tree: 262. CI: 0.37. RI: 0.72.

Analysis 4. Strict consensus tree. Number of trees retained: 999. Length of shortest tree: 252. CI= 0.47. RI=0.72.

	UPM EP-II-20(572)	PMO 214.578	UPM EP-II-23(744)	UPM EP-II-20(1075)	UPM EP-II-27(870) U.k.	UPM EP-II-22(1073) sometimes sp.	YKM 44028-7
premaxilla		x		x			
maxilla		x					
teeth	x	x					
jugal	x	x					
nasal	x	x		x		x	
lacrimal		x					
prefrontal		x					
postfrontal		x					
postorbital							
quadratojugal	x	x					
basisphenoid	x	x					
stapes	x	x	x			X	
exoccipital	x	x					
supraoccipital	x	x					
opisthotic	x	x				X - sp	
quadrate	x					X - sp	
basioccipital		x		x		X - sp	
dentary		x					
splenial		x					
surangular		x	x				
angular		x	x				
parietal	x						
cornu branchiale						X - sp	
articular	x						
scapula	x	x	x		X	X - sp	
clavicle	x	x					
coracoid	x	x	x			X - sp	
forefin	x	x	x	x			x
humerus	x	x	x	x	x	X - sp	x
radius	x	x	x	x	X	X - sp	x
ulna	x	x	x	x		X - sp	x
femur	x	x			x		
ischiopubis	x	x					

SOM 4. Overlap between preserved elements in *Undorosaurus* specimens