

APPENDIX 1. Character description.

1. Premaxilla posterior end—(0) concave and the dorsal process is longer than the ventral (Fig. 2A–C); (1) pointed, scarcely entering the external naris (Fig. 2D); (2) concave and the ventral process is longer than the dorsal (Fig. 2E, G, H). Unlike in other ichthyosaurs and basal diapsids, the premaxilla of *Mixosaurus* has a pointed posterior end that hardly enters the anterior margin of the external naris. Mazin (1981a) reconstructed a similar posterior end for the premaxilla of *Grippia longirostris*, but it is incorrect (Motani, 1997a).
2. Maxilla dorsal lamina—(0) absent (Fig. 2E, G, H); (1) present (Fig. 2A–D). [Maisch and Matzke, 1997:chars 2 and 3 (correlated)]
3. Maxilla/external naris contact—(0) present (Fig. 2A–D, H); (1) absent (Fig. 2E, G) [Maisch and Matzke, 1997:char 1]
4. External naris orientation—(0) dorso-lateral (Fig. 3A, B); (1) lateral, scarcely visible in dorsal view (Fig. 3C–H).
5. Nasal/external naris contact—(0) absent; (1) present.
6. Wide contact between nasal/postfrontal—(0) absent (Fig. 3A, B, D, F); (1) present (Fig. 3C, E–H). The two bones may be in contact in *Shastasaurus* (Fig. 3F), but not as clearly as in parvipelvians. [Maisch and Matzke, 1997:char 9].
7. Nasal/parietal contact lateral to frontal—(0) absent (Fig. 3A–G); (1) present (Fig. 3H).
8. Prefrontal/postfrontal contact—(0) absent, the dorsal margin of the orbit being formed by the frontal (Fig. 2A, B); (1) present, eliminating the frontal from the dorsal margin of the orbit (Fig. 2C–H).
9. Postfrontal postero-lateral process—(0) absent; (1) present, overlying the postorbital (Fig. 2A–H).
10. Postfrontal participation in UTF—(0) absent; (1) present (Fig. 3A–H).
11. Postorbital shape—(0) triradiate; (1) lunate, without posterior process (Fig. 2A–H).
12. Postorbital participation in UTF—(0) present (Fig. 2A, B); (1) absent (Fig. 2C–H).
13. Squamosal participation in UTF—(0) present (Fig. 2A, C, F); (1) absent (Fig. 2B, D, G, H); (2) squamosal absent (Fig. 2E).
14. Anterior terrace of upper temporal fenestra—(0) absent (Fig. 3E, G, H); (1) present, but small, reaching the posterior part of the frontal anteriorly (Fig. 3A–C, F); (2) present, and large, reaching the nasal anteriorly (Fig. 3D).
15. Frontal widest position—(0) located posteriorly (Fig. 3A–D); (1) at nasal suture (Fig. 3E–H).
16. Sagittal eminence—(0) absent; (1) present but small, involving only the parietal; (2) present and large, involving the parietal, frontal, and nasal. The parietals of some ichthyosaurs (e.g., *Cymbospondylus petrinus*) are nearly vertical along the median line, forming a small crest (Fig. 3C, F). This eminence is reduced in some forms, yet present (Fig. 3E, H). A large sagittal crest, reaching the nasal, is a characteristic of *Mixosaurus* (Fig. 3D).
17. Parietal ridge—(0) absent (Fig. 3A, B); (1) present (Fig. 3D, E, G, H). The parietal ridge (sensu McGowan, 1973) is a feature that is only present in derived ichthyosaurs. Its presence or absence has yet to be confirmed for *Shastasaurus* (Fig. 3F).
18. Parietal supratemporal process—(0) short (Fig. 3D, E, G, H); (1) long (Fig. 3A–C, F).
19. Right and left parietals' anterior processes—(0) contacting each other anteriorly, eliminating frontal from pineal foramen (Fig. 3A, B); (1) narrowly separated anteriorly, forming parietal fork, and frontal dorsally visible along the pineal foramen (Fig. 3C, D, F); (2) widely open, resulting in absence of clear fork (Fig. 3E, G, H). [Mazin, 1982:char 2; Callaway, 1989:char 2]
20. Supratemporal posterior slope—(0) absent; (1) present. In ichthyosaurs, the supratemporal has a slope on the postero-dorsal corner (Motani, 1997a). This posterior slope is small in *Utatusaurus* (Motani, 1997a), but well developed in *Mixosaurus* (Motani, 1997a) and in *Ichthyosaurus* (McGowan, 1973), forming a partial roof over the upper temporal fenestra.
21. Supratemporal posterior ridge—(0) absent; (1) present. The posterior ridge (Motani, 1997a) of the supratemporal is present in all ichthyosaurs with a known supratemporal (Motani, 1997a), but absent in basal diapsids.
22. Supratemporal ventral process—(0) absent; (1) present. The ventral process of the supratemporal is known in some derived ichthyosaurs, such as *Mixosaurus* (Motani, 1997a) and *Ichthyosaurus* (McGowan, 1973).
23. Jugal/quadratojugal dorsal contact—(0) absent (Fig. 3A, B); (1) present (Fig. 3C–H).
24. Jugal shape—(0) triradiate; (1) lunate, or J-shaped (Fig. 3A–H).
25. Cheek orientation—(0) mostly lateral; (1) largely posterior. In euhinosaurs and several other ichthyopterygians, the posterior curvature of the cheek region is so extensive that the region is better viewed posteriorly than laterally.
26. Pterygoid, transverse flange—(0) antero-lateral; (1) postero-lateral; (2) not well defined.
27. Interpterygoid vacuity—(0) present; (1) absent, or extremely reduced. [Maisch and Matzke, 1997:char 22]
28. Ectopterygoid—(0) present; (1) absent. [Callaway, 1989:char 9]
29. Basioccipital peg—(0) clearly present; (1) absent or extremely reduced.
30. Basioccipital extracondylar area—(0) wide; (1) reduced to a narrow band of concavity.
31. Basioccipital condyle—(0) flat or slightly concave; (1) hemispherical. [Callaway, 1989:char 1]
32. Angular lateral exposure—(0) extensive, at least as high and anteriorly as surangular exposure (Fig. 3G); (1) much smaller than surangular exposure (Fig. 3A–C, E).
33. Overbite—(0) absent or slight; (1) clearly present.
34. Snout extremely slender—(0) no; (1) yes.
35. Replacement teeth—(0) appear outside the pulp cavity of the predecessor; (1) inside.
36. Plicidentine—(0) absent; (1) present.
37. Tooth horizontal section—(0) circular; (1) disto-medially compressed; (2) laterally compressed.
38. Posterior tooth crown—(0) conical; (1) rounded; (2) flat.
39. Tooth size relative to the skull width—(0) normal (over 0.1); (1) small (below 0.05). This character is based on Massare's (1987) index to express the size of the teeth relative to the gullet width (substituted by skull width). There seems to be a clear dichotomy in the distribution of this feature among ichthyosaurs: the possession of small and numerous teeth is typical of some Early Triassic ichthyosaurs (Motani, 1996, 1997b), and *Mixosaurus cornalianus* (Motani, 1997a).
40. Maxillary tooth row—(0) single; (1) multiple.
41. Upper dental groove—(0) present throughout jaw margin; (1) only present anteriorly; (2) absent. A dental groove, homologous to that of the subthecondont condition in primitive amniotes, exists in most ichthyosaurs (Motani, 1997b).
42. Lower dental groove—(0) present throughout jaw margin; (1) only present anteriorly; (2) absent. The lower dental groove shows a different character-state distribution than its upper counterpart (Motani, 1997b), and is therefore treated as a separate character.
43. Bony fixation of teeth—(0) present; (1) absent.
44. Pterygoid teeth—(0) present; (1) absent. Pterygoid teeth are absent from ichthyosaurs, except in *Utatusaurus hataii*, which has vestigial teeth on the pterygoid.
45. Interclavicle shape—(0) cruciform; (1) triangular; (2) T-shaped.
46. Scapula antero-dorsal margin—(0) fan-shaped (Fig. 4A, B, D, E, G, H); (1) emarginated (Fig. 4C); (2) straight (Fig. 4F). [Callaway, 1989:char 23]
47. Scapular blade shaft—(0) absent (Fig. 4A–E); (1) present at least proximally (Fig. 4F–H). The narrow region in the scapula of *Cymbospondylus* (Fig. 4C) is not considered a shaft because the surface striation is radial, not being parallel to the margin.
48. Scapular axis and glenoid facet orientations—(0) nearly parallel (Fig. 4A–F); (1) at 60 degrees or more (Fig. 4G–I).
49. Coracoid facet on scapula—(0) scapula and coracoid fused; (1) absent; (2) equal or smaller than glenoid facet of scapula; (3) twice as large as glenoid facet.
50. Ossified sternum—(0) absent; (1) present.
51. Ossified cleithrum—(0) present; (1) absent.
52. Humerus distal articular facets—(0) not terminal; (1) terminal, radial facet being larger than ulnar facet; (2) terminal, two facets being nearly equal.

APPENDIX 1. Continued.

53. Humerus anterior flange—(0) absent; (1) present and complete; (2) present but reduced proximally. [Callaway, 1989:char 29]
54. Humerus relative width exclusive of anterior flange—(0) much longer than wide; (1) nearly squarish. [Callaway, 1989:char 28]
55. Humerus, distal and proximal ends, exclusive of anterior flange—(0) nearly equal; (1) distal end wider than proximal end.
56. Ridge on humerus plate-like—(0) no; (1) yes. The dorsal ridge in the Ophthalmosauria are well pronounced to form a plate-like eminence.
57. Humerus antero-distal facet for sesamoid—(0) absent; (1) present. [Godefroit, 1993:char 10]
58. Propodial + epipodial versus manus length—(0) propodial + epipodial longer; (1) manus longer. *Utatusaurus*, *Parvinator*, and most outgroup taxa have the primitive state.
59. Radius peripheral 'shaft'—(0) complete or nearly complete; (1) notch or largely reduced; (2) absent. The shaft of the long bones became reduced in two different phases, peripherally and contiguously, through ichthyopterygian evolution (Motani, 1997a). Also, these two phases started asynchronously in various elements (Motani, 1997a). Therefore, peripheral and contiguous shaft reductions in various elements are treated as separate characters. Although the degree of reduction can best be described as a continuous transformation series, such a character is not suitable for cladistic analyses. Therefore each of these characters is given only three discrete states. Also see Materials and Methods.
60. Radius contiguous 'shaft'—(0) complete or nearly complete; (1) notch or largely reduced; (2) absent.
61. Radius L/W ratio—(0) longer than wide; (1) wider than long. Epipodial elements are generally shorter in later ichthyosaurs. However, because the length/width ratios of radius and ulna show a continuous distribution among various ichthyosaurs, it is difficult to delineate between different states. The ratio seems to be roughly correlated with the degree of shaft reduction, therefore it would be redundant to make a separate character describing the details of length/width ratio variation. Accordingly I only give two discrete states to the present character, which supplements the shaft characters while not being redundant.
62. Ulna peripheral 'shaft'—(0) complete or nearly complete; (1) notch or largely reduced; (2) absent.
63. Ulna contiguous 'shaft'—(0) complete or nearly complete; (1) notch or largely reduced; (2) absent.
64. Radius/ulna relative size—(0) nearly equal; (1) radius much larger than ulna. This feature is independent of character 51, because a large ulna may have small articulation with the humerus.
65. Radiale, anterior notch—(0) absent; (1) preaxially present.
66. Ulnare/intermedium relative size—(0) ulnare larger than intermedium; (1) intermedium larger than ulnare; (2) intermedium lost.
67. Manual pisiform—(0) present; (1) absent.
68. Mc I peripheral 'shaft'—(0) complete or nearly complete; (1) notch or largely reduced; (2) absent; (3) mc1 not ossified.
69. Mc III 'shaft'—(0) present; (1) absent. [Callaway, 1989:char 33]
70. Mc V peripheral 'shaft'—(0) complete or nearly complete; (1) absent; (2) mc5 not ossified.
71. Manual digit 2 distal elements peripheral 'shaft'—(0) complete; (1) largely reduced or notch; (2) absent. The most distal element of any ichthyosaurian fin may not have any 'shaft' left, or yet formed. This character therefore refers to elements at about 80 percent count from the most proximal ones.
72. Manual accessory digit VI—(0) absent; (1) present. [Mazin, 1982:char 4]
73. Manual digit S4-5—(0) absent; (1) present.
74. Manual centralia—(0) present; (1) absent.
75. Manual anterior sesamoid e, and the digit distal to it—(0) absent; (1) present.
76. More than one extra anterior digit—(0) absent; (1) present.
77. Maximum phalangeal count—(0) five or less; (1) seven or more.
78. Interdigital separation—(0) present; (1) absent.
79. Forelimb/hindlimb ratio—(0) nearly equal or hind longer; (1) forelimb longer but less than twice as hindlimb; (2) forelimb longer twice as much as hindlimb. [Callaway, 1989:char 26; Godefroit, 1993:char 5]
80. Iliac blade shape—(0) with thick shaft (Fig. 6F); (1) plate-like (Fig. 6A-E, J); (2) narrow and styloid (Fig. 6I, K, L). [Callaway, 1989:char 24]
81. Iliac antero-medial prominence—(0) present (Fig. 6B, H-J); (1) absent (Fig. 6A, C-G, K, L). Merriam's (1902, 1908) identifications of the iliac orientation are inconsistent with each other, which led Maisch (1998:64) to doubt the homology of this prominence between *Californosaurus* and *Suevoleiathan*. When correctly oriented as in Fig. 6, the prominence is most likely homologous between the two.
82. Thyroid fenestra—(0) absent; (1) one median opening (Fig. 5F-K); (2) two openings, being medially separated (Fig. 5L-N).
83. Ischium-pubis fusion in adults—(0) complete; (1) absent (Fig. 5F-L); (2) present only medially (Fig. 5M); (3) present medially and laterally (Fig. 5N). [Mazin, 1982:char 13]
84. Pubis, obturator foramen—(0) completely enclosed in pubis (Fig. 5A, F-H); (1) mostly in pubis but open on one side (Fig. 5B, I, J); (2) part of obturator fossa (Fig. 5E, K-N). One possible problem of this character is the distinction between states (0) and (1), because the obturator foramen is incompletely closed in small juveniles of *Hovosaurus boulei* while fully closed in larger specimens (Currie, 1981). However, no fully closed obturator foramina are known for *Shastasaurus* or *Shonisaurus*, although known specimens are unlikely to be small juveniles. [Callaway, 1989:char 25]
85. Pubis, styloid or plate-like—(0) plate-like (Fig. 5A, B, F-K); (1) styloid (Fig. 5D, E, L-N).
86. Pubis/ischium relative length—(0) nearly equal or ischium slightly larger than pubis (Fig. 5G-N); (1) pubis twice as large as ischium (Fig. 5F).
87. Ischium, styloid or plate-like—(0) plate-like (Fig. 5F-K); (1) styloid (Fig. 5E, L-N). This character is independent of character 83.
88. Tibia and fibula—(0) in contact or closely placed with each other; (1) widely separated from each other.
89. Pes digit I—(0) present; (1) absent.
90. Tibia L/W ratio—(0) longer than wide; (1) wider than long.
91. Tibia contiguous 'shaft'—(0) complete or nearly complete; (1) absent.
92. Tibia peripheral 'shaft'—(0) complete or nearly complete; (1) notch or largely reduced; (2) absent.
93. Fibula posterior extent—(0) not fixed, fibula being mobile relative to femur; (1) much posterior to femur; (2) about the same level as femur.
94. Atlantal pleuro centrum—(0) separate from axis; (1) fused with axis.
95. Presacral count—(0) 30 or less; (1) between 40 and 50; (2) 55 or more. *Cymbospondylus buchseri* was coded as 2 (see Systematic Paleontology for explanation). [Callaway, 1989:character 13]
96. Caudal peak—(0) absent; (1) present. The term caudal peak refers to the curvature of the vertebral column in the middle of the tail, forming a peak. This structure corresponds to the tailbend in euichthyosaurs.
97. Posterior dorsal centra shape—(0) cylindrical; (1) discoidal. [Callaway, 1989:char 19]
98. Mid-caudal centra height change—(0) gradual decrease; (1) increase; (2) sudden decrease. The sudden decrease seems to be correlated to the formation of hypocercal caudal fin.
99. Cervical bicapital rib facet—(0) absent; (1) present. [Callaway, 1989:char 14]
100. Posterior-dorsal bicapital rib facet—(0) absent; (1) present, at least near pelvic girdle. [Callaway, 1989:character 14]
101. Antero-dorsal rib facets—(0) confluent with anterior facet in at least some centra; (1) not confluent in any of the centra.
102. Anterior dorsal neural spine—(0) normal; (1) narrow, high, and straight. Anterior dorsal neural spines of most ichthyosaurs are similarly shaped, although there are some variations. *Mixosaurus* differs from others in having narrow, high neural spines that are almost perpendicular to the vertebral column. [Callaway, 1989:character 16]
103. Neural spine anticlination in tail—(0) absent; (1) present.
104. Sacral ribs—(0) two, distinguishable; (1) not distinguishable.
105. Posterior gastralia—(0) present; (1) absent.