
Carboniferous recumbirostran elucidates the origins of terrestrial herbivory

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Characters used in the phylogenetic analysis

Character list is taken from Jenkins et al. (2025), which is in turn a recent modification of the list used in Mann et al. (2023). The recent history of the characters used in this list is abbreviated as follows:

HPSA, characters derived from Huttenlocker et al. 2013

MA, characters derived from Maddin and Anderson 2012

CABF, characters derived from Clack et al. 2012

N, neurocranial characters derived from Pardo et al. 2017

PSAA, character modifications presented in Pardo et al. 2017

C, composite character as per Pardo et al. 2017

MPS, characters derived from Mann et al. 2023

JEtAl, characters derived from Jenkins et al. 2025

1. Basal skull length (HPSA 001): (0) >70 mm; (1) 50–70 mm; (2) 30–50 mm; (3) <30 mm.
2. Skull:trunk ratio (HPSA 002): (0) 0.45; (1) 0.30–0.45; (2) 0.20–0.29; (3) 0.20.
3. Skull proportions (HPSA 003): (0) longer than wide; (1) wider than long.
4. Intertemporal (C 01): (0) present; (1) Replaced by anterior extension of supratemporal or tabular; (2) replaced by lateral extension of parietal.
5. Supratemporal (HPSA 005): (0) present; (1) absent.
6. ST exposure on occiput (HPSA 006): (0) absent; (1) present.
7. Postfrontal shape (HPSA 009): (0) broadly quadrangular; (1) falciform.
8. Squamosal-tabular contact (HPSA 010): (0) absent; (1) present; (2) fused.
9. Lacrimal-prefrontal suture (HPSA 012): (0) simple butt joint; (1) interdigitating; (2) prefrontal

broadly underplates lacrimal.

10. Lacrimal (HPSA 013): (0) present; (1) absent.
11. Lacrimal extends to naris (HPSA 014): (0) present; (1) absent.
12. Lacrimal extends to orbit (HPSA 015): (0) absent; (1) present.
13. Lacrimal orbital processes (HPSA 016): (0) only ventral present; (1) dorsal and ventral present; (2) neither present.
14. Lacrimal-jugal contact (HPSA 017): (0) present; (1) absent.
15. Quadratojugal (HPSA 018): (0) present; (1) absent.
16. Quadratojugal-jugal contact (HPSA 019): (0) present; (1) absent.
17. Quadratojugal-maxillary contact (HPSA 020): (0) present; (1) absent.
18. Frontals (HPSA 021): (0) paired; (1) fused.
19. Frontal into orbital margin (HPSA 022): (0) no; (1) yes.
20. Anterior laterally flaring frontals (HPSA 023): (0) absent; (1) present.
21. Nasals (HPSA 024): (0) present; (1) absent.
22. Narial flange (HPSA 025): (0) absent; (1) present.
23. Alary processes of premaxilla (HPSA 026): (0) absent; (1) present.
24. Septomaxilla (HPSA 028): (0) ossified; (1) unossified.
25. Prefrontal into external narial margin (HPSA 029): (0) distant from; (1) near; (2) present.
26. External naris in dorsal view (HPSA 030): (0) exposed; (1) not exposed.
27. External naris shape (HPSA 031): (0) circular; (1) posteriorly extended, along lacrimal-prefrontal suture; (2) posteriorly extended excavation of lacrimal only.
28. Dorsal exposure of premaxilla (HPSA 032): (0) broad pars dorsalis anteromedial to external naris; (1) pars dorsalis limited, but nasopremaxillary suture exposed dorsally; (2) none.

29. Dorsal shape of skull (HPSA 033): (0) triangular; (1) diamond; (2) rounded.
30. Posterior skull margin (HPSA 034): (0) concave; (1) straight; (2) convex; (3) undulating.
31. Snout shape (HPSA 035): (0) blunt; (1) pointed.
32. Snout length (HPSA 036): (0) less than 1/4 total skull length; (1) greater than 1/4 total skull length
33. Quadrate articulates along the internal flange of squamosal (HPSA 037): (0) absent; (1) present.
34. Otic/spiracular notch (HPSA 038): (0) present; (1) absent.
35. Large otic notch approaching orbit (HPSA 039): (0) more than 1/2 postorbital length of skull; (1) between 1/4 and 1/2 postorbital length of skull; (2) less than 1/4 postorbital length of skull.
36. Otic notch structure (HPSA 040): (0) open posteriorly; (1) closed posteriorly.
37. Semilunar flange of the supratemporal (HPSA 041): absent (0); present (1).
38. Supratympanic flange (HPSA 042): (0) absent; (1) present.
39. Supratympanic shelf (HPSA 043): (0) absent; (1) present.
40. Raised orbital rim (HPSA 044): (0) absent; (1) present.
41. Postorbital (HPSA 045): (0) present; (1) absent.
42. Jugal-postorbital interfingering processes (HPSA 046): (0) absent; (1) present.
43. Postorbital participates in orbital margin (HPSA 047): (0) present; (1) absent.
44. Shape of postorbital (HPSA 048): (0) irregular trapezoid; (1) triangular, apex caudal.
45. Palpebral ossifications (HPSA 049, PSAA modified): (0) absent; (1) mosaic of bony plates in orbit; (2) single large plate above orbit.
46. Parietal-tabular contact (HPSA 052): (0) absent; (1) present.
47. Postparietals (HPSA 053): (0) paired; (1) fused; (2) absent.

48. Parietal foramen (HPSA 054): (0) present; (1) absent.
49. Postparietal size (HPSA 055): (0) much smaller than parietals; (1) approximately as large or larger than parietals.
50. Postparietal squamosal contact (HPSA 056): (0) absent; (1) present.
51. Postparietal length (HPSA 057): (0) large, quadrangular; (1) abbreviated anteroposteriorly, elongate lateral rectangle.
52. Squamosal-jugal contact (HPSA 058): (0) present; (1) absent.
53. Tabular (HPSA 059): (0) present; (1) absent.
54. Posterolateral projection from lateral margin of tabular above squamosal (HPSA 060): absent (0); present (1).
55. Tabular horns (HPSA 061): absent (0); present (1).
56. Tabular horns shape (HPSA 062): (0) parallel or slightly divergent; (1) widely divergent.
57. Squamosal forms base of tabular horn (HPSA 063): (0) absent; (1) present.
58. Lateral line canal grooves (HPSA 064): (0) present; (1) absent.
59. Dermal sculpturing (HPSA 065): (0) circular pits; (1) shallow ridges and grooves; (2) little to none; (3) tuberculate.
60. Premaxilla anterior margin (HPSA 066): (0) vertical; (1) overturned.
61. Maxilla into external naris (HPSA 068): (0) present; (1) absent.
62. Maxilla entire ventral naris (HPSA 069): (0) absent; (1) present.
63. Maxilla (HPSA 070): (0) longer than palatine; (1) shorter than palatine.
64. Marginal teeth orientation (HPSA 071): (0) vertical; (1) turned medially.
65. Marginal teeth largest anterior (HPSA 072): (0) absent; (1) present.
66. Marginal teeth shape (HPSA 073): (0) pointed pegs; (1) blunt pegs; (2) large cones.

67. Number of premax teeth (HPSA 074): (0) 10–20; (1) 5–9; (2) <5; (3) 20 or more
68. Number of max teeth (HPSA 075): (0) 30–40; (1) 20–29; (2) 15–19; (3) <15; (4) >40.
69. Teeth laterally compressed (HPSA 076): (0) no; (1) yes.
70. Enlarged teeth mid toothrow (maxillary) (HPSA 077): (0) absent; (1) present.
71. Teeth (HPSA 078): (0) simple points; (1) multiple cusps.
72. Multiple cusp orientation (HPSA 079): (0) labio–lingual; (1) antero–posterior.
73. Enamel fluting (HPSA 080): (0) absent; (1) present.
74. Labyrinthine infolding (HPSA 081): (0) present; (1) absent.
75. Jaw articulation (HPSA 087): (0) posterior to occiput; (1) even with occiput; (2) anterior to occiput; (3) far anterior (>20% basal skull length).
76. Internal nares (HPSA 088): (0) widely separated; (1) narrowly separated.
77. Lateral exposure of the palatine (LEP) (HPSA 091): (0) absent; (1) present.
78. Anterior palatine (HPSA 092): (0) short anteromedial process articulating with vomer at choana; (1) long anteromedial process more medial than lateral; (2) palatine absent.
79. Teeth on pterygoid (HPSA 098): (0) absent; (1) present.
80. Tooth pedicely (HPSA 099): (0) absent; (1) present.
81. Palatal teeth size (HPSA 103): (0) larger than marginal teeth; (1) equal to marginal; (2) smaller than marginal.
82. Parasphenoid (HPSA 104): (0) medial of stapes; (1) under footplate of stapes.
83. Interpterygoid vacuities (HPSA 115): (0) narrow or closed; (1) wide; (2) fused at midline.
84. Anterior extent of pterygoids (C 02): (0) pterygoids contact anteriorly; (1) pterygoids exclude vomer from interpterygoid vacuity but excluded from median contact by parasphenoid; (2) pterygoids contact vomer but do not exclude vomer from interpterygoid vacuity; (3) pterygoids

reach anteriorly only as far as palatine; (4) pterygoids reach ectopterygoid only; (5) pterygoids do not contact lateral palatal bones at all.

(Note: PSAA modified this character to serve as a replacement for HPSA 116, 118, and 119)

85. Lateral process of pterygoid into posttemporal fossa (HPSA 120): (0) absent; (1) present.

86. Ectopterygoid palatine width (HPSA 122): (0) wider than maxilla; (1) narrower than maxilla.

87. Pharyngeobranchial pouches (HPSA 123): (0) absent; (1) present.

88. Dentary (HPSA 124): (0) tooth row greater than 50% of total jaw length; (1) tooth row less than 50% of total jaw length.

89. Dentary forms coronoid process (HPSA 125): (0) absent; (1) present.

90. Surangular (HPSA 126): (0) subequal in size to angular; (1) substantially smaller than angular; (2) absent.

91. Angular (HPSA 127): (0) approximately as deep as the dentary mid-tooth-row, or less; (1) deeper than dentary mid-toothrow.

92. Number of splenials (HPSA 128): (0) 2; (1) 1; (2) 0.

93. Splenial exposed laterally (HPSA 129): (0) present; (1) absent.

94. Meckelian fossae (HPSA 130): (0) 2 or more; (1) 1; (2) 0.

95. Ventral border of Meckel's fossa (HPSA 131): (0) splenial; (1) angular.

96. Retroarticular process presence (HPSA 132): (0) absent; (1) present.

97. Retroarticular process shape (HPSA 133): (0) straight; (1) hooked.

98. Vertical position of jaw articulation relative to tooth row (HPSA 134): (0) above; (1) equal; (2) below.

99. Extent of angular in lateral view (HPSA 135): (0) posterior tooth row; (1) middle of tooth row.

100. Number of coronoids (HPSA 136): (0) 3; (1) 2; (2) 1; (3) 0.
101. Splenial participates in symphysis (HPSA 139): (0) yes; (1) no.
102. Jaw sculpture (HPSA 140): (0) present; (1) absent.
103. Ossified hyoids (HPSA 141): (0) present; (1) absent.
104. Gill osteoderms (HPSA 142): (0) absent; (1) present noninterdigitating; (2) toothed interdigitating rakers.
105. Parahyoid (HPSA 143): (0) absent; (1) present.
106. Number of accessory articulations (HPSA 144): (0) 0; (1) 1; (2) 2 or more.
107. Number of presacrals (HPSA 145): (0) 25–35; (1) 20–24; (2) >35; (3) <20.
108. Vertebral development (HPSA 146): (0) arches then centra; (1) centra and arches simultaneously.
109. Caudal processes between depressions (HPSA 147): (0) absent; (1) present.
110. Trunk intercentra (HPSA 148): (0) present; (1) absent.
111. Trunk neural arch to centrum in adults (HPSA 149): (0) loosely articulated; (1) sutured; (2) fused.
112. Base of neural spine (HPSA 150): (0) equal to or wider than haemal; (1) smaller than haemal spine.
113. Height of neural spines (HPSA 151): (0) even; (1) alternating.
114. Dermal armor associated with neural arches (HPSA 152, PSAA modified): (0) absent; (1) present.
115. Neural spine shape in lateral view (HPSA 153): (0) anterior and posterior sides parallel, forming a rectangular surface; (1) non-parallel, triangular
116. Neural spine lateral surface (HPSA 154): (0) smooth; (1) crenulated.

117. Pleurocentra (HPSA 155): (0) paired rhachitomous; (1) closely approaching ventrally; (2) fused dominant weight bearing element; (3) embolomorous (PSAA added new state).
118. Haemal arch presence (HPSA 156): (0) present; (1) absent.
119. Haemal arch fusion (HPSA 157): (0) loosely articulated to intercentra; (1) fused to mid length of centrum.
120. Haemal arch length (HPSA 158): (0) longer than or equal to neurals; (1) shorter than neurals.
121. Haemal accessory articulations (HPSA 159): (0) none; (1) one; (2) two.
122. Haemal arch shape (HPSA 160): (0) non parallel triangular; (1) parallel rectangular.
123. Tail termination in skeleton (HPSA 161): (0) tapers; (1) deep with sudden end.
124. Tail length (HPSA 162): (0) elongate equal to or exceeding trunk and skull length; (1) foreshortened markedly shorter than trunk.
125. Trunk arches (HPSA 163): (0) paired; (1) fused.
126. Spinal nerve foramina (HPSA 164): (0) absent; (1) present.
127. Extended transverse processes (HPSA 165): (0) absent; (1) present.
128. Transverse process (HPSA 166): (0) on arch pedicle; (1) on centrum.
129. Atlas axis intercentra (HPSA 167): (0) present; (1) absent.
130. Atlas Anterior centrum (HPSA 168): (0) same size as posterior; (1) laterally expanded.
131. Atlas centrum (HPSA 169): (0) multipartite; (1) single notochordal; (2) single odontoid.
132. Atlas neural arch centrum fusion (HPSA 170): (0) loosely articulated; (1) sutured to centrum; (2) fused to centrum.
133. Atlas parapophyses (HPSA 171): (0) on centrum; (1) on transverse process; (2) absent.
134. Atlas neural arch midline fusion (HPSA 172): (0) paired; (1) sutured at midline; (2) fused at

midline.

135. Atlas accessory articulation (HPSA 173): (0) absent; (1) zygosphen; (2) zygantra.

136. Proatlantes (HPSA 174): (0) present; (1) absent.

137. Second cervical arch (HPSA 175): (0) more expanded to subsequent; (1) equal to subsequent; (2) shorter than subsequent.

138. Atlas ribs (HPSA 176): (0) one pair; (1) two pairs; (2) absent.

139. Cervical rib distal shape (HPSA 177): (0) spatulate; (1) pointed.

140. Ribs anterior to sacrum (HPSA 178): (0) short; (1) long.

141. Ribs (HPSA 179): (0) elongated and sometimes curved; (1) straight; (2) short simple rod.

142. Costal process at rib head (HPSA 180): (0) absent; (1) present.

143. Number of sacrals (HPSA 181): (0) 1; (1) 2; (2) 3.

144. Sacral parapophysis (HPSA 182): (0) on centrum; (1) on transverse process.

145. Number pairs of caudal ribs (HPSA 183): (0) 5 or more; (1) 4; (2) 3; (3) 2 or fewer.

146. Interclavicle posterior stem length (HPSA 184): (0) no or short; (1) long.

147. Interclavicle posterior stem breadth (HPSA 185): (0) wide; (1) narrow.

148. Interclavicle shape (HPSA 186): (0) diamond shaped; (1) T-shaped.

149. Interclavicle anterior plate (HPSA 187): (0) broad; (1) narrow.

150. Interclavicle shape (if diamond present) (HPSA 188): (0) broad diamond; (1) narrow diamond.

151. Interclavicle anterior fimbriation (HPSA 189): (0) present; (1) absent.

152. Interclavicle sculpture (HPSA 190): (0) present; (1) absent.

153. Cleithrum head dorsal extent (HPSA 191): (0) aligned along anterior rim of scapula; (1) posterodorsally enlarged head wrapping around dorsal scapula.

154. Cleithrum head size and shape (HPSA 192): (0) dorsally greatly expanded much wider than shaft; (1) simple rod without or slight dorsal expansion.
155. Cleithrum ossification (HPSA 193): (0) ossified; (1) unossified.
156. Cleithrum overall shape (HPSA 194): (0) rounded or pointed dorsally; (1) T or Y shaped.
157. Proximal clavicle blades (HPSA 195): (0) widely separate; (1) articulate medially; (2) interdigitate.
158. Supraglenoid foramen (HPSA 196): (0) present; (1) absent.
159. Number coracoid foramina (HPSA 197): (0) none; (1) 1; (2) 2.
160. Scapulocoracoid ossification (HPSA 198): (0) both; (1) scapula only; (2) absent.
161. Torsion in humerus (HPSA 200): (0) absent; (1) less than 80 degrees; (2) more than 80 degrees.
162. Deltapectoral crest (HPSA 201): (0) weak or absent; (1) intermediate; (2) prominent.
163. Supinator process (HPSA 202): (0) absent; (1) present.
164. Humerus length (HPSA 203): (0) long (~4 trunk centra); (1) short.
165. Radius-humerus ratio (HPSA 204): (0) > 0.7 ; (1) $0.5-0.7$; (2) < 0.5 .
166. Olecranon process (HPSA 205): (0) unossified; (1) ossified.
167. Carpals (HPSA 206): (0) fully or partially ossified; (1) unossified.
168. Basale commune (HPSA 207): (0) absent; (1) present.
169. Number digits manus (HPSA 208): (0) 5; (1) 4; (2) 3; (3) >5 .
170. Pelvis (HPSA 209): (0) fused; (1) sutured; (2) poorly ossified.
171. Anteriorly inclined ilium (HPSA 210): (0) absent; (1) present.
172. Iliac blade (HPSA 211): (0) 2 dorsal processes; (1) narrowly bifurcate; (2) single blade.
173. Internal trochanter articulation (HPSA 212): (0) distinct; (1) continuous.

174. Femoral shaft (HPSA 213): (0) robust; (1) slender.
175. Femur (HPSA 214): (0) long; (1) short.
176. Tarsals (HPSA 215): (0) ossified; (1) unossified.
177. Elongate tibiale and fibulare (HPSA 216): (0) absent; (1) present.
178. Number of distal tarsals (HPSA 217): (0) 6; (1) 5 or fewer.
179. Astragalus (HPSA 218): (0) absent; (1) present.
180. Number of digits pes (HPSA 219): (0) 5; (1) 4 or less; (2) >5.
181. Dorsal margin of splenial only contacts first coronoid (HPSA 220): (0) absent; (1) present.
182. Postparietal lappet (HPSA 224): (0) mostly exposed posteriorly; (1) equal posteriorly and dorsally; (2) mostly exposed dorsally.
183. Cheek emargination (HPSA 225): (0) absent; (1) present.
184. Parietal anterior waisting (HPSA 226): (0) absent; (1) present.
185. Parietal width relative to frontal (HPSA 227): (0) greater; (1) equal or less.
186. Trabecula cranii (N 01): (0) without significant median fusion posterior to solum nasi (platytrabic); (1) fused medially posterior to solum nasi to form elongate trabecula communis (tropitrabic).
187. Dorsal trabeculae (N 02): (0) dorsal trabeculae provide dorsolateral bridge between sphenoid region and nasal capsule; (1) dorsal trabeculae absent or incomplete, no dorsolateral bridge between sphenoid region and nasal capsule.
188. Ossification between optic foramen and pila antotica (N 03): (0) ossification complete between optic foramen and pila antotica; (1) pila metoptica and associated cartilaginous taenia unossified.
189. Ossification within columella ethmoidalis (N 04): (0) absent; (1) present.

190. Path of profundus branch of trigeminal nerve (N 05): (0) enclosed in lateral wall of sphenoid region of braincase and exits separately from maxillomandibular branch via series of small foramina; (1) extramural, exits antotic fissure with other branches of trigeminal.
191. Foramina for optic nerve and trigeminal nerve (N 06): (0) confluent; (1) widely separate.
192. Lateral head vein (N 07): (0) no distinct foramen for lateral head vein; (1) distinct foramen within the antotic fissure serving the lateral head vein.
193. Anterior extent of cultriform process of parasphenoid (N 08): (0) cultriform process extends to anterior margin of sphenethmoid; (1) cultriform process extends far anterior to sphenethmoid; (2) cultriform process does not reach anterior margin of sphenethmoid.
194. Olfactory bulbs (N 09): (0) narrow; (1) endocasts swollen, leaving considerable impressions in lateral and ventral wall of sphenoid region and in ventral surface of frontal.
195. Flange from skull roof articulating with sphenethmoid (modified from HPSA 223): (0) absent; (1) present on frontal and parietal; (2) present on frontal only.
196. Descending lamina of parietal invades medial orbital wall between 'pleurosphenoid' and 'sphenethmoid' elements (N 10): (0) no; (1) yes.
197. Foramen for oculomotor nerve (N 11): (0) exits braincase far dorsal to foramen for optic nerve; (1) exits braincase at or below optic nerve.
198. Intermaxillary fossa (modified from HPSA 095): (0) present; (1) absent.
199. Intermaxillary fossa (N 12): (0) paired; (1) unpaired.
200. Sphenethmoid forms interorbital septum (N 13): (0) no; (1) yes.
201. Anterior extent of cultriform process along palate (N 14): (0) cultriform process extends anteriorly to level of posterior margin of choana; (1) cultriform process dramatically shortened, barely reaching the level of the posterior margin of the orbit.

202. Sutural contact between cultriform process of parasphenoid and vomer (N 15): (0) no; (1) yes.

203. Lateral wall of the nasal capsule underplated by lateral processes of the vomer and palatine (N 16): (0) no; (1) yes.

204. Cultriform process vaulted high above palatal surface (N 17): (0) no; (1) yes.

205. Posterior extent of parasphenoid beneath braincase (N 18): (0) floors sphenoid region only; (1) floors sphenoid and otic region; (2) floors sphenoid, otic, and occipital regions.

206. Basal tubera (N 19): (0) present, with significant endochondral contribution; (1) present, with contribution of parasphenoid only; (2) absent.

207. Path of common internal carotid artery (N 20): (0) does not run alongside braincase, enters braincase directly in region of sella turcica; (1) follows vidian sulcus along posterior surface of basal plate of parasphenoid, enters parasphenoid via vidian canal in basal plate of parasphenoid, divides into cerebral and palatal branches after entering parasphenoid; (2) follows vidian sulcus along posterior surface of basal plate of parasphenoid or lateral wall of braincase, divides into cerebral and palatal branches prior to entering the skull.

208. Buccohypophyseal foramen in parasphenoid (N 21): (0) open; (1) absent.

209. Morphology of pila antotica (N 22): (0) pila antotica is a thin, broad sheet; (1) pila antotica is a robust dorsoventral pillar bracing the skull roof against the palate.

210. Basicranial fissure (N 23): (0) present; (1) absent.

211. Location of vidian sulcus (N 24): (0) along ventral surface of braincase; (1) along lateral surface of braincase.

212. Basispterygoid joint (N 25): (0) epipterygoid comprises entire conus recessus; (1) substantial contribution to conus recessus by pterygoid; (2) conus recessus comprised entirely of pterygoid

without epipterygoid participation; (3) pterygoid and parasphenoid broadly sutured without development of a conus recessus.

213. Hypophyseal fossa (N 26): (0) single unpaired sulcus; (1) paired sulci divided medially by ridge originating on dorsum sellae.

214. Bone flanking the dorsum sellae (N 27): (0) concurrent with fully ossified lateral braincase; (1) subparallel with sagittal plane ('pleurosphenoid'); (2) strongly oblique to or perpendicular to sagittal plane ('laterosphenoid'); (3) restricted to dorsum sellae only.

215. Basal plate of parasphenoid (HPSA 105): (0) roughly quadrangular, basipterygoid articulations narrowly spaced; (1) rectangular laterally, anteroposteriorly narrow, basipterygoid articulations distant.

216. Sphenethmoid (HPSA 114): (0) ossified; (1) unossified.

217. Ossification within the synotic tectum (N 28): (0) synotic tectum massively co-ossified with otic capsules; (1) supraoccipital paired at some point in ontogeny; (2) supraoccipital unpaired throughout ontogeny; (3) no supraoccipital bone; synotic tectum invaded by dorsal processes of exoccipitals.

218. Median ascending process of supraoccipital (N 29): (0) absent; (1) present.

219. Lateral ascending processes of the supraoccipital (N 30): (0) absent; (1) present.

220. Margin of fenestra vestibuli (N 31): (0) parasphenoid excluded by neurocranial elements (basisphenoid and basioccipital); (1) parasphenoid contributes to anteroventral margin of fenestra vestibuli; (2) parasphenoid floors entire fenestra vestibuli; (3) Ossification of otic capsule surrounds entire fenestra vestibuli.

221. Crista intervestibularis (N 32): (0) crista intervestibularis absent; (1) crista intervestibularis present.

222. Morphology of crista parotica (N 33): (0) crista parotica meets exoccipitals only, forming lateral wall of posttemporal fossa but not bracing against dermal skull; (1) crista parotica drawn out dorsolaterally into paroccipital process that contacts the tabular; (2) crista parotica drawn out laterally into paroccipital process that contacts the cheek and/or suspensorium.
223. Dorsal process of stapes (HPSA 111): (0) absent; (1) present.
224. Facets on dorsal surface of supraoccipital (N 34): (0) absent; (1) present.
225. Otoccipital fissure (N 35): (0) present; (1) absent.
226. Crista parotica (N 36): (0) descends posteriorly; (1) horizontal along the extent of its length.
227. Position of quadrate with respect to otic capsules (PSAA modified from HPSA 82): (0) quadrates ventral and lateral to otic capsules; (1) quadrates mostly lateral to and greater or equal to twice the width of the otic capsules; (2) quadrates mostly ventral to otic capsules; (3) quadrates approaching or abutting lateral wall of otic capsules.
228. Size of otic capsules (N 37): (0) otic capsules comprise less than $\frac{2}{3}$ the width of otoccipital region; (1) otic capsules comprise greater than $\frac{2}{3}$ total width of otoccipital region.
229. Otic trough (N 38): (0) absent; (1) present.
230. Articulation between the epipterygoid and prootic (N 39): (0) none; (1) elongate facet on anterior surface of prootic for articulation of epipterygoid.
231. Opisthotic obscures occipital in lateral view (N 40): (0) no; (1) yes.
232. Fenestra vestibularis at end of broad, winglike lateral extension of the otic capsule (N 41): (0) no; (1) yes.
233. Cristae in otoccipital region (N 42): (0) comprised primarily of ascending flanges from braincase; (1) comprised primarily of descending flanges from skull roof.

234. Opisthotic excluded from the occipital surface by tabular process of the exoccipital (N 43): (0) no; (1) yes.
235. Insertion of epaxial musculature on occiput (N 44): (0) deep within post-temporal fossae; (1) in broad, shallow fossae along occipital surface of postparietals.
236. Foramen for internal jugular vein (N 45): (0) between supraoccipital and exoccipital; (1) between opisthotic and exoccipital; (2) through exoccipital; (3) posterior notch of fenestra vestibule.
237. Foramina for hypoglossal nerve (N 46): (0) multiple; (1) single; (2) none.
238. Occipital condyle shape (HPSA 085, modified by PSAA): (0) round; (1) U-shaped; (2) paired.
239. Ventral process of exoccipital reaches basiptyergoid joint along palatal surface (N 47): (0) absent; (1) present.
240. Occipital condyle shape (HPSA 084): (0) concave; (1) convex.
241. Columella of stapes (HPSA 108, modified by PSAA): (0) perforate; (1) imperforate.
242. Orientation of stapes (HPSA 109, modified by PSAA): (0) dorsal, towards tabular or otic notch; (1) anteroventral, towards quadrate.
243. Stapedial footplate shape (HPSA 110): (0) oval; (1) round; (2) palmate.
244. Dorsal sinus between synotic tectum and skull roof (PSAA modified from HPSA 222): (0) absent; (1) present.
245. Ossification within septum internasale (N 48): (0) absent; (1) present, sphenethmoid; (2) present, mesethmoid.
246. Ossification of septum internasale invades nasal tectum (N 49): (0) absent; (1) present.
247. Insertion of hypaxial musculature (N 50): (0) sphenoid; (1) otic; (2) basioccipital.

248. Prootic supported by pedicel extending from basisphenoid lateral to prootic (N51): (0) no; (1) yes.
249. Position of pineal foramen with respect to hypophyseal foramen (N 52): (0) anterior to; (1) approximately the same; (2) far posterior to.
250. Pineal foramen or fossa (N 53): (0) well anterior to posterior margin of cerebral fossa; (1) at or behind posterior margin of cerebral fossa.
251. Opisthotic, contribution to median wall of otic capsule (N 54): (0) completely unossified; (1) opisthotic contributes to the median wall of otic capsule.
252. Conical recess in basioccipital (N 55): (0) absent; (1) present.
253. Semicircular canals (N 56): (0) separated from utricular region by bone; (1) not separated from utricular region by bone.
254. Basioccipital (N 57): (0) robust ossification ventral to foramen magnum present; (1) absent.
255. Accessory articulation processes with proatlantal facet on exoccipitals (N 58): (0) absent; (1) prominent.
256. Exoccipital proatlantal facets incorporated into occipital joint (N 59): (0) no; (1) yes.
257. Anterior tectal (modified from CABF 001): (0) anterior tectal present; (1) absent.
258. Ectopterygoid/palatine exposure (CABF 002): (0) more or less confined to tooth row; (1) broad medial exposure additional to tooth row; (2) reduced to thin sliver.
259. Ectopterygoid: (0) present; (1) absent.
260. Ectopterygoid as long or longer than palatines (CABF 003): (0) yes; (1) no.
261. Ectopterygoid reaches subtemporal fossa (CABF 004): (0) no; (1) yes.
262. Frontal (CABF 005): (0) absent; (1) present.
263. Jugal (CABF 007): (0) does not extend anterior to orbit; (1) extends anterior to orbit.

264. Lateral rostral present (CABF 009): (0) yes; (1) no.
265. Maxilla makes interdigitating suture with vomer (CABF 010): (0) no; (1) yes.
266. Maxilla external contact with premaxilla (CABF 011): (0) narrow contact point, not interdigitated; (1) interdigitating suture.
267. Maxilla extends behind level of posterior margin of orbit (CABF 012): (0) yes; (1) no.
268. Median rostral (CABF 013): (0) single; (1) paired; (2) absent.
269. Opercular (CABF 014): (0) present; (1) absent.
270. Prefrontal (CABF 015): (0) twice as long as broad, or less; (1) three times as long as broad.
271. Prefrontal (CABF 016): (0) transverse anterior suture with tectal; (1) tapers to a point anteriorly.
272. Preopercular (CABF 017): (0) present; (1) absent.
273. Pterygoid quadrate ramus margin in subtemporal vacuity (CABF 018): (0) concave; (1) with some convex component.
274. Vomers separated by parasphenoid > half length (CABF 019): (0) yes; (1) no.
275. Vomers (CABF 022): (0) as broad as long or broader; (1) about twice as long as broad or longer.
276. Basipterygoid process (CABF 023): (0) not strongly projecting with concave anterior face; (1) strongly projecting with flat anterior face.
277. Ethmoid (CABF 024): (0) fully ossified; (1) partly or wholly unossified.
278. Hypophyseal region (CABF 025): (0) solid side wall pierced by small foramina for pituitary vein and other vessels; (1) single large foramen.
279. Lateral commissure of otic capsule bearing hyomandibular facets (CABF 026): (0) present; (1) absent.

280. Parasphenoid (CABF 027): (0) does not overlap basioccipital; (1) overlaps basioccipital.
281. Denticulate field of parasphenoid (CABF 028): (0) present; (1) absent.
282. Sphenoid (CABF 029): (0) fully ossified, terminating posteriorly in intracranial joint or fused to otoccipital; (1) separated from otoccipital by unossified gap.
283. Ectopterygoid fang pairs (CABF 030): (0) present; (1) absent.
284. Ectopterygoid row (3+) of smaller teeth (CABF 031): (0) present; (1) absent.
285. Ectopterygoid/palatine shagreen field (CABF 032): (0) absent; (1) present.
286. Palatine row of smaller teeth (CABF 034): (0) present; (1) absent.
287. Pterygoid shagreen (palatine ramus) (CABF 035, modified by PSAA): (0) dense; (1) organized radiating rows of denticles; (2) disorganized patches or absent.
288. Dentition of transverse flange of pterygoid (new character): (0) denticle field indistinct from palatine denticle field; (1) distinct raised denticle field; (2) organized tooth row; (3) absent.
289. Premaxillary tooth proportions (CABF 036): (0) all approximately the same size; (1) posteriormost teeth at least twice the height of anteriormost teeth; (2) anteriormost teeth largest.
290. Vomerine fang pairs (CABF 037): (0) present; (1) absent.
291. Vomerine fang pairs are noticeably smaller than other palatal fang pairs (CABF 038): (0) no; (1) yes.
292. Vomer anterior wall forming posterior margin of palatal fossa bears tooth row meeting at midline (CABF 039): (0) yes; (1) no.
293. Vomerine row of teeth (CABF 040): (0) present; (1) absent.
294. Vomerine shagreen field (CABF 041): (0) absent; (1) present.
295. Adductor fossa (CABF 042): (0) faces dorsally; (1) faces medially.

296. Adductor crest (CABF 043): (0) absent; (1) peak anterior to adductor fossa, dorsal margin of fossa concave; (2) peak above anterior part of adductor fossa, dorsal margin of fossa convex.
297. Angular-prearticular contact (CABF 044): (0) prearticular contacts angular edge to edge; (1) absent; (2) medial lamina of angular sutures with prearticular.
298. Coronoid (anterior) contacts splenial (CABF 045): (0) no; (1) yes.
299. Prearticular extends between infradentaries and middle coronoid (CABF 046, modified by PSAA): (0) yes; (1) no.
300. Coronoid (middle) contacts postsplenial (CABF 047): (0) no; (1) yes.
301. Coronoid (posterior) posterodorsal process (CABF 048): (0) no; (1) yes.
302. Coronoid (posterior) posterodorsal process visible in lateral view (CABF 049): (0) no; (1) yes.
303. Dentary external to angular & surangular, with chamfered ventral edge and no interdigitations (CABF 050): (0) no; (1) yes.
304. Dentary ventral edge (CABF 051): (0) smooth continuous line; (1) abruptly tapering or "stepped" margin.
305. Dentary suture with splenial & postsplenial marked by deep furrow (CABF 052): (0) no; (1) yes.
306. Mandibular sensory canal (CABF 053): (0) present; (1) absent.
307. Mandibular canal exposure (CABF 054): (0) entirely enclosed, opens through lines of pores; (1) mostly enclosed, short sections of open grooves; (2) mostly open grooves, short sections opening through pores; (3) entirely open.
308. Oral sulcus/surangular pit line of mandible (CABF 055): (0) present; (1) absent.
309. Meckelian bone floors precoronoid sulcus (CABF 056): (0) yes; (1) no.

310. Meckelian bone ossified in the middle part of the jaw (CABF 057): (0) yes; (1) little or no ossification.
311. Meckelian bone exposure in middle part of jaw (CABF 058): (0) depth much less than prearticular; (1) depth similar to prearticular.
312. Meckelian foramina/fenestrae, dorsal margins (CABF 059): (0) Meckelian bone; (1) prearticular; (2) infradentary.
313. Meckelian foramina/fenestrae height (CABF 060): (0) much lower than adjacent prearticular; (1) equal to or greater than depth of adjacent prearticular.
314. Parasymphyseal lateral foramen present (CABF 061): (0) no; (1) yes.
315. Parasymphyseal mesial foramen present (CABF 062): (0) no; (1) yes.
316. Postsplenial with mesial lamina (CABF 063): no (0), small (1), expanded, contacting precoronoid (2).
317. Postsplenial, pit line present (CABF 064): yes (0), no (1).
318. Postsplenial, suture with prearticular present (CABF 065): no (0), yes (1).
319. Prearticular sutures with surangular (CABF 066): (0) no; (1) yes.
320. Medial lamina of splenial (CABF 067, modified by PSAA): (0) absent; (1) present.
321. Prearticular with longitudinal ridge below coronoids (CABF 068): (0) no; (1) yes.
322. Prearticular with mesially-projecting flange on dorsal edge along posterior border of adductor fossa (CABF 069): (0) no; (1) yes.
323. Prearticular centre of radiation of striations (CABF 070): (0) level with posterior end of posterior coronoid; (1) level with middle of adductor fossa; (2) level with posterior end of adductor fossa.
324. Splenial has free ventral flange (CABF 071): (0) yes; (1) no.

325. Splenial, rearmost extension of medial lamina (CABF 072): (0) closer to anterior end of jaw than to adductor fossa; (1) equidistant; (2) closer to anterior margin of adductor fossa than to the anterior end of the jaw.
326. Coronoids: at least one has a fang pair recognizable because at least twice the height of coronoid or marginal teeth (CABF 073): (0) yes; (1) no.
327. Coronoids: at least one has fangs recognizable because of noticeable lingual to vertical lamina of bone and to all other teeth (CABF 074): (0) yes; (1) no.
328. Coronoids: at least one has organized tooth row (CABF 075): (0) yes; (1) no.
329. Coronoids: at least one carries shagreen (CABF 076): (0) no; (1) yes.
330. Coronoids: size of teeth (excluding fangs) on anterior and middle coronoids relative to dentary tooth size (CABF 077): (0) about the same; (1) half the height or less.
331. Dentary tooth row (CABF 078): (0) homodont; (1) markedly heterodont.
332. Dentary with parasymphyseal fangs internal to marginal tooth row (CABF 079): (0) yes; (1) no.
333. Dentary teeth (CABF 080): (0) same size as maxillary teeth; (1) larger than maxillary teeth; (2) smaller than maxillary teeth.
334. Dentary with a row of very small teeth or denticles lateral to tooth row (CABF 081): (0) yes; (1) no.
335. Parasymphyseal tooth plate (CABF 082): (0) present; (1) absent.
336. Parasymphyseal plate dentition (CABF 083): (0) shagreen or irregular tooth field; (1) organized dentition aligned parallel to jaw margin; (2) no dentition.
337. Parasymphyseal plate has fang pair (CABF 084): (0) no; (1) yes.

338. Parasymphyseal plate has tooth row (CABF 085): (0) no; (1) short tooth row, separated from coronoid row by diastema; (2) long tooth row reaching coronoid.
339. Prearticular shagreen field distribution (CABF 086): (0) gradually decreasing from dorsal to ventral; (1) well-defined dorsal longitudinal band; (2) scattered patches or absent.
340. Dorsal fontanelle on snout (CABF 088): (0) absent; (1) present.
341. Interpterygoid vacuities (CABF 089): (0) absent; (1) at least 2x wider than long; (2) 2x longer than wide.
342. Intracranial joint (CABF 090): (0) present in dermal skull roof; (1) absent in dermal skull roof.
343. Nature of ornament: starbursts of radiating ornament on at least some bones (CABF 092): (0) no; (1) yes.
344. Anocleithrum (CABF 093): (0) oblong with distinct anterior overlap area; (1) drop-shaped with no anterior overlap area; (2) absent.
345. Cleithrum (CABF 094): (0) ornamented; (1) not ornamented.
346. Cleithrum, postbranchial lamina (CABF 095): present (0), absent (1).
347. Autopod (modified from CABF 096): (0) radials; (1) digits.
348. Humerus (CABF 097): (0) narrow tapering entepicondyle; (1) square or parallelogram-shaped entepicondyle.
349. Ilium, iliac canal (CABF 098): (0) absent; (1) present.
350. Ilium, posterior process (CABF 099): (0) oriented posterodorsally; (1) oriented approximately horizontally posteriorly.
351. Interclavicle (CABF 100): (0) small and concealed or absent; (1) large and exposed.
352. Interclavicle shape (CABF 101): (0) ovoid; (1) kite shaped; (2) with posterior stem.

353. Lepidotrichia in paired appendages (CABF 102): (0) present; (1) absent.
354. Posttemporal and supracleithrum (CABF 103): (0) present; (1) absent.
355. Radius and ulna (CABF 104): (0) radius much longer than ulna; (1) approximately equal in length.
356. Ribs, trunk (CABF 107): (0) all cylindrical; (1) some or all bear flanges from posterior margin which narrow distally; (2) some or all flare distally.
357. Scapular blade (CABF 108): (0) absent; (1) small with narrow top; (2) large with broad top.
358. Scapulocoracoid (modified from CABF 109): (0) small and tripodal; (1) large plate.
359. Subscapular fossa (CABF 110): (0) broad and shallow; (1) deeply impressed posteriorly.
360. Squamation (CABF 111): (0) complete body covering of scales, all similar; (1) ventral armor of gastralia.
361. Pectoral process (CABF112): (0) absent; (1) present.
362. Proximal limb of oblique ridge (CABF 113): (0) present, separated from anterior margin of humerus by prepectoral space; (1) absent, replaced by deltopectoral crest.
363. Latissimus dorsi attachment (CABF 114): (0) diffuse ridged area; (1) distinct process.
364. Foramina piercing oblique ventral ridge (CABF 115): (0) many; (1) one moderately large foramen in addition to entepicondylar foramen; (2) entepicondylar foramen is the only large opening, other foramina are pinpricks or absent; (3) none.
365. Humerus with well-developed anterior plate (PSAA 367): (0) yes; (1) no.
366. Subclavicular ossifications (PSAA 368): (0) Absent; (1) Sometimes present.
367. Radial capitulum (PSAA 369, modified from Sigurdsen & Green, 2011): (0) approximately same size as ulnar facet; (1) greatly enlarged and rounded, >2x size of ulnar facet.
368. Lissamphibian inner ear sensu Maddin and Anderson (2012) (MA 220): (0) no; (1) yes.

369. Enlarged cranial foramina on supraorbital region (MPS 371): (0) absent, (1) present.
370. Distribution of enlarged cranial foramina on supraorbital region (MPS 372): (0) lateral margins of frontals and postfrontal, (1) only on lateral margins of frontals, (2) lateral margins of frontals and extending onto prefrontals.
371. Transverse flange of the pterygoid (MPS 373): (0) absent, (1) present.
372. Orientation of the transverse flange of the pterygoid (MPS 374): (0) posterolateral orientation of the transverse flange, (1) anterolateral orientation of the transverse flange.
373. Supraneural caudal skeleton (JP24): present (0), absent (1).
374. Cranial notochord (JP24): unrestricted (0), restricted in chordal region (1), absent in postembryonic individuals (2).
375. Premaxilla, if snout recumbent, morphology of anterior margin of supranarial (=dorsal) process (JEtAl 375): (0) strongly convex or rounded; (1) straight anteriorly forming a pointed snout.
376. Maxilla, medial surface, medial caniniform buttress (JEtAl 376): (0) absent; (1) present, distinct swelling or ridge present above caniniform region.
377. Maxilla, lateral surface, lateral caniniform buttress (JEtAl 377): (0) absent or slight swelling; (1) present.
378. Parietals and frontals, suture with contralateral elements (JEtAl 378): (0) weak or simple, frontals and parietals contact contralateral elements at a straight suture; (1) strong suture between contralateral elements, forming tongue-in-groove or interdigitating sutures.
379. Prefrontal, ventromedial process forming antorbital buttress (JEtAl 379): (0) absent; (1) present, transversely broad process of prefrontal underplates lacrimal only; (2) present, transversely broad process of prefrontal buttresses against palatine.

380. Jugal, if contact with SQ/QJ present, free dorsal margin (JEtAl 380): (0) absent; (1) present.
381. Supratemporal, contact with postfrontal (JEtAl 381): (0) absent; (1) present.
382. Tabular, contact with postfrontal (JEtAl 382): (0) absent; (1) present.
383. Postorbital, contact with parietal (JEtAl 383): (0) present; (1) absent.
384. Squamosal, contact with quadrate ramus of pterygoid (JEtAl 384): (0) present; (1) absent, pterygoid does not contact squamosal.
385. Postparietals or parietal, ventral contact with exoccipital (JEtAl 385): (0) absent, postparietals separate from exoccipital due to an unossified gap, synoptic tectum, or other cranial element; (1) present.
386. Postparietals or parietals, contact with main body opisthotic medial to posttemporal fossa or fenestra (JEtAl 386): (0) present; (1) absent, postparietals separated from opisthotics.
387. Synotic tectum, contribution to the endosseous labyrinth (JEtAl 397): (0) absent; (1) present, pathway of semicircular canals visible in synoptic tectum.
388. Synotic tectum, ventral surface (JEtAl 388): (0) synotic tectum forms around endolymphatic act resulting in paired fossae on the ventral surface; (1) ventral surface of synotic tectum is flat or mildly concave.
389. Prootic and opisthotic, ampullary fossae (JEtAl 389): no distinct ampullary fossae marking the position of the ampullae (0), well-developed ampullary fossa present (1).
390. Pterygoid, transverse flange, ventral deflection (JEtAl 390): (0) absent, transverse flange not deflected ventrally; (1) present, transverse flange deflected ventrally below margin of skull.
391. Pterygoid, quadrate ramus, arcuate flange (JEtAl 391): (0) absent; (1) present, quadrate ramus of pterygoid bears a transversely developed flange or keel.

392. Palate, suborbital opening (JEtAl 392): (0) absent; (1) present, suborbital foramen or fenestra between ectopterygoid, pterygoid, and palatine; (2) present, suborbital foramen/fenestra present between maxilla and palatal elements; (3) present between jugal and pterygoid.
393. Quadrate, medial surface (JEtAl 393): (0) flat or featureless; (1) distinct stapedial recess present; (2) raised stapedial shelf.
394. Prootic, location of trigeminal nerve (CN V)(JEtAl 394): (0) on anteroventral margin of prootic; (1) on dorsal surface of prootic, dorsal to anterior semicircular canal.
395. Orbitosphenoid, if contacts frontal, mediolateral expansion of dorsal surface (JEtAl 395): (0) absent, orbitosphenoid is mediolaterally thin at frontal contact; (1) present, orbitosphenoid is mediolaterally expanded, interfingering with ventral surface of frontal.
396. Orbitosphenoid, processes vomeronasale (JEtAl 396): (0) absent; (1) present, processes vomeronasale separates pathway of vomeronasale and olfactory tracts.
397. Posterior median ossification 'subiculum infundibulum' of ethmoid trabeculae JEtAl 397: (0) absent; (1) present.
398. Posterior median ossification, if present, osseous contact with 'pleurosfenoids' (JEtAl 398): (0) absent; (1) present.
399. Gastralia, if present, morphology (JEtAl 399): (0) rectilinear scales; (1) rod-like bones.
400. Tarsus, number of pedal centralia (JEtAl 400): (0) three or more; (1) two discrete ossification centers at some point in ontogeny; (2) a single ossification center throughout ontogeny.
401. Cervical vertebrae, centra length (JEtAl 401): (0) shorter or subequal to dorsal centra; (1) markedly longer than dorsal centra.

402. Massively enlarged crushing teeth on the palatal apparatus (JEtAl): absent (0), present (1).

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