**Online Supplementary Material**

## Appendix 1: Analysis of sarcopterygians, including rhizodontids

### Selected species

Friedman *et al.* (2007) analysed the interrelationships of 32 sarcopterygians and five outgroup OTUs (one acanthodian and four actinopterygians) using 216 characters. The ingroup included representatives of all the conventionally recognised groups of basal sarcopterygians: coelacanths, lungfishes, porolepiforms and stem-tetrapods (including three rhizodontids: *Gooloogongia*, *Sauripterus* and *Barameda*). In this reanalysis three more rhizodontids were added (*Rhizodus*, *Strepsodus* and *Screbinodus*) and the scores given originally for *Gooloogongia*, *Sauripterus* and *Barameda* were reviewed.

### Character list

Notes are included where the additional rhizodontids add new data to the matrix, or where there have been other changes to the original matrix of Friedman *et al.* (2007).

1. Skull shape between orbits: interorbital skull roof wide and arched dorsal orbits (0), interorbital skull roof flat or concave (1)

The skull roofs of *Barameda*, *Gooloogongia* and *Screbinodus* are well-known. That of *Sauripterus* is unknown. The score for *Strepsodus* is based on the shape of the postparietals; the score for *Rhizodus* is tentative, based on Andrews’ (1985) description of two bones as postparietals.

1. Premaxilla: absent (0), present (1)

Premaxillae have been described for all rhizodontids except *Sauripterus*.

1. Contribution to orbital margin by premaxilla: absent (0), present (1)

The articular surfaces of the premaxillae in *Barameda*, *Gooloogongia*, *Screbinodus* and *Strepsodus* preclude any contribution to the orbital margin. The shape of the premaxilla is poorly known in *Rhizodus*, and a contribution to the orbital margin cannot be ruled out.

1. Posterodorsal process on posterior portion of premaxilla: absent (0), present (1)

This process is absent in all rhizodontids where the premaxilla is known, including *Rhizodus*.

1. Postrostral: absent (0), mosaic (1), median postrostral (2), paired bones (e.g. E-bones of some lungfishes) (3)

The snout is only well known in *Barameda* and *Gooloogongia*, both of which have a mosaic of bones .

1. Paired bones anterior to parietals : absent (0), present (1)
2. Tectals: absent (0), present (1)
3. Number of tectals: one (0), two or more (1)
4. Supraorbital: absent (0), present (1)
5. Number of supraorbitals: one (0), two (1), more than two (2)
6. Median bone of dermal skull roof in contact with postparietals (B-bone): absent (0), present (1)

In *Screbinodus* the median bone is scored as absent, although the exact layout of the anterior skull roof is unclear, is certainly involves paired bones and not a median bone.

1. Anterior margin of parietal: between or in front of orbits (0), slightly posterior to orbits (1), far posterior to orbits (2)

The score for *Screbinodus* is tentative, based on the interpretation of parietals in SME 4714.

1. Pineal opening: open (0), closed (1)

The score for *Screbinodus* is tentative, based on the interpretation of parietals in SME 4714.

1. Parietal-supraorbital contact: absent (0), present (1)
2. Extratemporal: absent (0), present (1)

The extratemporal is absent in *Screbinodus*.

1. Intertemporal: present (0), absent (1)

The score for *Screbinodus* is tentative, based on the interpretation of SME 4714.

1. Number of marginal bones alongside postparietal: single (0), two or more (1)

The postparietal shield is well-known in *Screbinodus*. *Strepsodus* is interpreted as having more than one bone (1) based on the articular surfaces of numerous postparietals.

1. Dermal joint between parietal and postparietal : absent (0), present (1)

The condition in *Screbinodus* and *Strepsodus* is surmised from the shape of the anterior end of the postparietal.

1. Number of extrascapulars: two (0), three (1), four (2), five (3)

*Screbinodus* and *Strepsodus* both have three extrascapulars.

1. Median extrascapular overlap: median extrascapular overlapped by lateral extrascapulars (0), median extrascapular overlaps lateral extrascapulars (1), median extrascapular abuts lateral extrascapulars (2)

The median extrascapular is overlapped by lateral extrascapulars (0) in all rhizodonts, except *Rhizodus* and *Sauripterus*, where the condition is unknown.

1. Position of anterior nostril: facial (0), marginal (1), palatal (2)

In *Screbinodus* the shape of the maxilla and premaxilla shows that the anterior nostril was not marginal (state 1), what is known of the palate allows the tentative conclusion that it was not palatal (state 2).

1. Dermintermedial process: absent (0), present (1)
2. Position of posterior nostril : external, far from jaw margin (0), external, close to jaw margin (1), palatal (2)

In *Screbinodus* the choanal channel on the vomer shows that there was a palatal posterior nostril.

1. Posterior nostril: associated with orbit (0), not associated with orbit (1)

In *Screbinodus* the choanal channel on the vomer shows that there was a palatal posterior nostril, not associated with the orbit.

1. Lachrymal posteriorly enclosing posterior nostril : absent (0), present (1)

In *Screbinodus* the lachrymal is not associated with a nostril.

1. Number of sclerotic plates: five or less (0), more than five (1)

*Strepsodus* NMS GY 1980.40.36 is preserved with many sclerotic plates.

1. Ethmoid commissure: present (0), absent (1)
2. Course of ethmoid commissure: middle portion through median rostral (0), sutural course through bone (1), centre of premaxilla (2)
3. Course of supraorbital canal: posterior or lateral to anterior nostril (0), anterior or mesial to anterior nostril (1)
4. Course of supraorbital canal: straight (0), lyre-shaped (1)
5. Contact of supraorbital and infraorbital canals: in contact rostrally (0), not in contact (1)
6. Relationship of infraorbital canal to premaxilla: infraorbital canal entering premaxilla (0), infraorbital canal following dorsal margin of premaxilla (1)

The course of the canal can be traced in the maxilla of *Screbinodus*.

1. Posterior end of supraorbital canal : in postparietal (0), in parietal (1), in intertemporal (2)

The score for *Screbinodus* (state 2) is tentative, based on the interpretation of an intertemporal in SME 4714.

1. Contact of otic and supraorbital canals: not in contact (0), in contact (1)

The possible intertemporal in SME 4714 shows that the two canals are in contact in *Screbinodus*.

1. Position of the anterior pit-line: on postparietal (0), on parietal (1)
2. Course of otic canal in relation to anterior portion of postparietal: through marginal bones; alongside postparietal (0), along the margin of the postparietal (1), through postpareital (2)

The postparietals carry at least part of the otic canal in *Screbinodus* and *Strepsodus*.

1. Maxilla: absent (0), present (1)

The maxilla has been described in all rhizodontids except *Sauripterus*. The score for *Rhizodus* is tentative, based on the assignment of the isolated maxilla NMS GY 1894.183.30.

1. Posterior expansion of maxilla: present (0), absent (1)
2. Dermohyal: absent (0), present (1)

The dermohyal is absent in *Screbinodus*.

1. Number of cheek bones bearing preopercular canal posterior to jugal: one (0), two (1)

In *Screbinodus* the preopercular canal runs across the squamosal, and based on its course it probably also ran through the preopercular (unknown in *Screbinodus*).

1. Bone bearing both preopercular canal and quadratojugal pitline: absent (0), present (1)

The quadratojugal does not bear a canal or a pit line in *Screbinodus*.

1. Subsquamosals: absent (0), present (1)

There are no subsquamosals in *Screbinodus*.

1. Preopercular-maxillary contact: present (0), absent (1)

Although the preopercular is unknown in *Screbinodus*, it could not contact the maxilla, because of the position of the quadratojugal.

1. Jugal-quadratojugal contact: absent (0), present (1)

The jugal and quadratojugal have a long contact in *Screbinodus*.

1. Preoperculosubmandibular: absent (0), present (1)

There are no preoperculosubmandibular in *Screbinodus*.

1. Foramina on dermal cheek bones: absent (0), present (1)

The cheek bones are solid plates in *Screbinodus* and *Strepsodus*.

1. Vertical bar-like preopercular: absent (0), present (1)

In both *Screbinodus* and *Strepsodus* the shape of the squamosal suggests that the preopercular was bar-like.

1. Jugal canal: present (0), absent (1)

The jugal canal is present in *Screbinodus*.

1. Relative length of dentary: long (0), short (1)

The dentary is long in all rhizodontids.

1. Marginal teeth on dentary: present (0), absent (1)

The dentary bears marginal teeth in all rhizodontids.

1. Parasymphysial tooth whorl: absent (0), present (1)

A parasymphysial has been described in all rhizodontids except *Screbinodus*.

1. Meckelian bone exposed anterior to first coronoid: yes (0), no (1)

There is no Meckelian bone exposed anterior to the first coronoid in *Rhizodus*, *Screbinodus* and *Strepsodus*, nor any break in the coronoid or dentary which would allow unossified Meckelian cartilage to be exposed..

1. Number of infradentaries: one (0), two (1), three (2), four (3)

Four infradentaries are known in *Rhizodus*, *Screbinodus* and *Strepsodus*.

1. Raised crest on posterior infradentary: absent (0), present (1)

This crest is not present in rhizodontids (although the condition is unknown in *Barameda*)

1. Coronoids: present (0), absent (1)

Coronoids have been reported in all rhizodontids except *Sauripterus* (where the condition is unknown).

1. Tusks of coronoids: absent (0), present (1)

Coronoid tusks have been reported in all rhizodontids except *Sauripterus* (where the condition is unknown).

1. Dentition on coronoids: broad marginal 'tooth field' (0), narrow marginal tooth row (1), single tooth row (2), only tusk (3)

State 3 was added to accommodate the condition in *Rhizodus*. *Barameda* and *Gooloogongia* are rescored to state 1 (after Brazeau 2005). *Strepsodus* is tentatively scored as state 1 (cf. Brazeau 2005, where a coronoid on NEWHM G19.18 bears ‘at most three tooth bases’).

1. Anterior end of prearticular: far from jaw symphysis (0), near jaw symphysis (1)

The prearticular runs up to the first coronoid in *Rhizodus* and *Strepsodus*. The condition is unknown in other rhizodontids.

1. Prearticular-dentary contact: present (0), absent (1)

The prearticular does not contact the dentary in *Rhizodus* (1) and probably did not do so in *Strepsodus* (based on the similar overlap surfaces on the first coronoid on *Strepsodus* NEWHM 19.18 to those of *Rhizodus*).

1. Radial tooth rows on prearticular: absent (0), present (1)

Radial tooth rows are absent in *Rhizodus* and *Strepsodus* (the condition is unknown in other rhizodontids)

1. Anterior mandibular (precoronoid) fossa: absent (0), present (1)

There is no precoronoid fossa in *Rhizodus* or *Strepsodus*.

1. Labial pit: absent (0), present (1)

The labial pit is absent in all rhizodontids.

1. Large foramina on external surface of lower jaw: absent (0), present (1)

No foramina have been described on the external surface of lower jaw in any rhizodontid.

1. Horizontal pit-line of lower jaw: not developed into enclosed canal (0), developed into enclosed canal or intermediate morphology (1)
2. Anterior pit-line of lower jaw: not developed into enclosed canal (0), developed into enclosed canal (1)
3. Course of mandibular canal: passing through dentary (0), not passing through dentary (1)

The mandibular canal does not pass through the dentary in *Rhizodus*, *Screbinodus* and *Strepsodus* (the condition is unknown in other rhizodontids).

1. Course of mandibular canal: not passing through most posterior infradentary (0), passing through most posterior infradentary (1)

The posterior course of the mandibular canal is known only in *Rhizodus* and *Screbinodus*, where it passes through the posterior infradentary.

1. Branchiostegal series: present (0), absent (1)

Branchiostegals are known in *Barameda*, *Gooloogongia*, *Sauripterus* and *Screbinodus*.

1. Number of branchiostegals per side, excluding opercular, subopercular, and gular plates: ten or more (0), two or seven (1), one (2), zero (3)

The branchiostegal series is only well known in *Screbinodus*, where seven are known.

1. Submandibulars: absent (0), present (1)

Submandibulars have been reported in *Sauripterus* and *Screbinodus*, but the condition is unknown in other rhizodontids.

1. Width of submandibulars: narrow (0), broad (1)

The submandibulars are only well known in *Screbinodus*, where they are narrow.

1. Median gular: present (0), absent (1)

Median gulars have been reported in *Barameda* and *Screbinodus*, but the condition is unknown in other rhizodontids.

1. Size of lateral gular: lateral gular and branchiostegal rays of similar size (0), lateral gular covering approximately half of intermandibular space (1)

The lateral gulars cover approximately half of intermandibular space in *Sauripterus* and *Screbinodus*. The score given for *Barameda* by Friedman *et al.* (2007) is presumably based on isolated gulars (see Holland *et al.* 2007; Long 1989).

1. Palatal opening surrounded by premaxilla, maxilla, dermopalatine, and vomer (choana): absent (0), present (1)

The presence of the choana in *Screbinodus* is inferred from the morphology of the constituent bones.

1. Posterior process of vomer: absent (0), present (1)

Vomers are known in *Barameda*, *Rhizodus* (assuming this is the correct designation of the large vomer NMS GY 1975.5.9) and *Screbinodus*. All lack the posterior process.

1. Articulation of vomers: absent (0), present (1)

Articulating vomers are preserved *in situ* in *Barameda* and *Screbinodus* (1). The isolated large vomer NMS GY 1975.5.9 (attributed to *Rhizodus*) bears articular surfaces similar to those of *Screbinodus*, implying that it also articulated with its antimere.

1. Vomerine tusks: absent (0), present (1)

Vomerine tusks are known in *Barameda*, *Rhizodus* (based on NMS GY 1975.5.9), *Screbinodus* and *Strepsodus* (based on three fragmentary specimens).

1. Articulation of pterygoids: not articulating with one another (0), articulating with one another (1)
2. Position of parasphenoid: beneath sphenethmoid region of neurocranium (0), beneath sphenethmoid and otoccipital region (1)
3. Parasphenoid: protruding forward into ethmoid region of neurocranium (0), behind ethmoid region of neurocranium (1)
4. Denticulated field of parasphenoid : without spiracular groove (0), with spiracular groove (1)
5. Dental plate: denticles on entopterygoid/prearticular or naked bone surface (0), tooth plate on entopterygoid/prearticular (1), dentine plate on entopterygoid/prearticular (2)

Prearticulars with denticles are known in *Barameda*, *Screbinodus* and *Strepsodus*. The only prearticular known in *Rhizodus* is damaged and the condition is not clear.

1. Form of head of hyomandibular: single headed (0), double headed (1)

A hyomandibular attributed to *Rhizodus* (Brazeau & Jeffery 2008) is double-headed.

1. Posterior margin of palatoquadrate : sloping forward (0), erect or sloping backward (1)
2. Endoskeletal intracranial joint: absent (0), present (1)
3. Orientation of intracranial joint or fissure : anteroventrally slanting (posteriorly reclined) (0), posteroventrally slanting (anteriorly reclined) (1)
4. Position of intracranial joint or fissure relative to cranial nerves: joint through profundus foramen (0), joint through trigeminal foramen (1)
5. Proecess descendens of sphenoid: absent (0), present (1)
6. Anterior palatal fenestra: absent (0), present (1)

The anterior margin of the vomer of *Screbinodus* and *Rhizodus* (based on NMS GY 1975.5.9) show a curve for the anterior palatal.

1. Paired internasal pits: absent (0), present (1)

The apparent poor of ossification of the braincases of Carboniferous rhizodontids makes it impossible to assess whether the pits were present in the cartilaginous braincase.

1. Vomeral area with grooves and raised areas: absent (0), present (1)

Almost nothing is known of the ventral ethmoid region in rhizodontids.

1. Fenestra ventrolateralis: absent (0), present (1), common ventral fenestra for anterior and posterior nostrils (2)
2. Large median (profundus canal) and several small dorsolateral openings in postnasal wall: absent (0), present (1)
3. Eye stalk or unfinished area for similar structure: absent (0), present (1)
4. Postorbital process on braincase: present (0), absent (1)
5. Basipterygoid (postorbital) pila: absent (0), present (1)
6. Position of exit of pitutitary vein: anterior to basipterygoid process (0), dorsal to vertical portion of basipterygoid process (1), posterior to basipterygoid process (2)
7. Basicranial fenestra: absent (0), present (1)
8. Unconstricted cranial notochord: absent (0), present (1)
9. Supraotic cavity: absent (0), present (1)
10. Posttemporal fossae: absent (0), present (1)
11. Anocleithrum: bone developed as a postcleithrum (0), bone developed as an anocleithrum *sensu stricto* (1), bone absent (2)

An anocleithrum (or evidence for its existence, if not preserved) is known for *Gooloogongia*, *Sauripterus*, *Screbinodus* and *Strepsodus*. The condition is unknown in other rhizodontids.

1. Presupracleithrum: absent (0), present (1)

A presupracleithrum is known to be absent *Gooloogongia*, *Sauripterus* and *Strepsodus*. It is almost certainly absent in *Screbinodus*, although dermal pectoral girdle is incompletely known. The condition is unknown in other rhizodontids.

1. Pectoral girdle with additional dermal ossification: absent (0), present (1)

There are only two ossifications (cleithrum and clavicle) in all rhizodontids.

1. Dorsal end of cleithrum: pointed (0), broad and rounded (1)

The dorsal part of the cleithrum is broad in all rhizodontids.

1. Paired pectoral spines: absent (0), present (1)

Pectoral spines are absent in all rhizodontids.

1. Relationship of clavicle to cleithrum : ascending process of clavicle overlapping cleithrum laterally (0), ascending process of clavicle wrapping around anterior edge of cleithrum, overlapping it both laterally and mesially (1)

All rhizodontids show the more complex lateral and mesial overlap relationship.

1. Interclavicle: absent (0), present (1)

An interclavicle has only been identified in *Sauripterus*.

1. Triradiate scapulocoracoid: absent (0), present (1)

Triradiate scapulocoracoids are known for *Sauripterus*, *Rhizodus* (assuming that NMS GY 1963.16.16 and PMG 298 are correctly identified) and *Strepsodus*. The scapulocoracoid is poorly known in other rhizodontids.

1. Scapulocoracoid: attached to dermal girdle, not separated by foramina (0), attached to dermal girdle by buttresses and separated from dermal girdle by foramina (1), attached to dermal girdle, foramina run through scapulocoracoid (2)

The scapulocoracoid of *Sauripterus* is attached to the dermal girdle by buttresses. The scapulocoracoid of *Rhizodus* (assuming that NMS GY 1963.16.16 and PMG 298 are correctly identified) and *Strepsodus* are attached to the dermal girdle and pierced by foramina.

1. Endoskeletal supports in pectoral fin : multiple elements articulating with girdle (0), single element articulating with girdle (1)

All rhizodontids have a single fin element articulating with the girdle. The fin endoskeleton is poorly known in *Screbinodus*, but the proximal elements can be seen in NMS GY 1964.28.8 figured by Andrews & Westoll (1970); specimen now lost).

1. Deltoid and supinator processes: absent (0), present (1), continuous dorsal ridge (2)

This character was modified from Friedman *et al.* (2007) with the addition of state 2, which more accurately reflected the condition in those rhizodontids where the humerus was known in detail. These are *Barameda*, *Sauripterus*, *Rhizodus* and *Strepsodus*.

1. Metapterygial 'axis' of pectoral fin skeleton (jointed 'axes' only): less than 5 (0), more than 5 (1)

The metapterygial axes of *Barameda*, *Gooloogongia*, *Sauripterus*, *Screbinodus* and *Strepsodus* all have less than five mesomeres (the condition in *Screbinodus* is judged from the figure of NMS GY 1964.28.8 in Andrews & Westoll (1970). The condition is unknown in *Rhizodus*.

1. Pectoral fin radials: unjointed (0), jointed (1)

All rhizodontids have jointed fin radials (the condition in *Screbinodus* is judged from the figure of NMS GY 1964.28.8 in Andrews & Westoll (1970).

1. Pectoral fin radials: 'preaxial' radials only (0), 'preaxial' radials plus 'postaxial' radials (1)
2. Dorsal fin: double (0), single (1)

*Strepsodus* has two dorsal fins.

1. Dorsal and anal fins: present (0), absent (1)

Dorsal and anal fins are present in *Gooloogongia* and *Strepsodus*.

1. Basal scutes on fins: absent (0), present (1)

Basal scutes are absent in *Gooloogongia*, *Sauripterus*, *Screbinodus* and *Strepsodus*. The condition is unknown in other rhizodontids.

1. Basal fulcra: absent (0), present (1)

Basal fulcra are absent in *Gooloogongia*, *Sauripterus*, *Screbinodus* and *Strepsodus*. The condition is unknown in other rhizodontids.

1. Median fin spines: absent (0), present (1)

Median fin spines absent in *Gooloogongia* and *Strepsodus*. The condition is unknown in other rhizodontids.

1. Epichordal lepidotrichia in tail: absent (0), present (1)

Epichordal lepidotrichia are present in *Gooloogongia*, *Sauripterus* and *Strepsodus*. The condition is unknown in other rhizodontids.

1. Relative size of epichordal and hypochordal lobes of caudal fin: epichordal lobe less developed than hypochordal (0), epichordal and hypochordal lobes equally developed (1), epichordal lobe more developed than hypochordal (2)

The epichordal lobe is slightly smaller in *Gooloogongia*. The lobes are equally developed in *Strepsodus*. The condition is unknown in other rhizodontids; although the fin is preserved in one specimen of *Sauripterus*, it is incomplete and the relative sizes of the lobes cannot be judged.

1. Supraneural spines : present on thoracic and abdominal vertebrae (0), restricted to a few vertebrae at anterior end of column or absent (1)
2. Well-ossified ribs: absent (0), present (1)

Well-ossified ribs are known in *Barameda*, *Sauripterus* and *Screbinodus*. The condition is unknown in other rhizodontids.

1. Scales: rhombic (0), rounded (1)

The scales are rounded in all rhizodontids.

1. Peg on rhombic scale: narrow (0), broad (1)
2. Anterodorsal peg-like process on rhombic scale: absent (0), present (1)
3. Endochondral bone: absent (0), present (1)

Endochondral bone is known in all rhizodontids.

1. Pore-canal network : absent (0), present (1)

A pore-canal network is absent in all rhizodontids (see character 130, below).

1. 'Cosmine' with large pore ornamentation : absent (0), present (1)

Full-body specimens are known for *Gooloogongia*, *Sauripterus* and *Strepsodus* (the latter two are juveniles). Scales from adults are known for all rhizodontids, as are isolated dermal bones. Cosmine has never been observed on any of these specimens, and so all six rhizodontids are (tentatively) scored as cosmine absent.

1. Enamel lining pore canals: absent (0), present (1)
2. Westoll-lines: absent (0), present (1)
3. Pore clusters on 'cosmine': absent (0), present (1)
4. Rostral tubuli: absent (0), present (1)
5. Acrodin tooth caps: absent (0), present (1)

Acrodin tooth caps are absent in *Rhizodus*, *Screbinodus* and *Strepsodus*. The condition is unknown in other rhizodontids.

1. Ganoine (= enamel): single-layered (0), multilayered (1)

Enamel is single-layered in *Rhizodus* and *Strepsodus*. The condition is unknown in other rhizodontids.

1. Plicidentine: absent (0), simple (1), labyrinthodont (2), dendrodont (3)

The teeth of *Barameda*, *Rhizodus*, *Screbinodus* and *Strepsodus* all show ‘simple’ plicidentine. The condition is unknown in other rhizodontids.

1. Syndentine: absent (0), present (1)

Syndentine is absent in *Barameda*, *Rhizodus*, *Screbinodus* and *Strepsodus*. The condition is unknown in other rhizodontids.

1. Tooth-bearing median rostral: absent (0), present (1)

There is no tooth-bearing median rostral in *Barameda*, *Gooloogongia*, *Screbinodus* and *Strepsodus*. The condition is unknown in other rhizodontids.

1. Rostral organ: absent (0), present (1)

The rostral organ is absent in *Barameda*, *Gooloogongia* and *Screbinodus*, but the condition is unknown in other rhizodontids.

1. Pineal eminence (in those taxa with no pineal foramen): absent (0), present (1)
2. Margins of postparietal and parietals participating in dermal intracranial joint : smooth (0), jagged (1)

The margins is more-or-less straight is *Gooloogongia*, but jagged in *Barameda*, *Screbinodus* and *Strepsodus* (the condition in *Screbinodus* and *Strepsodus* is assumed from the shape of the postparietal).

1. Complete enclosure of spiracle by bones bearing the otic and infraorbital canals : absent (0), present (1)
2. Premaxillae with inturned symphysial processes: absent (0), present (1)

This process is absent is *Rhizodus*, *Screbinodus* and *Strepsodus*. The condition is unknown in other rhizodontids.

1. Posterior extension of premaxilla reaching level of orbit: absent (0), present (1)

This premaxilla does not reach the level of the orbit is absent is *Barameda*, *Gooloogongia* and *Screbinodus*. The condition is unknown in other rhizodontids.

1. Contribution of maxilla to posterior margin of cheek: present (0), absent (1)

The maxilla does not contribute to the posterior margin of the cheek in *Gooloogongia* or *Screbinodus*. The condition is unknown in other rhizodontids.

1. Sensory canal or pit-line associated with maxilla: absent (0), present (1)

The maxilla does not contribute to the posterior margin of the cheek in *Gooloogongia* or *Screbinodus*. The condition is unknown in other rhizodontids.

1. Opercular: absent (0), present (1)

The opercular is present in all rhizodontids.

1. Strong posterior flexion of symphysis : absent (0), present (1)

There is not strong posterior flexion of the symphysis in *Barameda*, *Gooloogongia*, *Rhizodus*, *Screbinodus* and *Strepsodus*. The condition is unknown in *Sauripterus*.

1. Large ventromesially directed flange of anteriormost dentary: absent (0), present (1)

There is no ventromesially directed flange in *Barameda*, *Rhizodus*, *Screbinodus* and *Strepsodus*. The condition is unknown in *Gooloogongia* and *Sauripterus*.

1. Teeth of outer dental arcade: several rows of disorganized teeth (0), two rows, with large teeth lingually and small teeth labially (1), single row of teeth (2)

All rhizodontids have a single row of teeth.

1. Number of coronoids: five (0), four (1), three (2)

There are three coronoids in *Rhizodus*, *Screbinodus* and *Strepsodus*. The condition is unknown other rhizodontids.

1. Flange-like extension composed of prearticular and Meckelian ossification: absent (0), present (1)

The flange-like extension is absent in *Rhizodus* and *Strepsodus*. The condition is unknown other rhizodontids.

1. Large facet or articular condyle posterior to and in line with glenoid: absent (0), present (1)

The condyle is absent in *Rhizodus* and *Screbinodus*. The condition is unknown other rhizodontids.

1. Linear, subparallel ridges of remodeled denticles on dermal bones lining the oral cavity: absent (0), present (1)
2. Fenestra in palatoquadrate marking position of basal articulation: absent (0), present (1)
3. Foramen in hyomandibular: absent (0), present (1)

The hyomandibular foramen is present a hyomandibular attributed to *Rhizodus* (Brazeau & Jeffery 2008).

1. Endoskeletal 'urohyal': absent (0), present (1)
2. 'Urohyal' morphology: dorsoventrally compressed and rod-like, may bifurcate posteriorly (0), vertical plate (1)
3. Entopterygoid proportions: anterior end level or slightly anterior to processus ascendens (0), anterior end considerably anterior to processus ascendens (1)
4. Number of dermopalatines: multiple (0), single (1)

There is a single dermopalatine in *Barameda* and *Screbinodus*. The condition is unknown other rhizodontids.

1. Denticle field of parasphenoid with multifid anterior margin: no (0), yes (1)
2. Shape of parasphenoid denticle field : splint-shaped (0), lozenge-shaped (1)
3. Denticle field of parasphenoid with anteriorly divergent lateral margins: no (0), yes (1)
4. Denticulated field of the parasphenoid : terminates at or anterior to level of foramina for internal carotid arteries (0), extends posterior to foramina for internal carotid arteries (1)
5. Co-mineralised ethmosphenoid region: present (0), absent (1)

There is no co-mineralization in the ethmosphenoid region of *Screbinodus*. The condition is unknown other rhizodontids.

1. Ethmoid articulation for palatoquadrate : placed on postnasal wall (0), majority of facet located anterior to postnasal wall (1), extends posteriorly to the level of N.II (2)
2. Autopalatine fossa bearing unfinished articular surfaces: absent (0), present (1)
3. Interorbital space: broad (0), narrow (1)

The interorbital space is broad in *Gooloogongia* and *Screbinodus* (based on the partially preserved braincase on SME 4714). The condition is unknown other rhizodontids.

1. Hyomandibular facets in those taxa where they straddle the level of the jugular canal: narrowly separated or confluent (0), broadly separated (1)

The hyomandibular facets are broadly separated in a hyomandibular attributed to *Rhizodus* (Brazeau & Jeffery 2008).

1. Position of lateral commissure: overlying root of N.V (0), posterior to root of N.V (1)
2. Single posterior foramen for jugular canal and ramus hyomandibularis N.VII: absent (0), present (1)
3. Vestibular fontanelles: absent (0), present (1)
4. Accessory fenestration in otic capsule : absent (0), present (1)
5. Parachordal plates: separated from the otic capsule (0), sutured or co-mineralised with the otic capsule (1)
6. Enclosed canal for dorsal aorta within basioccipital region: absent (0), present (1)
7. Otoccipital fissure: absent (0), present (1)
8. Lepidotrichia: absent (0), present (1)

Lepidotrichia are known in all rhizodontids.

1. Interlocking lepidotrichia: absent (0), present (1)

Interlocking lepidotrichia are absent in all rhizodontids.

1. Fringing fulcra: absent (0), present as modified distal tips of lepidotrichia (1), present as 'true' fringing fulcra (2)

Fringing fulcra are absent in *Barameda*, *Gooloogongia*, *Sauripterus*, *Screbinodus* and *Strepsodus*. The condition is unknown in *Rhizodus*.

1. Pectoral fin endoskeleton: extends far beyond body wall (fins lobate) (0), barely extends beyond body wall (fins not lobate) (1)

The pectoral fins are lobate in all rhizodontids.

1. Pelvic fin endoskeleton: extends far beyond body wall (fins lobate) (0), barely extends beyond body wall (fins not lobate) (1)

The pelvic fins are known to be lobate in *Gooloogongia*, *Rhizodus* (pers. obs.) and *Strepsodus*. The condition is unknown in other rhizodontids.

1. Resorption and redeposition of odontotes and enamel: absent (0), incomplete resorption (1), complete resorption (2)
2. Ethmosphenoid region significantly longer than otoccipital region: no (0), yes (1)

The ethmosphenoid region is significantly longer than otoccipital region in *Barameda*, *Gooloogongia* and *Screbinodus* (based on the dermal skeleton).

1. Premaxillary fang: absent (0), present (1)

The premaxillary fang is present in *Barameda*, *Rhizodus*, *Screbinodus* and *Strepsodus*. The condition is unknown in other rhizodontids.

1. Lachrymal excluded from orbit: no (0), yes (1)

The lachrymal forms part of the orbit in *Barameda*, *Gooloogongia* and *Screbinodus*. The condition is unknown in other rhizodontids.

1. Jugal extends anterior to middle of orbit : no (0), yes (1)

The jugal does not extend anterior to the middle of the orbit in *Barameda*, *Gooloogongia* and *Screbinodus*. The condition is unknown in other rhizodontids.

1. Extratemporal/supratemporal contact : absent (0), present (1)
2. Dentary fang: absent (0), present (1)

The dentary fang is present in all rhizodontids.

1. Anterior infradentary sutured to prearticular: no (0), yes (1)

The anterior infradentary is not sutured to the prearticular in *Barameda*, *Rhizodus* and *Screbinodus*. The condition is unknown in other rhizodontids.

1. Posterior coronoid: subequal (0), much longer than penultimate coronoid (1)

The posterior coronoid is approximately the same size as the penultimate coronoid in *Rhizodus*. The condition is unknown in other rhizodontids.

1. Extrascapular series: present (0), absent (1)

The extrascapular series is present in *Barameda*, *Gooloogongia*, *Sauripterus*, *Screbinodus* and *Strepsodus*. The condition is unknown in *Rhizodus*.

1. Anocleithrum: subdermal (0), exposed (1)

The anocleithrum is subdermal in *Gooloogongia*, *Sauripterus*, *Screbinodus* (a tentative conclusion based on SME 4714) and *Strepsodus*. The condition is unknown in *Rhizodus* and *Barameda*.

1. Cleithrum 'waisted': no (0), yes (1)

The cleithrum is waisted in all rhizodontids except *Gooloogongia*.

1. Position of scapulocoracoid on cleithrum: ventrally positioned (0), dorsally positioned (1)

The scapulocoracoid is dorsally positioned in all rhizodontids.

1. Pectoral fin: unrotated (0), rotated (1)

The pectoral fin is unrotated in all rhizodontids (the condition in *Screbinodus* is based on the external aspect of the fin in NMS 1874.6).

1. Basal segments of pectoral lepidotrichia: elongated (0), not elongated (1)

The basal segments of pectoral lepidotrichia are elongated in all rhizodontids.

1. Fin web: asymmetrical (0), symmetrical (1)

The fin web is asymmetrical in *Gooloogongia*, *Sauripterus*, *Screbinodus* and *Strepsodus*. The condition is unknown in other rhizodontids.

1. Propterygial canal: absent (0), present (1)
2. Metapterygial segmentation: absent (0), present (1)

The metapterygium is segmented in all rhizodontids.

1. Pectoral radials: do not bifurcate (0), bifurcate (1)

Pectoral radials bifurcate in all rhizodontids (although the conclusion is tentative for *Gooloogongia*).

1. Pectoral radials: all bear fin rays or lepidotrichia (0), some 'naked' (1)

The pectoral radials all bear lepidotrichia in *Gooloogongia*, *Sauripterus*, *Screbinodus* (based on external aspect of NMS 1874.6) and *Strepsodus*. The condition is unknown in *Barameda* and *Rhizodus*.

1. Postaxial radials: restricted distal to ulna (0), first present on ulna (1)

Postaxial radials are first present on the ulna of *Barameda*, *Sauripterus*, *Rhizodus* (based on the articular facets of the ulna), *Screbinodus* (based on NMS GY 1964.28.8, figured by Andrews & Westoll (1970); specimen now lost) and *Strepsodus*. The condition is unknown in *Gooloogongia*.

1. Caput humeri: concave to slightly convex (0), ball-shaped (1)

Caput humeri is ball-shaped in *Barameda*, *Sauripterus*, *Rhizodus* and *Strepsodus*. The condition is unknown in other rhizodontids.

1. Body of humerus: cylindrical (0), flattened with rectangular cross-section (1)

Body of the humerus is cylindrical in *Barameda*, *Sauripterus*, *Rhizodus* and *Strepsodus*. The condition is unknown in other rhizodontids.

1. Humeral processes: imperforate (0), perforate (1)

Humeral processes is perforated in *Barameda*, *Sauripterus*, *Rhizodus* and *Strepsodus*. The condition is unknown in other rhizodontids.

1. Entepicondyle (posterior process from most proximal mesomere): absent (0), present (1)

The entepicondyle is present in *Barameda*, *Gooloogongia*, *Sauripterus*, *Rhizodus* and *Strepsodus*. The condition is unknown in *Screbinodus*.

1. Humeral radials: present (0), absent (1)

Humeral radials are present in *Barameda*, *Sauripterus*, *Rhizodus*, *Screbinodus* and *Strepsodus*. The condition is unknown in *Gooloogongia*.

1. Radius of equal length or shorter than humerus: no (0), yes (1)

The radius is shorter than the humerus in *Barameda* and *Rhizodus*, and longer than the humerus in *Sauripterus*. The condition is unknown in other rhizodontids.

1. Dorsal and ventral processes present on distal pectoral mesomeres: no (0), yes (1)

These processes are absent in *Barameda*, *Gooloogongia*, *Sauripterus*, *Rhizodus* and *Strepsodus*. The condition is unknown in other *Screbinodus*.

1. Posterior process on distal mesomere(s): absent (0), present (1)

Posterior processes are absent in *Barameda*, *Gooloogongia*, *Sauripterus*, *Rhizodus* and *Strepsodus*. The condition is unknown in other *Screbinodus*.

1. Distal fin or limb domain expanded across A-P axis: no (0), yes (1)

The fins are expanded in all rhizodontids.

1. Proximal process of median fin basal plates: broad base (0), narrow base (1)
2. Ossified ring centra: absent (0), present (1)

Ossified ring centra have been described in *Barameda* and *Strepsodus*. The condition is unknown in other rhizodontids.

1. Internal boss on round scale: absent (0), present (1)

Internal bosses are found on the scales of all rhizodontids.

1. Lateral line: single (0), multiple (1)

Multiple lateral lines are known in *Gooloogongia*, *Sauripterus* and *Strepsodus*. The condition is unknown in other rhizodontids.

### Data matrix

Key: **-** = inapplicable; **?**= missing; **X** = polymorphic (0&1); **Y** = polymorphic (1&2); **Z** = polymorphic (0&2)

**5 10 15 20 25 30 35 40 45 50**

**OTU [Missing/Uncertain] . . . . . . . . . .**

*Barameda* [96 chars, 44.4%]  01001 01011 00011 01110 0?210 ?0211 00211 0110? ????? 0?000

*Gooloogongia*  [110 chars, 50.9%]  01001 01011 00011 01110 0??10 ????? ????1 01101 00?0? 00?00

*Rhizodus*   [138 chars, 63.9%]  01?0? ????? ????? ????? ????? ????? ????? ?1??? ????? ???01

*Sauripterus*  [157 chars, 72.7%]  ????? ????? ????? ????? ????? ????? ????? ????? ????? ???0?

*Screbinodus*  [101 chars, 46.8%]  0100? ????? 000?0 01110 0?210 ????? ?021? 01101 00110 01001

*Strepsodus*  [117 chars, 54.2%]  0100? ????? ????? ?1110 ????? 1???? ????? 011?? ????? 01?01

*Acanthodes*  [158 chars, 73.1%]  0---- ----- ----- ----- --??? 0?-?? 0--0- ----- ----- --0--

*Acanthostega*  [56 chars, 25.9%]  11000 11011 00010 110-- 0?210 1???0 00??? ?1101 0011? 01000

*Achoania* [140 chars, 64.8%]  0100? 0???? ??0?? ??1?? 01011 ????0 ??1?? ????? ????? ???00

*Cheirolepis*  [79 chars, 36.6%]  01X1Y 00?1? 00XX0 X000? 00000 0??00 1000? 01010 00000 00100

*Diabolepis*  [127 chars, 58.8%]  0100? 0??1? 1210? 010?? 1?11? ????1 ??101 1???? ????? ???10

*Diplocercides*  [68 chars, 31.5%]  01001 01?12 00110 10111 0?011 ????? ???10 20-01 10-?0 00010

*Dipnorhynchus*  [120 chars, 55.6%]  00--1 1111? 12000 0103? 2-210 ?1?11 1-101 00-?1 0?-?? ???11

*Dipterus*  [75 chars, 34.7%]  00--3 11?11 12100 0103? 2-210 ?X?11 1-111 00-01 00-11 00011

*Eusthenopteron*  [11 chars, 5.1%]  01002 01011 00010 01110 01210 10211 00211 01101 00100 01000

*Gavinia*   [163 chars, 75.5%]  01001 ???12 ????? 0???? ????? ????? ?0??? ???00 10??? 0??10

*Glyptolepis* [21 chars, 9.7%]  01001 01110 01101 10111 00011 ?0?11 00111 21101 01101 00000

*Gogonasus*   [35 chars, 16.2%]  01002 01111 00011 01110 0121X 1??11 ??211 01101 00100 01000

*Howqualepis*  [75 chars, 34.7%]  01110 00?0- 000?0 0000? 0000- 00000 ?0000 01010 00000 00100

*Ichthyostega*  [57 chars, 26.4%]  11000 11011 00010 110-- 1?210 ?0?10 002?? 01101 00110 01000

*Kenichthys*  [87 chars, 40.3%]  0100? 01011 0?011 01110 01111 ?0111 01211 01100 100?0 10000

*Latimeria*   [25 chars, 11.6%]  01001 01112 00110 1013? 00000 ?0101 01?1? 20-01 10-?0 00010

*Megalichthys*  [48 chars, 22.2%]  01003 110?? 001?? 011?? 0?210 ?0211 00211 01101 0010? 01?00

*Miguashaia*  [107 chars, 49.5%]  010?1 0??12 00110 0011? 0???? 10??? ?021? 00?01 10-?0 00010

*Mimia*  [32 chars, 14.8%]  01110 00?0- 000-0 0000? 0000- 00000 10000 01010 00000 00100

*Moythomasia*  [35 chars, 16.2%]  01110 00?0- 000-0 0002? 0000- 00000 10000 01010 00000 00100

*Neoceratodus*  [85 chars, 39.4%]  00--? ???0- 1?1-0 ??0-- 2-21? ?1??1 0-?1? ?0-01 00-?0 0?010

*Onychodus*   [45 chars, 20.8%]  01001 01111 00111 11112 00011 10010 01??1 01011 100?0 00000

*Osteolepis*  [58 chars, 26.9%]  0100Y 01011 00011 01110 0???0 10211 00211 01101 00100 01000

*Panderichthys*  [26 chars, 12.0%]  11001 11011 00010 01010 01210 ?0?1? 0021? 01101 00110 01000

*Porolepis*   [38 chars, 17.6%]  01001 01111 01101 10111 00011 ?0011 00111 21101 01101 00000

*Powichthys*  [80 chars, 37.0%]  01001 01110 01001 01011 01011 ?0?11 01101 0???? ????1 ???00

*Psarolepis*  [93 chars, 43.1%]  0111? 0???? 0?0?? ??1?? 01010 ?00?0 10001 110?0 ?00?? 10000

*Rhizodopsis*  [93 chars, 43.1%]  01??? 0???? 001?? ?111? ????? ????? ????? ?1101 00100 01?00

*Shoshonia*   [195 chars, 90.3%]  ????? ????? ????? ????? ????? ????? ????? ????? ????? ?????

*Strunius*  [120 chars, 55.6%]  0100? 0???? 001?0 0110? ????? 1???? ??Y?1 01011 ?00?0 00000

*Styloichthys*  [102 chars, 47.2%]  01?0? 0???? 010?? 011?? 00??? ?0111 01201 011?0 100?? 1?010

*Tiktaalik*  [89 chars, 41.2%]  110?1 1??11 00010 110-- 0?210 ????0 ????? ?1101 0011? 01?00

*Uranolophus*  [104 chars, 48.1%]  00--1 111?? 12100 010?? 2-21? ?1??1 1-101 00-?? ??-?? ???1?

*Youngolepis*  [69 chars, 31.9%]  0100? 0???? 0?1?1 010?? 01111 ?0111 01101 11100 100?? 10000

**55 60 65 70 75 80 85 90 95 100**

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*Barameda* 0???0 11??0 ?00?? ??0?? ?0110 11000 ?0??? ????? ????? ?????

*Gooloogongia* 0??00 11??? ?00?? ??0?? ????? ????? ????1 10??? ???01 0????

*Rhizodus* 01300 13110 000?? 11??? ????0 11??? ??1?? ???1? ????? ?????

*Sauripterus* 0??0? ????? ?00?? ??0?1 ??1?? ????? ????? ????? ????? ?????

*Screbinodus* ?1300 1???? ?00?? 11011 00110 11??? ?0??? ???1? ?-??? ?????

*Strepsodus* 01300 11110 000?? 1???? ????? ?1??? ?0??? ????? ????? ?????

*Acanthodes* 0---- ----- ----- --000 ?1--- --0-- --000 --0?? ????0 ??0??

*Acanthostega* 01300 02110 00000 111-- ---10 11101 00?00 --01? ???01 0?0??

*Achoania* 1?3?0 ??110 00100 ????? ???0? 0?001 00??1 01101 0001? 11?1?

*Cheirolepis* 0?100 00000 0000? 00000 -000? ?0000 0000? ????0 ?0??? ?????

*Diabolepis* 0-301 --101 01000 1???? ????0 00000 11??? ??000 1100? 0????

*Diplocercides* 0?110 00110 00000 11130 -11-? ??000 00111 110?0 00001 0?110

*Dipnorhynchus* 0-301 --101 01011 10??? ???-? ??111 -2?10 -??00 ?200? ??011

*Dipterus*  0-301 --101 ?1011 10011 101-? ??111 -1?10 -??00 ?200? ??0??

*Eusthenopteron* 00300 12110 10000 11011 00111 11000 00101 10010 01001 00111

*Gavinia* 1??1? ????? ????0 110?? ????? ????? ??10? ????? ????? ?????

*Glyptolepis* 10300 12110 10000 11001 01100 01001 10101 10001 01101 0111?

*Gogonasus* 00?00 12110 10X00 11011 00110 11000 00101 10010 11?01 0011?

*Howqualepis* ?1100 00000 00000 00000 -000? ??00? 1000? ????? ????? ??0??

*Ichthyostega* 01300 02110 0000? 111-- ---10 11101 00?00 --010 ?1??? ??00?

*Kenichthys* 00300 10110 10000 110X1 0010? ??000 00??1 1?001 1100? 0????

*Latimeria* 00110 00110 00000 11130 -11-0 10000 00111 11000 00001 0?110

*Megalichthys* 00300 12110 10000 110?? ???11 11000 00?01 ??010 11??1 ???1?

*Miguashaia* 0?110 00110 00000 11130 -11?? ??0?? ?0?1? ????? ????? ?????

*Mimia* 01200 00000 00000 01000 -0000 00000 10000 --100 00000 02000

*Moythomasia* 01100 00000 00000 00000 -0000 00000 10000 --?00 00000 02000

*Neoceratodus* 0-101 --1?1 01011 11030 -1??? 10111 -1?10 --?00 02?01 ??000

*Onychodus* 10300 00110 000X1 10011 111-- --001 00001 10001 0??01 01?1?

*Osteolepis* 00300 11?10 10000 11011 001?? ?1000 00101 100?? ?1001 0??1?

*Panderichthys* 00300 12110 10000 11011 00111 11000 00101 ??010 ?1001 0?11?

*Porolepis* 10300 12110 10000 11001 00100 01001 10101 10001 01101 0111?

*Powichthys* 10300 10110 00100 110X1 ?0100 01001 10?0? ??101 01101 ?111?

*Psarolepis* 10300 11110 00100 11??? ???0? 0?001 000?1 01101 0001? 11?11

*Rhizodopsis* 0?300 1???? ?00?? ??011 001?? ???1? 0?1?1 100?? ???01 001??

*Shoshonia* ????? ????? ????? ????? ????? ????? ????? ????? ????? ?????

*Strunius* 1010? ??1?0 00000 10021 1?1?? ????? ?0??? ????? ????? ?????

*Styloichthys* 10300 ??110 00100 11??? ????? ??000 001?1 11101 01011 1111?

*Tiktaalik* 00300 12110 100?? ??0?1 ?0?11 1?000 0011? ??0?0 ????? ?????

*Uranolophus* 0-301 --100 01011 1?011 1?1-? ??111 00?10 --?00 ?2??? ??0??

*Youngolepis* 10300 10110 00100 110Y1 00100 01000 10100 ??101 11001 01011

**105 110 115 120 125 130 135 140 145 150**

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*Barameda* ???11 01??? 1201? ????? ???11 --100 ---?? ?1000 -10?0 ?0100

*Gooloogongia* ?1011 01??? 1?01? ?0000 10??1 --100 ---?? ???00 -00?0 1?10?

*Rhizodus*  ???11 01?12 12?1? ????? ????1 --100 ---?0 010?? ???0? ??100

*Sauripterus* ?1011 01111 1201? ??00? 1??11 --100 ---?? ????? ????? ??1??

*Screbinodus* ?1011 01??? 1?01? ??00? ???11 --100 ---?0 ?1000 ?1?00 10100

*Strepsodus* ?1011 01?12 1201? 00000 11??1 --100 ---?0 0100? ?1?0? ?0100

*Acanthodes* ?---- 1--?- 0?000 10001 -010? -000- ---?- ?---? ----- -?00-

*Acanthostega* 11011 0?1?2 11010 -100? 12110 -010- ---?0 ?2000 --000 10-00

*Achoania* ????? ????? ????? ????? ????? ???11 ?0??0 ?1?10 -0?11 ???11

*Cheirolepis* ?0X10 0011Y 0??0? 10010 10??0 ?010- ---?0 10000 0-1?X 01100

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*Diplocercides* 1?011 00??? ????? 00000 11101 --10- ---00 ?00?1 010?0 --100

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*Dipterus* ?1011 01??? 1?111 00000 10011 --110 111?0 00100 0-0-- --100

*Eusthenopteron* 11011 01111 11000 00100 11111 --10- ---00 01000 -0000 10100

*Gavinia*  ????? ????? ????? ?0000 100?1 --10- ---?? ??0?1 ????0 ??10?

*Glyptolepis* 11011 01?X0 10111 00000 10001 --10- ---00 ?3000 10000 1010?

*Gogonasus* 11?1? 01??? 11000 ?01?0 ?0??0 10110 0X?00 01000 -0000 10100

*Howqualepis* ?0110 00??? 0??00 10010 10100 0110- ---?? ?0010 --1?1 0?110

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*Kenichthys* ???11 0???? ????? ??1?? ????0 10110 ?01?0 ?1000 -0000 10101

*Latimeria* 11000 01000 100X1 00000 11101 --10- ---00 00001 00000 --100

*Megalichthys* 11011 01?11 11000 00100 10100 ?0110 ??1?? ?1000 00010 1?100

*Miguashaia* ?1000 00??? ????? 00000 10?01 --10- ---?? ?0001 010?0 ??101

*Mimia* 00110 0011Y 00?00 10010 00000 0110- ---01 10000 --101 01100

*Moythomasia* 00110 0011Y 00?00 10010 00000 0110- ---01 100X0 --101 01100

*Neoceratodus* 01011 0?000 10111 ?100? ?2001 --00- ---10 ?0100 0-?-- --100

*Onychodus* 01010 00000 10??? 00000 11?01 --10- ---?0 00000 01011 01110

*Osteolepis* 11011 011?? ????? 00100 10100 10110 00100 0?000 -00?0 1010?

*Panderichthys* 11011 011?2 11000 -1000 12110 1010- ---00 02000 ?-000 10100

*Porolepis* ?1011 01??? ????? 00010 00??0 10110 10110 03000 10000 1010?

*Powichthys* 0??11 0??1? ????? ????? ????0 10110 10110 01000 -?010 ???01

*Psarolepis* 0??X0 10?00 0???? ????1 ????? ??111 000?0 ?1010 -0?11 01?11

*Rhizodopsis* 1??11 01111 11000 00100 10?0X ?01X0 ????? ???00 000?0 1?100

*Shoshonia* ????? 0???? 1?001 ????? ????1 --?0- ---?? ????? ????? ?????

*Strunius* ???10 00?0Z ????? 00000 11?01 --10- ---?0 ?000? 00011 01111

*Styloichthys* ???10 01?11 1???? ????? ????? ??111 00??0 ??000 -10?? 10?00

*Tiktaalik* ?1011 0???2 11011 -100? ??110 ??10- ---?? ?2??0 --0?? 10000

*Uranolophus* ??011 01?11 ????? 00010 ?0100 10110 11010 00100 0-0-- --100

*Youngolepis* 0??11 01?11 1???? ????? ????0 10110 10110 01000 1-000 10?01

**155 160 165 170 175 180 185 190 195 200**

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*Barameda* 2???0 ?1??? 1000? ????? ????? ??100 0??01 00110 ?0?11 00?-1

*Gooloogongia* 2???? ????? ????? ??00? ????? ??100 00?0? 0011? ?0001 000?1

*Rhizodus* 2200? ?1??? ??-?? ????1 ????? ??10? 00??1 ???10 0??11 00?-1

*Sauripterus* 2???? ????? ????? ????? ????? ??100 0???? ???1? ?0011 000-1

*Screbinodus* 22?0? ????? 1?-?? 1??0? ????? ??100 0??01 00-1? ?0011 000-1

*Strepsodus* 220?? ????? ??-?? ????? ????? ??100 00??1 ???10 ?0011 000-1

*Acanthodes* ---0- 000-- ----- 1???- 0??00 ?10-- 1?00- ----- ----- 0-000

*Acanthostega* 22000 01??1 1000? 1?00- --101 01100 00?10 11?11 11000 0??-1

*Achoania* 10000 ????? ?0110 0200? ????? ?1??? ????0 ???00 ????? ?????

*Cheirolepis* 11000 10??- 0001? 0???? ????1 1?101 0?000 00?00 ?0?10 0000?

*Diabolepis* -?0?0 ????- ?0011 0000? 11?1? ????? ??200 ???00 -???? ?????

*Diplocercides* Z?111 01101 ?0011 01000 11011 00110 ???10 ?1?00 10?00 ?????

*Dipnorhynchus* --00? ????- ?---- 0??00 ?1001 01??? ???1- 00?00 -0??? ?????

*Dipterus*  --00? ????- ?---- 0??0? ?0001 00102 0021- 00?00 -000? 111?1

*Eusthenopteron* 22000 01111 10001 00001 11101 01100 00?10 00?01 10100 000-1

*Gavinia* 2??1? ?1??? ????? ????0 ????? ??110 ????0 00?0? ????? ?????

*Glyptolepis* 220?0 01100 10001 0110? 11??0 0?100 00?00 00000 00000 011?1

*Gogonasus* 22000 01110 10001 00001 11101 011?? 0??00 00000 001?? ?10-1

*Howqualepis* 1?000 ?0??- 01011 ????? ??1?1 11101 11?00 00?00 ?0?10 000??

*Ichthyostega* 22000 01??1 10001 ????- --101 01100 00?10 11?11 11?00 0??-1

*Kenichthys* 220?0 ????? ?0001 00??? ????? ????? ???00 00000 00??? ?????

*Latimeria* 20111 01101 00010 ?1000 11000 00100 00?10 ?1?00 10000 101-1

*Megalichthys* 22000 0???0 10001 01?0? ??0?1 0?100 00?01 00?11 00100 010-1

*Miguashaia* 2?111 0???? ????? ????? ????? ??110 00?00 ?0?00 1000? 0X???

*Mimia*  11000 110-- 01001 0001- 01101 11102 11000 00?00 00?10 0X010

*Moythomasia* 11000 110-- 01011 0001- 01101 11102 11000 00?00 ?0?10 0X010

*Neoceratodus* --000 ?00-- ----- ???0? ?000? 000-- 00?0- 00?00 -1000 1-1-1

*Onychodus* 11000 ?0??? 0X100 0000? 1?110 ?1100 ???01 00100 00000 ???-1

*Osteolepis* ??0?? ?1??? ?0?01 000?1 11?0? ??100 00200 0000? ?010? 000??

*Panderichthys* Y2000 ?0111 10001 00001 11101 0?100 00?10 00?11 10100 000-1

*Porolepis* 220?0 01100 ?0000 0110? 111?0 0?100 00200 00000 ?0?00 0?1??

*Powichthys* 1?000 0???0 10001 0000? 111?1 01??? ??200 0?000 00?0? ?????

*Psarolepis* 10000 ????? ?0100 0200? 11?00 ?1??? ??100 ???00 0??00 ?????

*Rhizodopsis* Y?0?? ????? ????? 0?001 11001 00100 00?01 00?1? ?0?00 010-1

*Shoshonia* ????? ????? ????? ????? ????? ??110 0???? ????? ????? ?00?1

*Strunius* 1?0?0 ????? ????? ????? ????? ??100 11?00 ???00 ?0?00 0?0??

*Styloichthys* 2?111 ????? ?0011 01000 1?011 0???? ??10? ???00 ???00 ?????

*Tiktaalik* 22000 ??????000? ????? ????? ??100 00?1? 01?11 11100 000-1

*Uranolophus* --000 ????- ?000? 0???? ??0?1 0?100 ??21- ???00 -??00 ?????

*Youngolepis* 12000 ????? ?00X1 00001 11111 01??? ??200 ?0000 0??00 ?????

205 210 215

. . .

*Barameda* 1?110 11010 01?01 ?

*Gooloogongia* 10??? ?1??0 01??1 1

*Rhizodus* 1?110 11010 01??1 ?

*Sauripterus* 10110 11000 01?01 1

*Screbinodus* 101?? ??0?? ?1??1 ?

*Strepsodus* 10110 110?0 01?11 1

*Acanthodes* 00-?- -0--- -0?0? 0

*Acanthostega* 11?01 11010 01-0- ?

*Achoania* ????? ????? ????? ?

*Cheirolepis* ????? ????? ???0- 0

*Diabolepis* ????? ????? ????? ?

*Diplocercides* ????? ????? ???00 0

*Dipnorhynchus* ????? ????? ????? ?

*Dipterus* 0???? ????? ?0000 0

*Eusthenopteron* 00-00 11000 10101 0

*Gavinia* ????? ????? ??000 ?

*Glyptolepis* 01000 011?1 00000 0

*Gogonasus* 00?00 11000 10??- ?

*Howqiualepis* 00??? ????? ???0- 0

*Ichthyostega* ?1?01 11010 01-0? ?

*Kenichthys* ????? ????? ????- ?

*Latimeria* 01000 01011 00?00 0

*Megalichthys* 0??00 11000 1011- ?

*Miguashaia* ????? ????? ???00 0

*Mimia* 00-?- -0--- -0?0- 0

*Moythomasia* 00-?- -0--- -0?0- 0

*Neoceratodus* 10100 011?0 00?00 0

*Onychodus* ???00 100?? ??000 0

*Osteolepis* ????? ????? ??00- 0

*Panderichthys* 00?01 11010 00-0- 0

*Porolepis* ????? ????? ???0- 0

*Powichthys* ????? ????? ????- ?

*Psarolepis* ????? ????? ????? ?

*Rhizodopsis* ?0?00 11000 10111 ?

*Shoshonia* 000?? ????1 00??0 ?

*Strunius* ????? ????? ???0? 0

*Styloichthys* ????? ????? ????? ?

*Tiktaalik* 10001 11010 00-0- ?

*Uranolophus* ????? ????? ???0- 0

*Youngolepis* ????? ????? ????- ?

## Appendix 2: Data for the analysis of rhizodontid interrelationships

### Selected species

The seven best known rhizodontid taxa were selected; the Devonian species *Aztecia mahalae*, *Gooloogongia loomesi* and *Sauripterus taylori*, and the Carboniferous species *Rhizodus hibberti*, *Screbinodus ornatus* and *Strepsodus sauroides*. The two species of *Barameda* (*B*. *decipiens* and *B*. *mitchelli*) were treated as a combined, genus–level OTU, because where comparisons were possible there were few differences with respect to the character set. Two species of rhizodontids were not included in the analysis (*Archichthys portlocki* and *Letognathus hardingi*) because not enough material has been described to allow for a reasonably complete data set. The outgroup taxa were selected with reference to their phylogenetic position on the sarcopterygian analysis (see above) and the quality of the published sources. These are the Devonian porolepiform *Glyptolepis groenlandica*, the osteolepid *Medoevia lata* and tristichopterid *Eusthenopteron foordi* (both Devonian), and the Carboniferous Megalichthyid *Cladarosymblema narrienense*.

### Character scores

The following characters were used in the phylogenetic analysis. All characters were treated as unordered. *Rhizodus hibberti*, *Screbinodus ornatus* and *Strepsodus sauroides* were mostly scored from personal observations. The remaining species were mostly scored from the following sources; *Aztecia mahalae* (Johanson 2004; Johanson & Ahlberg 2001); *Barameda* sp. (Garvey *et al.* 2005; Holland *et al.* 2007; Johanson & Ahlberg 2001; Long 1989); *Cladarosymblema narrienense* (Foxet al*.* 1995); *Eusthenopteron foordi* (Jarvik 1944a, b; 1980; Schultze 1969); *Glyptolepis groenlandica* (Ahlberg 1989; Jarvik 1972); *Gooloogongia loomesi* (Johanson & Ahlberg 1998, 2001); *Medoevia lata* (Lebedev 1995); *Sauripterus taylori* (Davis *et al.* 2001, 2004). The use of a character in a previously published matrix is noted using the following abbreviations: JA98 = Johanson & Ahlberg (1998); J99 = Jeffery (1999); JA01 = Johanson & Ahlberg (2001); J04 = Johanson (2004); B05 = Brazeau (2005); P05 = Parker *et al.*(2005); H07 = Holland *et al*. (2007). Additionally, several synapomorphies of the pectoral girdle in rhizodontids were first highlighted in Andrews & Westoll (1970), although not within a formal cladistic framework. This is noted by the abbreviation AW70.

### Character list

1. Premaxillary tusk: absent (0), present (1).

Character history: JA99 character 3; J99 character 2; JA01 character 3; B05 character 15. (Internal ID CH02095)

1. Dentary tusks: absent (0), present (1).

Character history: J99 character 42; B05 character 2; H07 character 14 (modified). (Internal ID CH02114)

1. Cross section of fangs and teeth: round/oval (0), lenticulate (1).

*G*. *groenlandica* is poorly illustrated in Jarvik (1972), but the fangs appear to be round (e.g. coronoid tusks on plate 18). The tusks and fangs are definitely round in *G*. *paucidens* (e.g. Ahlberg 1989, fig 25). Character history: J99 character 57; B05 character 8 (edited); H07 character 17 (approx.). (Internal ID CH02118)

1. The replacement pair of the fangs in the palate and mandible: separate sockets (0), share a single, oversized socket (1).

The score for *Barameda* is tentative, based on Long (1989, figs 4a, 6a). Ahlberg (1989, p. 118) stated that the mesial face of the jaw of *G*. *groenlandica* (Ahlberg 1989, p. 119, fig. 25) and *Glyptolepis* sp. ‘Thurso’ (Ahlberg 1989, p. 121, fig. 26) showed separate sockets. Character history: J99 character 53. (Internal ID CH02115)

1. Marginal tooth rows on dentaries: complete and meet mesially (0), diastema at the symphysis or by the symphysial tusks, not caused by presence of median bones (1), tooth row interrupted by presence of median bones (2).

The score in *Screbinodus* is tentative, based on SME 4714. The score in *Gooloogongia* is based on Johanson & Ahlberg (2001, fig. 5) and Martin Brazeau, (pers. comm.). Character history: B05 character 4 (modified from Jeffery (2003) mapping character 3). (Internal ID CH02157)

1. Parasymphysial denticle field: reaches posterior margin of the parasymphysial (0), does not reach posterior margin of the parasymphysial (1).

Character history: JA01 character 2. (Internal ID CH02109)

1. Precoronoid (anterior mandibular) fossa: absent (0), present (1).

The score in *Strepsodus* is tentative, based on NEWHM G19.18 and NMS G 1975.48.31. Ahlberg (1989, p. 118) stated that the mesial face of the jaw of *G*. *groenlandica*‘does not appear to differ significantly from those of other holoptychiids’; the fossa is absent is *G*. *paucidens* (Ahlberg 1989, p. 119, fig. 25) and *Glyptolepis* sp. ‘Thurso’ (Ahlberg 1989, p. 121, fig. 26). Character history: J99 character 46; B05 character 17; H07 character 8. (Internal ID CH02111)

1. Parasymphysial bone: contacts the coronoid (0), does not contact coronoid (1).

The condition is *G*. *paucidens* is not well figured or described in the literature (e.g. Ahlberg 1989, p. 118; Jarvik 1972, p. 118) but Johanson & Ahlberg (2001, p. 73) scored the parasymphysial bone as not contacting the coronoid in their cladistic data table. Character history: JA99 character 1; JA01 character 1; H07 character 5. (Internal ID CH02108)

1. Coronoid fangs: straight (0) or recurved (1).

The fangs are only slightly recurved in *Eusthenopteron*. Character history: J99 character 56. (Internal ID CH02117)

1. Body of the first coronoid: shallow with a lingual lamina (0), deep dorsoventrally without lingual lamina (1).

The shape of the coronoid in *Cladarosymblema* is assumed from the external appearance of the jaw (Fox *et al.* 1995, p. 168). Character history: J99 character 45; B05 character 22 (approx.); H07 character 7 (approx.). (Internal ID CH02110)

1. Cross-section of the mandible at the level of second coronoid: square or wide (0), dorsoventrally deep (1).

Character history: J99 character 40; B05 character 18 (approx.); H07 character 11 (approx.). See Jeffery (2003, fig. 3) for an illustration. (Internal ID CH02105)

1. Meckelian bone: poorly ossified (0), well ossified (1).

Character history: J99 character 48; B05 character 5 (approx.); H07 character 6 (approx.). (Internal ID CH02106)

1. Intramandibular canal: open along its ventral edge (0), closed except for 1 to 3 Meckelian foramina (1).

The score for *Medoevia* is tentative, based on Lebedev (1995, p. 319). Character history: J99 character 49. (Internal ID CH02107)

1. Fourth infradentary: makes little or no contribution to dorsal margin of the adductor fossa (0), forms about half of the dorsal margin (1).

Character history: J99 character 41. (Internal ID CH02113)

1. Deepest (dorsoventral) part of maxilla: posterior to the jugal (0), adjacent or anterior to jugal (1).

*Gooloogongia* lacks a posterior process on the maxilla (Johanson & Ahlberg 2001, p. 49). Character history: J99 character 7 (edited). (Internal ID CH02097)

1. Preopercular: tall-and-thin (0), sub-rhomboid (1).

The preopercular is unknown in *Screbinodus* and *Cladarosymblema* and the scores are based on the shape of the surrounding bones. Character history: JA99 character 9; J99 character 9 (edited); JA01 character 7. (Internal ID CH02098)

1. Pineal foramen: open (0), closed (1).

The score in *Screbinodus* is tentative, based on SME 4714. Character history: J99 character 19. (Internal ID CH02099)

1. Dermocranial joint: closely-fitting/interdigitated (0), loosely fitting (1).

The joint in *Gooloogongia* appears to be more closely fitting than in*Barameda* or *Screbinodus*, and has an additional 4-5mm ‘shelf’ projecting from parietals Johanson & Ahlberg (2001, p. 49). Character history: JA99 character 5; J99 character 20. (Internal ID CH02100)

1. Articulation of intertemporal and supratemporal: short (0), long and oblique (1).

The interpretation of the intertemporal is tentative in *Screbinodus* (see main text), but the position of the postorbital and the supratemporal suggests a long and oblique articulation. The postparietal shield is largely fused in *Medoevia*, but the overall contact of intertemporal and postparietal shield is short Lebedev (1995, pp. 296, 307). *Glyptolepis* lacks both a supratemporal and intertemporal.

Character history: J99 character 21. (Internal ID CH02102)

1. Extratemporals: absent (0), present (1), present and in contact with the supratemporal (2).

Separate extratemporals are not readily visible beneath the cosmine in *Medoevia*. The presence of the extratemporals in *G*. *groenlandica* is based on Jarvik (1972, p. 109), following Ahlberg’s (1989) reinterpretation of the bone homology. Character history: JA99 character 8; J99 character 18; JA01 character 6; H07 character 3. (Internal ID CH02103)

1. Main otic lateral line canal: runs only through the temporal series (0), also has a diversion through the postparietals (1).

Although the course of the canal is not clear in *Gooloogongia*, it ‘does not appear to cross onto the postparietal or extend in this direction’ (Johanson & Ahlberg 2001, p. 49). Very little data on the course of the canals is available for *Medoevia*. It is difficult to assess the condition in *Glyptolepis* because of the loss or fusion of the elements in the postparietal shield. Character history: JA99 character 7; J99 character 16; JA01 character 5; H07 character 1. (Internal ID CH02104)

1. Posterior end of postparietals: straight with median and lateral extrascapular in line (0), postparietal ‘tail’, with lateral extrascapulars extending anterior to the median extrascapular (1).

The condition in *Rhizodus* is unclear, *contra* Andrews (1985). Character history: JA99 character 6; J99 character 11; H07 character 2. (Internal ID CH02119)

1. Ventral lamina of cleithrum: small (0), expanded in width relative to the dorsal lamina (1).

The ventral lamina of *G*. *groenlandica* is long but not expanded (see Jarvik 1972, pl. 18.2).

Character history: AW70; J99 character 63; JA01 character 11; P05 character 3; H07 character 22. (Internal ID CH02123)

1. ‘Waist’ in the cliethrum near angle of dorsal and ventral laminae: absent (0), present (1).

The cleithra of *Aztecia* and *Sauripterus* are only slightly waisted. Character history: JA01 character 10; P05 character 2; H07 character 21. (Internal ID CH02122)

1. Posterior flange of the cleithrum: flange absent (0), present, weakly developed, tapers away dorsally (1), present, well developed, and tapers away dorsally (2), present, robust and confluent with the postbranchial lamina (3).

Character history: AW70; JA99 character 12; J99 character 64 & 65; JA01 character 9 (approx.); P05 character 1 (approx.); H07 character 20. (Internal ID CH02124)

1. Mesial part of cleithrum: overlaps internal to the clavicle (0), overlaps external to the clavicle (1).

The score for *Glyptolepis* is based on Jarvik (1972, p. 128, pl. 18.2). See also Ahlberg (1989, p. 231), where a groove in the clavicle to receive the cleithrum is only present laterally.

Character history: AW70; JA99 character 15; J99 character 62; JA01 character 13; P05 character 6; H07 character 23. (Internal ID CH02121)

1. Anocleithrum: positioned superficially (0), positioned subdermally (1).

The score for *Aztecia* is tentative, following the conclusions of Johanson & Ahlberg (2001, p. 62, fig. 15c). The score for *Screbinodus* is tentative, based on the close similarity of the anocleithrum on SME 4714 to those of *Strepsodus* (e.g. Parker *et al.* 2005). Character history: JA99 character 16; J99 character 70; JA01 character 14; P05 character 7 (approx.). (Internal ID CH02120)

1. Sensory pores on the cleithrum: absent (0), lateral line pores present (1), pit-lines present (2).

Character history: J99 character 66; JA01 character 24; P05 character 18. (Internal ID CH02125)

1. Scapulocoracoid: in ventral position on cleithrum, close to angle of ventral and dorsal laminae (0), more dorsally positioned (1).

The position of the scapulocoracoid in *Gooloogongia* is tentative, based on position of the fin-base (cf. Johanson & Ahlberg 2001, p. 54). The score for *Glyptolepis* is based on *G*. *baltica* (cf. Jarvik 1972, fig. 53g). Character history: JA99 character 13; JA01 character 12; P05 character 4. (Internal ID CH02126)

1. Caput humeri: ovoid or saddle-shaped (0), semi-spherical end to body of humerus (1), ball separated from body of humerus by a neck (2).

The humerus is too poorly preserved in *G*. *groenlandica* to score this character with any certainty. Character history: JA99 character 17; J99 character 77 (edited); JA01 character 15 (approx.); P05 character 8; H07 character 24 (modified). (Internal ID CH02127)

1. Ulnal and radial condyles: distinct (0), largely continuous (1)

Only one mesomere contacts the humerus in *Glyptolepis* and so there is only one distal condyle.

Character history: J04 character 28. (Internal ID CH02215)

1. Contact between dorsal ridge and ulnar condyle: absent (0), present (1).

The ridges on the humerus of *Glyptolepis* are not easily homologised with the ridges on the humeri of stem-tetrapods.

Character history: P05 character 12; H07 character 26. (Internal ID CH02131)

1. Ectepicondyle and dorsal ridges arranged to form a ‘v’: absent (0), present (1).

The score for *Aztecia* is tentative, based on Johanson (2004, figs 4, 5). The ectepicondyle is not clear on the humerus of *Barameda* (Garvey *et al.* 2005) or *Rhizodus* (Jeffery 2001). In *Strepsodus* the ridges converge but may or may not actually meet (cf. Jeffery 2001; Parker *et al.* 2005). The ridges on the humerus of *Glyptolepis* are not easily homologised with the ridges on the humeri of stem-tetrapods.

Character history: P05 character 13; H25 character 30. (Internal ID CH02132)

1. Pectoral lepidotrichia: jointed along their whole length (0), unjointed for their proximal half (1), unjointed for over 90% of their length (2).

Character history: JA99 character 23; J99 character 71; JA01 character 19; P05 character 17; H07 character 30. (Internal ID CH02129)

1. Tail: heterocercal (0), diphycercal (1).

Character history: JA99 character 29; JA01 character 22. (Internal ID CH02130)

### Data matrix

**5 10 15 20 25 30 35**

**OTU [Missing/Uncertain] . . . . . . .**

Aztecia [25 chars, 71.4%] ????? ????? ????? ????? ???11 11111 101??

Sauripterus [21 chars, 60.0%] ?1??? ????? ????? ????? ??110 11111 10021

Rhizodus [11 chars, 31.4%] 11111 ?0101 1001? ????? ??113 1?112 0002?

Barameda [12 chars, 34.3%] 11001 1?01? ????? ?0112 01112 1??12 01?2?

Screbinodus [11 chars, 31.4%] 11111 ???0? 1??11 00110 11112 1121? ???2?

Gooloogongia [13 chars, 37.1%] 010?0 0?01? ????1 10002 01?00 ?111? ???10

Strepsodus [7 chars, 20.0%] 11011 10111 100?? ????? 11112 11112 01121

Glyptolepis [7 chars, 20.0%] 00002 00110 011?1 110?1 ?0000 1101? ???00

Cladarosymblema [5 chars, 14.3%] 11001 01010 01100 11011 00000 0000? ???0?

Eusthenopteron [2 chars, 5.7%] 00000 ?1?10 01100 00000 00000 00000 00001

Medoevia [7 chars, 20.0%] 10000 010?0 01100 0000? ?0000 00000 ??1??