Supplementary table 1: details on specimens scanned

Taxon	Specimen number	Scan Location	Scanner Model	Voxel size (*μ*m)	Current (*μA)*	Power (kV)	Filter	Projections
Acanthodes	NHMUK PV P.8065	Department of Life Sciences, Bristol University	Nikon XT H 225 ST	44.9	165	215	0.1 mm Sn	3142
Acanthodopsis	NHMUK PV P.10383	Department of Life Sciences, Bristol University	Nikon XT H 225 ST	22.6	92	180	None	3142
Atopacanthus	NHMUK PV P.10978	Imaging and analysis centre, NHMUK	Metris X-Tek HMX ST 225	19.508	154	130	0.1 mm Cu	3142
Ischnacanthus	NHMUK PV P.40124	Department of Life Sciences, Bristol University	Nikon XT H 225 ST	24.6	105	222	0.5 mm Cu	3142
Taemasacanthus	NHMUK PV P.33706	Imaging and analysis centre, NHMUK	Metris X-Tek HMX ST 225	17.3	131	130	0.1 mm Cu	3142

Notes on phylogenetic analysis

Changes made to the phylogenetic matrix of Dearden *et al* are detailed below.

Taxon addition: *Acanthodopsis*

Of the taxa in our list *Acanthodopsis* is the only one with sufficient characters to code into the wider matrix. Scorings were taken from our data and Burrow (2004).

Character addition (character 268): Mandibular splint:

(0) absent, (1) present.

As discussed in the main text a mandibular splint, defined as a smooth dermal bone along the ventrolateral margin of the jaw, is present in acanthodid acanthodians.

Character addition (character 269): Dental plates with smooth occlusal surface:

(0) absent, (1) present

This is taken from character 261 of Burrow *et al.* (2016). The dermal jaw plates of putative diplacanthid stem-chondrichthyans are smoothly convex bones with a completely unornamented surface, as discussed in the main text. This character is inapplicable for taxa without dermal jaw plates.

Character addition (character 270): Expanded mandibular symphysis at anterior tip of Meckel's cartilage:

(0) absent, (1) present

As noted in the main text some acanthodids have an expanded region at the anterior end of the Meckelian cartilage. *Acanthodopsis* exhibits the same morphology as *Acanthodes* (RPD, pers. obs.). *Cheiracanthus* and *Homalacanthus* also appear to share the same form (see Burrow et al., 2020 fig 7.1; Miles, 1966 fig 16B). In *Halimacanthodes* the symphysis is rounded, but otherwise has the same morphology (Burrow et al., 2012).

Ischnacanthus and close relatives appear to lack this morphology (Blais et al., 2015; Burrow et al., 2018), as does *Promesacanthus* (Hanke and Wilson, 2004). Meckel's cartilages in most other acanthodian-grade stem-chondrichthyans are poorly known, but it appears to be absent in stem-chondrichthyans *Gladbachus*, *Doliodus*, and *Pucapampella* (Coates et al., 2018; Maisey et al., 2019; Miller et al., 2003).

This character is scored inapplicable for taxa with a fused mandibular symphysis.

Character addition (character 271): Scapular Process has expanded waist:

(0) absent, (1) present

In *Acanthodes* and *Acanthodopsis* the scapular process bulges outwards about halfway up its length (Burrow, 2004; Miles, 1973). This distinctive morphology is absent in other chondrichthyans and in other 'acanthodians', and notably absent in *Halimacanthodes*, which is otherwise anatomically similar to *Acanthodes* (Burrow et al., 2012). This character is contingent on having a scapular process.

Coding change: (character 114) Dorsal process on lower dermal jaw plate

This character was originally erected to capture a similar dorsal process between the "Meckelian elements" of *Tetanopsyrus* and *Uraniacanthus* (Brazeau, 2009; Hanke and

Wilson, 2004). This character has been redefined to explicitly refer to a lower dermal jaw plate rather than a "Meckelian bone or cartilage". It is inapplicable for taxa without a dermal jaw plate of the lower jaw.

Dorsal processes of the dermal jaw plate are only present in *Uraniacanthus* (Hanke and Davis, 2008; Newman et al., 2012) and *Culmacanthus* (Burrow and Young, 2012). *Tetanopsyrus* is coded 0 as its "dorsal process" is of the Meckelian element - the lower dental plate has no process (Hanke et al., 2001). *Diplacanthus* has in the past been scored present for this character (Davis et al., 2012): this is likely due to observation of the articular part of the Meckelian cartilage in NMS 1891.92.334 (Watson, 1937): its occlusal plate lacks a dorsal process (Burrow et al., 2016) and so it is scored 0. This character is sometimes coded present in the problematic gnathostome *Ramirosuarezia* (e.g. Coates *et al.* (2018)) on the basis of a dorsal process on what is interpreted as its Meckel's cartilage (Pradel et al., 2009). However this is non-homologous with the dermal plate of diplacanthids, evidenced by the fact that it bears tooth plates, and we score *Ramirosuarezia* is here scored 0 for this character.

Coding change: Jaw dermal plates (Character 94)

The scoring for *Culmacanthus* was changed from ? to 1 on the basis of it's having occlusal plates (Burrow and Young, 2012)

Coding change: Gnathal plates mesial (Character 95)

The scoring for *Culmacanthus* was changed from 0 to ? on the basis of its occlusal plates not being preserved in articulation with jaws (Burrow and Young, 2012).

Coding change: Tooth whorls (Character 84)

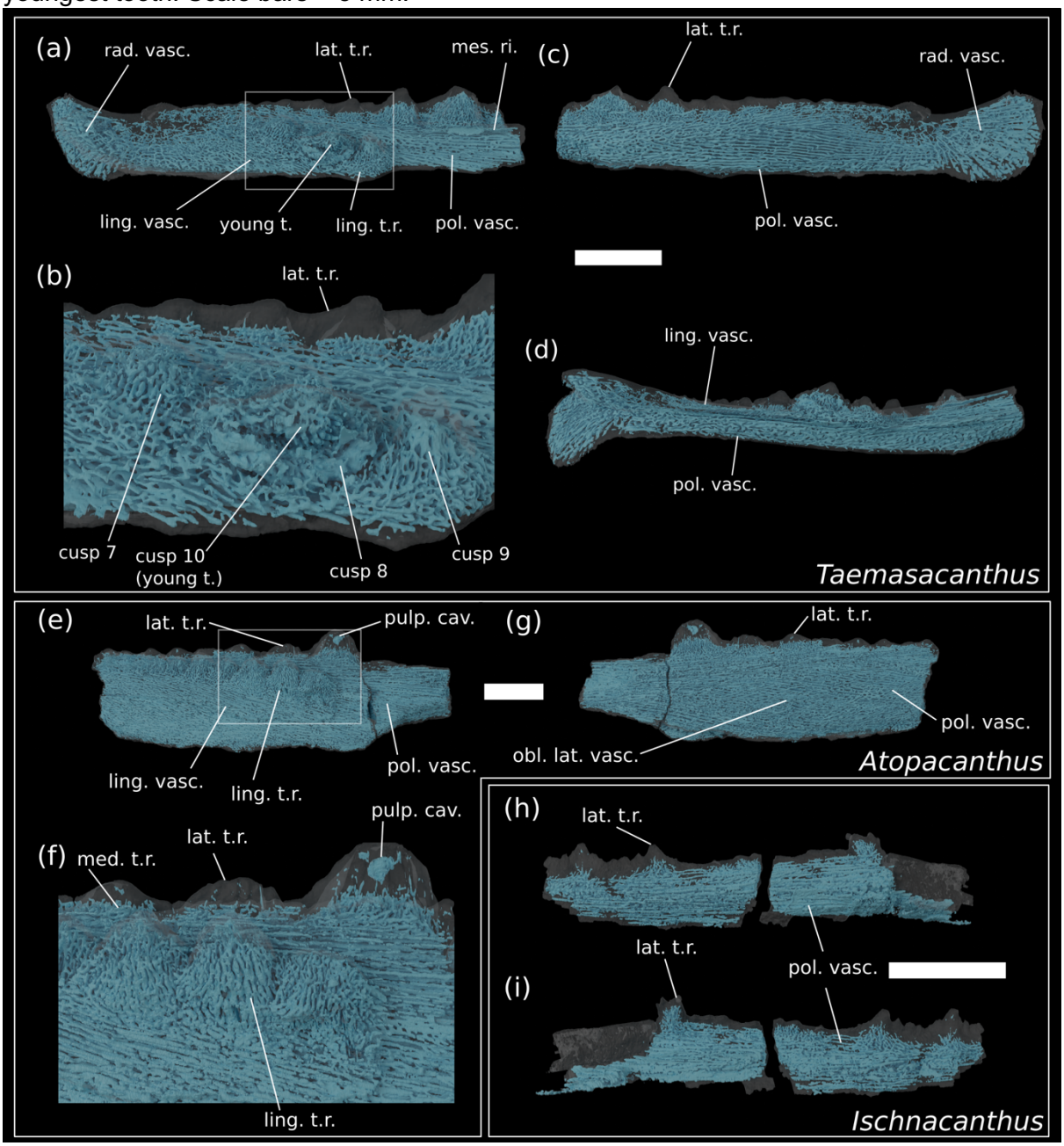
The scoring for *Lupopsyrus* and *Halimacanthodes* was changed from 0 to – as in other toothless taxa so as to be consistent with this character's contingency on having teeth.

Coding change: Oral tubercles on jaws (Character 82)

Tetanopsyrus is described as having teeth by Hanke, Davis and Wilson (2001) on the basis of an isolated pair of jaws (Hanke et al., 2001 fig. 3B) found close to the articulated *Tetanopsyrus lindoei* specimen UALVP 32571. These jaws are preserved in lingual view and comprise high-profiled Meckel's cartilages with a what are interpreted as smooth occlusal plates with a row of tooth-like tubercles on the lingual face. These isolated jaws do not belong to UALVP 32571 itself, which has lower jaws preserved in articulation (Hanke et al., 2001 fig. 3A) . They are attributed to *Tetanopsyrus* presumably on the basis of having a "smooth" occlusal plate (which is not seen in lingual view in any other published specimen) as well as a similarly profiled Meckelian cartilage. However, no clear characters place the jaws in the genus Tetanopsyrus.

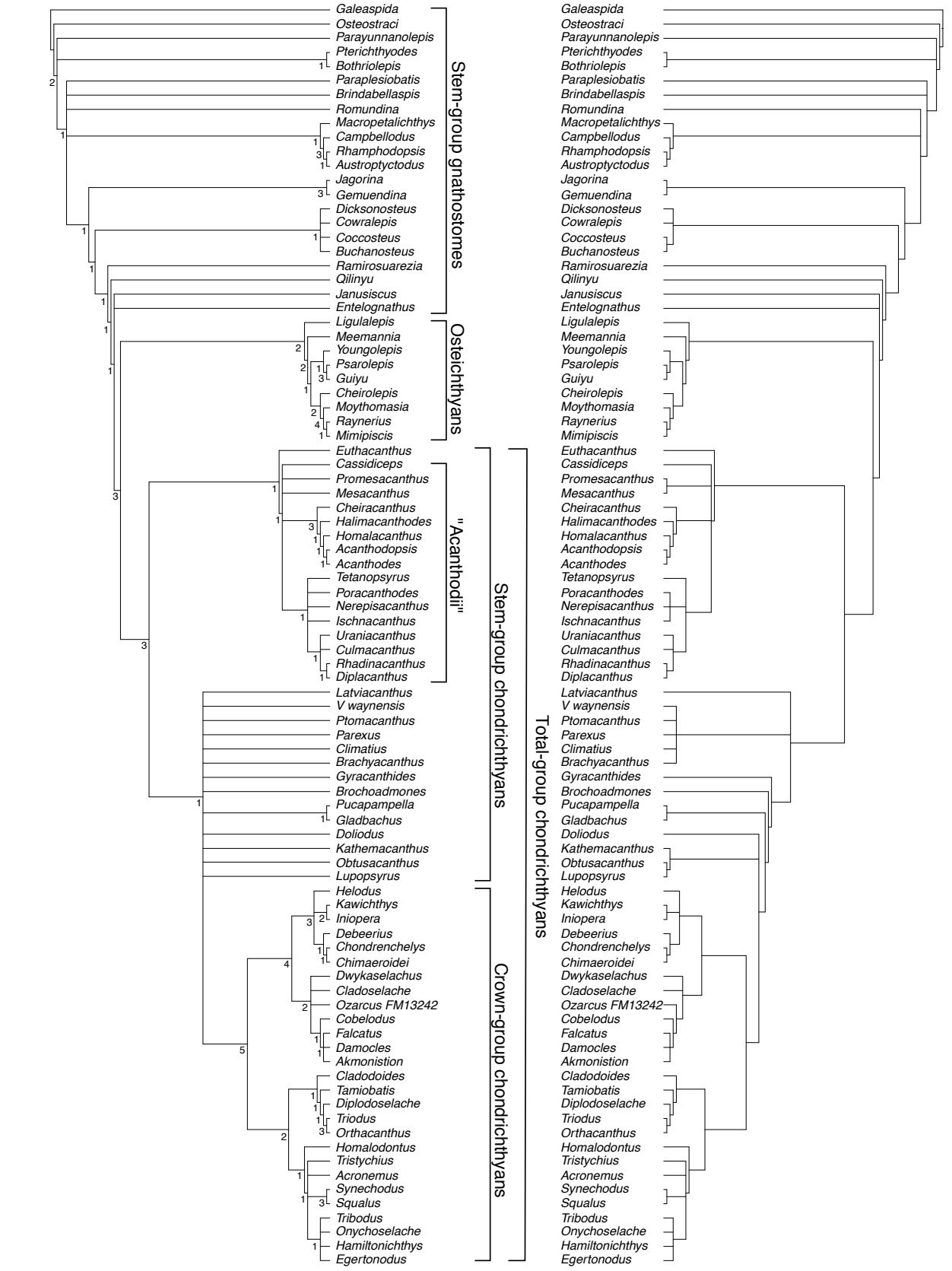
While these jaws may prove to belong to *Tetanopsyrus*, here we have taken a conservative approach, and have code *Tetanopsyrus* ? for the presence of teeth (character 82) and for all contingent characters.

Supplementary figure 1. Vasculature in dentigerous jaw bones in *Taemasacanthus* NHM PV P.33706 (a) medial view, (b) close-up of boxed area in (a), (c) lateral view, and (d) ventral view. *Atopacanthus* NHMUK PV P.10978 in (e) medial view, (f) close up of boxed area in (e) and (g) lateral view. *Ischnacanthus* NHMUK PV P.40124 in (h) lateral, and (i) medial view. Abbreviations: lat.t.r., lateral tooth row; ling.t.r, lingual tooth row; ling. vasc, lingual vasculature; med.t.r., medial tooth row; mes.ri, mesial ridge; pol. vasc, polarised vasculature; pulp. cav., pulp cavity; rad. vasc., radial vasculature; young.t, out-of-order youngest tooth. Scale bars = 5 mm.



Supplementary figure 2. Complete results of the parsimony analysis in main text Fig. 5. (a) strict consensus tree with Bremer support values on dichotomous nodes. (b) Adams consensus.

(a) (b)



Supplementary figure 3. Majority rule consensus tree for the Bayesian analysis of the phylogenetic dataset. Nodes are labelled with posterior probabilities.