Supplementary material for:

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Biomechanics of *Machaeracanthus* pectoral fin spines provide evidence for distinctive spine function and lifestyle among early chondrichthyans

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Figures S1-7

Table S1

Other Supplementary Materials for this manuscript include the following:

Data S1

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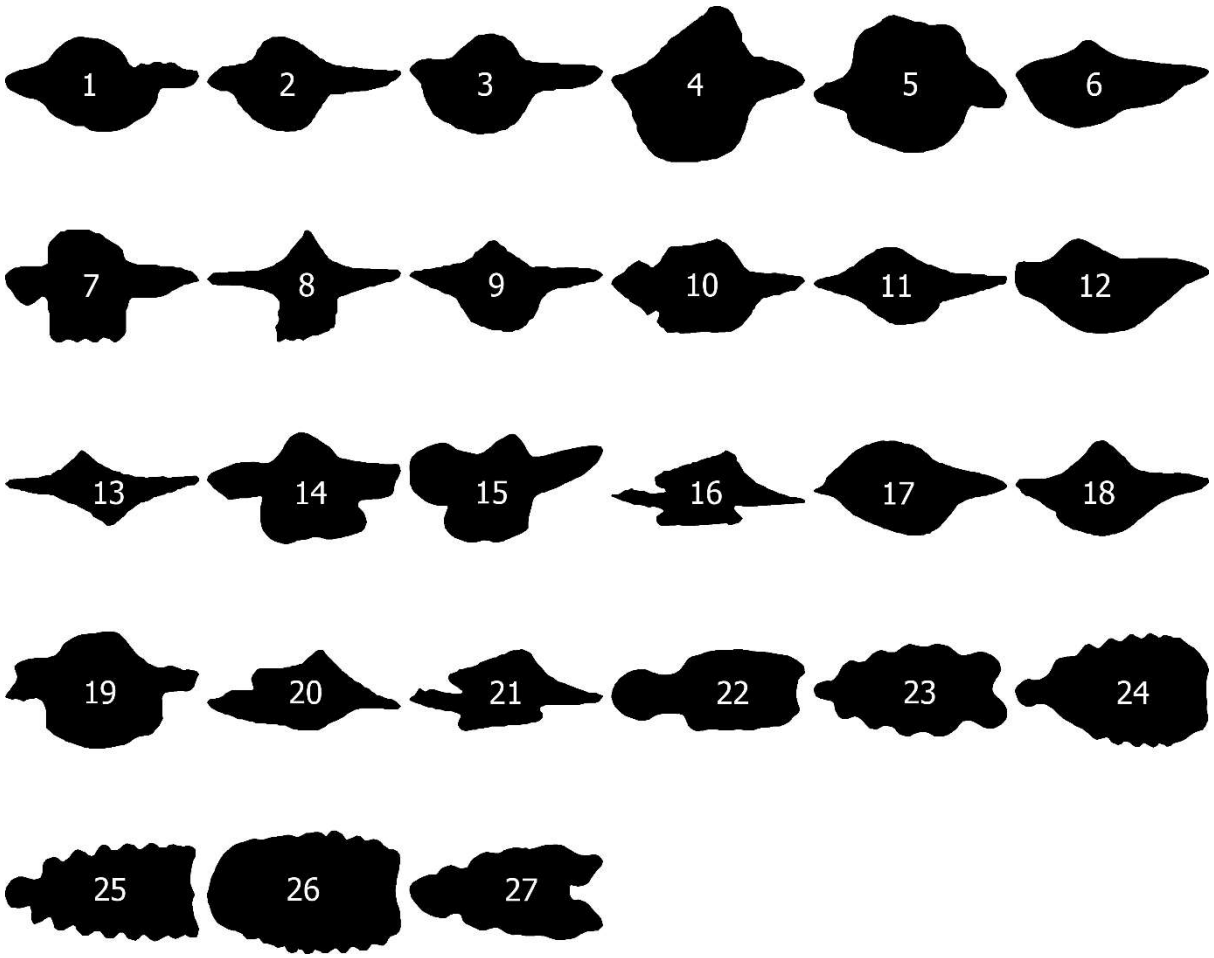

Figure S1. Mid-length spine cross-sectional outlines of the acanthodian taxa included in the Elliptic Fourier analysis. Numbers correspond to specimens in Table S1.

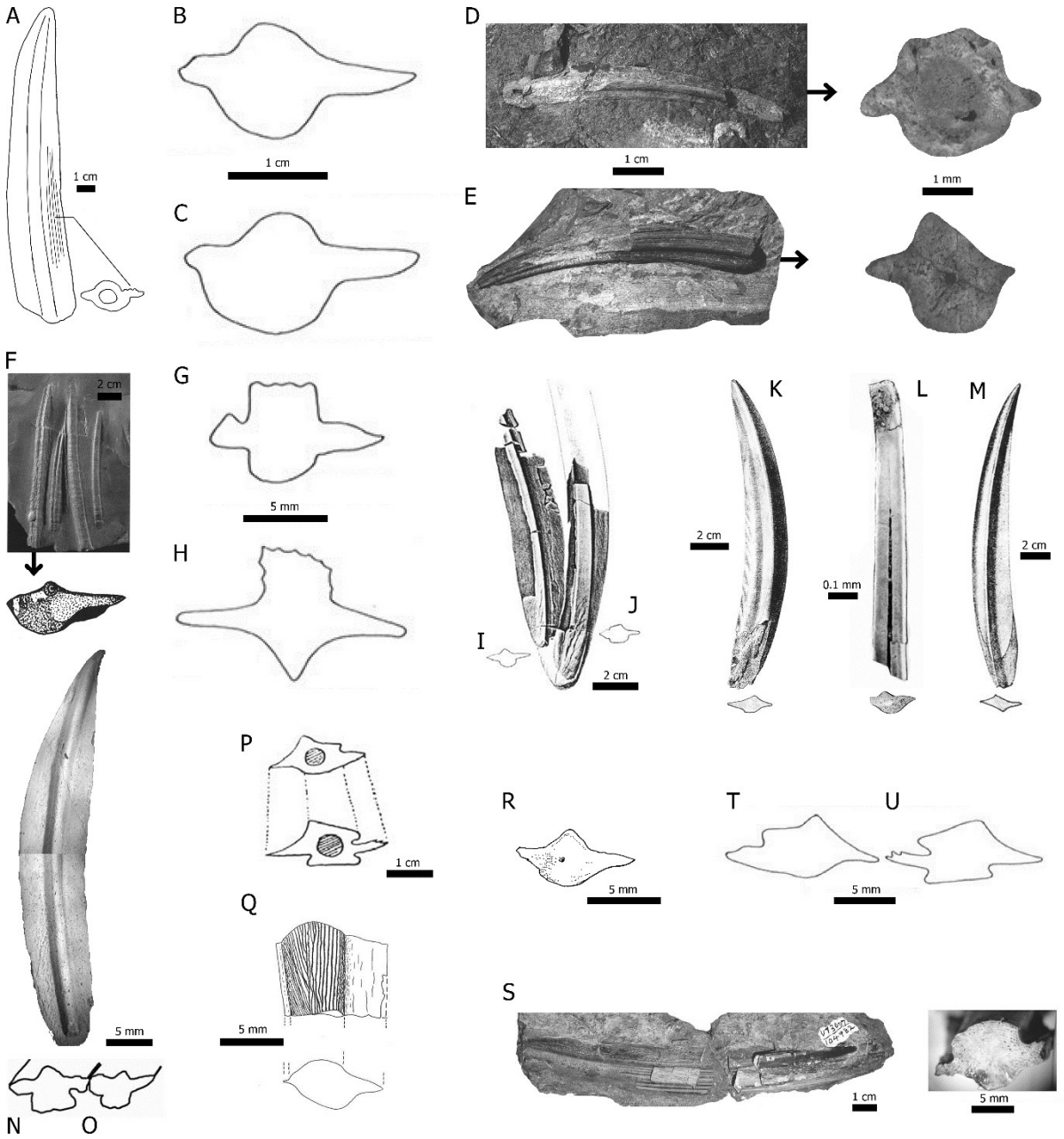

Figure S2. *Machaeracanthus* specimens considered on this study. A, *M. bezier*; B, *M. bohemicus*; C, *M. bohemicus*; D, *M. goujeti*; E, *M. goujeti*; F, *M. hunsrueckianum*; G, *M. kayseri*; H, *M. kayseri*; I, *M. longaevus*; J, *M. longaevus*; K, *M. major*; L, *M. pectinatus*; M, *M. peracutus*; N, *M. polonicus*; O, *M. polonicus*; P, *M. retusus*; Q, *M. sarlei*; R, *M. sp.*; S, *M. sulcatus*; T, *M. westfalicus*; U, *M. westfalicus*. References for sources in Table S1.

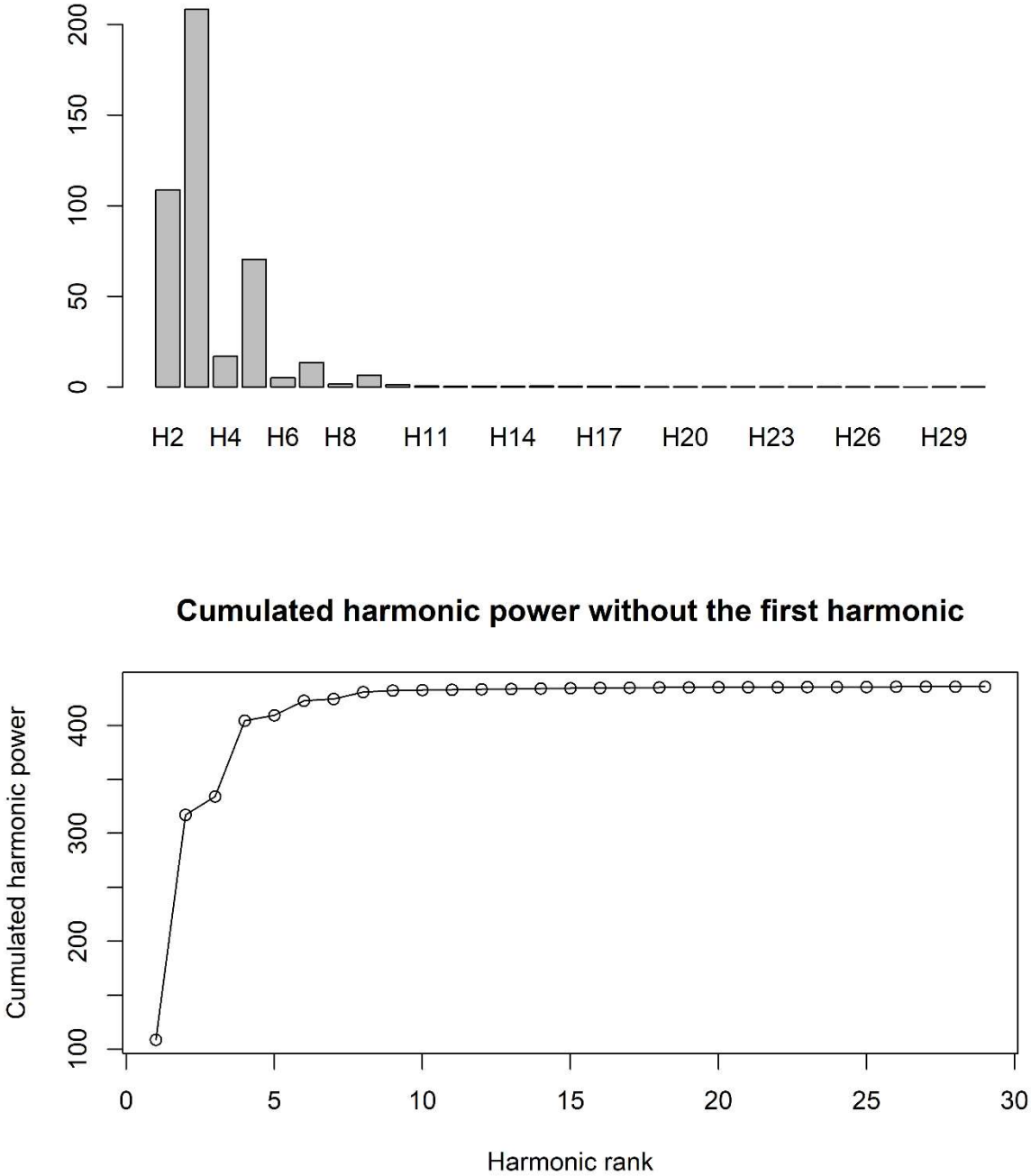

Figure S3. Cumulated harmonic Fourier power calculated from the mid-length spine cross-sectional outlines dataset.

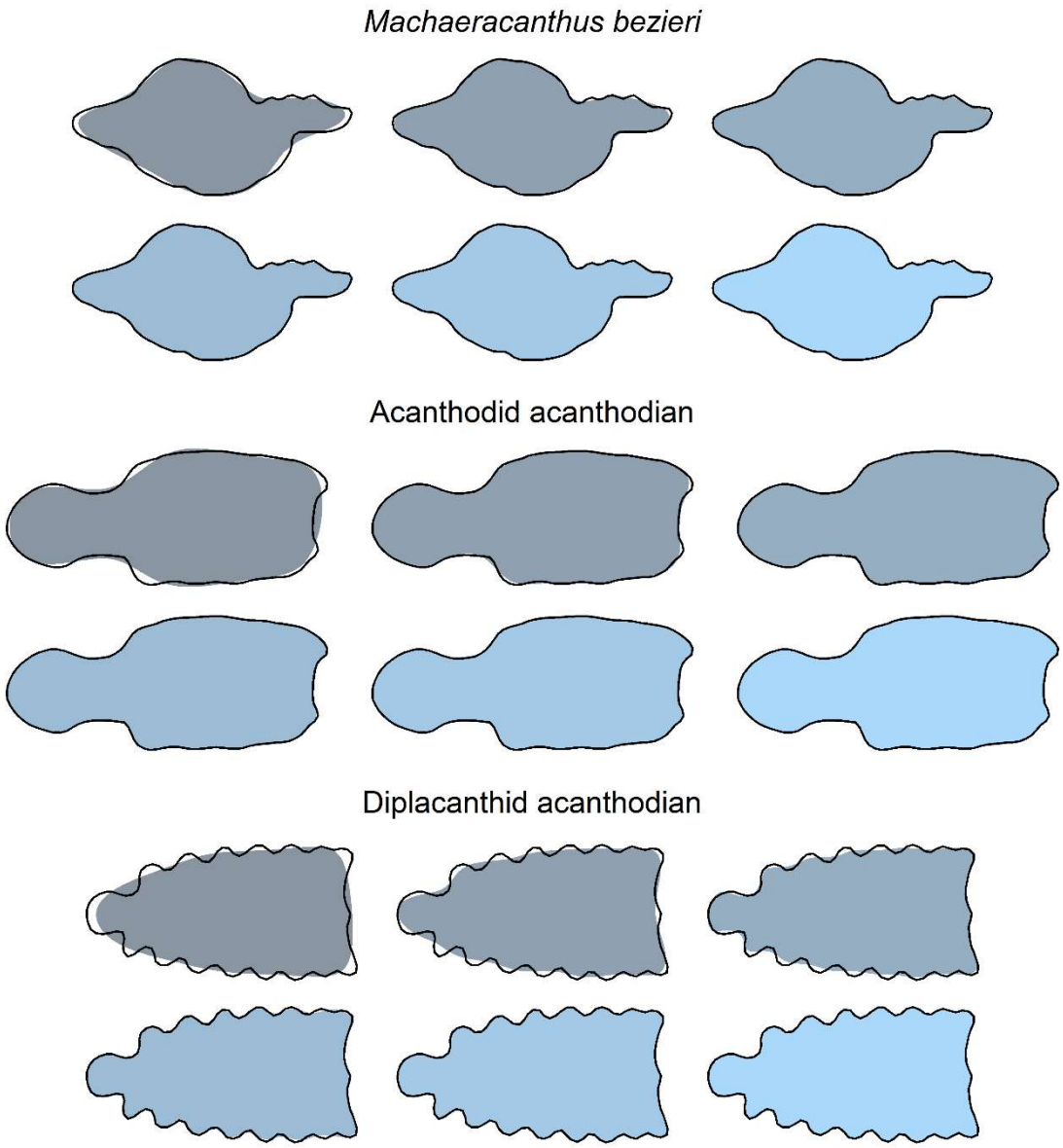

Figure S4. Three acanthodian mid-length spine cross-sectional outlines reconstructed from different numbers of harmonics (5, 10, 15, 20, 25 and 30, from left to right and top to bottom) (from top to bottom: *Machaeracanthus bezieri*, *Acanthodes lopatini*, and *Diplacanthus crassisimus*).

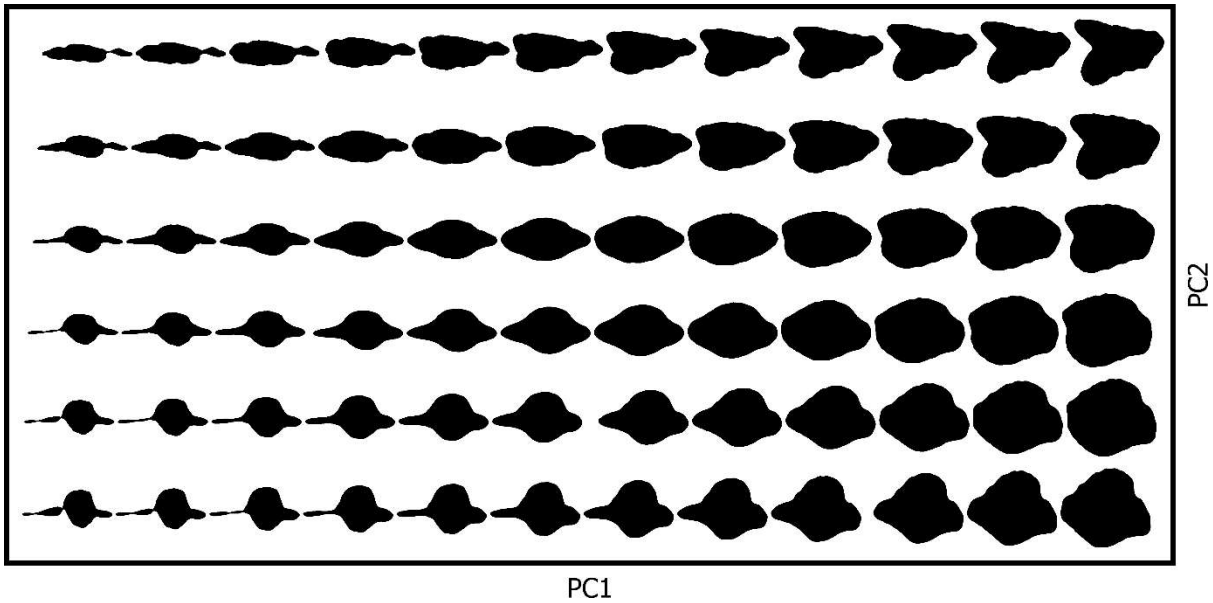

Figure S5. Spine cross-sectional outlines extracted from the virtual morphospace for biomechanical analyses.

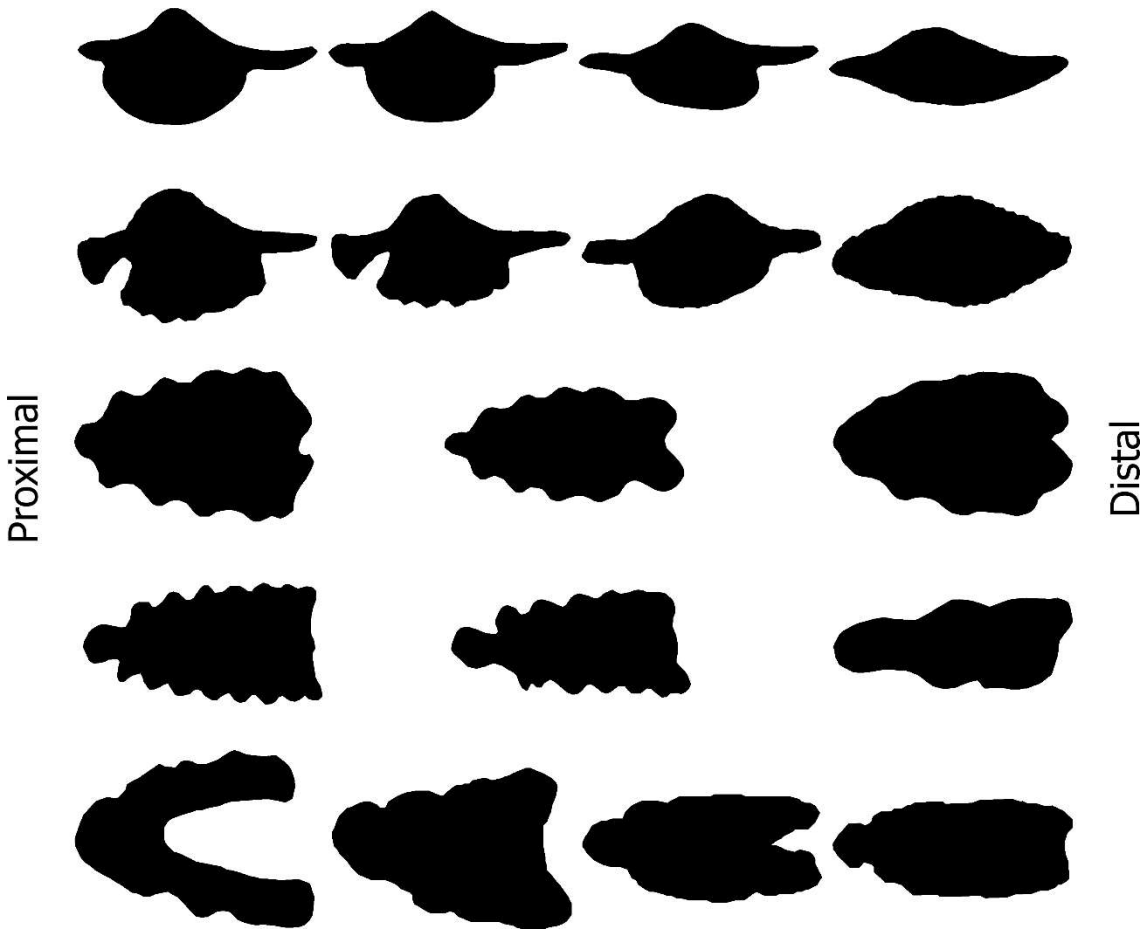

Figure S6. Spine serial cross-sectional outlines of two *Machaeracanthus* species (i.e. *M. bezieri* and M. *kayseri*), one climatiid (Climatiidae sp.), one diplacanthid (*Diplacanthus crassisimus*) and one ischnacanthid (*Ischnacanthus gracilis*) acanthodian (from top to bottom).

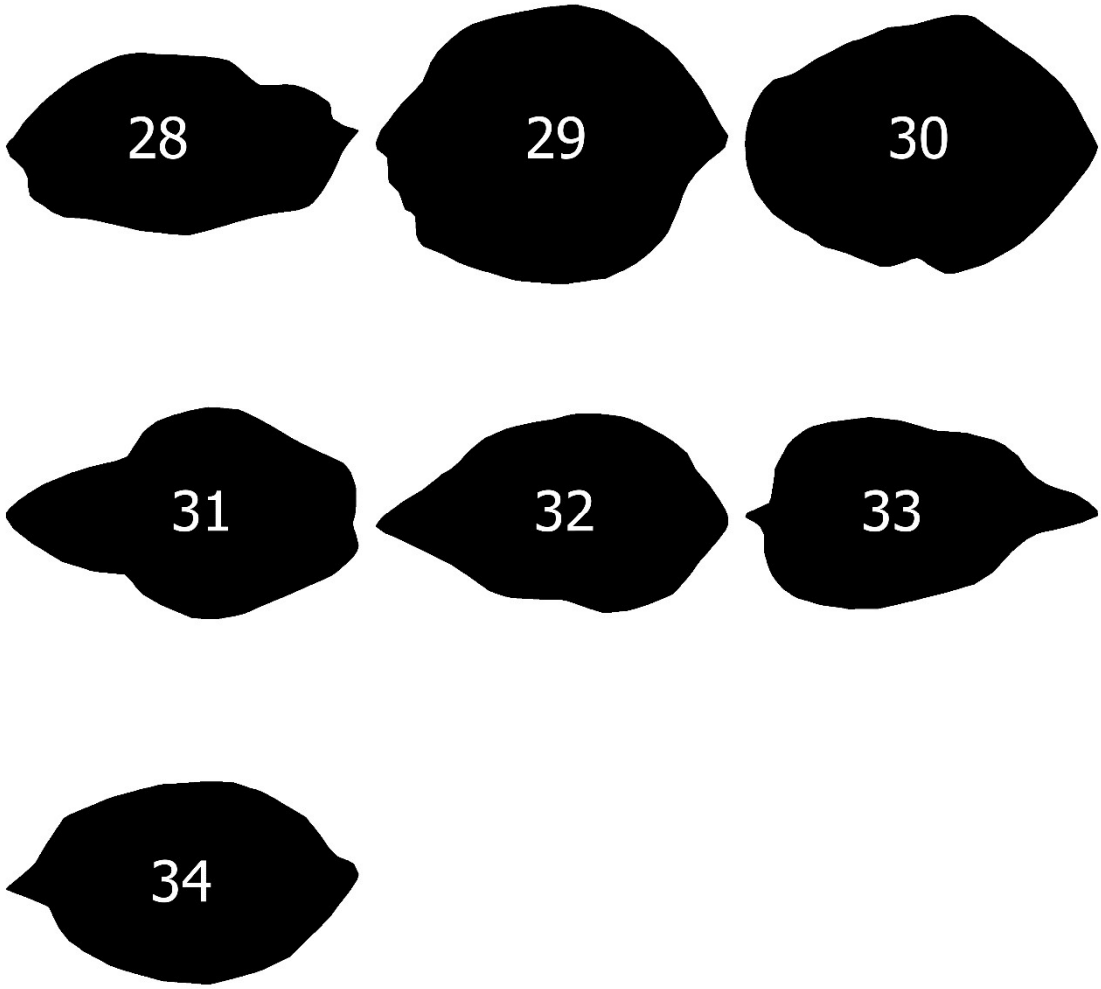

Figure S7. Mid-length spine cross-sectional outlines of the siluriform taxa included in the Elliptic Fourier analysis. Numbers correspond to specimens in Table S1.

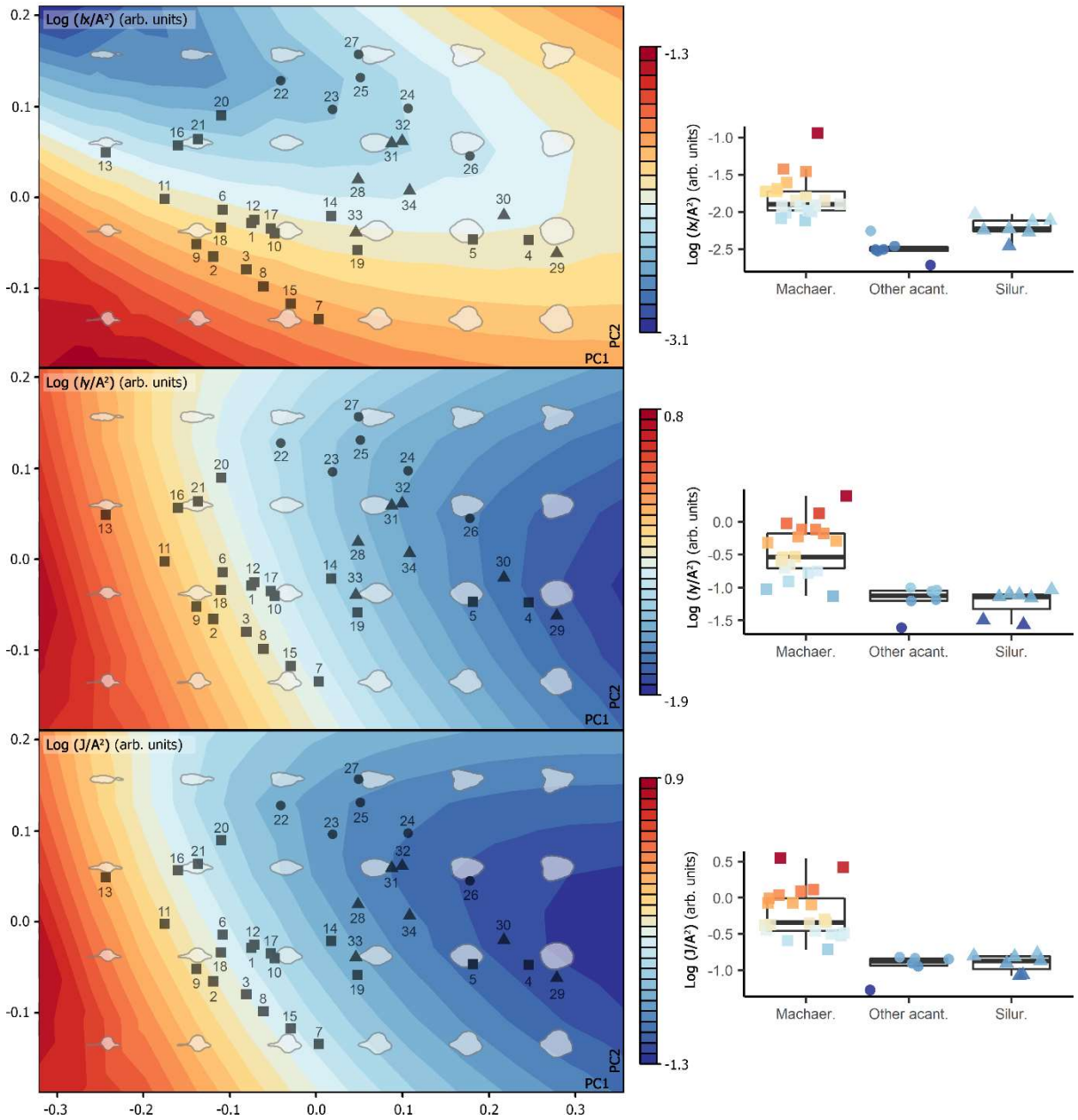

Figure S8. Biomechanical performance of acanthodian and siluriform spine cross-sections. Left panels show performance heatmaps plotted over the obtained virtual morphospaces, representing resistance to bending in dorsoventral (**I_x**) and anteroposterior (**I_y**) directions and resistance to torsion (**J**) normalized by spine cross-sectional area squared (in the upper, middle, and lower thirds of the figure, respectively). Squares (*Machaeracanthus*), circles (other acanthodians) and triangles (siluriforms) indicate the position of actual specimens in morphospace. The right and left sides of the cross-sectional outlines correspond to the leading and trailing edge of the spine, respectively. Right panels show I_x, I_y and J estimates

derived from actual specimens. Higher values of I_x, I_y and J entails higher resistance to bending and torsion. 1, *M. bezier*; 2, *M. bohemicus*; 3, *M. bohemicus*; 4, *M. goujeti*; 5, *M. goujeti*; 6, *M. hunsrueckianum*; 7, *M. kayseri*; 8, *M. kayseri*; 9, *M. longaevus*; 10, *M. longaevus*; 11, *M. major*; 12, *M. pectinatus*; 13, *M. peracutus*; 14, *M. polonicus*; 15, *M. polonicus*; 16, *M. retusus*; 17, *M. sarlei*; 18, *M. sp.*; 19, *M. sulcatus*; 20, *M. westfalicus*; 21, *M. westfalicus*; 22, *Acanthodes lopatini*; 23, Climatiidae sp.; 24 and 25, *Diplacanthus crassisimus*; 26, *"Gyracanthus" sherwoodi*; 27, *Ischnacanthus gracilis*; 28, *Chiloglanis productus*; 29, *Dianema longibarbis*; 30, *Horabagrus brachysoma*; 31, *Lophiobagrus cyclurus*; 32, *Plotosus canius*; 33, *Pseudolais pleurotaenia*; 34, *Schilbe mystus*. *Machaeracanthus* specimens are represented by circles, the rest of acanthodians are represented by squares, and siluriforms are represented by triangles in all panels.

Table S1. Acanthodian and siluriform specimens analysed in this study. *M. pectinatus* specimen is tentatively considered as a pectoral fin spine but see Burrow and Young (2005).

Species	Major group	Source	Specimen number
Mid-length spine cross-sections			
Machaeracanthus bezier	Machaeracanthidae	(Burrow and Gendry, 2017 fig 3A)	1
Machaeracanthus bohemicus	Machaeracanthidae	(Zidek, 1981 fig. 2B)	2
Machaeracanthus bohemicus	Machaeracanthidae	(Zidek, 1981 fig. 2B)	3
Machaeracanthus goujeti	Machaeracanthidae	(Botella et al., 2012 fig. 4J)	4
Machaeracanthus goujeti	Machaeracanthidae	(Botella et al., 2012 fig. 4K)	5
Machaeracanthus hunsrueckianum	Machaeracanthidae	(Südkamp and Burrow, 2007 fig. 2B)	6
Machaeracanthus kayseri	Machaeracanthidae	(Zidek, 1981 fig. 2C)	7
Machaeracanthus kayseri	Machaeracanthidae	(Zidek, 1981 fig. 2C)	8
Machaeracanthus longaevus	Machaeracanthidae	(Burrow et al., 2010 fig. 1F)	9
Machaeracanthus longaevus	Machaeracanthidae	(Burrow et al., 2010 fig. 1F)	10
Machaeracanthus major	Machaeracanthidae	(Burrow et al., 2010 fig. 1B)	11
Machaeracanthus pectinatus	Machaeracanthidae	(Burrow and Young, 2005 fig. 8C)	12
Machaeracanthus peracutus	Machaeracanthidae	(Burrow et al., 2010 fig. 1A)	13
Machaeracanthus polonicus	Machaeracanthidae	(Burrow and Szrek, 2018 fig. 4K)	14
Machaeracanthus polonicus	Machaeracanthidae	(Burrow and Szrek, 2018 fig. 4K)	15
Machaeracanthus retusus	Machaeracanthidae	(Burrow et al., 2010 fig. 1J)	16
Machaeracanthus sarlei	Machaeracanthidae	(Zidek, 1981 fig. 1)	17
Machaeracanthus sp.	Machaeracanthidae	(Reed, 1986 fig. 1B)	18
Machaeracanthus sulcatus	Machaeracanthidae	(Burrow et al., 2010 fig. 4E)	19
Machaeracanthus westfalicus	Machaeracanthidae	(Zidek, 1981 fig. 2K)	20
Machaeracanthus westfalicus	Machaeracanthidae	(Zidek, 1981 fig. 2K)	21
Acanthodes lopatini	Acanthodidae	(Beznosov, 2009 fig. 6C)	22
Climatiidae sp.	Climatiidae	(Jerve et al., 2017 fig. 4.2)	23
Diplacanthus crassisimus	Diplacanthidae	(Burrow et al., 2016 fig. 5.10)	24
Diplacanthus crassisimus	Diplacanthidae	(Burrow et al., 2016 fig. 6.6)	25
"Gyracanthus" sherwoodi	Gyracanthidae	(Snyder et al., 2017 fig. 4E)	26
Ischnacanthus gracilis	Ischnacanthidae	(Burrow et al., 2018 fig. 11.34)	27
Chiloglanis productus	Siluriformes (Mochokidae)	(Wright, 2009 fig. 3B)	28
Dianema longibarbis	Siluriformes (Callichthyidae)	(Wright, 2009 fig. 2C)	29
Horabagrus brachysoma	Siluriformes (Bagridae)	(Wright, 2009 fig. 3F)	30
Lophiobagrus cyclurus	Siluriformes (Claroteidae)	(Wright, 2009 fig. 2E)	31
Plotosus canius	Siluriformes (Plotosidae)	(Wright, 2009 fig. 3D)	32
Pseudolais pleurotaenia	Siluriformes (Pangasiidae)	(Wright, 2009 fig. 3C)	33
Schilbe mystus	Siluriformes (Schilbeidae)	(Wright, 2009 fig. 2E)	34
Spine serial cross-sections			
Machaeracanthus bezieri	Machaeracanthidae	(Burrow and Gendry, 2017 fig 3F)	-
Machaeracanthus kayseri	Machaeracanthidae	(Burrow et al., 2010 fig. 1G)	-
Climatiidae sp.	Climatiidae	(Jerve et al., 2017 fig. 4.1-3)	-
Diplacanthus crassisimus	Diplacanthidae	(Burrow et al., 2016 fig. 6.6)	-
Ischnacanthus gracilis	Ischnacanthidae	(Burrow et al., 2018 fig. 11)	-

LITERATURE CITED

Beznosov, P. 2009. A redescription of the Early Carboniferous acanthodian *Acanthodes lopatini* Rohon, 1889. Acta Zoologica 90:183–193.

Botella, H., C. Martínez-Pérez, and R. Soler-Gijón. 2012. *Machaeracanthus goujeti* n. sp. (Acanthodii) from the Lower Devonian of Spain and northwest France, with special reference to spine histology. Geodiversitas 34:761–783.

Burrow, C. J., and D. Gendry. 2017. Lost and found *Machaeracanthus* spines from the Lower Devonian of western France. Annales de La Société Geologique Du Nord (2nd Series) 24:71–78.

Burrow, C. J., and P. Szrek. 2018. Acanthodians from the Lower Devonian (Emsian) 'Placoderm Sandstone', Holy Cross Mountains, Poland. Acta Geologica Polonica 68:307–320.

Burrow, C. J., and G. Young. 2005. The acanthodian fauna of the Craven Peaks Beds (Early to Middle Devonian) western Queensland. Memoirs of the Queensland Museum 51:3–25.

Burrow, C., J. den Blaauwen, M. Newman, and R. Davidson. 2016. The diplacanthid fishes (Acanthodii, Diplacanthiformes, Diplacanthidae) from the Middle Devonian of Scotland. Palaeontologia Electronica 19:19.1.10A.

Burrow, C. J., S. Desbiens, B. Ekrt, and W. H. Südkamp. 2010. A new look at *Machaeracanthus*; pp. 59–84 in D. K. Elliott, J. G. Maisey, X. Yu, and D. Miao (eds.), Morphology, phylogeny and paleobiogeography of fossil fishes. Verlag Dr. Friedrich Pfeil, München, Germany.

Burrow, C. J., M. Newman, J. Den Blaauwen, R. Jones, and R. Davidson. 2018. The Early Devonian ischnacanthiform acanthodian *Ischnacanthus gracilis* (Egerton, 1861) from the Midland Valley of Scotland. Acta Geologica Polonica 68:335–362.

Jerve, A., O. Bremer, S. Sanchez, and P. E. Ahlberg. 2017. Morphology and histology of acanthodian fin spines from the late Silurian Ramsåsa E locality, Skane, Sweden. Palaeontologia Electronica 20:20.3.56A.

Reed, J. W. 1986. The acanthodian genera *Machaeracanthus* and *Persacanthus* from the Devonian of Red Hill, Nevada. Geobios 19:409–419.

Snyder, D., S. Turner, C. J. Burrow, and E. B. Daeschler. 2017. *"Gyracanthus" sherwoodi* (Gnathostomata, Gyracanthidae) from the Late Devonian of North America. Proceedings of the Academy of Natural Sciences of Philadelphia 165:195–219.

Südkamp, W. H., and C. J. Burrow. 2007. The acanthodian *Machaeracanthus* from the Lower Devonian Hunsrück Slate of the Hunsrück region (Germany). Paläontologische Zeitschrift 81:97–104.

Wright, J. J. 2009. Diversity, phylogenetic distribution, and origins of venomous catfishes. BMC Evolutionary Biology 9:282.

Zidek, J. 1981. *Machaeracanthus* Newberry (Acanthodii: Ischnacanthiformes) – morphology and systematic position. Neues Jahrbuch Für Geologie Und Paläontologie, Monatsheft 12:742–748.