SUPPLEMENTARY DATA:

RESOLUTION OF THE EARLY JURASSIC ACTINOPTERYGIAN FISH
PACHYCORMUS AND A DISPERSAL HYPOTHESIS FOR
PACHYCORMIFORMES

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MEASUREMENTS

TABLE S1. Maximum body length and cranium measurements (mm) for specimens of *Pachycormus curtus* (n=8), *P. macropterus* (n=3), *P. bollensis* (n=6), and *Pachycormus* sp. (n=14).

Catalog number	Species	Maximum Body Length	Cranium	Ratio
GPIT/74332-4	<i>P. curtus</i>	256	66	3.9:1
SMNS 87771	<i>P. curtus</i>	200	57	3.5:1
SMNS 96618	<i>P. curtus</i>	260	55	4.7:1
SMNS 55300	<i>P. curtus</i>	380	94	4:1
SMNS 87762	<i>P. curtus</i>	310	80	3.8:1
PMU 24211	<i>P. curtus</i>	380	94	4:1
UMH unregistered specimen 1	<i>P. curtus</i>	500	125	4:1
UMH unregistered specimen 2	<i>P. curtus</i>	370	105	3.5:1
UMH unregistered specimen 3	<i>P. macropterus</i>	530	135	3.9:1
P7569 (BMNH)	<i>P. macropterus</i>	670	179	3.7:1
P12913 (BMNH)	<i>P. macropterus</i>	520	135	3.9:1
GPIT/OS/777	<i>P. bollensis</i>	850	250	3.4:1
GPIT/OS/776	<i>P. bollensis</i>	890	210	4.2:1
UMH unregistered specimen 4	<i>P. bollensis</i>	890	235	3.8:1
UMH unregistered specimen 5	<i>P. bollensis</i>	750	174	4.3:1
UMH unregistered specimen 6	<i>P. bollensis</i>	750	190	3.9:1
PMU 24210	<i>P. bollensis</i>	860	235	3.7:1
SMNS 87772	<i>Pachycormus</i> sp.	420	120	3.5:1
SMNS 87763	<i>Pachycormus</i> sp.	300	74	4.1:1
SMNS 95835	<i>Pachycormus</i> sp.	410	106	3.9:1
SMNS 65230	<i>Pachycormus</i> sp.	420	110	3.8:1
SMNS 51031	<i>Pachycormus</i> sp.	575	140	4.1:1
SMNS 18189	<i>Pachycormus</i> sp.	245	74	3.3:1
UMH unregistered specimen 7	<i>Pachycormus</i> sp.	1020	275	3.7:1
UMH unregistered specimen 8	<i>Pachycormus</i> sp.	635	168	3.8:1
UMH unregistered specimen 9	<i>Pachycormus</i> sp.	483	130	3.7:1
UMH unregistered specimen 10	<i>Pachycormus</i> sp.	490	90	5.4:1
UMH unregistered specimen 11	<i>Pachycormus</i> sp.	350	88	4:1
UMH unregistered specimen 12	<i>Pachycormus</i> sp.	920	190	4.8:1
UMH unregistered specimen 13	<i>Pachycormus</i> sp.	850	220	3.9:1
UMH unregistered specimen 14	<i>Pachycormus</i> sp.	895	210	4.7:1

TABLE S2. Cranium and preorbital measurements (mm) for specimens of *Pachycormus curtus* (n=8), *P. macropterus* (n=5) *P. bollensis* (n=7), and *Pachycormus* sp. (n=17).

Catalog number	Species	Cranium	Preorbital	Ratio
GPIT/74332-4	<i>P. curtus</i>	66	29	2.3:1
SMNS 87771	<i>P. curtus</i>	57	24	2.4:1
SMNS 96618	<i>P. curtus</i>	55	15	3.7:1
SMNS 55300	<i>P. curtus</i>	94	27	3:1
SMNS 87762	<i>P. curtus</i>	80	38	2:1
PMU 24210	<i>P. curtus</i>	94	37	2.5:1
UMH unregistered specimen 1	<i>P. curtus</i>	125	36	3:1
UMH unregistered specimen 2	<i>P. curtus</i>	105	37	2.2:1
GPIT/773	<i>P. macropterus</i>	139	47	3:1
GPIT/774	<i>P. macropterus</i>	110	43	2.5:1
UMH unregistered specimen 3	<i>P. macropterus</i>	135	50	3:1
P7569 (BMNH)	<i>P. macropterus</i>	179	73	2.5:1
P12913 (BMNH)	<i>P. macropterus</i>	135	44	3:1
GPIT/OS/777	<i>P. bollensis</i>	250	100	2.5:1
GPIT/OS/776	<i>P. bollensis</i>	210	80	2.5:1
UMH unregistered specimen 4	<i>P. bollensis</i>	235	85	3:1
UMH unregistered specimen 15	<i>P. bollensis</i>	168	60	3:1
UMH unregistered specimen 5	<i>P. bollensis</i>	174	70	2.5:1
UMH unregistered specimen 6	<i>P. bollensis</i>	190	70	2.5:1
PMU P1191	<i>P. bollensis</i>	235	91	2.5:1
SMNS 87769	<i>Pachycormus</i> sp.	180	76	2.5:1
SMNS 87772	<i>Pachycormus</i> sp.	120	40	3:1
SMNS 87763	<i>Pachycormus</i> sp.	74	30	2.5:1
SMNS 87760	<i>Pachycormus</i> sp.	50	16	3:1
SMNS 95835	<i>Pachycormus</i> sp.	106	45	2.5:1
SMNS 53425	<i>Pachycormus</i> sp.	240	90	2.5:1
SMNS 65230	<i>Pachycormus</i> sp.	110	60	2:1
SMNS 51031	<i>Pachycormus</i> sp.	140	54	3:1
SMNS 18189	<i>Pachycormus</i> sp.	74	29	2.5:1
UMH unregistered specimen 7	<i>Pachycormus</i> sp.	275	90	3:1
UMH unregistered specimen 8	<i>Pachycormus</i> sp.	168	54	3:1
UMH unregistered specimen 9	<i>Pachycormus</i> sp.	130	60	2.2:1
UMH unregistered specimen 10	<i>Pachycormus</i> sp.	90	43	2.1:1
UMH unregistered specimen 11	<i>Pachycormus</i> sp.	88	37	2.4:1
UMH unregistered specimen 12	<i>Pachycormus</i> sp.	190	80	2.4:1
UMH unregistered specimen 13	<i>Pachycormus</i> sp.	220	80	2.8:1
UMH unregistered specimen 14	<i>Pachycormus</i> sp.	210	85	2.5:1

TABLE S3. Opercular measurements (mm) for specimens of *Pachycormus curtus* (n=6) and *P. macropterus* (n=3).

Catalog number	Species	Length	Height	Ratio	Position of ventral angle
P2037a (BMNH)	<i>P. curtus</i>	40	20	2:1	Midlength
32435 (BMNH)	<i>P. curtus</i>	31.7	15.8	2:1	Midlength
32439 (BMNH)	<i>P. curtus</i>	41.2	20.6	2:1	Midlength
32427 (BMNH)	<i>P. curtus</i>	32.3	15.4	2.1:1	Midlength
32425 (BMNH)	<i>P. curtus</i>	32.3	20	1.6:1	Midlength
P12913 (BMNH)	<i>P. macropterus</i>	48.8	32.4	1.5:1	Midlength
P7569 (BMNH)	<i>P. macropterus</i>	70	38	1.8:1	Midlength
GPIT/774	<i>P. macropterus</i>	36	20	1.8:1	Midlength
GPIT/OS/776	<i>P. bollensis</i>	45	25	1.8:1	Anterior to midlength

FIGURE S1. Examples of *Pachycormus* from the UMH illustrating morphotype variation: (A) unregistered specimen 2, *P. curtus*; (B) unregistered specimen 5, *P. bollensis*; (C) unregistered specimen 6, *P. bollensis*; (D) unregistered specimen 11, *Pachycormus* sp. Scales equal 50 mm. Additional photographs of other UMH specimens are available from the authors upon request.

FIGURE S2. Fixed anatomically corresponding landmarks designated for the relative warps analysis. Only skeletally complete specimens (n=14) were assessed, with 2/14 (7%) lacking fully intact pectoral and caudal fins. Representative species labelled as *Pachycormus curtus* in the FMHS (unregistered specimen displayed behind glass and not accessible for study).

TABLE S4. Morphological variance contributing to relative warps.

RW	% variance	Cummulative %
1	36.09%	36.09%
2	27.62%	63.71%
3	15.14%	78.85%
4	6.49%	85.34%
5	5.47%	90.80%

PHYLOGENETIC AND PALEOBIOGEOGRAPHICAL DATA SCORES

Revised character scores (NEXUS format) for the Friedman (2012) pachycormiform matrix.

Pachycormus_macropterus

00101100000-00-0111000?0001010100001001-0101-

01100101100000000100001?0101000000010000000001110100?111001001101110?11-000

Pachycormus_curtus

00101100000-00-0111000?0001010100001001-0101-

01100101100000000100001?0101000000010000000001110(01)00?111001001101110?11-000

Pachycormus_bollensis

????????????????????????????????0100001?01-010--

01100?011000001001000011??0???0???100?????0???10100?11100??01???110011-000

TABLE S5. Paleobiogeographical area state codes for pachycormiform taxa. A: Boreal Tethys; B: Western Interior Seaway; C: Eromanga Seaway; D: Western Pacific rim; E: Hispanic corridor; F: Proto–Atlantic; G: Equatorial Tethys; H: Eastern Pacific rim; I: Australasian Tethys; J: Eastern Atlantic rim. Reference literature: Mainwaring (1978); Stewart (1988); McNamara et al. (1993); Lambers (1992); Kear (2007); Kear et al. (2009); Friedman et al. (2010); Liston (2010); Arratia and Scultze (2013); Friedman et al. (2013); Bazzi et al., (2015), Schumacher et al., (2016).

Taxon	Score
<i>Asthenocormus</i>	1001000000
<i>Australopachycormus</i>	0010000000
<i>Bonnerichthys</i>	0101000001
<i>Euthynotus</i>	1000000000
<i>Hypocormus</i>	1000000000
<i>Leedsichthys</i>	1000000100
<i>Martillichthys</i>	1000000000
<i>Ohmdenia</i>	1000000000
<i>Orthocormus</i>	1000000000
<i>Pachycormus</i>	1000000000
<i>Protosphyraena</i>	1100010010
<i>Rhinconichthys</i>	1101000000
<i>Saurostomus</i>	1000000000

LITERATURE CITED

- Arratia, G., and H.-P. Schultze. 2013. Outstanding features of a new Late Jurassic pachycormiform fish from the Kimmeridgian of Brunn, Germany and comments on current understanding of pachycormiforms; pp. 87–120 in G. Arratia, H.-P. Schultze, and M. V. H. Wilson (eds.), *Mesozoic Fishes 5 – Global Diversity and Evolution*. Verlag Dr. Friedrich Pfeil, München.
- Bazzi, M., E. Einarsson, and B. P. Kear. 2015. Late Cretaceous (Campanian) actinopterygian fishes from the Kristianstad Basin of southern Sweden; DOI:10.1144/SP434.5 in B. P. Kear, J. Lundgren, J. H. Hurum, J. Milàn, and V. Vajda (eds.), *Mesozoic Biotas of Scandinavia and its Arctic Territories*. Geological Society, London, Special Publications 434.
- Friedman, M., K. Shimada, L. D. Martin, M. J. Everhart, J. Liston, A. Maltese, and M. Triebold. 2010. 100-million year dynasty of giant planktivorous bony fishes in the Mesozoic seas. *Science* 327:990–993.
- Friedman, M. 2012. Parallel evolutionary trajectories underlie the origin of giant suspension-feeding whales and bony fishes. *Proceeding of the Royal Society B* 279:944–951.
- Friedman, M., K. Shimada, M. J. Everhart, K. J. Irwin, B. S. Grandstaff, and J. D. Stewart. 2013. Geographic and stratigraphic distribution of the Late Cretaceous suspension-feeding bony fish *Bonnerichthys gladius* (Teleostei, Pachycormiformes). *Journal of Vertebrate Paleontology* 33:35–47.
- Kear, B. 2007. First record of a pachycormid fish (Actinopterygii: Pachycormiformes) from the lower Cretaceous of Australia. *Journal of Vertebrate Paleontology* 27:1033–1038.
- Kear, B. P., T. H. Rich, M. A. Ali, Y. A. Al-Mufarrih, A. H. Matiri, A. M. Al-Masary, and Y. Attia. 2009. An Upper Cretaceous (Campanian-Maastrichtian) actinopterygian fish assemblage from the marginal marine Adaffa Formation of Saudi Arabia. *Cretaceous Research* 30: 1164–1168.
- Lambers P. 1992. On the Ichthyofauna of the Solnhofen lithographic limestone (Upper Jurassic, Germany). Unpublished Ph.D. dissertation, University of Groningen, Groningen, The Netherlands, 336 pp.
- Liston, J. 2010. The occurrence of the Middle Jurassic pachycormid fish *Leedsichthys*. *Oryctos* 1–36.
- McNamara, K. H., D. Friend, and J. Long. 1993. A Guide to fossils of the Gingsin Chalk. Western Australian Museum, Perth, 16 pp.
- Mainwaring, A. J. 1978. Anatomical and systematic revision of the Pachycormidae, a family of Mesozoic fossil fishes. Unpublished Ph.D. dissertation, Westfield College, London, 162 pp.
- Schumacher, B. A., K. Shimada, J. Liston, & A. Maltese. 2016. Highly specialized suspension-feeding bony fish *Rhinconichthys* (Actinopterygii: Pachycormiformes) from the mid-Cretaceous of the United States, England, and Japan. *Cretaceous Research* 61:71–85.
- Stewart, J. D. 1988. The stratigraphic distribution of Late Cretaceous *Protosphyraena* in Kansas and Alabama; pp. 80–94 in M. E. Nelson (ed.), *Geology, Paleontology and Biostratigraphy of Western Kansas: Articles in Honor of Myrl V. Walker* (Fort Hays Studies, Third Series (Science) Number 10). Fort Hays State University, Hays, Kansas.