Supplementary information

Laterality is universal among fishes but increasingly cryptic among derived groups

Supplementary Table 1. List of the species analyzed and the model-fitting results. Fish species analyzed as representatives of each extant fish orders are listed with both Latin and common names, sample sizes, Akaike information criterion (AIC) values of the model fitted to the two measurements (bold: AIC of the selected model), sampling locations, and sources. *P*-values in LRT are from likelihood ratio test between FA model and AS model. Common names follow those used by FishBase (http://www.fishbase.org/). The index numbers of fish orders follow the classification used in Nelson (2006). Phylogenetic groupings for teleosts in this study, however, are slightly modified from Nelson's system based on Betancur-R et al. (2013).

Supplementary Figure 1. Classification and phylogenetic tree of the extant orders of teleost fishes used in this study. Phylogenetic trees are modified following Betancur-R et al. (2013). The classification is based on Nelson (2006), with a slight modification following Betancur-R et al. (2013) as shown in Supplementary Table 1 (colors are the same as those in Fig. 3A). The blue plot shows deep-sea fishes.

Supplementary Figure 2. Laterality of the Japanese stingray (*Dasyatis akajei*). (A, B) Cartilaginous bones showing the data points used for measurements. **(A)** Ventral view of the jaw arch and a close-up of the left mandibular cartilage showing the data points for the index of asymmetry (*IAS*) of the mandibles. The arrow indicates the height of the mandible at the posterior end (HMPE), which is the distance from the postero-dorsal edge of the sustentaculum in the mandibular cartilage (PE) to the ventral corner of the mandibular cartilage (VC). In cartilaginous fishes (except in chimaeras), the sustentaculum functions as the mandibular surface of the hyomandibular-mandibular joint, and the nodule on the VC functions as the attachment point of the depressor mandibularis (Dean and Motta, 2004; Wilga 2005), such that the HMPE provides a functional measure equivalent to that of teleost fishes. **(B)** Ventral view of head and vertebrae showing data points for the head angle (θ), which is the angle between the head and vertebrae on the ventral side of the anterior part of the skeleton. CC: the small foramen near the center of the cranial cartilage; PC: the midline of the postero-ventral margin of the cranium; PV: the first large process on the ventral sagittal line of the vertebra. **(C, D)** Frequency distributions of the **(C)** *IAS* of the mandibles and **(D)** θ in the Japanese stingray. Lines show the probability densities derived from the three models (see Methods). The model selected by the lowest Akaike information criterion (AIC) value is indicated by the thick line.

Supplementary Figure 3. Relationship between growth and laterality in largemouth bass (*Micropterus salmoides*). The absolute values of the index of asymmetry (*IAS*) of mandibles and the head angles (θ) in three size classes did not differ significantly (ANOVA, $P = 0.2379$ for *IAS* and $P = 0.7791$ for θ). Individuals were sampled from the same population in Lake Biwa, Japan, in 2004–2008. Vertical bars indicate standard deviations (s.d.). Small fish were primarily 0^+ (***n*** = 20, standard length [SL; mean ± s.d.] = 76.1 ± 4.1 mm), medium fish were primarily 1^+ (***n*** = 20, SL = 125.1 ± 13.6 mm), and large fish were primarily $\geq 2^+$ (***n*** = 20, SL = 173.4 ± 16.8 mm).

Supplementary Figure 4. Laterality of the flatfishes. Frequency distributions of the **(A)** index of symmetry (*IAS*) of the mandibles and **(B)** head angles in flathead flounder (*Hippoglossoides dubius*; upper) and olive flounder (*Paralichthys olivaceus*; lower). The lines are the same as those used in Figure 2. In both species, the model with the best fit to the distributions of *IAS* was fluctuating asymmetry, whereas the best model for head angle was anti-symmetry (see Supplementary Table 1).

Supplementary Figure 5. Laterality of the hagfish. (A, B) Data for measurements from inshore hagfish (*Eptatretus burgeri*). **(A)** Ventral view of the mouthparts of a moderately boiled fish sample. A pair of flat cartilaginous structures behind the tooth plates is exposed. FC: the length of the flat cartilaginous structure used for the index of asymmetry (*IAS*). **(B)** Dorsal view of the anterior part of the body in a transparent preparation showing data for the head angle. CN: the center of the cartilaginous rings of the nasal tube; MC: the posterior end of the membranous cranium; DP: the dorsal datum point equidistant from MC to CN–MC on the sagittal line. Head angle (θ) is defined as the angle of the line extending anteriorly from MC–DP to CN–MC. A fish with a clockwise positive angle is defined as left type, whereas a fish with a negative angle is defined as right type. The definitions of right and left types are consistent with those shown in the ventral view of Figure 1. **(C, D)** Frequency distributions of **(C)** *IAS* of the flat cartilaginous structure and **(D)** θ in inshore hagfish. The lines are the same as those used in Figure 2. Both distributions showed anti-symmetry (see Supplementary Table 1).

Supplementary Figure 6. Laterality of the lamprey. (A, B) Data points used for measurements in arctic lamprey (*Lampetra japonica*). **(A)** Ventral view of a mouthpart in which a pair of spinose cartilaginous structures behind the suction cup are exposed in a moderately boiled fish sample. SC: the length of the spinose cartilage used for the index of asymmetry (*IAS*). **(B)** Dorsal view of the anterior part of the body in a transparent specimen showing the data points used for head angle (θ) on the ventral sagittal line. PD: the anterior end of the posterior dorsal cartilage; PO: the posterior end of the postero-occipital cartilaginous ring; DP: the dorsal datum point equidistant to PD–PO. θ is defined as the angle from the line extending anteriorly from PO–DP to PD–PO. A fish with a clockwise positive angle is defined as left type, whereas a fish with a negative angle is defined as right type. **(C, D)** Frequency distributions of the **(C)** *IAS* of spinose cartilaginous structures and **(D)** θ in arctic lamprey. The lines are the same as those in Figure 2. Both distributions showed anti-symmetry (see Supplementary Table 1).

Supplementary Figure 7. The degree of laterality in extant cartilaginous fish orders and sturgeons. Two measures of the laterality, the index of asymmetry (*IAS*) of the mandibles and the head angle, are displayed as in Figure 3A. Fish species are grouped into four color-coded categories.

Supplementary References

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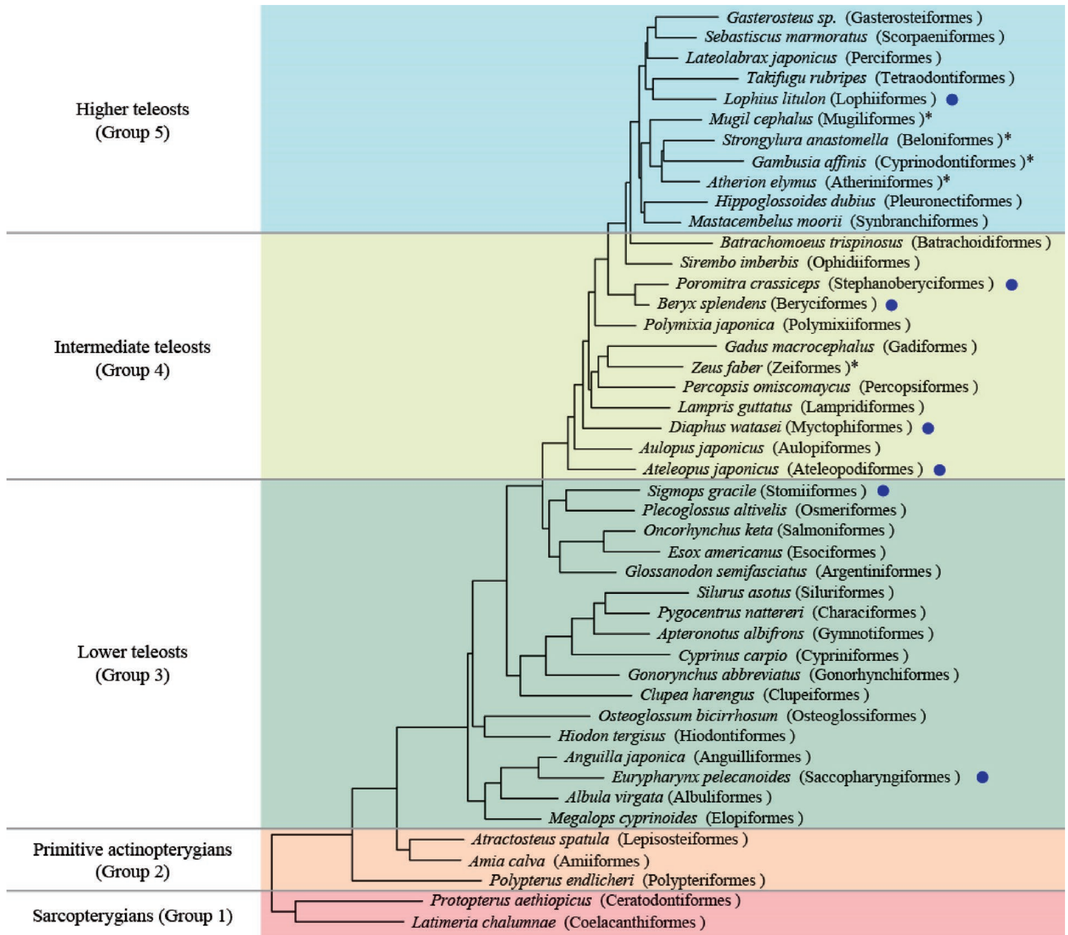
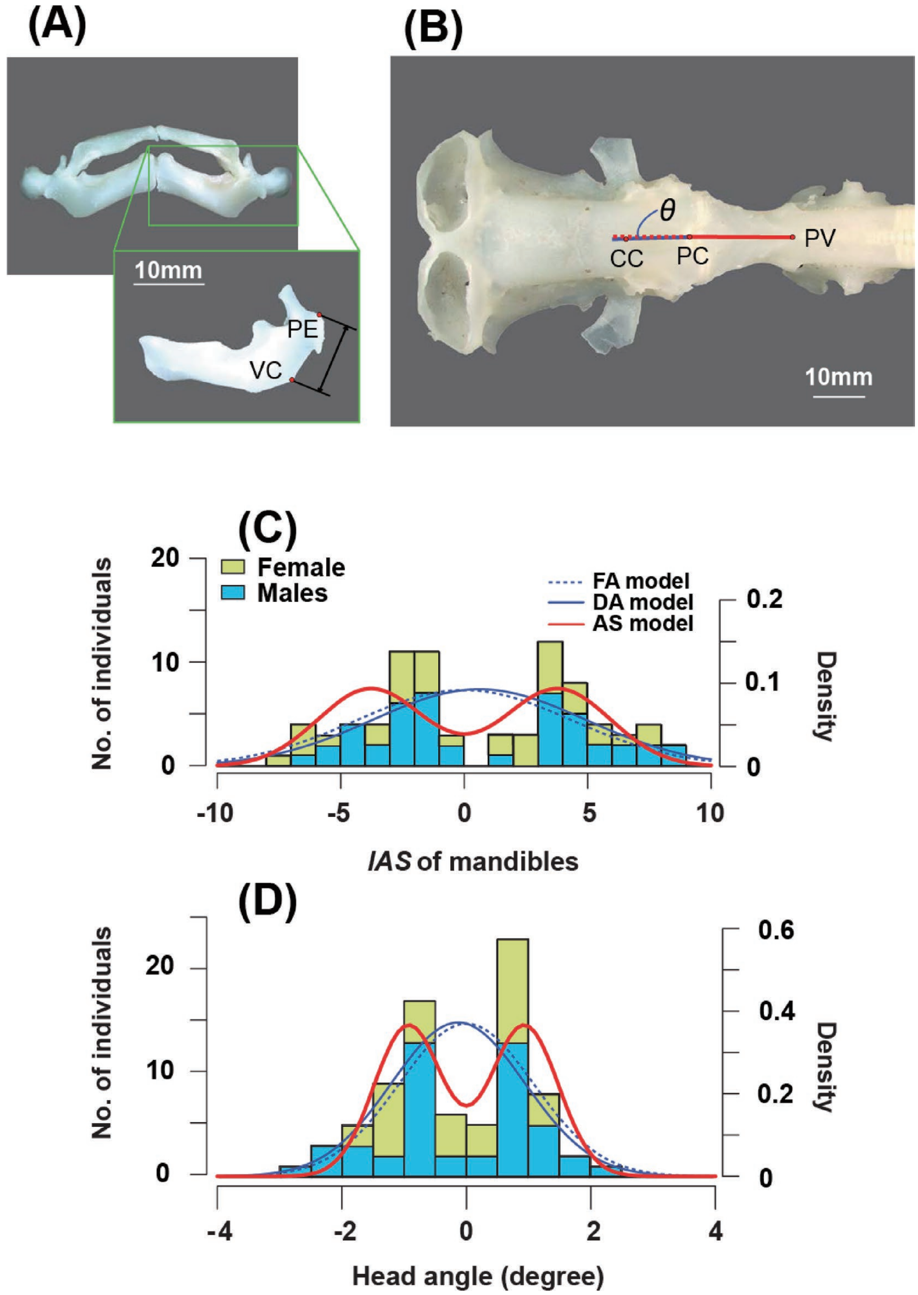
Supplementary Table S1. List of species analyzed and model-fitting results. Fish species analyzed as representatives of each extant fish orders are listed with both Latin and common names, sample sizes, Akaike information criterion (AIC) values of the model fitted to the two measurements (bold: AIC of the selected model), sampling locations, and sources. *P*-values in LRT are from likelihood ratio test between FA model and AS model. Common names follow those used by FishBase (http://www.fishbase.org/).The index numbers of fish orders follow the classification used in Nelson (2006). Phylogenetic groupings for teleosts in this study, however, are slightly modified from Nelson's system based on Betancur-R et al. (2013).

No. of order #	Group in Fig. 3	Order Name	Species Name ‡	English Name	Sample size *	|IAS|		|angle|		DLI	AIC in IAS of mandibles				AIC in angle between the head and vertebrae				Locality of materials	Source of materials
						mean	S.D.	mean	S.D.		FAmodel	DAmodel	ASmodel	LRT pV of AS to FA	FAmodel	DAmodel	ASmodel	LRT pV of AS to FA		
1	-	Myxiniformes	*Eptatretus burgeri*	Inshore hagfish	11 (5)	3.65	1.09	1.82	0.76	-	62.63	64.21	**52.36**	< 0.001	48.18	50.17	**44.42**	0.016	The Pacific of southern	Collected by ourselves
2	-	Petromyzontiformes	*Lampetra japonica*	Arctic lamprey	11 (5)	4.11	1.94	4.06	1.28	-	66.52	67.76	**64.97**	0.060	65.08	67.07	**55.91**	< 0.001	Northern Japan	Purchased from fisherman
3	-	Chimaeriformes	*Chimaera phantasma*	Silver chimaera	10 (7)	4.82	1.33	2.63	0.85	-	62.58	63.85	**51.93**	< 0.001	50.68	52.21	**41.94**	0.001	The Pacific of southern	Collected by ourselves
4	-	Heterodontiformes	*Heterodontus japonicus*	bullhead shark	10 (4)	3.56	1.51	2.10	0.98	-	57.43	59.36	**54.55**	0.027	47.20	48.27	**45.79**	0.065	The Pacific of southern	Purchased from fisherman
5	-	Orectolobiformes	*Chiloscyllium punctatum*	Brownbanded bambooshark	10 (6)	2.42	0.74	1.77	0.83	-	53.66	55.50	**43.77**	< 0.001	47.95	49.75	**46.22**	0.053	East China Sea	Courtesy of Dr. K. Sato (Okinawa Churaumi Aquarium)
6	-	Lamniformes	*Lamna ditropis*	Salmon shark	11 (1)	4.08	2.03	2.74	0.86	-	66.58	**62.02**	65.89	0.101	56.42	50.43	**47.04**	< 0.001	The Pacific of eastern	Purchased from fisherman
7	-	Carcharhiniformes	*Mustelus griseus*	Spotless smooth-hound	11 (3)	2.86	0.86	1.69	0.57	-	57.30	55.39	**47.08**	< 0.001	45.98	45.39	**38.13**	0.002	The Pacific of southern	Purchased from fisherman
8	-	Hexanchiformes	*Heptranchias perlo*	Sharpnose sevengill shark#	5 (5)	5.24	1.31	2.42	0.35	-	-	-	-	-	-	-	-	-	East China Sea	Preserved in Hokkaido University Museum
9	-	Echinorhiniformes	*Echinorhinus brucus*	Bramble shark#	1 (1)	3.46	-	1.80	-	-	-	-	-	-	-	-	-	-	South Africa	Preserved in Hokkaido University Museum
10	-	Squaliformes	*Squalus acanthias*	Piked dogfish	10 (3)	3.61	1.30	1.21	0.53	-	57.25	57.36	**51.54**	0.005	35.94	37.29	**33.67**	0.039	The Pacific of eastern	Purchased from fisherman
11	-	Squatiniformes	*Squatina japonica*	Japanese angelshark	10 (5)	3.43	1.44	2.63	1.10	-	56.64	58.27	**53.52**	0.024	51.34	53.34	**48.03**	0.021	The Pacific of southern	Collected by ourselves
12	-	Pristiophoriformes	*Pristiophorus japonicus*	Japanese sawshark#	5 (1)	4.62	1.43	3.19	0.85	-	-	-	-	-	-	-	-	-	East China Sea	Preserved in Hokkaido University Museum
13	-	Torpediniformes	*Narke japonica*	Japanese sleeper ray	11 (4)	3.49	1.37	1.38	0.66	-	62.27	62.91	**57.33**	0.008	42.54	42.49	**41.30**	0.072	The Pacific of southern	Collected by ourselves
14	-	Pristiformes	*Pristis microdon*	Largetooth sawfish#	1 (0)	3.69	-	1.76	-	-	-	-	-	-	-	-	-	-	The coast of Australia	Preserved in KAIYUKAN Aquarium
15	-	Rajiformes	*Okamejei kenojei*	Ocellate spot skate	10 (4)	3.36	1.33	1.13	0.47	-	56.08	58.08	**51.90**	0.013	34.43	35.08	**31.31**	0.024	The Pacific of southern	Collected by ourselves
16	-	Myliobatiformes	*Dasyatis akajei*	Japanese stingray	80 (39)	3.86	2.00	0.95	0.51	-	464.05	464.45	**449.51**	< 0.001	241.27	242.07	**232.96**	0.001	The Pacific of southern	Purchased from fisherman
17	2	Polypteriformes	*Polypterus endlicheri*	Saddled bichir	10 (7)	4.74	1.11	2.03	0.76	3.735	62.04	61.84	**48.24**	< 0.001	45.87	47.15	**40.82**	0.008	Lake Tanganyika & other	Collected by ourselves & Purchased from pet shop
18	-	Acipenseriformes	*Acipenser* sp.	Sturgeon	12 (7)	4.42	1.74	2.23	0.95	-	73.36	74.18	**67.02**	0.004	57.26	59.04	**52.65**	0.010	Western Japan	Purchased from farmer
19	2	Lepisosteiformes	*Atractosteus spatula*	Alligator gar	10 (6)	4.75	1.83	3.06	1.07	4.691	62.90	64.65	**58.30**	0.010	53.92	55.08	**47.66**	0.004	South America	Purchased from pet shop
20	2	Amiiformes	*Amia calva*	Bowfin	10 (5)	4.95	1.12	3.04	0.91	4.741	62.87	64.85	**48.52**	< 0.001	53.44	55.23	**44.29**	< 0.001	Georgia, USA	Courtesy of Dr. M. Kibbey & Purchased from pet shop
21	3	Hiodontiformes	*Hiodon tergisus*	Mooneye	10 (4)	4.86	1.36	2.76	0.58	4.437	62.77	64.43	**52.41**	< 0.001	51.12	52.91	**35.37**	< 0.001	Ohio, USA	Courtesy of Dr. M. Kibbey (Ohio State University)
22	3	Osteoglossiformes	*Osteoglossum*	Arowana	10 (3)	5.75	1.25	1.75	0.74	3.992	65.82	64.75	**50.65**	< 0.001	43.16	42.69	**40.09**	0.024	Brasil	Purchased from pet shop
23	3	Elopiformes	*Megalops cyprinoides*	Indo-Pacific tarpon	10 (3)	4.80	1.97	2.15	0.70	3.862	63.31	62.63	**59.75**	0.018	46.72	46.31	**39.13**	0.002	Cultured in Southeast Asia	Purchased from pet shop
24	3	Albuliformes	*Albula virgata*	Bonefish	10 (6)	2.61	1.08	2.11	0.56	3.021	51.14	53.10	**47.72**	0.020	46.04	47.48	**34.80**	< 0.001	Hawaii, USA	Courtesy of Dr. A. Rossiter (Waikiki Aquarium)
25	3	Anguilliformes	*Anguilla japonica*	Japanese eel	10 (7)	4.78	1.18	1.81	0.72	3.576	62.26	62.81	**49.54**	< 0.001	43.67	44.29	**39.73**	0.015	Western of Japan	Collected by ourselves & Purchase from fishery
26	Deep	Saccopharyngiforme	*Eurypharynx*	Pelican eel#	1 (0)	11.07	-	3.24	-	7.601	-	-	-	-	-	-	-	-	The Pacific of southern	Courtesy of JAMSTEC
27	3	Clupeiformes	*Clupea harengus*	Atlantic herring	10 (3)	6.29	2.81	1.62	0.63	4.181	68.97	69.74	**66.65**	0.038	41.47	41.91	**37.12**	0.012	Norway	Purchased from fisherman
28	3	Gonorynchiformes	*Gonorynchus abbreviatus*	Bighead beaked sandfish	11 (7)	5.21	1.47	2.18	1.01	4.063	70.37	71.92	**59.01**	< 0.001	52.52	53.97	**50.57**	0.047	The Pacific of southern	Collected by ourselves & Purchase from fishery
29	3	Cypriniformes	*Cyprinus carpio*	Common carp	10 (5)	6.06	2.76	1.99	0.84	4.308	68.29	70.28	**66.42**	0.049	45.81	47.33	**42.74**	0.024	Western Japan	Purchased from fisherman
30	3	Characiformes	*Pygocentrus nattereri*	Red piranha	10 (6)	3.54	1.30	1.83	0.57	3.064	56.90	57.54	**51.44**	0.006	43.36	44.41	**35.13**	0.001	South America	Purchased from pet shop
31	3	Siluriformes	*Silurus asotus*	Far Eastern catfish	110 (53)	6.00	3.65	1.61	0.91	4.027	742.15	743.06	**736.88**	0.007	449.28	450.12	**439.73**	< 0.001	Western of Japan	Collected by ourselves
32	3	Gymnotiformes	*Apteronotus albifrons*	Black ghost	10 (4)	5.72	1.26	1.88	0.64	4.067	65.74	67.73	**50.88**	< 0.001	43.55	45.54	**30.89**	< 0.001	Cultured in Southeast Asia	Purchased from pet shop
33	3	Argentiniformes	*Glossanodon*	Deepsea smelt	10 (5)	4.42	1.76	1.55	0.65	3.213	61.58	63.35	**57.48**	0.014	40.78	42.53	**37.71**	0.024	Sea of Japan	Purchased from fisherman
34	3	Osmeriformes	*Plecoglossus altivelis*	Ayu	12 (5)	4.43	1.21	2.28	0.67	3.825	72.66	74.57	**59.29**	< 0.001	56.77	58.45	**44.98**	< 0.001	Western Japan	Collected by ourselves
35	3	Salmoniformes	*Oncorhynchus keta*	Chum salmon	10 (2)	5.28	1.69	1.97	0.60	3.928	64.62	63.83	**56.78**	0.002	44.82	44.45	**36.11**	0.001	Northern Japan	Purchased from fisherman
36	3	Esociformes	*Esox americanus*	Redfin pickerel	10 (4)	6.35	1.39	2.04	0.68	4.482	67.80	68.84	**52.84**	< 0.001	45.71	47.21	**38.71**	0.003	Ohio, USA	Courtesy of Dr. M. Kibbey (Ohio State University)
37	Deep	Stomiiformes	*Sigmops gracile*	Slender fangjaw	11 (5)	6.76	1.26	2.55	1.21	5.05	75.64	77.39	**55.46**	< 0.001	56.06	56.17	**54.53**	0.060	The Pacific of southern	Courtesy of JAMSTEC
38	Deep	Ateleopodiformes	*Ateleopus japonicus*	Pacific jellynose fish	12 (10)	3.67	1.25	1.92	0.61	3.197	68.56	62.36	**59.99**	0.001	52.90	50.77	**42.94**	< 0.001	The Pacific of southern	Collected by ourselves
39	4	Aulopiformes	*Aulopus japonicus*	Japanese thread-sail fish	12 (6)	3.38	1.57	1.73	0.80	2.91	67.62	69.11	**65.38**	0.039	51.58	53.46	**49.18**	0.036	The Pacific of southern	Collected by ourselves
40	Deep	Myctophiformes	*Diaphus watasei*	Watases lanternfish	10 (6)	5.22	1.62	4.01	1.68	5.82	64.34	66.05	**55.90**	0.001	59.76	61.31	**56.50**	0.022	The Pacific of southern	Collected by ourselves
41	4	Lampridiformes	*Lampris guttatus*	Opah	10 (3)	2.91	1.72	2.11	0.80	3.113	54.75	**51.71**	56.08	0.413	46.67	46.45	**41.74**	0.008	The Pacific of southern	Purchased from fisherman
42	4	Polymixiiformes	*Polymixia japonica*	Silver eye	10 (5)	2.88	1.12	2.66	1.24	3.694	52.95	54.35	**48.49**	0.011	51.91	53.75	**50.47**	0.064	The Pacific of southern	Collected by ourselves
43	4	Percopsiformes	*Percopsis omiscomaycus*	Trout-perch	10 (6)	4.47	1.08	2.13	0.82	3.707	60.90	62.44	**47.86**	< 0.001	46.93	48.12	**42.37**	0.010	Ohio, USA	Courtesy of Dr. M. Kibbey (Ohio State University)
44	4	Gadiformes	*Gadus macrocephalus*	Pacific cod	10 (7)	2.88	0.96	2.25	0.92	3.251	52.58	53.57	**45.39**	0.002	48.11	48.07	**44.65**	0.019	The Pacific of northern	Purchased from fisherman
45	4	Ophidiiformes	*Sirembo imberbis*	Golden cusk	10 (6)	3.34	1.00	2.41	1.02	3.561	55.35	55.33	**46.24**	< 0.001	49.59	51.56	**46.62**	0.026	The Pacific of southern	Collected by ourselves & Purchased from fishery
46	4	Batrachoidiformes	*Batrachomoeus*	Three-spined toadfish	10 (3)	6.52	1.46	1.84	0.60	4.433	68.35	67.52	**53.81**	< 0.001	43.58	44.47	**36.08**	0.002	Southeast Asia	Purchased from pet shop
47	Deep	Lophiiformes	*Lophius litulon*	Anglerfish	12 (8)	7.84	2.53	3.41	1.15	6.222	86.58	85.94	**75.97**	< 0.001	66.72	64.99	**57.13**	< 0.001	The Pacific of southern	Collected by ourselves & Purchased from fishery
48	5	Mugiliformes	*Mugil cephalus*	Flathead mullet	11 (4)	4.40	1.51	2.35	0.87	3.878	67.02	68.70	**59.45**	0.002	53.44	53.28	**47.41**	0.005	Western Japan	Courtesy of Dr.M. Nakamura (Corbicula Research Institute)
49	5	Atheriniformes	*Atherion elymus*	Bearded silverside	10 (6)	4.17	0.88	3.08	0.86	4.52	59.35	61.09	**43.77**	< 0.001	53.59	55.58	**43.16**	< 0.001	The Pacific of southern	Collected by ourselves
50	5	Beloniformes	*Strongylura anastomella*	Needlefish	10 (8)	3.85	1.14	1.96	0.66	3.305	58.15	56.40	**48.82**	< 0.001	44.88	40.44	**38.01**	0.003	Western Japan	Courtesy of Dr.M. Nakamura (Corbicula Research Institute)
50-2	-	Beloniformes	*Prognichthys brevipinnis*	Shortfin flyingfish	10 (6)	4.28	0.92	1.30	0.27	-	59.93	61.63	**44.66**	< 0.001	36.05	37.67	**20.01**	< 0.001	The Pacific of southern	Purchased from fisherman
51	5	Cyprinodontiformes	*Gambusia affinis*	Mosquitofish	10 (5)	5.13	0.73	1.71	0.23	3.665	63.29	64.66	**39.93**	< 0.001	41.24	43.23	**16.62**	< 0.001	Western Japan	Collected by ourselves
52	Deep	Stephanoberyciform	*Poromitra crassiceps*	Crested bigscale	10 (6)	4.96	1.13	4.81	2.25	6.615	62.91	64.77	**48.69**	< 0.001	63.75	65.56	**62.23**	0.061	The Pacific of northern	Preserved in Hokkaido University Museum
53	Deep	Beryciformes	*Beryx splendens*	Splendid alfonsino	11 (6)	2.97	1.25	2.92	1.42	4.005	53.76	53.43	**50.56**	0.023	53.90	55.16	**52.69**	0.073	The Pacific of southern	Purchased from fisherman
54	4	Zeiformes	*Zeus faber*	John dory	12 (6)	2.20	0.63	2.71	1.23	3.589	55.89	57.89	**43.77**	< 0.001	62.19	64.09	**59.54**	0.031	The Pacific of southern	Purchased from fisherman
55	5	Gasterosteiformes	*Gasterosteus* sp.	Three-spined stickleback	10 (5)	6.90	2.02	1.52	0.38	4.443	69.83	71.81	**60.34**	< 0.001	39.38	41.35	**26.91**	< 0.001	Northern Japan (the Sea of	Courtesy of Dr. S. Mori (Gifu Economy University)
56	5	Synbranchiformes	*Mastacembelus moorii*	Spiny eel	12 (3)	3.82	1.36	1.95	0.41	3.284	69.66	70.42	**62.13**	0.002	52.63	51.91	**33.30**	< 0.001	Lake Tanganyika	Collected by ourselves
57	5	Scorpaeniformes	*Sebastiscus marmoratus*	False kelpfish	10 (5)	3.51	0.81	2.17	0.85	3.376	56.06	58.02	**42.05**	< 0.001	47.32	49.32	**43.13**	0.013	The Pacific of southern	Purchased from fisherman
58	5	Perciformes	*Lateolabrax japonicus*	Japanese seaperch	11 (3)	4.46	1.40	1.60	0.52	3.269	67.14	65.32	**57.92**	< 0.001	44.58	43.90	**35.89**	0.001	The Pacific of southern	Purchased from fisherman
58-2	-		*Seriola quinqueradiata*	Japanese amberjack	100 (44)	2.83	1.64	1.51	0.72	-	523.08	519.15	**516.29**	0.003	388.44	388.68	**359.58**	< 0.001	Sea of Japan	Purchased from fisherman
58-3	-		*Perissodus microlepis*	L. Tanganyika scale-eater	10 (3)	9.63	1.56	1.99	0.41	-	75.86	76.59	**50.74**	< 0.001	45.15	44.84	**37.51**	0.002	Lake Tanganyika	Collected by ourselves
59	5	Pleuronectiformes	*Hippoglossoides dubius*	Flathead flounder	50 (28)	4.11	3.32	2.23	1.05	3.655	**310.37**	312.26	312.37	1.000	234.13	234.55	**219.42**	< 0.001	Western Japan	Purchased from fisherman
59-2	-		*Paralichthys olivaceus*	Olive flounder	51 (21)	4.55	4.00	2.78	1.62	-	**330.43**	330.85	332.43	1.000	266.02	265.99	**263.35**	0.031	Western Japan	Purchased from fisherman
60	5	Tetraodontiformes	*Takifugu rubripes*	Japanese pufferfish	10 (4)	3.91	0.93	2.89	0.78	4.24	58.18	60.00	**44.77**	< 0.001	52.28	53.94	**41.38**	< 0.001	Western Japan	Purchased from fisherman
61	1	Coelacanthiformes	*Latimeria chalumnae*	Coelacanth#	2 (2)	4.20	0.13	4.33	0.81	5.889	-	-	-	-	-	-	-	-	Coast of Tanzania	Preserved in Tokyo Institute of Technology
62	1	Ceratodontiformes	*Protopterus aethiopicus*	Marbled lungfish	11 (5)	3.68	1.43	2.88	1.21	4.159	63.42	64.66	**58.40**	0.008	58.24	59.82	**54.54**	0.017	East Africa	Collected by ourselves & Purchased from pet shop

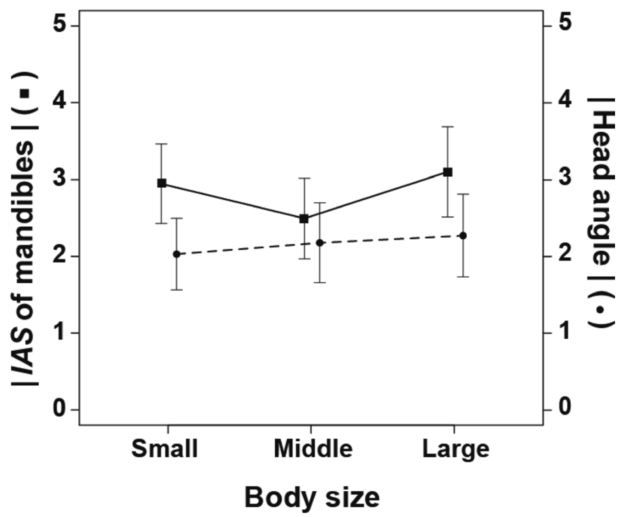
Numbers of order follow Nelson (2002).
‡ Species whose samples are less than 10.
* Figures in parentheses indicate the number of righty individuals in the samples.



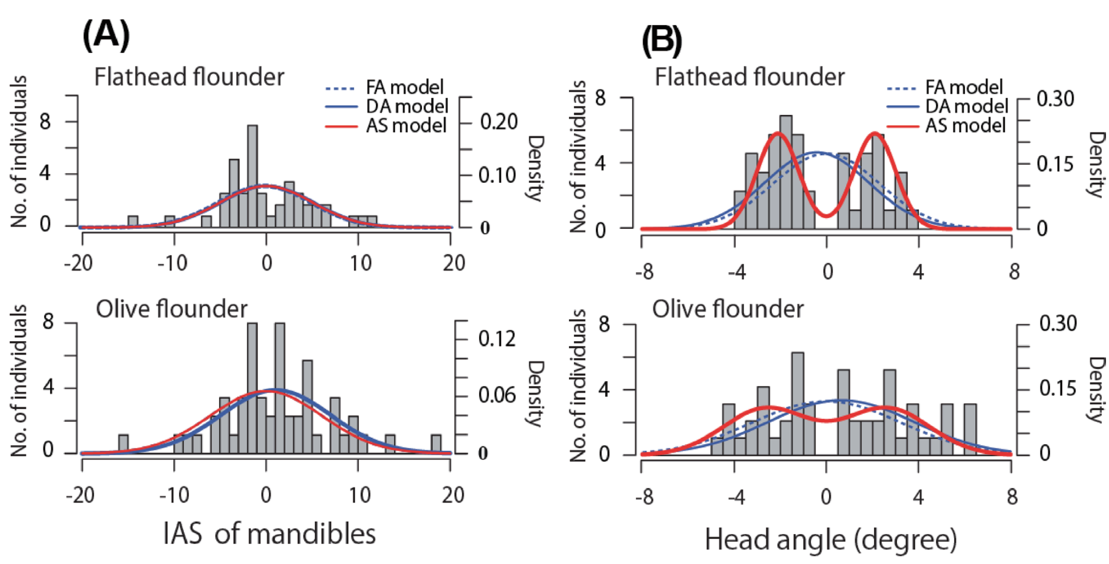
Supplementary Figure S1. Classification and phylogenetic tree of the extant orders of teleost fishes used in this study. Phylogenetic trees are modified following Betancur-R et al. (2013). The classification is based on Nelson (2006), with a slight modification following Betancur-R et al. (2013) as shown in Supplementary Table 1 (colors are the same as those in Fig. 3A). The blue plot shows deep-sea fishes.



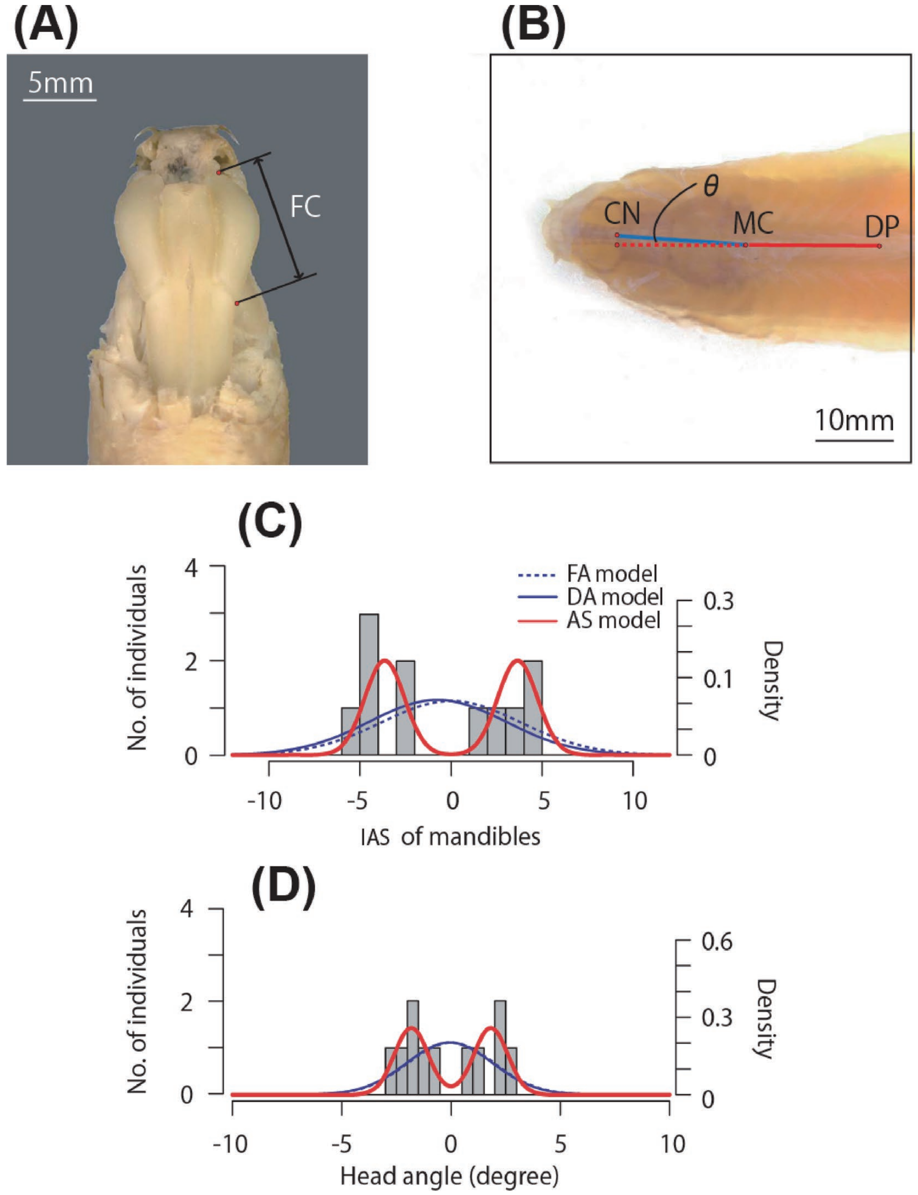
Supplementary Figure S2. Laterality of the Japanese stingray (*Dasyatis akajei*). **(A, B)** Cartilaginous bones showing the data points used for measurements. **(A)** Ventral view of the jaw arch and a close-up of the left mandibular cartilage showing the data points for the index of asymmetry (*IAS*) of the mandibles. The arrow indicates the height of the mandible at the posterior end (HMPE), which is the distance from the postero-dorsal edge of the sustentaculum in the mandibular cartilage (PE) to the ventral corner of the mandibular cartilage (VC). In cartilaginous fishes (except in chimaeras), the sustentaculum functions as the mandibular surface of the hyomandibular-mandibular joint, and the nodule on the VC functions as the attachment point of the depressor mandibularis (Dean and Motta, 2004; Wilga 2005), such that the HMPE provides a functional measure equivalent to that of teleost fishes. **(B)** Ventral view of head and vertebrae showing data points for the head angle (θ), which is the angle between the head and vertebrae on the ventral side of the anterior part of the skeleton. CC: the small foramen near the center of the cranial cartilage; PC: the midline of the postero-ventral margin of the cranium; PV: the first large process on the ventral sagittal line of the vertebra. **(C, D)** Frequency distributions of the **(C)** *IAS* of the mandibles and **(D)** θ in the Japanese stingray. Lines show the probability densities derived from the three models (see Methods). The model selected by the lowest Akaike information criterion (AIC) value is indicated by the thick line.



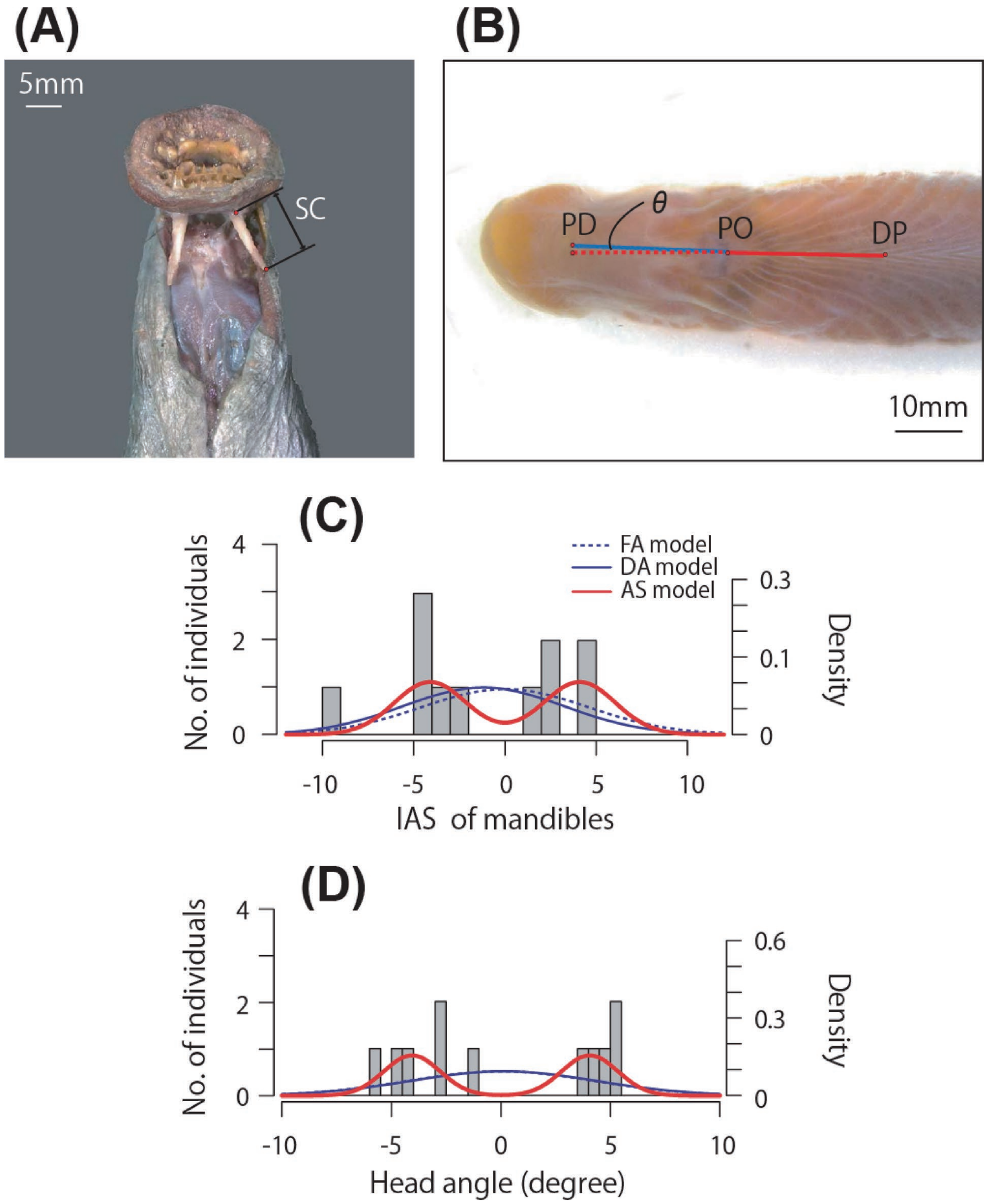
Supplementary Figure S3. Relationship between growth and laterality in largemouth bass (*Micropterus salmoides*). The absolute values of the index of asymmetry (*IAS*) of mandibles and the head angles (θ) in three size classes did not differ significantly (ANOVA, P = 0.2379 for *IAS* and P = 0.7791 for θ). Individuals were sampled from the same population in Lake Biwa, Japan, in 2004–2008. Vertical bars indicate standard deviations (s.d.). Small fish were primarily 0^+ ($\boldsymbol{n}$ = 20, standard length [SL; mean ± s.d.] = 76.1 ± 4.1 mm), medium fish were primarily 1^+ ($\boldsymbol{n}$ = 20, SL = 125.1 ± 13.6 mm), and large fish were primarily ≥ 2^+ ($\boldsymbol{n}$ = 20, SL = 173.4 ± 16.8 mm).



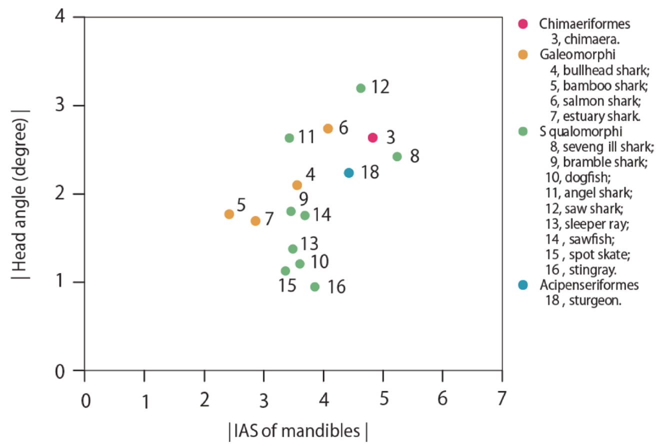
Supplementary Figure S4. Laterality of the flatfishes. Frequency distributions of the **(A)** index of symmetry (*IAS*) of the mandibles and **(B)** head angles in flathead flounder (*Hippoglossoides dubius*; upper) and olive flounder (*Paralichthys olivaceus*; lower). The lines are the same as those used in Fig. 2. In both species, the model with the best fit to the distributions of *IAS* was fluctuating asymmetry, whereas the best model for head angle was anti-symmetry (see Supplementary Table 1).



Supplementary Figure S5. Laterality of the hagfish. **(A, B)** Data for measurements from inshore hagfish (*Eptatretus burgeri*). **(A)** Ventral view of the mouthparts of a moderately boiled fish sample. A pair of flat cartilaginous structures behind the tooth plates is exposed. FC: the length of the flat cartilaginous structure used for the index of asymmetry (*IAS*). **(B)** Dorsal view of the anterior part of the body in a transparent preparation showing data for the head angle. CN: the center of the cartilaginous rings of the nasal tube; MC: the posterior end of the membranous cranium; DP: the dorsal datum point equidistant from MC to CN–MC on the sagittal line. Head angle (θ) is defined as the angle of the line extending anteriorly from MC–DP to CN–MC. A fish with a clockwise positive angle is defined as left type, whereas a fish with a negative angle is defined as right type. The definitions of right and left types are consistent with those shown in the ventral view of Fig. 1. **(C, D)** Frequency distributions of **(C)** *IAS* of the flat cartilaginous structure and **(D)** θ in inshore hagfish. The lines are the same as those used in Fig. 2. Both distributions showed anti-symmetry (see Supplementary Table 1).



Supplementary Figure S6. Laterality of the lamprey. **(A, B)** Data points used for measurements in arctic lamprey (*Lampetra japonica*). **(A)** Ventral view of a mouthpart in which a pair of spinose cartilaginous structures behind the suction cup are exposed in a moderately boiled fish sample. SC: the length of the spinose cartilage used for the index of asymmetry (*IAS*). **(B)** Dorsal view of the anterior part of the body in a transparent specimen showing the data points used for head angle (θ) on the ventral sagittal line. PD: the anterior end of the posterior dorsal cartilage; PO: the posterior end of the postero-occipital cartilaginous ring; DP: the dorsal datum point equidistant to PD–PO. θ is defined as the angle from the line extending anteriorly from PO–DP to PD–PO. A fish with a clockwise positive angle is defined as left type, whereas a fish with a negative angle is defined as right type. **(C, D)** Frequency distributions of the **(C)** *IAS* of spinose cartilaginous structures and **(D)** θ in arctic lamprey. The lines are the same as those in Fig. 2. Both distributions showed anti-symmetry (see Supplementary Table 1).



Supplementary Figure S7. Degrees of laterality in extant cartilaginous fish orders and sturgeons. Two measures of the laterality, the index of asymmetry (*IAS*) of the mandibles and the head angle, are displayed as in Fig. 3A. Fish species are grouped into four color-coded categories.