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Supplementary material

Age and growth of sharks: do vertebral band pairs record age?

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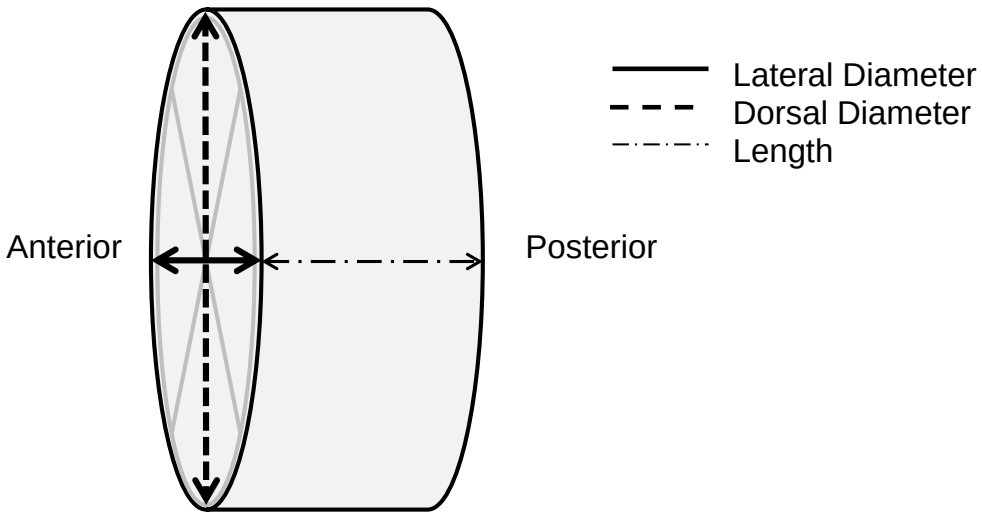

Fig. S1. Locations of vertebral measurements.

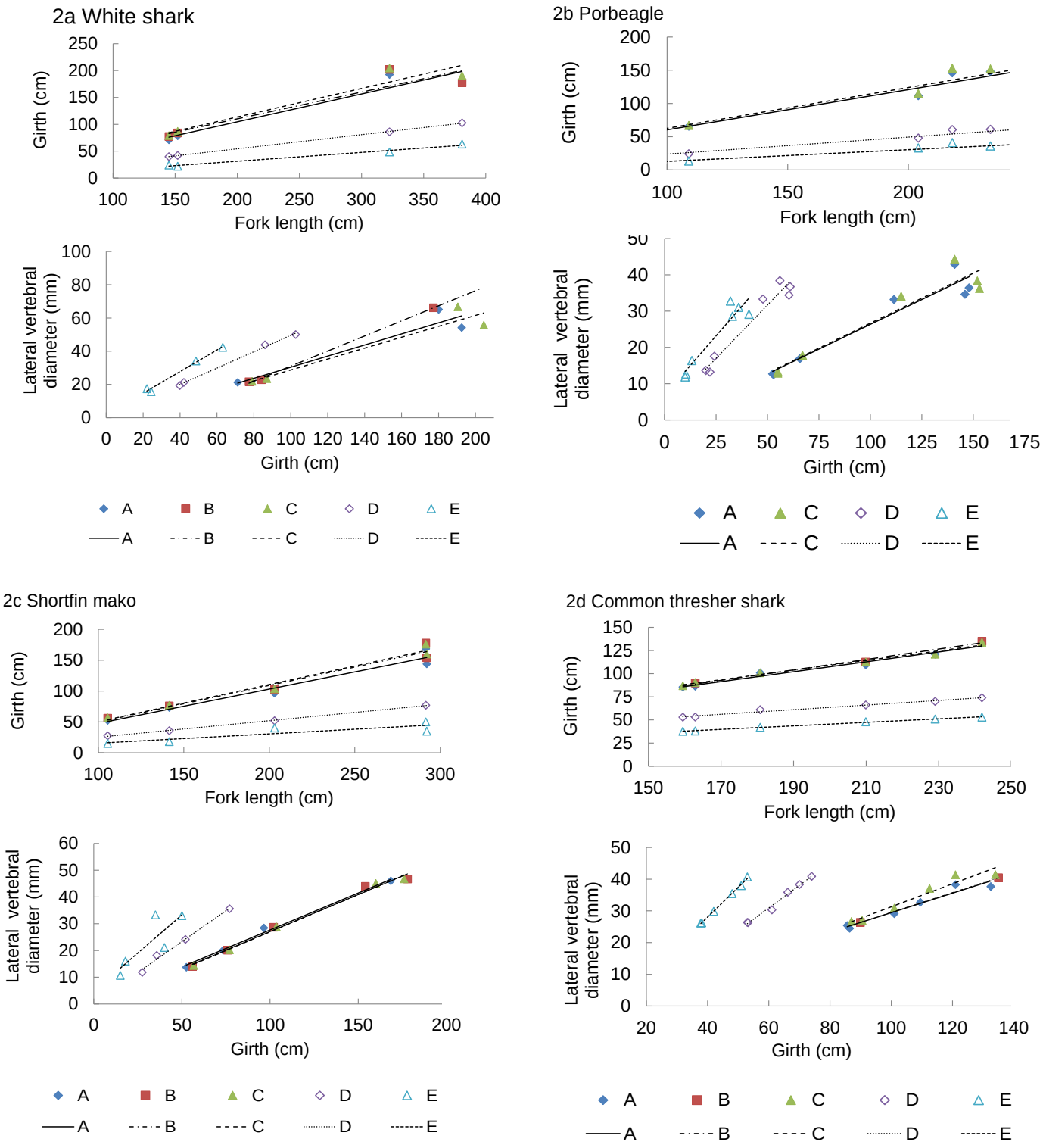

Fig. S2. Girth measurements by species relative to: (*a*) fork length; (*b*) lateral vertebral diameter; (A) white shark, *Carcharodon carcharias*; (B) porbeagle, *Lamna nasus*; (C) shortfin mako, *Isurus oxyrinchus*; (D) common thresher shark, *Alopias vulpinus*; (E) blue shark, *Prionace glauca*; (F) dusky shark, *Carcharhinus obscurus*.

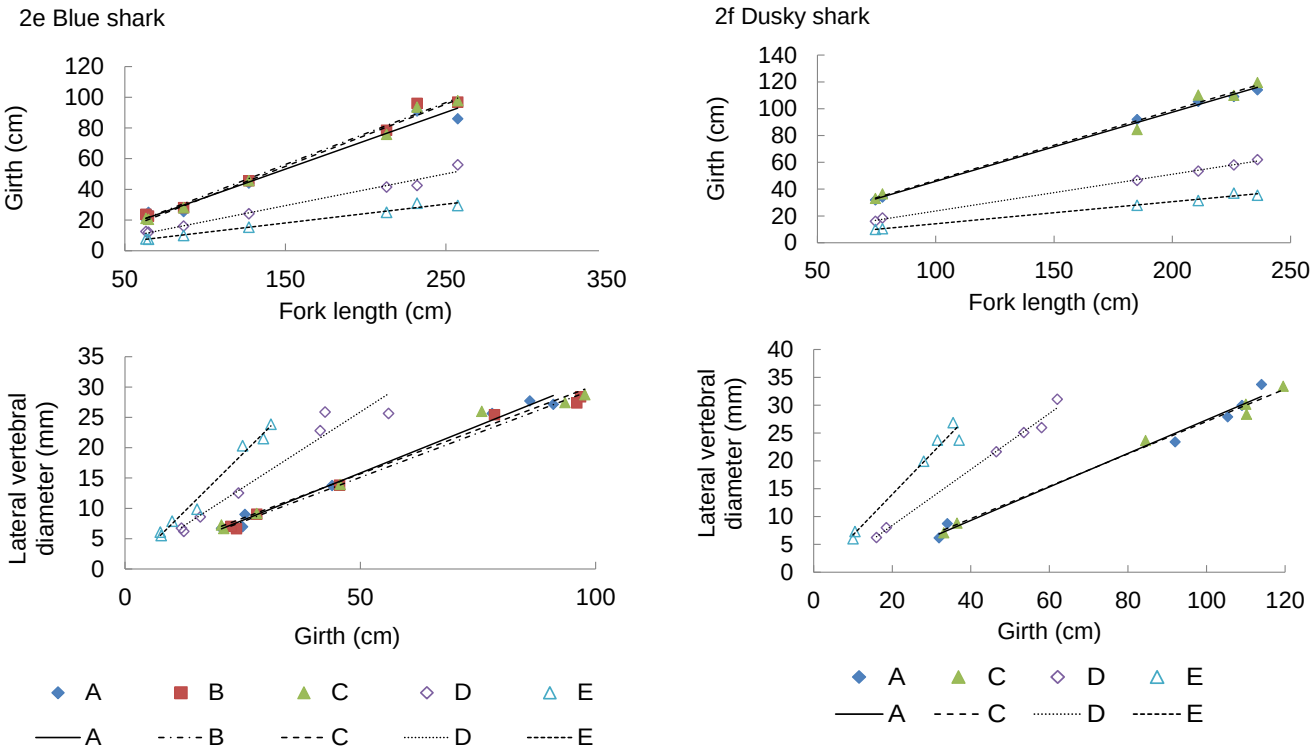

Fig. S2. (*Cont.*)

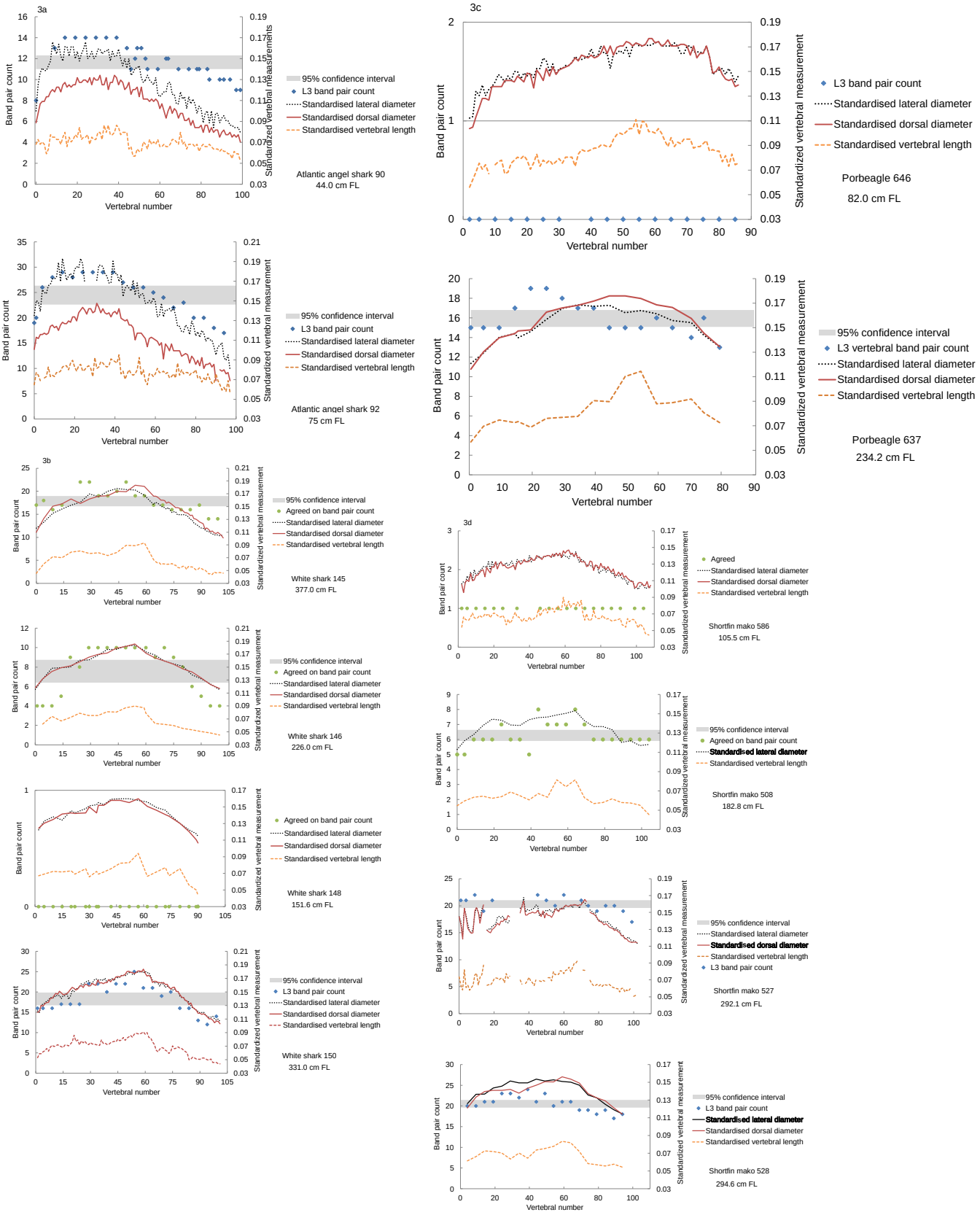

Fig. S3. Band pair count and measurements related to position along the vertebral column for all column specimens of: (*a*) Atlantic Angel shark, *Squatina dumeril*; (*b*) white shark, *Carcharodon carcharias*; (*c*) porbeagle, *Lamna nasus*; (*d*) shortfin mako, *Isurus oxyrinchus*; (*e*) common thresher shark, *Alopias vulpinus*; (*f*) blue shark, *Prionace glauca*; and (*g*) dusky shark, *Carcharhinus obscurus.* L3, band pair counts of the primary reader; G1, band pair counts of second reader; 0, birth band.

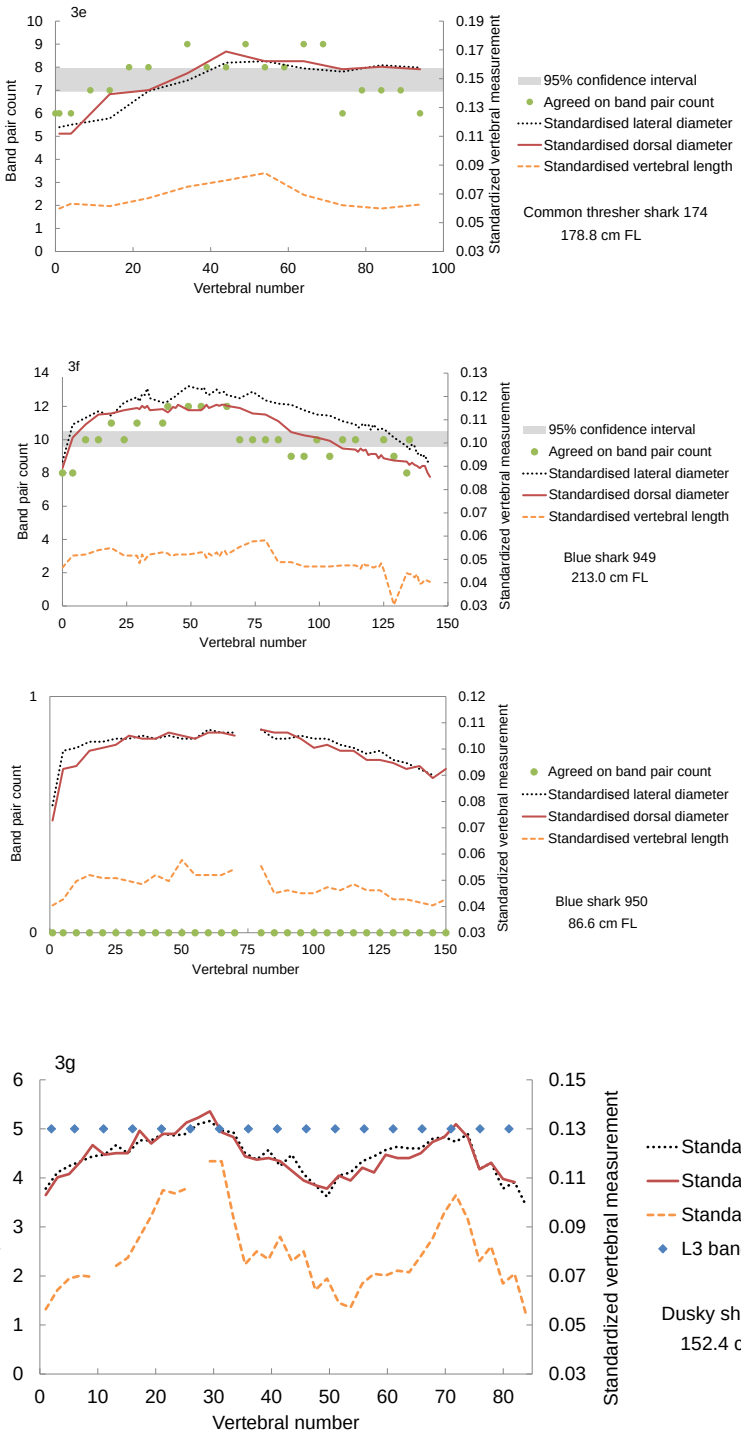

Fig. S3. (*Cont.*)

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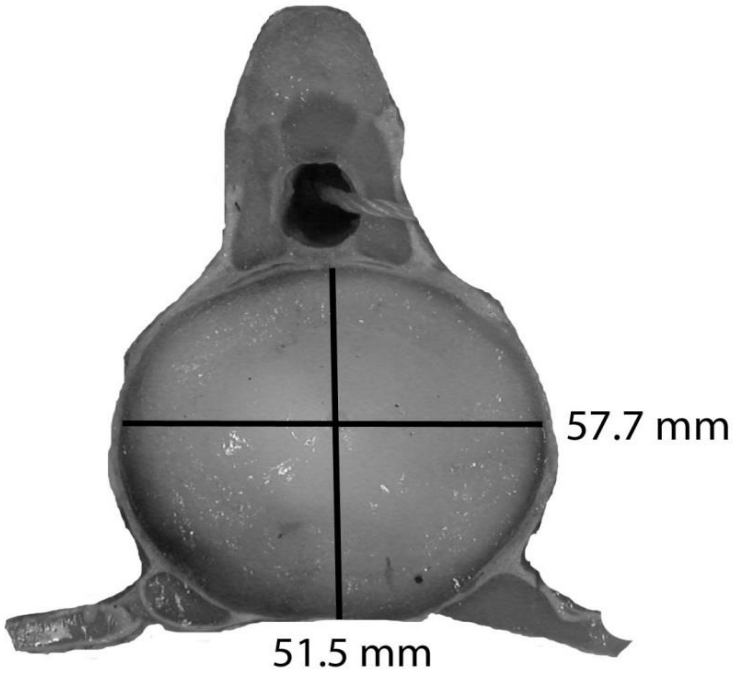

Fig. S4. Photograph of abdominal vertebra (#43) of a 343-cm fork length (FL) female shortfin mako (M524), *Isurus oxyrinchus*, indicating the change in shape that occurs in larger specimens.

Table S1. Sample data on sharks collected for this study

Fork length (FL) (cm), sex and disposition of the samples. Individual sample Coefficient of variation (CV) was presented by individual for column samples with over one band pair for both intra-reader comparison (primary readers second (L2) and third counts (L3)) and inter-reader comparison (between L3 and the secondary readers, first count (G1)). Results of Evans and Hoenig (1998) and CV pooled by species for L2-L3 are also shown. d.f., degrees of freedon; χ^2, calculated Chi-Square value; asterisks (*) denote significance at the 0.05 level. F, female; M, male; Unk, unknown sex; YOY, young of the year

Family						CV		Evans–Hoenig L2 to L3		
Species	Sample	FL (cm)	Sex	Whole column	Cross sections	L2-L3	L3-G1	d.f.	χ^2	*P*
Squatinidae										
Atlantic angel shark	Pooled					1.54		4	2.06	0.72
Small	101	27.8	F		X					
	200	39.5	M		X					
	90	44.0	M	X		0.66	3.55			
Medium	92	75.0	Unk	X		0.64	3.96			
	103	79.2	F		X					
	102	91.0	M		X					
	201	105.1	M		X					
Large	100	106.0	M	X	X	3.67	4.74			
	202	107.5	F		X					
Lamnidae										
White shark	Pooled					6.87		7	6.68	0.46
Small	147	144.9	M		X					
	148	151.6	M	X	X					
Medium	146	226.0	F	X		10.03	23.21			
	153[B]	322.4	M	X	X					
Large	150	331.0	M	X		6.22	5.45			
	145	377.0	M	X		7.22	9.23			
	149	380.9	M	X	X	3.57	11.05			
Porbeagle	Pooled					4.96		4	4.33	0.36
Small	646	82.0	F	X						
	634	85.6	M		X					
	651	89.6	F		X					

Family Species	Sample	FL (cm)	Sex	Whole column	Cross sections	CV L2-L3	 L3-G1	Evans–Hoenig L2 to L3 d.f.	 χ^2	 *P*
Lamnidae (*Cont.*)										
Porbeagle										
Medium	635	109.0	M		X					
	647	204.1	F		X					
	648	218.2	F		X					
Large	638	234.0	F		X					
	637[C]	234.2	F	X		4.73	4.60			
	633	247.6	F	X		5.17	6.87			
	650	248.0	F		X					
Shortfin mako	Pooled					11.44		6	10.30	0.11
Small	586	105.5	M	X	X					
	592	141.5	M		X					
Medium	509	174.5	M	X						
	508	182.8	M	X		9.74	12.69			
	593	203.1	F		X					
Large	594	291.5	F		X					
	527	292.1	F	X	X	5.61	2.84			
	528	294.6	F	X		5.38	7.16			
	524	343.0	F	X		4.62	3.92			
Common thresher shark	Pooled					7.17		4	23.72	0.00*
Small	375[D]	159.5	F		X					
	368[D]	162.9	F		X					
Medium	174	178.8	M	X		6.41	12.68			
	367	180.8	F		X					
Large	366	209.9	M		X					
	376	229.0	F		X					
	140	234.5	F	X		7.93	4.17			
	369	241.9	F		X					
Carcharinidae										
Blue shark	Pooled					21.88		14	21.34	0.09
Small	917	63.1	F		X					
	916	64.7	M		X					
	950	86.6	F	X	X					
Medium	915	127.3	F		X					
	949[B]	213.0	M	X	X	18.28	30.49			

Family Species	Sample	FL (cm)	Sex	Whole column	Cross sections	CV L2-L3	 L3-G1	Evans–Hoenig L2 to L3 d.f.	 χ^2	 *P*
Carcharinidae (*Cont.*)										
Blue shark										
Large	933	232.0	M		X					
	835	240.5	M	X		25.11	3.44			
	918	257.3	M		X					
Dusky shark	Pooled					2.97		4	6.00	0.20
Small	397	74.5	M		X					
	399	77.5	M		X					
Medium	365	152.4	F	X		3.03	0.00			
	398	185.1	F		X					
	435	211.0	F		X					
	436	226.0	F		X					
Large	400	236.0	M		X					
	282	270.0	F	X		2.90	2.57			

[A]This female was from the Pacific Ocean.

[B]Classified as medium for these purposes despite being mature based on maximum sizes.

[C]Oxytetracycline injected recapture.

[D]Classified as small for these purposes despite being 1 year because of the inability to obtain YOY.

Table S2. ANCOVA results comparing relationships of fork length (FL) to girths and lateral vertebral measurements to girth measurements along the vertebral columns of each species

Initial tests relate all girths to girth A, when significant differences occurred specific tests were run to look for differences between those girths. BCS, body-cross section location; asterisks (*) denote significance at the 0.05 level. Linear regression equations are provided for these analyses. Sample numbers are the degrees of freedom (d.f.) +2

		Fork length to girth by location					Girth to lateral measurement by location					FL = (*a*)girth × *b* Adjusted						Lateral = (*a*)girth × *b* Adjusted					
Species	BCS	Estimate	s.e.	*t*-value	Pr(>|t|)		Estimate	s.e.	*t*-value	Pr(>|t|)		*a*	*b*	r^2	*P*	d.f.		*a*	*b*	r^2	*P*	d.f.	
Atlantic angel shark																							
Initial	Intercept	–0.0937	1.4713	–0.0640	9.50E–01		–0.4726	0.8990	–0.5260	6.04E–01													
	A	0.4248	0.0166	25.6030	<2E–16	*	0.4106	0.0239	17.1800	3.11E–14	*	0.4248	–0.0937	0.9859	5.13E–06	5	*	0.4106	–0.4726	0.9755	2.03E–05	5	*
	B	0.0426	0.0235	1.8170	8.04E–02	*	0.0014	0.0323	0.0450	9.65E–01		0.4674	–2.0010	0.9900	2.18E–06	5	*	0.4121	–0.2455	0.9937	6.75E–07	5	*
	C	0.0721	0.0291	2.4810	1.96E–02	*	–0.0361	0.0379	–0.9520	3.51E–01		0.4969	–1.3435	0.9893	3.06E–04	3	*	0.3746	–0.5335	0.9932	1.54E–04	3	*
	D	–0.1941	0.0235	–8.2700	7.05E–09	*	0.2717	0.0501	5.4270	1.88E–05	*	0.2307	–0.7622	0.9844	6.53E–06	5	*	0.6823	–0.8434	0.9880	3.42E–06	5	*
	E	–0.3277	0.0235	–13.9650	7.17E–14	*	0.5874	0.1089	5.3960	2.03E–05	*	0.0971	0.4760	0.9645	5.15E–05	5	*	0.9980	–0.1438	0.9566	1.55E–02	3	*
	G	–0.1342	0.0236	–5.6850	4.87E–06	*	0.2103	0.0551	3.8190	9.37E–04	*	0.2906	–1.2546	0.9778	5.04E–01	4	*	0.6209	–1.5198	0.9992	1.24E–02	1	*
Specific	Intercept	–0.7622	1.1785	–0.6470	5.28E–01		–0.8434	1.0505	–0.8030	4.43E–01													
	D	0.2307	0.0133	17.3620	7.25E–11	*	0.6823	0.0531	12.8410	4.31E–07	*												
	E	–0.1336	0.0188	–7.1090	5.26E–06	*	0.3157	0.1389	2.2730	4.91E–02	*												
	G	0.0598	0.0189	3.1630	6.91E–03	*	–0.0614	0.0801	–0.7660	4.63E–01													
Specific	Intercept	–1.3435	1.8762	–0.7160	4.84E–01		–0.5335	1.4070	–0.3790	7.11E–01													
	C	0.4969	0.0205	24.3000	1.22E–14	*	0.3746	0.0317	11.7990	5.84E–08	*												
	D	–0.2661	0.0249	–10.6840	5.82E–09	*	0.3078	0.0571	5.3920	1.62E–04	*												
	E	–0.3997	0.0249	–16.0480	1.06E–11	*	0.6235	0.1189	5.2450	2.06E–04	*												
	G	–0.2063	0.0250	–8.2480	2.40E–07	*	0.2464	0.0622	3.9600	1.89E–03	*												
White shark																							
Initial	Intercept	0.9718	24.6630	0.0390	9.69E–01		–2.9841	6.6791	–0.4470	6.66E–01													
	A	0.5182	0.0911	5.6880	2.02E–04	*	0.3339	0.0470	7.0990	5.67E–05	*	0.5182	0.9718	0.8849	3.91E–02	2	*	0.3339	–2.9841	0.8846	3.93E–02	2	*
	B	–0.0200	0.1288	–0.1550	8.80E–01		0.1194	0.0815	1.4640	1.77E–01		0.4982	10.5432	0.8132	6.43E–02	2		0.4532	–14.2731	0.9976	2.19E–02	1	*
	C	0.0134	0.1288	0.1040	9.19E–01		–0.0052	0.0656	–0.0800	9.38E–01		0.5316	7.3025	0.8785	4.14E–02	2	*	0.3286	–4.1309	0.8819	4.02E–02	2	*
	D	–0.2546	0.1288	–1.9760	7.64E–02	*	0.1603	0.1071	1.4980	1.69E–01		0.2637	1.6727	0.9996	1.30E–04	2	*	0.4942	0.1927	0.9946	1.80E–03	2	*
	E	–0.3543	0.1288	–2.7500	2.05E–02	*	0.3162	0.1605	1.9700	8.04E–02	*	0.1639	–1.5158	0.9758	8.11E–03	2	*	0.6500	1.7655	0.9804	6.56E–03	2	*
Specific	Intercept	1.6727	2.9008	0.5770	5.95E–01		0.1927	2.0237	0.0950	9.29E–01													
	D	0.2637	0.0107	24.6050	1.62E–05	*	0.4942	0.0278	17.8080	5.84E–05	*												
	E	–0.0997	0.0152	–6.5810	2.76E–03	*	0.1558	0.0523	2.9820	4.07E–02	*												
Porbeagle																							
Initial	Intercept	–0.3114	8.4574	–0.0370	9.71E–01		–1.0191	3.5471	–0.2870	7.77E–01													
	A	0.6057	0.0464	13.0600	3.00E–11	*	0.2738	0.0321	8.5280	4.28E–08	*	0.6057	–0.3114	0.9527	1.06E–04	5	*	0.2738	–1.0191	0.9118	5.11E–04	5	*
	C	0.0087	0.0656	0.1320	8.96E–01		0.0017	0.0449	0.0380	9.70E–01		0.6144	1.1196	0.9450	2.29E–04	5	*	0.2755	–0.8628	0.9000	7.01E–04	5	*
	D	–0.3494	0.0656	–5.3270	3.26E–05	*	0.3135	0.0822	3.8150	1.08E–03	*	0.2563	–1.8779	0.9450	1.55E–04	5	*	0.5873	2.2996	0.9410	1.86E–04	5	*
	E	–0.4296	0.0656	–6.5500	2.21E–06	*	0.3770	0.1116	3.3790	2.98E–03	*	0.1761	–4.8132	0.8793	1.13E–03	5	*	0.6509	6.9008	0.8799	1.12E–03	5	*
Specific	Intercept	–1.8779	4.6925	–0.4000	6.97E–01		2.2996	2.9064	0.7910	4.47E–01													
	D	0.2563	0.0257	9.9610	1.65E–06	*	0.5873	0.0644	9.1250	3.66E–06	*												
	E	–0.0802	0.0364	–2.2050	5.20E–02	*	0.0636	0.1114	0.5700	5.81E–01													

		Fork length to girth by location					Girth to lateral measurement by location					FL = (*a*)girth × *b* Adjusted						Lateral = (*a*)girth × *b* Adjusted					
Species	BCS	Estimate	s.e.	*t*-value	Pr(>|t|)		Estimate	s.e.	*t*-value	Pr(>|t|)		*a*	*b*	r^2	*P*	d.f.		*a*	*b*	r^2	*P*	d.f.	
Shortfin mako																							
Initial	Intercept	–7.9724	12.2369	–0.6510	5.25E–01		0.0574	4.0901	0.0140	9.89E–01													
	A	0.5560	0.0555	10.0110	9.22E–08	*	0.2762	0.0382	7.2300	6.65E–06	*	0.5560	–7.9724	0.9433	3.77E–03	3	*	0.2762	0.0574	0.9898	3.41E–03	2	*
	B	0.0385	0.0786	0.4900	6.32E–01		0.0006	0.0501	0.0120	9.90E–01		0.5945	–9.7028	0.9499	3.12E–03	3	*	0.2768	–0.6372	0.9847	5.23E–04	3	*
	C	0.0454	0.0786	0.5780	5.73E–01		0.0029	0.0500	0.0590	9.54E–01		0.6014	–9.6968	0.9708	1.39E–03	3	*	0.2791	–0.9201	0.9924	1.81E–04	3	*
	D	–0.2882	0.0871	–3.3090	5.17E–03	*	0.1848	0.0963	1.9190	7.72E–02	*	0.2679	–1.6122	0.9979	6.94E–04	2	*	0.4610	0.2739	0.9827	5.77E–03	2	*
	E	–0.4047	0.0786	–5.1520	1.47E–04	*	0.2940	0.1189	2.4730	2.80E–02	*	0.1513	0.3135	0.6712	5.64E–02	3		0.5702	4.8024	0.5987	7.77E–02	3	
Specific	Intercept	–1.6122	9.3158	–0.1730	8.69E–01		0.2739	6.8817	0.0400	9.70E–01													
	D	0.2679	0.0470	5.7030	2.31E–03	*	0.4610	0.1333	3.4590	1.81E–02	*												
	E	–0.1165	0.0610	–1.9110	1.14E–01		0.1092	0.2158	0.5060	6.34E–01													
Common thresher shark																							
Initial	Intercept	0.4453	5.7504	0.0770	9.39E–01		–1.3992	3.2908	–0.4250	6.76E–01													
	A	0.5349	0.0288	18.5920	9.84E–13	*	0.3083	0.0306	10.0610	2.53E–08	*	0.5349	0.4453	0.9735	1.70E–04	4	*	0.3083	–1.3992	0.9294	1.22E–03	4	*
	C	–0.0148	0.0407	–0.3650	7.20E–01		0.0547	0.0440	1.2420	2.32E–01		0.5201	5.0404	0.9790	1.07E–04	4	*	0.3630	–4.9809	0.9267	1.32E–03	4	*
	D	–0.2863	0.0407	–7.0360	2.00E–06	*	0.4027	0.0728	5.5320	4.55E–05	*	0.2486	13.8397	0.9768	1.30E–04	4	*	0.7110	–11.7075	0.9845	5.82E–05	4	*
	E	–0.3454	0.0407	–8.4900	1.61E–07	*	0.6278	0.0925	6.7850	4.38E–06	*	0.1895	7.5964	0.9958	4.33E–06	4	*	0.9362	–9.3776	0.9972	1.89E–06	4	*
Specific	Intercept	13.8397	2.5392	5.4500	6.08E–04	*	–11.7075	1.9401	–6.0340	3.11E–04	*												
	D	0.2486	0.0127	19.5690	4.83E–08	*	0.7110	0.0306	23.2360	1.25E–08	*												
	E	–0.0592	0.0180	–3.2930	1.10E–02	*	0.2251	0.0507	4.4370	2.18E–03	*												
Blue shark																							
Initial	Intercept	–2.3721	2.9321	–0.8090	4.26E–01		0.2380	1.1579	0.2060	8.39E–01													
	A	0.3703	0.0175	21.2020	<2E–16	*	0.3117	0.0192	16.2140	8.92E–15	*	0.3703	–2.3721	0.9721	2.82E–05	5	*	0.3117	0.2380	0.9890	2.75E–06	5	*
	B	0.0327	0.0247	1.3240	1.98E–01		–0.0195	0.0262	–0.7450	4.63E–01		0.4030	–4.2335	0.9863	4.77E–06	5	*	0.2922	0.4881	0.9874	3.85E–06	5	*
	C	0.0355	0.0247	1.4370	1.63E–01		–0.0196	0.0261	–0.7520	4.59E–01		0.4058	–5.9240	0.9906	1.84E–06	5	*	0.2921	1.1098	0.9802	1.19E–05	5	*
	D	–0.1631	0.0247	–6.6030	6.43E–07	*	0.1894	0.0394	4.8060	6.16E–05	*	0.2072	–1.6751	0.9757	1.99E–05	5	*	0.5012	0.8520	0.9335	2.50E–04	5	*
	E	–0.2479	0.0247	–10.0350	2.99E–10	*	0.4571	0.0613	7.4510	8.37E–08	*	0.1224	–0.2764	0.9766	1.82E–05	5	*	0.7688	–0.2414	0.9818	9.65E–06	5	*
Specific	Intercept	–1.6751	1.8275	–0.9170	3.81E–01		0.8520	1.4125	0.6030	5.60E–01													
	D	0.2072	0.0109	19.0340	3.48E–09	*	0.5012	0.0423	11.8450	3.30E–07	*												
	E	–0.0848	0.0154	–5.5060	2.60E–04	*	0.2676	0.0832	3.2170	9.22E–03	*												
Dusky Shark																							
Initial	Intercept	–5.7314	2.9485	–1.9440	6.97E–02	*	–2.7659	1.4642	–1.8890	7.72E–02	*												
	A	0.515482	0.0163	31.6870	7.24E–16	*	0.3012	0.0166	18.1330	4.31E–12	*	0.5155	–5.7314	0.9968	2.45E–06	4	*	0.3012	–2.7659	0.9811	8.60E–05	4	*
	C	0.0062	0.0230	0.2720	7.89E–01		–0.0097	0.0233	–0.4180	6.81E–01		0.5217	–5.5332	0.9855	5.08E–05	4	*	0.2915	–2.0571	0.9906	2.11E–05	4	*
	D	–0.2414	0.0230	–10.4940	1.40E–08	*	0.2025	0.0354	5.7200	3.16E–05	*	0.2741	–3.7210	0.9980	9.31E–07	4	*	0.5037	–1.6781	0.9881	3.38E–05	4	*
	E	–0.3509	0.0230	–15.2510	5.96E–11	*	0.4283	0.0545	7.8670	6.89E–07	*	0.1646	–2.2963	0.9892	2.82E–05	4	*	0.7295	–0.6226	0.9628	3.35E–04	4	*
Specific	Intercept	–3.7210	1.2075	–3.0810	1.51E–02	*	–1.6781	1.4949	–1.1230	2.94E–01													
	D	0.2741	0.0067	41.1360	1.34E–10	*	0.5037	0.0323	15.5810	2.87E–07	*												
	E	–0.1094	0.0094	–11.6160	2.75E–06	*	0.2259	0.0626	3.6070	6.91E–03	*												

[A]Reference to trade names does not imply endorsement from NOAA Fisheries.

Reference

Evans, G. T., and Hoenig, J. M. (1998). Testing and viewing symmetry in contingency tables, with application to readers of fish ages. *Biometrics* **54**, 620–629.
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