Radiographic characterisation of spinal curvature development in farmed New Zealand Chinook salmon *Oncorhynchus tshawytscha* throughout seawater production

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Supplementary Table 1. Mean body weight (BW) ± S.E of Study I individuals with (n = 284) and without (n = 1,677) radiographic spinal curvature (rSC) at assessments 1, 2, 4, 5, 8, 11 and 13 (harvest) months (M) post seawater-transfer. Significance values pertain to independent t-tests/non-parametric Mann Whitney U tests of BW differences between groups with and without radiographic spinal curvature at each assessment.* denotes statistically significant differences between groups. † = mean and standard error undefined as only one individual was diagnosed with curvature at this assessment.

Assessment	**Mean BW (g)**			**Significance**
	All	**No rSC**	**rSC**	**(*t/U*, p)**
M1	163 ± 1.3	162 ± 1	169 ± 5	U = 1270.00, 0.29
M2	390 ± 7	390 ± 7	320†	t = 0.62, 0.54
M4	679 ± 9	679 ± 9	658 ± 35	U = 253.00, 0.78
M5	953 ± 13	955 ± 14	779 ± 133	U = 382.00, 0.24
M8	1883 ± 21	1884 ± 22	1870 ± 72	t = 0.19, 0.85
M11	2743 ± 34	2766 ± 45	2704 ± 49	t = 0.88, 0.38
M13	3734 ± 48	3851 ± 67	3578 ± 66	U = 8344.50, < 0.01*

Supplementary Table 2. Prevalence of external aberrations in Study I individuals with and without radiographic spinal curvature (rSC) at assessments 1, 2, 4, 5, 8, 11 and 13 (harvest) months (M) post-seawater transfer. n = 1,756.

Assessment	n			Scale loss			Eye Anomalies			Spots			Lesions			Fin split/rot		
	All	No rSC	rSC	All	No rSC	rSC	All	No rSC	rSC	All	No rSC	rSC	All	No rSC	rSC	All	No rSC	rSC
M1	205	194	11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
M2	294	293	1	50.3% (148)	50.5% (148)	0% (0)	65.0% (191)	64.9% (190)	100% (1)	1.4% (4)	1.4% (4)	0% (0)	0.3% (1)	0.3% (1)	0% (0)	1.0% (3)	1.0% (3)	0% (0)
M4	288	286	2	63.9% (184)	64.0% (183)	50.0% (1)	90.6% (261)	90.9% (260)	50.0% (1)	6.3% (18)	6.3% (18)	0% (0)	0.7% (2)	0.7% (2)	0% (0)	1.0% (3)	1.1% (3)	0% (0)
M5	294	290	4	71.4% (210)	71.7% (208)	50.0% (2)	40.1% (118)	40.0% (116)	50.0% (2)	27.6% (81)	27.2% (79)	50.0% (2)	8.5% (25)	8.6% (25)	0% (0)	0.7% (2)	0.7% (2)	0.0% (0)
M8	277	252	25	67.2% (186)	66.7% (168)	72.0% (18)	64.3% (178)	63.1% (159)	36.0% (9)	42.2% (117)	42.9% (108)	36.0% (9)	49.8% (138)	48.4% (122)	64.0% (16)	10.8% (30)	11.5% (29)	4.0% (1)
M11	303	191	112	37.3% (113)	36.7% (70)	38.9% (43)	8.9% (27)	10.5% (20)	6.3% (7)	59.7% (181)	59.2% (113)	60.7% (68)	19.8% (60)	18.3% (35)	22.3% (25)	13.9% (42)	13.6% (26)	14.3% (16)
M13	300	171	129	46.0% (138)	48.0% (82)	43.4% (56)	0% (0)	0% (0)	0% (0)	56.3% (169)	59.2% (95)	57.4% (74)	33.7% (101)	33.9% (58)	33.3% (43)	17.3% (52)	19.3% (33)	14.7% (19)
Total	**1,756**	**1,483**	**273**	**55.8% (979)**	**57.9% (859)**	**44.0% (120)**	**47.2% (828)**	**52.3% (775)**	**19.4% (53)**	**32.6% (570)**	**28.1% (417)**	**56.0% (153)**	**18.6% (327)**	**16.4% (243)**	**30.8% (84)**	**7.5% (132)**	**6.5% (96)**	**13.2% (36)**

Supplementary Table 3. Onset (initial radiographic detection), prevalence and severity of radiographic spinal curvature (rSC) and presence of visual SC (P = present, A = absent) in Study II individuals with radiographic curvature at harvest at assessments 5, 11, 13 and 15 (harvest) months (M) post-seawater transfer, in order of increasing harvest curvature severity. n = 25. BW = body weight (g). L = lordosis, K = kyphosis, S = scoliosis. Coloured cells indicate rSC onset for each individual. Dashes indicate the absence of a given anomaly.

Fish ID	Visual SC M15	BW (g) at rSC onset	rSC sev M5	rSC sev M11	rSC sev M13	rSC sev M15	rSC types M11	rSC types M13	rSC types M15
15616039	A	4890	0	0	0	1	-	-	K
42610872	A	3080	0	0	1	1	-	K	K
73593256	A	3280	0	0	3	1	-	L+K	L+K
0A00065617	A	3750	0	0	0	1	-	-	K
14260345	A	1720	0	0	1	2	-	K	K
29885009	A	2050	0	0	2	2	-	L+K	L+K
42609823	A	3920	0	0	1	2	-	L	L+K
95815277	A	5470	0	0	0	2	-	-	L+K
107037017	A	4960	0	0	0	2	-	-	K+S
107074117	P	2300	0	0	3	3	-	L+K	L+K+S
42771042	A	1170	0	0	4	4	-	L+K	L+K+S
107032257	P	1320	0	3	4	4	L+K	L+K+S	L+K+S
21342850	P	2570	0	0	3	5	-	L+K	L+K+S
42629834	P	2200	0	3	5	5	L+K	L+K+S	L+K+S
107070031	P	1490	0	0	3	5	-	L+K	L+K+S
107070534	P	1130	0	0	2	5	-	L+K	L+K+S
0A00143331	P	2810	0	0	6	5	-	L+K+S	L+K+S
0A00157114	P	3410	0	0	0	6	-	-	L+K+S
42636326	P	3030	0	0	4	7	-	L+K	L+K+S
0A00151003	P	3350	0	0	5	7	-	L+K+S	L+K+S
42775544	P	2620	0	3	6	8	L+K+S	L+K+S	L+K+S
0A00066055	P	1800	0	1	7	8	K	L+K+S	L+K+S
42603784	P	1440	0	2	7	9	L+K	L+K+S	L+K+S
42605638	P	970	0	7	7	9	L+K+S	L+K+S	L+K+S
42783519	P	1940	0	4	8	9	L+K	L+K+S	L+K+S

Supplementary Table 4. Mean body weight (BW) ± S.E of Study II individuals with (n = 25) and without (n = 38) radiographic spinal curvature (rSC) at harvest at assessments 5, 9, 11, 13 and 15 (harvest) months (M) post-seawater transfer. Significance values pertain to independent t-tests/non-parametric Mann Whitney U tests of BW differences between groups with and without rSC at each assessment. * denotes statistically significant differences between groups.

Assessment	**Mean BW (g)**			**Significance (*t/U*, p)**
	All	**No rSC**	**rSC**	
M5	759 ± 15	769 ± 20	744 ± 24	*U* = 379.00, 0.18
M9	1648 ± 39	1630 ± 51	1675 ± 61	*t* = -0.57, 0.57
M11	1666 ± 61	1617 ± 78	1741 ± 99	*t* = -1.00, 0.32
M13	2464 ± 112	2384 ± 150	2587 ± 168	*t* = -0.89, 0.38
M15	3451 ± 195	3375 ± 263	3566 ± 289	*U* = 498.00, 0.75

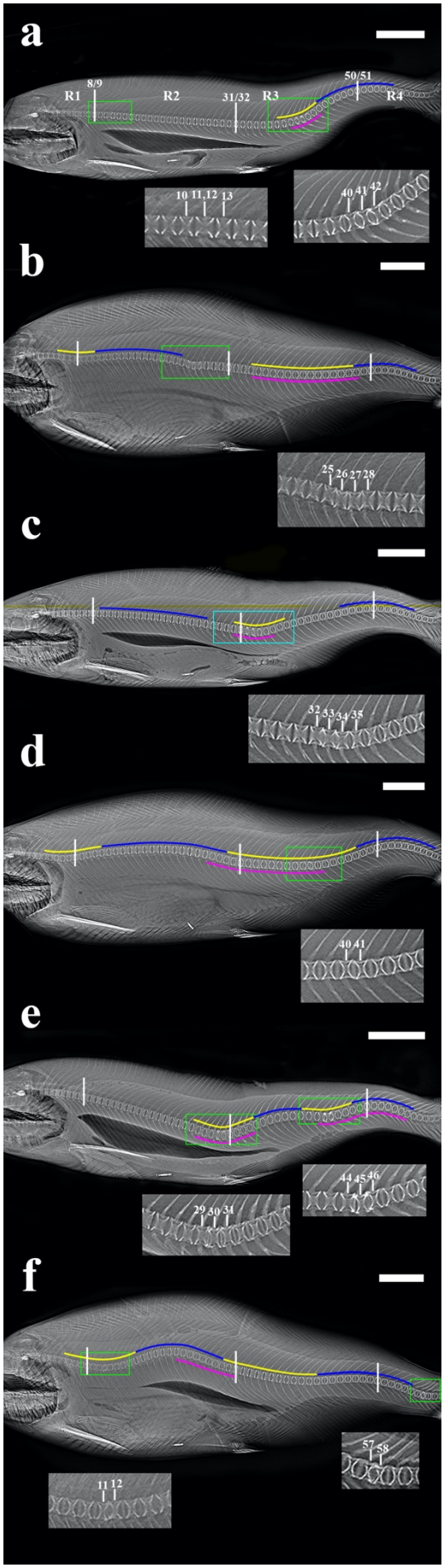
Supplementary Table 5. Prevalence of external aberrations in Study II individuals with (n = 25) and without (n = 38) radiographic spinal curvature (rSC) at harvest at assessments 5, 9, 11, 13 and 15 (harvest) months (M) post-seawater transfer.

Assessment	n			Scale loss			Eye anomalies			Spots			Lesions			Fin split/rot		
	All	No rSC	rSC	All	No rSC	rSC	All	No rSC	rSC	All	No rSC	rSC	All	No rSC	rSC	All	No rSC	rSC
M5	63	38	25	7.9% (5)	5.3% (2)	12.0% (3)	6.4% (4)	5.3% (2)	8.0% (2)	3.2% (2)	5.3% (2)	0% (0)	1.6% (1)	2.6% (1)	0% (0)	0% (0)	0% (0)	0% (0)
M9				28.6% (18)	26.3% (10)	32.0% (8)	0% (0)	0% (0)	0% (0)	73.0% (46)	86.8% (33)	52.0% (13)	17.5% (11)	13.2% (5)	24.0% (6)	0% (0)	0% (0)	0% (0)
M11				49.2% (31)	50.0% (19)	48.0% (12)	7.9% (5)	5.3% (2)	12.0% (3)	71.4% (45)	76.3% (29)	64.0% (16)	14.3% (9)	7.9% (3)	24.0% (6)	4.8% (3)	5.3% (2)	4.0% (1)
M13				39.7% (25)	42.1 (16)	36.0% (9)	9.5% (6)	0% (0)	24.0% (6)	33.3% (21)	34.2% (13)	32.0% (8)	36.5% (23)	31.6% (12)	44.0% (11)	3.2% (2)	2.6% (1)	4.0% (1)
M15				44.4% (28)	44.7% (17)	44.0% (11)	1.6% (1)	0% (0)	4.0% (1)	22.2% (14)	29.0% (11)	12.0% (3)	25.4% (16)	26.3% (10)	24.0% (6)	4.8% (3)	5.3% (2)	4.0% (1)

Supplementary Table 6. Patterns of radiographic spinal curvature (L = lordosis, K = kyphosis, S = scoliosis) in vertebral column regions 1 (R1, vertebra (V)1-8), 2 (R2, V9-31), 3 (R3, V32-50), and 4 (R4, V50 – 62+) of Study II individuals at initial radiographic detection (onset) and harvest (15 months (M) post-seawater transfer). n = 25. Apex corresponds to the spinal region(s) which contained the peak(s) of each curvature type. Max severity (Max sev) corresponds to the vertebral column region with the highest severity score for each curvature type.

Fish #ID	Regions affected at SC onset	Regions affected at M15	Apex L M15	Apex K M15	Apex S M15	Max sev L M15	Max sev K M15	Max sev S M15
15616039	R1	R1	-	R1	-	-	R1	-
42610872	R2	R2	-	R2	-	-	R2	-
73593256	R1,R2,R3	R4	R4	-	-	R4	-	-
0A00065617	R2	R2	-	R2	-	-	R2	-
14260345	R2	R1,R2	-	R2	-	-	R2	-
29885009	R1,R2	R1,R2	R1	R2	-	R1	R2	-
42609823	R1	R1,R2	R1	R2	-	R1	R2	-
95815277	R1,R2	R1,R2	R1	R2	-	R1	R2	-
107037017	R2,R3	R2,R3	-	R2	R3	-	R2	R3
107074117	R2,R3,R4	R3,R4	R3	R4	-	R3	R4	-
42771042	ALL	ALL	R2	R2	R3	R2	R2	R3
107032257	R2,R3,R4	R3,R4	R3	R2	R3	R3	R2	R3
21342850	R2,R3,R4	ALL	R1,R3	R2,R4	R3	R3	R2	R3
42629834	R2,R3,R4	ALL	R1,R3	R2,R4	R3	R1	R4	R3
107070031	R2,R3,R4	R2,R3,R4	R3	R2,R4	R3	R3	R4	R3
107070534	R1,R2	ALL	R2	R1,R2	R3,R4	R2	R2	R3
0A00143331	ALL	R2,R3,R4	R3	R2,R4	R2,R3	R3	R2	R3
0A00157114	ALL	ALL	R2,R3	R2,R4	R2,R3	R2	R2	R2
42636326	ALL	ALL	R1,R3	R2,R4	R3	R3	R4	R3
0A00151003	ALL	ALL	R1,R3	R2,R4	R3	R3	R4	R3
42775544	R1,R2,R3	ALL	R3,R4	R2,R4	R1,R3	R3	R4	R3
0A00066055	R4	ALL	R2,R3	R2,R4	R1,R3	R2	R2	R3
42603784	R2,R3	ALL	R2,R3	R2,R4	R3	R3	R2	R3
42605638	ALL	ALL	R2,R3	R2,R3,R4	R2,R3	R2	R4	R3
42783519	ALL	ALL	R2,R3	R2,R4	R2,R3	R2	R2	R2

Supplementary Figure 7. Variations in end-stage spinal phenotype evident on lateral radiographs of Study II individuals with both spinal curvature (SC) and vertebral body anomalies (VA) at harvest (15 months post-seawater transfer), in order of increasing summed radiographic SC severity. Labels R1, R2, R3 and R4 in (a) correspond to vertebral column regions 1 (vertebra (V)1-8), 2 (V9-31), 3 (V32-50) and 4 (V51-62+). Small white vertical lines in (a) – (f) indicate the transition points between the four vertebral column regions. Coloured lines indicate lordosis (yellow), kyphosis (blue) and scoliosis (pink). Scale bars = 5 cm. (a) Summed curvature severity = 2. Lordosis and scoliosis are present in R3 and kyphosis at the R3/R4 junction. V11 and V12 are completely fused. V10, V13 and V40-42 are compressed. V41 and V42 are vertically shifted. (b) Summed curvature severity = 5. Lordosis is present at the R1/R2 junction and in R3, kyphosis in R2 and at the R3/R4 junction, and scoliosis in R3. V25-28 are compressed, and V26 and V27 are also vertically shifted. (c) Summed curvature severity = 5. Lordosis and scoliosis are present at the R2/R3 junction. Kyphosis is present in R2 and at the R3/R4 junction. V32-35 are compressed and V33 and V34 are also vertically shifted. (d) Summed curvature severity = 7. Lordosis is present at the R1/R2 junction and in R3, kyphosis in R2 and at the R3/R4 junction, and scoliosis at the R2/R3 junction. V40-41 are vertically shifted. (e) Summed curvature severity = 9. Lordosis is present at the R2/R3 junction and in R3, kyphosis in R3 and at the R3/R4 junction, and scoliosis at the R2/R3 and R3/R4 junctions. V29-31 and V44-46 are compressed and V30 and V45 are vertically shifted. (f) Summed curvature severity = 9. Lordosis is present at the R1/R2 junction and in R3, kyphosis in R2 and at the R3/R4 junction, and scoliosis in R2. V11-12 and V57-58 are compressed and vertically shifted.


a
8/9
R1
R2
31/32
R3
50/51
R4
10 11,12 13
40 41 42
b
25 26 27 28
c
32 33 34 35
d
40 41
e
44 45 46
29 30 31
f
57 58
11 12

Supplementary Table 8. Onset (initial radiographic detection), prevalence and severity of vertebral body anomalies (VA) at assessments 5, 11, 13 and 15 (harvest) months (M) post-seawater transfer in Study II individuals affected (SC + VA, n = 14) and unaffected (VA-only, n = 13) by radiographic spinal curvature (rSC). F = fusion, C = compression and VS = vertical shift. P = present, A = absent. n = 27. Dashes indicate the absence of a given anomaly.

Fish ID	Group	rSC onset	VA onset	VA sev M5	VA sev M11	VA sev M13	VA sev M15	F	F onset	F sev onset	F sev M15	C	C onset	C sev onset	C sev M15	VS	VS onset	VS sev onset	VS sev M15
15616039	SC + VA	M15	M5	3	2	2	4	P	M5	1	1	P	M5	2	1	P	M15	2	2
42610872	SC + VA	M13	M5	4	4	6	6	P	M5	2	2	P	M5	2	3	P	M13	1	1
73593256	SC + VA	M13	M5	1	1	0	2	P	M5	1	1	P	M15	1	1	P	M15	1	1
107037017	SC + VA	M15	M15	0	0	8	8	A	-	-	-	P	M13	4	4	P	M13	4	4
107032257	SC + VA	M11	M11	4	4	8	8	P	M5	2	2	P	M5	2	4	P	M13	2	2
42629834	SC + VA	M11	M13	0	0	2	4	A	-	-	-	P	M13	2	2	P	M15	2	2
107070031	SC + VA	M13	M13	0	0	4	4	A	-	-	-	P	M13	2	2	P	M13	2	2
107070534	SC + VA	M13	M5	5	5	4	3	A	-	-	-	P	M5	3	2	P	M5	2	1
0A00157114	SC + VA	M15	M11	0	2	2	2	P	M15	2	2	P	M11	2	0	A	-	-	-
42636326	SC + VA	M13	M15	0	0	0	4	A	-	-	-	P	M15	2	2	P	M15	2	2
42775544	SC + VA	M11	M5	1	1	5	3	A	-	-	-	P	M13	2	1	P	M5	1	2
0A00066055	SC + VA	M11	M15	0	0	0	2	A	-	-	-	P	M15	1	1	P	M15	1	1
42605638	SC + VA	M11	M11	0	4	7	4	A	-	-	-	P	M11	2	2	P	M11	2	2
42783519	SC + VA	M11	M13	0	0	8	8	A	-	-	-	P	M13	4	4	P	M13	4	4
14127533	VA-only	-	M13	0	0	2	4	A	-	-	-	P	M13	1	2	P	M13	1	2
14256529	VA-only	-	M5	1	2	1	4	P	M11	2	1	P	M5	1	2	P	M15	1	1
42619571	VA-only	-	M15	0	0	0	1	A	-	-	-	P	M15	1	1	A	-	-	-
42632873	VA-only	-	M11	0	1	0	1	A	-	-	-	P	M11	1	1	A	-	-	-
42634351	VA-only	-	M5	3	1	0	2	A	-	-	-	P	M5	2	1	P	M5	1	1
42773088	VA-only	-	M13	0	0	2	1	A	-	-	-	P	M13	2	1	A	-	-	-
42778094	VA-only	-	M5	9	9	14	13	P	M5	4	6	P	M5	5	6	P	M5	1	1
82102311	VA-only	-	M5	2	4	4	6	P	M11	1	2	P	M5	2	4	A	-	-	-
91258527	VA-only	-	M13	0	0	0	2	A	-	-	-	P	M15	1	1	P	M15	1	1
96576792	VA-only	-	M13	0	0	0	1	A	-	-	-	A	-	-	-	P	M15	1	1
107035889	VA-only	-	M5	1	0	2	4	P	M15	2	2	P	M13	1	1	P	M5	1	1
107894521	VA-only	-	M5	14	11	12	10	P	M5	6	3	P	M5	5	5	P	M5	3	2
0A00151232	VA-only	-	M15	0	0	0	1	A	-	-	-	A	-	-	-	P	M15	1	1