The following supplement accompanies the article

Habitat use by juvenile salmon, other migratory fish, and resident fish species underscores the importance of estuarine habitat mosaics

Lia Chalifour*, David C. Scott, Misty MacDuffee, Josephine C. Iacarella, Tara G. Martin, Julia K. Baum

*Corresponding author: lia.chalifour@gmail.com

Marine Ecology Progress Series 625: 145–162 (2019)

Table S1. Summary of covariates included in fish catch models for the Fraser River estuary (prior to standardization). Mean, median, and measured range across all sites are shown for each habitat. Julian day was modeled as a quadratic variable in models that had a strong non-linear relationship between abundance and time.

	Marsh		Eelgrass		Sand flat	
Variable	**Mean**	**Median (Range)**	**Mean**	**Median (Range)**	**Mean**	**Median (Range)**
Year	0.48	0 (0:1)	0.45	0 (0:1)	0.44	0 (0:1)
Julian day	157	151 (64:282)	163	153 (79:286)	159	154 (79:285)
Temperature (°C)	13.36	13.30 (3.43:18.32)	13.64	13.85 (7.49:18.85)	14.38	14.21 (7.55:20.41)
Dissolved oxygen (mg L^{-1})	10.46	10.74 (4.68:15.50)	9.97	10.16 (5.53:14.19	10.28	10.36 (4.04:14.56)
pH	8.06	7.91 (6.44:10.46)	8.31	8.30 (7.78:9.00)	8.19	8.14 (7.81:8.70)
Salinity (ppt)	2.33	0.89 (0.00:19.4)	25.56	27.36 (10.38:33.92)	11.70	10.97(0.55:30.84)
Channel width (m)	51.26	53.90 (18.80:170.07)	NA	NA	NA	NA
Vegetation elevation (m)	1.25	1.25 (0.32:2.58)	NA	NA	NA	NA
Mean Turbidity (FNU)	35.95	37.47 (29.87:41.52)	4.43	3.47 (2.02:9.30)	12.41	11.90 (8.97:17.81)
Habitat (categorical)	NA	NA	Eelgrass	NA	Sand flat	NA

Table S2. Total sampling effort by habitat, season, and year. One sampling event represents one site visit with three non-overlapping seine hauls collected.

		Marsh	Eelgrass	Sand Flat	Total
2016	Spring	12	12	16	40 (26 %)
	Summer	25	28	30	83 (54%)
	Fall	7	12	12	31 (20 %)
		44	**52**	**58**	**154**
2017	Spring	19	23	23	65 (49%)
	Summer	21	24	24	69 (51%)
	Fall	0	0	0	0
		40	**47**	**47**	**134**
	Grand totals	**84**	**99**	**105**	**288**

Table S3. Summary of abiotic model results determining water quality parameter differences between years, habitats, and months. Site was included as a random effect in all models. Month estimates are relative to March, year estimates are relative to 2016, and habitat estimates are relative to marsh. N for each parameter = 51, 253. Number of sites with measurements = 18. * indicates significance level (p < 0.001 '***', 0.001 '**', 0.01 '*'). R^2 = conditional R^2, *Mar.* R^2 = marginal R^2.

	Parameter	Estimate	(SE)	R^2	*Mar.* R^2
Temperature C					
	Year	-0.670***	(0.013)	0.738	0.579
	Eelgrass	0.638	(0.529)		
	Sand flat	1.665**	(0.547)		
	April	2.619***	(0.040)		
	May	3.456***	(0.039)		
	June	4.352***	(0.039)		
	July	6.428***	(0.040)		
	August	8.608***	(0.064)		
	September	2.504***	(0.043)		
	October	0.869***	(0.066)		
Dissolved oxygen (mg L^{-1})					
	Year	-0.493***	(0.009)	0.630	0.484
	Eelgrass	-0.564	(0.302)		
	Sand flat	-0.203	(0.313)		
	April	2.429***	(0.028)		
	May	1.604***	(0.028)		
	June	-0.041	(0.028)		
	July	0.651***	(0.028)		
	August	-1.087***	(0.045)		
	September	-0.129***	(0.031)		
	October	-2.057***	(0.047)		
Salinity (PPT)					
	Year	-1.919***	(0.040)	0.884	0.811
	Eelgrass	23.318***	(1.633)		
	Sand flat	8.236***	(1.689)		
	April	-2.466***	(0.121)		
	May	-2.829***	(0.118)		
	June	-2.186***	(0.119)		
	July	-1.938***	(0.119)		
	August	2.555***	(0.194)		
	September	3.310***	(0.131)		
	October	2.999***	(0.198)		
pH					
	Year	-0.008*	(0.003)	0.580	0.466
	Eelgrass	0.255**	(0.080)		
	Sand flat	0.082	(0.083)		
	April	0.557***	(0.009)		
	May	0.259***	(0.009)		
	June	0.127***	(0.009)		
	July	0.574***	(0.009)		
	August	-0.476***	(0.014)		
	September	-0.113***	(0.010)		
	October	-0.083***	(0.015)		

Table S4. Summary of top models (i.e. those with a **ΔAICc <4)** estimating the catch of the four species groups in marsh habitat (i.e. beach seine sites): Chinook salmon (a), Chum salmon (b), Other migratory fishes (c), and Resident fishes (d). Plus signs indicate the presence of variables within each model in the top model set. Variables with RVI scores greater than 0.5 are in bold.

Rank	**Year**	**J. day**	**J. day^2**	**Temp.**	**D.O.**	**pH**	**Sal.**	**Turb.**	**Width**	**Veg. elev.**	***df***	**AICc**	**ΔAICc**	***w***	***R^2***
a) Chinook															
1	+	+		+		+			+		7	434.82	0.00	0.21	0.51
2	+	+		+					+		6	435.31	0.48	0.16	0.48
3	+	+		+					+	+	7	436.81	1.99	0.08	0.49
4	+	+		+		+	+		+		8	436.82	2.00	0.08	0.51
5	+	+		+		+			+	+	8	437.18	2.36	0.06	0.51
6	+	+		+	+	+			+		8	437.23	2.41	0.06	0.51
7	+	+		+			+		+		7	437.39	2.56	0.06	0.49
8	+	+		+				+	+		7	437.40	2.58	0.06	0.49
9	+	+		+		+		+	+		8	437.42	2.60	0.06	0.51
10	+	+	+	+		+			+		8	437.43	2.60	0.06	0.51
11	+	+		+	+				+		7	437.56	2.74	0.05	0.48
12	+	+	+	+					+		7	437.73	2.90	0.05	0.48
13	+	+		+				+			6	438.79	3.96	0.03	0.45
RVI	**1.00**	**1.00**	0.10	**1.00**	0.11	**0.52**	0.13	0.14	**0.97**	0.14					
b) Chum															
1		+			+						4	226.76	0.00	0.08	0.33
2					+						3	226.91	0.15	0.07	0.27
3				+	+						4	227.53	0.77	0.05	0.32
4		+			+			+			5	227.57	0.81	0.05	0.37
5					+			+			4	227.86	1.09	0.05	0.31
6	+	+			+						5	228.49	1.73	0.03	0.36
7					+					+	4	228.78	2.02	0.03	0.29
8					+		+				4	228.91	2.15	0.03	0.29
9		+		+	+						5	229.00	2.23	0.03	0.35
10	+				+						4	229.02	2.25	0.03	0.29
11			+		+						4	229.11	2.35	0.02	0.28
12			+								3	229.12	2.35	0.02	0.23
13				+	+			+			5	229.25	2.48	0.02	0.34
14		+			+					+	5	229.25	2.48	0.02	0.34
15			+			+					4	229.26	2.50	0.02	0.28
16			+	+							4	229.28	2.52	0.02	0.28
17		+	+		+						5	229.33	2.57	0.02	0.34
18					+	+					4	229.45	2.69	0.02	0.28
19		+			+		+				5	229.48	2.72	0.02	0.34

Rank	Year	J. day	J. day^2	Temp.	D.O.	pH	Sal.	Turb.	Width	Veg. elev.	*df*	AICc	ΔAICc	*w*	R^2
b) Chum continued															
20			+	+	+						5	229.55	2.79	0.02	0.33
21		+			+	+					5	229.58	2.81	0.02	0.33
22					+			+		+	5	229.69	2.93	0.02	0.33
23				+	+					+	5	229.74	2.98	0.02	0.33
24	+	+			+			+			6	229.75	2.99	0.02	0.39
25	+		+								4	229.77	3.00	0.02	0.27
26			+			+		+			5	229.85	3.08	0.02	0.33
27			+	+		+					5	229.92	3.15	0.02	0.33
28					+		+	+			5	229.97	3.21	0.02	0.33
29		+			+			+		+	6	230.18	3.42	0.01	0.38
30					+	+		+			5	230.20	3.43	0.01	0.32
31		+			+	+		+			6	230.23	3.47	0.01	0.38
32	+			+	+						5	230.33	3.57	0.01	0.32
33	+				+			+			5	230.35	3.59	0.01	0.32
34				+	+	+					5	230.38	3.61	0.01	0.32
35				+	+		+				5	230.39	3.62	0.01	0.32
36		+		+	+			+			6	230.41	3.64	0.01	0.38
37			+		+			+			5	230.45	3.68	0.01	0.32
38		+			+		+	+			6	230.50	3.74	0.01	0.38
39	+	+	+								5	230.57	3.81	0.01	0.31
40		+	+			+					5	230.59	3.83	0.01	0.31
41		+	+		+			+			6	230.59	3.83	0.01	0.37
42		+	+								4	230.63	3.87	0.01	0.25
RVI	0.13	0.40	0.25	0.23	**0.84**	0.15	0.09	0.30	NA	0.10					
c) Other Migratory															
1							+			+	4	106.21	0.00	0.38	0.54
2							+	+		+	5	107.68	1.47	0.18	0.61
3							+				3	108.15	1.94	0.14	0.37
4										+	3	109.19	2.98	0.09	0.33
5							+		+	+	5	109.20	2.99	0.09	0.57
6					+		+			+	5	109.59	3.37	0.07	0.56
7								+		+	4	110.04	3.82	0.06	0.42
RVI	0.16	NA	NA	NA	0.13	NA	**0.76**	0.20	0.07	**0.88**					
c) Resident															
1	+	+	+			+		+			7	746.75	0.00	0.22	0.54
2	+	+	+		+	+		+			8	747.74	0.99	0.14	0.55
3	+	+	+			+		+	+		8	747.77	1.02	0.13	0.55
4	+	+	+		+	+		+	+		9	748.47	1.72	0.09	0.56
5	+	+	+			+	+	+			8	748.77	2.02	0.08	0.55
Rank	**Year**	**J. day**	**J. day^2**	**Temp.**	**D.O.**	**pH**	**Sal.**	**Turb.**	**Width**	**Veg. elev.**	***df***	**AICc**	**ΔAICc**	***w***	**R^2**

c) Resident continued

6	+	+	+			+		+		+	8	749.09	2.34	0.07	0.54
7	+	+	+		+	+	+	+			9	749.80	3.05	0.05	0.55
8	+	+	+		+	+		+		+	9	749.89	3.14	0.05	0.55
9	+	+	+			+	+	+	+		9	749.97	3.22	0.04	0.55
10	+	+	+			+		+	+	+	9	750.23	3.49	0.04	0.55
11	+	+	+					+			6	750.23	3.49	0.04	0.51
12	+	+	+					+	+		7	750.32	3.58	0.04	0.52
RVI	**1.00**	**1.00**	**1.00**	NA	0.33	**0.92**	0.18	**1.00**	**0.35**	0.16					

Year = year of surveys (2016 and 2017); J. day = Julian day; J. day^2 = quadratic modifier of Julian day (Julian day squared); Temp. = surface water temperature measured during each sampling event; D.O. = surface water dissolved oxygen measured during each sampling event; pH = surface water pH measured during each sampling event; Sal. = surface water salinity measured during each sampling event; Turb. = mean turbidity measured over all sampling events in 2016; Width = marsh channel width; Veg. elev. = mean elevation of lowest marsh vegetation relative to the base of the channel; *df* = degrees of freedom; AIC_c = AIC corrected for small sample sizes; ΔAIC_c = difference from the lowest AIC_c value; *w* = model weight; R^2 = pseudo R^2; RVI = relative variable importance.

Table S5. Top models (i.e. those with a ΔAICc <4) describing catch of four species groups in eelgrass/sand flat habitats (i.e. purse seine sites): Chinook salmon (a), Chum salmon (b), Other migratory fishes (c), and Resident fishes (d). Plus signs indicate the presence of variables within each model in the top model set. Variables with RVI scores greater than 0.5 that were included in the top model are in bold.

Rank	Hab.	Year	J. day	J. day^2	Temp.	D.O.	pH	Sal.	Mean turb.	*df*	AICc	ΔAICc	*w*	R^2	*Mar.* R^2
	a) Chinook														
1	+	+				+				6	361.75	0.00	0.27	0.50	0.34
2		+				+				5	362.31	0.56	0.20	0.50	0.25
3	+	+	+			+				7	363.56	1.80	0.11	0.52	0.35
4		+	+			+				6	363.93	2.18	0.09	0.52	0.27
5	+	+				+	+			7	364.04	2.29	0.08	0.51	0.34
6	+	+			+	+				7	364.12	2.37	0.08	0.50	0.34
7		+			+	+				6	364.54	2.79	0.07	0.50	0.26
8		+				+	+			6	364.60	2.85	0.06	0.50	0.26
9	+	+	+		+	+				8	365.67	3.92	0.04	0.52	0.36
RVI	**0.58**	**1.00**	0.24	NA	0.19	**1.00**	0.2	NA	NA						
	b) Chum														
1		+	+	+					+	7	220.62	0.00	0.35	0.95	0.44
2		+	+	+						6	222.22	1.60	0.16	0.96	0.33
3	+	+	+	+						7	222.24	1.63	0.16	0.96	0.44
4		+	+	+		+			+	8	222.78	2.17	0.12	0.96	0.43
5		+	+	+		+				7	223.03	2.42	0.11	0.96	0.32
6	+	+	+	+					+	8	224.33	3.72	0.06	0.95	0.45
7	+	+	+	+		+				8	224.53	3.92	0.05	0.96	0.41
RVI	0.26	**1.00**	**1.00**	**1.00**	NA	0.28	NA	NA	**0.53**						

Rank	Hab.	Year	J. day	J. day^2	Temp.	D.O.	pH	Sal.	Mean turb.	*df*	AICc	ΔAICc	*w*	R^2	*Mar.* R^2
	c) Other Migratory														
1			+			+				5	720.21	0.00	0.20	0.91	0.55
2	+		+			+				6	720.26	0.06	0.20	0.90	0.69
3	+					+				5	721.27	1.07	0.12	0.90	0.70
4			+			+	+			6	722.15	1.95	0.08	0.91	0.54
5	+	+	+			+				7	722.23	2.02	0.07	0.90	0.73
6		+	+			+				6	722.27	2.06	0.07	0.91	0.57
7						+				4	722.58	2.37	0.06	0.91	0.43
8	+		+			+	+			7	722.62	2.41	0.06	0.90	0.69
9	+					+	+			6	723.55	3.34	0.04	0.90	0.69
10	+	+				+				6	723.56	3.35	0.04	0.90	0.70
11		+	+			+	+			7	723.97	3.77	0.03	0.91	0.58
12						+	+			5	724.15	3.95	0.03	0.91	0.46
RVI	**0.53**	0.21	**0.71**	NA	NA	**1.00**	0.2	NA	NA						

Rank	Hab.	Year	J. day	J. day^2	Temp.	D.O.	pH	Sal.	Mean turb.	*df*	AICc	ΔAICc	*w*	R^2	*Mar.* R^2
	d) Resident														
1	+				+					5	2116.58	0.00	0.16	1.00	0.91
2	+		+		+					6	2116.70	0.11	0.15	1.00	0.92
3	+		+		+	+				7	2117.21	0.62	0.11	1.00	0.93
4	+		+		+			+		7	2117.86	1.28	0.08	1.00	0.91
5	+	+			+					6	2117.95	1.36	0.08	1.00	0.91
6	+				+			+		6	2118.46	1.87	0.06	1.00	0.90
7	+				+	+				6	2118.53	1.94	0.06	1.00	0.91
8	+	+	+		+					7	2118.54	1.96	0.06	1.00	0.92
9	+		+		+	+		+		8	2118.86	2.28	0.05	1.00	0.92
10	+	+	+		+	+				8	2119.05	2.46	0.05	1.00	0.93
11	+	+	+		+			+		8	2119.38	2.79	0.04	1.00	0.91
12	+	+			+			+		7	2119.43	2.84	0.04	1.00	0.90
13	+	+			+	+				7	2119.77	3.19	0.03	1.00	0.91
14	+	+	+		+	+		+		9	2120.46	3.88	0.02	1.00	0.92
15	+				+	+		+		7	2120.54	3.95	0.02	1.00	0.90
RVI	**1.00**	0.31	**0.56**	NA	**1.00**	0.34	NA	0.31	NA						

Hab. = habitat (effect of sand flat relative to eelgrass); Year = year of surveys (2016 and 2017); J. day = Julian day; J. day^2 = quadratic modifier of Julian day (Julian day squared); Temp. = surface water temperature measured during each sampling event; DO = surface water dissolved oxygen measured during each sampling event; pH = surface water pH measured during each sampling event; Sal = surface water salinity measured during each sampling event; Mean turb. = mean turbidity measured over all sampling events in 2016; *df* = degrees of freedom; AIC_c = AIC corrected for small sample sizes; ΔAIC_c = difference from the lowest AIC_c value; *w* = model weight; R^2 = conditional R^2 (proportion of variance explained by both fixed and random effects); *Mar.* R^2 = Marginal R^2 (proportion of variance explained by fixed effects only); RVI = relative variable importance.

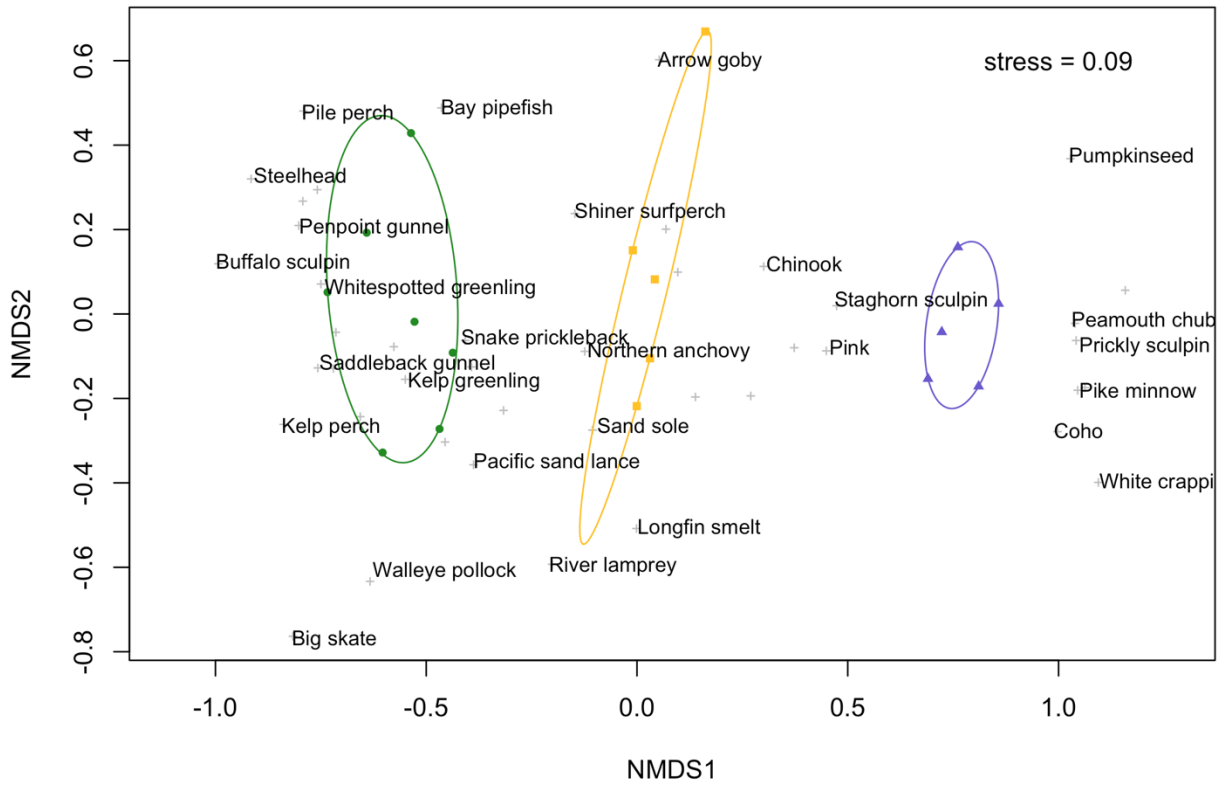

Fig. S1. Non-metric multidimensional scaling (NMDS) plot depicting Bray-Curtis deviation of fish communities by site. Species counts were summed across all sampling events for each site prior to analysis. Degree of clustering is shown for marsh (blue triangles), eelgrass (green circles), and sand flat (yellow squares) habitat categories. Select species (grey plus symbols) are identified by common name to highlight community examples.