Supplementary Materials

2. Modelling of the Peel-Harvey catchment

S2. Catchment hydrological model bias correction: The catchment hydrological model was mostly calibrated to flow data from 2000–15, which had less rainfall and river flow than prior years. To support historical estuary model simulations undertaken in other aspects of this study (see Chapter 3), pre-2000 catchment model flows and nutrient loads required bias correction. Catchments that required bias correction were identified by the model validation statistics for pre-2000 data. Three catchments (Mayfield Drain, Coolup-Harvey and Coolup-Peel) did not require any bias correction as the catchment model replicated pre-2000 flows adequately, while all other catchments required bias correction. For these catchments, daily flows and nutrient loads were increased by the annual factor given in Supplementary Material S2.1. This annual factor was taken as the annual volume bias between measured and modelled flows at Baden Powel (AWRC ref 614006), which had the longest records of measured flows in the catchment (1952-current). Supplementary Material S2.2 summarises the hydrological model pre-2000 validation statistics with and without bias corrections. This bias correction method was exclusively used when providing results for the estuary model.

S2.1. Annual bias correction factor.

Year	Bias adjustment factor
Pre 1970	1.18
1970	1.18
1971	1.21
1972	1.15
1973	1.12
1974	1.51
1975	1.57
1976	1.13
1977	1.07
1978	1.11
1979	1.07
1980	1.02
1981	1.40
1982	1.23
1983	1.54
1984	1.34
1985	1.67
1986	1.31
1987	1.09
1988	1.25
1989	1.22
1990	1.75
1991	1.22
1992	1.45
1993	1.57
1994	1.41
1995	1.18
1996	1.39
1997	1.15
1998	1.05
1999	1.15
Post 1999	1.00

S2.2. Validation statistics for modelled flows at flow gauging sites with and without bias correction.

Reporting catchment	Gauge	Modelled flow statistics (1980-1999)				Bias corrected modelled flow (1980-1999)			
		Daily NSE	Monthly NSE	Annual NSE	Bias	Daily NSE	Monthly NSE	Annual NSE	Bias
Harvey	613052	0.80	0.81	0.17	-29%	0.87	0.91	0.65	-6%
Coolup (Harvey)	613027	0.78	0.90	0.83	-9%	-	-	-	-
Mayfield Drain	613031	0.82	0.93	0.87	1%	-	-	-	-
Upper Murray	614006	0.85	0.89	0.68	-25%	0.93	0.99	1.00	0%
Upper Murray	614065	0.88	0.90	0.63	-25%	0.95	0.98	0.98	-2%
Upper Serpentine	614030	0.76	0.74	-0.20	-40%	0.87	0.90	0.57	-21%
Nambeelup	614063	0.68	0.75	0.48	-32%	0.71	0.82	0.66	-8%
Dirk Brook	614094	0.84	0.92	0.75	-14%	0.89	0.96	0.97	3%

6. Sediment condition in the Peel-Harvey

S6.1. Proportions of the variation in Rapid Assessment Protocol (RAP) sediment condition scores across all basin and river sites explained by the predictors of water depth, %mud and enrichment, as determined by distance-based linear modelling. Reproduced from Hallett et al. (2019) with permission from the Royal Society of Chemistry.

Test	Predictor	SS(trace)	Pseudo-F	Proportion explained	Cumulative proportion explained (R^2)	Res. SS	Res. df
Basin sites (*n* = 62; Total SS = 184.55)							
Marginal	Water depth	38.76	15.95	0.21*			60
	Mud	84.05	50.18	0.46*			60
	Enrichment	105.74	80.50	0.57*			60
Sequential	Water depth	38.76	15.95	0.21*	0.21		60
	+Mud	46.46	27.59	0.25*	0.46		59
	+Enrichment	29.53	24.53	0.16*	0.62	69.80	58
Sequential	Mud	84.05	50.18	0.46*	0.46		60
	+Enrichment	29.50	24.52	0.16*	0.62	71.0	59
Sequential	Enrichment	105.74	80.50	0.57*	0.57		60
	+Mud	7.82	6.50	0.04*	0.62	70.99	59
River sites (*n* = 35; Total SS = 212.59)							
Marginal	Water depth	13.17	2.18	0.06			33
	Mud	88.21	23.40	0.41*			33
	Enrichment	111.36	36.31	0.52*			33
Sequential	Mud	88.21	23.40	0.41*	0.41		33
	+Enrichment	26.25	8.56	0.12*	0.54	98.14	32
Sequential	Enrichment	111.36	36.31	0.52*	0.52	101.23	33

Marginal tests indicate the proportion of the variation the predictor accounts for alone, while sequential tests indicate the proportion added by the predictor to the cumulative proportion of explained variation.
** Significant ($p<0.05$); non-significant predictors were excluded from subsequent models.*

SS = sum of squares; df = degrees of freedom; Res. = residual.

7. Seagrass and macroalgal communities of the Peel-Harvey Estuary from 1978 to 2018

S7.1. Three-way crossed PERMANOVA (Permutational MANOVA and ANOVA) of the biomass composition of the macrophyte community recorded in each interannual period from 1978–2018 in each region and water depth of the Peel-Harvey Estuary. Separate tests were undertaken for data collected in autumn and spring. As the focus of these tests was to explore period differences, only those significant terms involving period (*P* < 0.01; shown in bold text) were further interpreted. Df, degrees of freedom; MS, Mean squares; *P*, significance value; COV, Components of variation.

	Autumn					Spring				
	df	MS	Pseudo-F	*P*	COV	df	MS	Pseudo-F	*P*	COV
Period (P)	**4**	**13190**	**10.667**	**0.001**	**19.577**	**3**	**9594.4**	**7.348**	**0.001**	**16.591**
Region (R)	3	10336	8.359	0.001	18.362	3	14292	10.946	0.001	22.039
Depth (D)	1	9987.1	8.0769	0.001	12.738	1	12190	9.3362	0.001	14.348
P × R	**12**	**3103.1**	**2.5096**	**0.001**	**15.44**	**9**	**3818.8**	**2.9247**	**0.001**	**18.041**
P × D	**4**	**2100.8**	**1.699**	**0.039**	**7.4449**	3	2044	1.5655	0.082	7.003
R × D	3	729.84	0.5902	0.861	−6.1276	3	3443.7	2.6374	0.003	12.647
P × R × D	12	1168	0.9446	0.598	−4.1829	9	1489.1	1.1404	0.267	6.8914
Residual	125	1236.5			35.164	101	1305.7			36.135

S7.2. Biomass (g m^{-2}, dry weight) of each macrophyte species found across all 51 sites in the Peel-Harvey Estuary in spring 2017 and autumn 2018. Total biomass (and percentage contribution to the total; %) summed for all sites and both seasons is provided, as well as the average seasonal biomass (with standard deviation in superscript text; ^{SD}) and corresponding percentage contribution. Species contributing >2% to the total are shaded grey. Macrophyte taxa are coded for their broader group, i.e. ● Seagrass; ● Green macroalgae; ● Red macroalgae; ● Brown macroalgae; ● Charophyte.

Group	Macrophyte species	Total site biomass	%	Average spring 2017 biomass ^{SD}	%	Average autumn 2018 biomass ^{SD}	%
●	*Ruppia* sp.	7,945.11	44.29	78.11 $^{130.52}$	41.96	80.85 $^{150.34}$	46.91
●	*Willeella* sp.	3,320.72	18.51	38.90 $^{248.60}$	20.90	27.28 $^{137.70}$	15.83
●	*Chaetomorpha* sp.	2,274.13	12.68	26.53 $^{46.75}$	14.25	18.80 $^{40.57}$	10.91
●	*Halophila* sp.	1,517.85	8.46	9.48 $^{38.30}$	5.09	21.11 $^{69.63}$	12.25
●	*Zostera* sp.	524.15	2.92	6.38 $^{21.19}$	3.43	4.06 $^{16.15}$	2.35
●	*Lamprothamnium* sp.	419.18	2.34	7.96 $^{45.24}$	4.28	0.27 $^{0.86}$	0.16
●	*Hormophysa* sp.	321.95	1.79			6.57 $^{39.19}$	3.81
●	*Chondria* sp.	308.34	1.72	1.28 $^{3.25}$	0.69	4.96 $^{11.58}$	2.88
●	*Spyridia* sp.	307.61	1.71	3.17 $^{11.35}$	1.70	2.98 $^{13.37}$	1.73
●	*Ulva* sp.	277.40	1.55	5.00 $^{15.14}$	2.69	0.46 $^{1.64}$	0.27
●	*Rhizoclonium* sp.	185.90	1.04	3.39 $^{12.33}$	1.82	0.27 $^{1.33}$	0.16
●	*Gracilaria* sp.	128.29	0.72	2.50 $^{8.52}$	1.34	0.02 $^{0.14}$	0.01
●	*Ceramium* sp.	91.58	0.51	1.48 $^{3.25}$	0.79	0.33 $^{1.26}$	0.19
●	*Laurencia* sp.	81.73	0.46	1.37 $^{5.00}$	0.74	0.24 $^{0.51}$	0.14
●	*Cystoseira* sp.	69.40	0.39			1.42 $^{8.90}$	0.82
●	*Jania* sp.	49.00	0.27	0.04 $^{0.32}$	0.02	0.95 $^{4.38}$	0.55
●	*Dictyota* sp.	47.02	0.26	0.12 $^{0.52}$	0.06	0.84 $^{3.07}$	0.49
●	*Caulerpa* sp.	30.06	0.17	0.11 $^{0.52}$	0.06	0.50 $^{1.87}$	0.29
●	*Polysiphonia* sp.	16.85	0.09			0.34 $^{2.41}$	0.20
●	*Hincksia* sp.	16.55	0.09	0.30 $^{1.96}$	0.16	0.02 $^{0.14}$	0.01
●	*Acetabularia* sp.	3.82	0.02			0.08 $^{0.33}$	0.05
●	*Amphiora* sp.	3.27	0.02	0.06 $^{0.46}$	0.03		
●	*Heterosiphonia* sp.	0.06	<0.01			<0.01 $^{0.01}$	<0.01
	Number of species	**23**		**18**		**22**	
	Sum of biomass	**17,940**		**186**		**172**	

S7.3. Three-way crossed PERMANOVA (Permutational MANOVA and ANOVA) of the biomass composition of the macrophyte community in each region and water depth of the Peel-Harvey Estuary in spring 2017 and autumn 2018. Significant terms (*P* < 0.01) are in bold text). df, degrees of freedom; MS, Mean squares; *P*, significance value; COV, Components of variation.

	df	MS	Pseudo-F	P	COV
Region (R)	**3**	**11621**	**3.9693**	**0.001**	**19.856**
Season (S)	1	4507.9	1.5397	0.118	6.0389
Depth (D)	**1**	**23586**	**8.0558**	**0.001**	**21.836**
R × S	3	1485.2	0.50726	0.986	-11.439
R × D	**3**	**6283.8**	**2.1462**	**0.003**	**17.447**
S × D	1	3433.4	1.1727	0.279	4.8308
R × S × D	3	1748.4	0.59716	0.966	-14.627
Residual	84	2927.8			54.11

8. Assessing the health of the Peel-Harvey Estuary through its benthic invertebrate fauna

S8.1. List of benthic macroinvertebrate taxa recorded in all regions of the Peel-Harvey Estuary (WP/NH, Western Peel Inlet/Northern Harvey Estuary; EP, Eastern Peel Inlet; SH, Southern Harvey Estuary; SP, Serpentine River; LM, Lower Murray River; UM, Upper Murray River) during winter 2017 and summer 2018. M ^{SD}, Mean density (invertebrates 0.1 m^2) and standard deviation; %C, percentage contribution; R, rank by abundance. The phyla (Ph) to which taxa belongs is also provided (Ar, Arthropoda; A, Annelida; C, Cnidaria; Echinodermata; M, Mollusca; N, Nematoda; Ne, Nemertea; P, Phorinida; S, Sipuncula). The most abundant taxa (those contributing >5%) are highlighted in grey for each region.

		NH/WP			EP			SH			SP			LM			UM		
Invertebrate taxa	Ph	M ^{SD}	%C	R	M ^{SD}	%C	R	M ^{SD}	%C	R	M ^{SD}	%C	R	M ^{SD}	%C	R	M ^{SD}	%C	R
Corophium minor	Ar	$397.9^{698.7}$	21.8	1	$502.3^{778.9}$	28.3	1	$574.4^{877.9}$	19.0	1	$106.1^{198.1}$	3.1	8	$17.7^{59.1}$	0.9	15			
Heteromastus filiformis	A	$343.1^{678.7}$	18.8	2	$61.9^{114.7}$	3.5	6	$32.0^{48.6}$	1.1	19									
Mysella spp.	M	$132.6^{227.8}$	7.3	3	$279.4^{483.5}$	15.7	3	$111.2^{206.3}$	3.7	8	$5.3^{23.7}$	0.2	22						
Chironomidae spp.	Ar	$123.8^{297.0}$	6.8	4	$46.0^{98.1}$	2.6	8	$45.5^{161.8}$	1.5	14				$40.7^{129.5}$	2.1	12	$47.8^{107.2}$	7.1	7
Prionospio cirrifera	A	$107.9^{233.4}$	5.9	5	$316.6^{693.6}$	17.8	2	$141.5^{358.1}$	4.7	7	$33.6^{92.9}$	1.0	12	$19.5^{63.4}$	1.0	14			
Tanaidacea	Ar	$65.4^{161.2}$	3.6	6	$1.8^{7.9}$	0.1	36	498.6^{2047}	16.5	2									
Spisula trigonella	M	$63.7^{139.0}$	3.5	7	$8.8^{27.8}$	0.5	23	$20.2^{57.7}$	0.7	22									
Grandidierella spp.	Ar	$61.9^{93.1}$	3.4	8	$70.7^{157.8}$	4.0	5	$70.7^{180.7}$	2.3	11	$31.8^{72.5}$	0.9	13	$173.3^{315.5}$	9.1	3	$60.1^{202.1}$	9.0	5
Eusiridae spp.	Ar	$60.1^{135.8}$	3.3	9	$31.8^{70.7}$	1.8	12	$38.7^{109.0}$	1.3	16							$3.5^{10.9}$	0.5	16
Capitella sp. 1	A	$51.3^{90.0}$	2.8	10	$37.1^{59.1}$	2.1	11	$74.1^{174.7}$	2.4	10	$507.6^{596.0}$	15.0	3	$47.8^{80.6}$	2.5	10			
Nematoda spp.	N	$47.8^{213.6}$	2.6	11	$23.0^{94.8}$	1.3	14	$45.5^{170.8}$	1.5	13	$5.3^{17.3}$	0.2	23						
Prionospio multipinnulata	A	$46.0^{189.7}$	2.5	12															
Paracorophium excavatum	Ar	$35.4^{92.5}$	1.9	13	$28.3^{118.5}$	1.6	13	$106.1^{307.0}$	3.5	9	$150.3^{319.5}$	4.5	6	737.5^{1916}	38.5	1	$74.3^{172.5}$	11.1	2
Amphipoda spp.	Ar	$24.8^{83.6}$	1.4	14				$23.6^{108.1}$	0.8	21									
Aoridae spp.	Ar	$24.8^{70.8}$	1.4	15	$3.5^{15.8}$	0.2	28				$7.1^{24.6}$	0.2	18						
Nemertea spp.	Ne	$19.5^{40.5}$	1.1	16	$12.4^{33.0}$	0.7	18												
Polydora tentaculata	A	$19.5^{64.4}$	1.1	17				$3.4^{15.4}$	0.1	32									
Caprella scaura	Ar	$17.7^{52.0}$	1.0	18				$25.3^{108.0}$	0.8	20									
Theora lubrica	M	$17.7^{45.2}$	1.0	19	$5.3^{13.0}$	0.3	27												
Arcuatula senhousia	M	$12.4^{38.5}$	0.7	20										$97.3^{208.8}$	5.1	6	180.4^{303}	27.0	1
Bivalvia spp.	M	$12.4^{26.4}$	0.7	21	$3.5^{10.9}$	0.2	29	$1.7^{7.7}$	0.1	34									

		NH/WP			EP			SH			SP			LM			UM		
Invertebrate taxa	Ph	M ^{SD}	%C	R	M ^{SD}	%C	R	M ^{SD}	%C	R	M ^{SD}	%C	R	M ^{SD}	%C	R	M ^{SD}	%C	R
Oedicerotidae sp. 1	Ar	12.4 $^{38.5}$	0.7	22				11.8 $^{54.0}$	0.4	24									
Malacoceros sp. 1	A	10.6 $^{32.7}$	0.6	23															
Desdemona ornata	A	8.8 $^{19.5}$	0.5	24	97.3 $^{209.7}$	5.5	4	35.4 $^{85.9}$	1.2	17	589 $^{1083.9}$	17.5	2	58.4 $^{113.2}$	3.0	9	1.8 $^{7.9}$	0.3	17
Exogone heterosetosa	A	8.8 $^{32.2}$	0.5	25				3.4 $^{15.4}$	0.1	30									
Scoloplos normalis	A	8.8 $^{32.2}$	0.5	26	38.9 $^{114.1}$	2.2	9	33.7 $^{91.9}$	1.1	18	47.8 $^{79.7}$	1.4	11	72.5 $^{97.7}$	3.8	8	49.5 $^{99.7}$	7.4	6
Brania sp. 1	A	7.1 $^{18.5}$	0.4	27				5.1 $^{16.9}$	0.2	29	8.8 $^{32.2}$	0.3	16	5.3 $^{17.3}$	0.3	18			
Cumacea spp.	Ar	7.1 $^{24.6}$	0.4	28															
Mediomastus sp. 1	A	7.1 $^{31.6}$	0.4	29	3.5 $^{15.8}$	0.2	30												
Micromaldane sp. 1	A	7.1 $^{24.6}$	0.4	30															
Barnardomelita matilda	Ar	5.3 $^{13.0}$	0.3	31	17.7 $^{33.5}$	1.0	15	195.4 $^{428.8}$	6.5	4	77.8 $^{174.7}$	2.3	10	5.3 $^{17.3}$	0.3	19	1.8 $^{7.9}$	0.3	18
Nephtys sp. 1	A	5.3 $^{17.3}$	0.3	32	8.8 $^{25.3}$	0.5	21												
Carazziella victoriensis	A	3.5 $^{10.9}$	0.2	33	14.1 $^{37.0}$	0.8	17	64.0 $^{179.9}$	2.1	12	146.8 $^{478.9}$	4.4	7						
Nassarius sp. 1	M	3.5 $^{10.9}$	0.2	34															
Galathowenia sp. 1	A	3.5 $^{15.8}$	0.2	35							1.8 $^{7.9}$	0.1	25						
Simplisetia spp.	A	3.5 $^{10.9}$	0.2	36	38.9 $^{88.8}$	2.2	10	193.7 $^{373.6}$	6.4	5	249.4 $^{294.7}$	7.4	4	107.9 $^{235.9}$	5.6	4	35.4 $^{69.8}$	5.3	9
Ampharetinae sp. 1	A	1.8 $^{7.9}$	0.1	37															
Arthritica semen	M	1.8 $^{7.9}$	0.1	38	14.1 $^{35.2}$	0.8	16	392.5 $^{517.9}$	13.0	3	1065 ^{1717}	31.6	1	102.6 $^{260.7}$	5.4	5	63.7 $^{194.3}$	9.5	4
Assiminea sp. 1	M	1.8 $^{7.9}$	0.1	39				1.7 $^{7.7}$	0.1	33									
Caulleriella sp. 1	A	1.8 $^{7.9}$	0.1	40															
Copepoda spp.	Ar	1.8 $^{7.9}$	0.1	41							19.5 $^{60.2}$	0.6	14						
Glycera tridactyla	A	1.8 $^{7.9}$	0.1	42															
Halicarcinus ovatus	Ar	1.8 $^{7.9}$	0.1	43															
Nasutoplax rostratus	Ar	1.8 $^{7.9}$	0.1	44															
Magelona sp. 1	A	1.8 $^{7.9}$	0.1	45															
Marphysa sanguinea	A	1.8 $^{7.9}$	0.1	46										1.8 $^{7.9}$	0.1	21			
Oligochaeta spp.	A	1.8 $^{7.9}$	0.1	47	10.6 $^{25.9}$	0.6	20	183.6 $^{403.9}$	6.1	6	178.6 $^{582.8}$	5.3	5	77.8 $^{165.0}$	4.1	7	7.1 $^{24.6}$	1.1	12
Ophiurida spp.	E	1.8 $^{7.9}$	0.1	48															
Phoronis sp. 1	P	1.8 $^{7.9}$	0.1	49															
Polychaeta spp.	A	1.8 $^{7.9}$	0.1	50	1.8 $^{7.9}$	0.1	34	6.7 $^{24.0}$	0.2	28				7.1 $^{31.6}$	0.4	17			
Polychaeta sp. 1	A	1.8 $^{7.9}$	0.1	51															
Sipuncula spp.	S	1.8 $^{7.9}$	0.1	52				1.7 $^{7.7}$	0.1	37									
Sphaeromatidae spp.	Ar	1.8 $^{7.9}$	0.1	53							1.8 $^{7.9}$	0.1	27	23.0 $^{94.8}$	1.2	13	7.1 $^{24.6}$	1.1	13

		NH/WP			EP			SH			SP			LM			UM		
Invertebrate taxa	Ph	M^{SD}	%C	R	M^{SD}	%C	R	M^{SD}	%C	R	M^{SD}	%C	R	M^{SD}	%C	R	M^{SD}	%C	R
Sphaerosyllis sp. 1	A	$1.8^{7.9}$	0.1	54													$10.6^{39.9}$	1.6	10
Tanea sp. 1	M	$1.8^{7.9}$	0.1	55	$54.8^{229.1}$	3.1	7	$45.5^{138.4}$	1.5	15	$7.1^{31.6}$	0.2	20						
Australonereis ehlersi	A				$10.6^{23.2}$	0.6	19	$6.7^{24.0}$	0.2	27	$7.1^{18.5}$	0.2	19						
Palaemonetes australis	Ar				$8.8^{25.3}$	0.5	22	$8.4^{24.8}$	0.3	26									
Actiniaria spp.	C				$7.1^{31.6}$	0.4	24	$8.4^{24.8}$	0.3	25	$7.1^{31.6}$	0.2	17	$1.8^{7.9}$	0.1	20			
Ampithoe sp. 1	Ar				$5.3^{23.7}$	0.3	25												
Mysida spp.	Ar				$5.3^{17.3}$	0.3	26	$3.4^{10.6}$	0.1	31	$3.5^{10.9}$	0.1	24						
Donax sp. 1	M				$1.8^{7.9}$	0.1	31												
Olividae sp. 1	M				$1.8^{7.9}$	0.1	32												
Plecoptera sp. 1	Ar				$1.8^{7.9}$	0.1	33												
Hiatula biradiata	M				$1.8^{7.9}$	0.1	35	$1.7^{7.7}$	0.1	36				$15.9^{63.4}$	0.8	16			
Boccardia chilensis	A							$11.8^{40.8}$	0.4	23	$5.3^{23.7}$	0.2	21						
Pseudopolydora kempi	A							$1.7^{7.7}$	0.1	35	$99.0^{334.5}$	2.9	9	$254.7^{543.2}$	13.3	2	$40.7^{142.1}$	6.1	8
Boccardiella limnicola	A										$8.8^{27.8}$	0.3	15	$46.0^{107.7}$	2.4	11	$70.7^{78.7}$	10.6	3
Serpulidae sp. 1	A										$1.8^{7.9}$	0.1	26						
Diptera spp.	Ar																$7.1^{18.5}$	1.1	11
Caenidae spp.	Ar																$3.5^{10.9}$	0.5	14
Coleoptera spp.	Ar																$3.5^{10.9}$	0.5	15
Total density		**36,434**			**35,550**			**60,311**			**67,457**			**38,274**			**13,371**		
Number of taxa		**55**			**36**			**37**			**27**			**21**			**18**		

S8.2. Three-way crossed PERMANOVA (Permutational MANOVA and ANOVA) of the species composition of the Peel-Harvey benthic macroinvertebrate community recorded in (a) each region, season and water depth; (b) each region, depth and sediment condition during winter and (c) each region, depth and sediment condition during summer. Note that for the latter two tests, only those significant terms involving sediment condition were interpreted. Significant terms (*P* <0.01) are shown in bold text. df, degrees of freedom; MS, Mean squares; P, significance value; COV, Components of variation. **Term has one or more empty cells.

(a)

	df	MS	Pseudo-F	*P*	COV
Region (R)	**5**	**18229**	**7.1748**	**0.001**	**28.248**
Season (S)	**1**	**10773**	**4.2401**	**0.001**	**11.815**
Depth (D)	**1**	**16649**	**6.553**	**0.001**	**15.467**
R x S	**5**	**5503.1**	**2.166**	**0.001**	**17.359**
R x D	**5**	**5977.2**	**2.3526**	**0.001**	**18.697**
S x D	**1**	**4365.7**	**1.7183**	**0.039**	**7.8669**
R x S x D	5	2993.5	1.1782	0.116	9.597
Residual	96	2540.7			50.406

(b)

	df	MS	Pseudo-F	*P*	COV
Region (R)	**5**	**7204.9**	**3.1857**	**0.001**	**29.465**
Depth (D)	1	3228.2	1.4274	0.14	10.859
Condition (C)	**2**	**6763.8**	**2.9907**	**0.001**	**21.964**
R x D	5	2578.2	1.14	0.222	11.794
R x C	**10**	**3255.3**	**1.4394**	**0.004**	**22.62**
D x C	2	2337.3	1.0335	0.423	5.6965
R x D x C**	1	3010.2	1.331	0.197	21.449
Residual	33	2261.6			47.556

(c)

	df	MS	Pseudo-F	*P*	COV
Region (R)	**5**	**6862.7**	**3.073**	**0.001**	**26.452**
Depth (D)	**1**	**6752.9**	**3.0238**	**0.002**	**20.213**
Condition (C)	**2**	**4520.5**	**2.0242**	**0.004**	**16.07**
R x D	**5**	**4112.5**	**1.8415**	**0.001**	**25.653**
R x C**	6	2419.1	1.0832	0.318	8.7013
D x C	2	3205.1	1.4352	0.078	15.892
R x D x C**	3	2259.3	1.0117	0.487	4.1102
Residual	35	2233.2			47.257

9. Assessing the health of the Peel-Harvey Estuary through its fish communities

S9.1. List of fish species caught in the Peel-Harvey Estuary during historical (1979–2014) and/or contemporary (2016–2018) studies. Their functional guild (group) allocations are also provided, reflecting their habitat (D, demersal; P, pelagic; BP, bentho-pelagic; SP, small pelagic; SB, small benthic), estuary usage (MS, marine straggler; MM, marine migrant; SA, semi-anadromous; ES, estuarine species; FM, freshwater migrant) and feeding mode (ZB, zoobenthivore; PV, piscivore; ZP, zooplanktivore; DV, detritivore; OV, omnivore/ opportunist; HV, herbivore. See Hallett et al. (2012a) for explanation of these guilds.

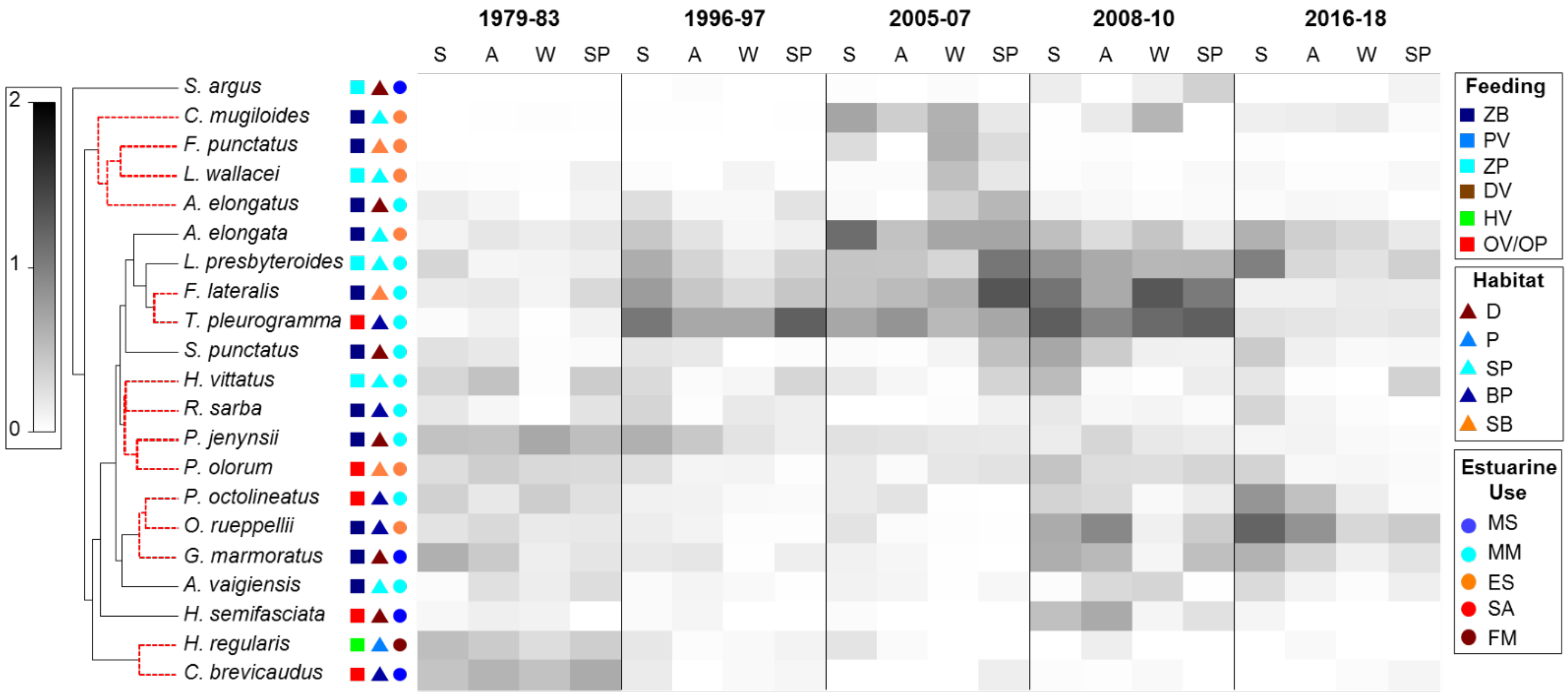
Species name	Common name	Habitat group	Estuary usage/life history group	Feeding group
Bathytoshia brevicaudata	Smooth stingray	D	MS	ZB
Myliobatis tenuicaudatus	Southern eagle ray	D	MS	ZB
Elops machnata	Giant herring	P	MS	PV
Hyperlophus vittatus	Whitebait / Sandy sprat	SP	MM	ZP
Spratelloides robustus	Blue sprat	SP	MM	ZP
Sardinops neopilchardus	Australian pilchard	P	MS	ZP
Nematalosa vlaminghi	Perth herring	BP	SA	DV
Engraulis australis	Southern anchovy	SP	ES	ZP
Galaxias occidentalis	Western minnow	SB	FM	ZB
Galaxias maculatus	Common jollytail	BP	FM	OV
Cnidoglanis macrocephalus	Estuarine cobbler	D	MM	ZB
Hyporhamphus melanochir	Southern sea garfish	P	ES	HV
Hyporhamphus regularis	Western river garfish	P	ES	HV
Gambusia holbrooki	Mosquito fish	SP	FM	ZB
Atherinosoma elongata	Elongate hardyhead	SP	ES	ZB
Leptatherina presbyteroides	Presbyter's hardyhead	SP	MM	ZP
Atherinomorus vaigensis	Ogilby's hardyhead	SP	MM	ZB
Craterocephalus mugiloides	Mugil's hardyhead	SP	ES	ZB
Leptatherina wallacei	Wallace's hardyhead	SP	ES	ZP
Stigmatophora nigra	Wide-bodied pipefish	D	MS	ZB
Hippocampus angustus	Western spiny seahorse	D	MS	ZP
Stigmatophora argus	Spotted pipefish	D	MS	ZP
Urocampus carinirostris	Hairy pipefish	D	ES	ZP
Filicampus tigris	Tiger pipefish	D	MS	ZP
Pugnaso curtirostris	Pugnose pipefish	D	MS	ZP
Gymnapistes marmoratus	Devilfish	D	MS	ZB
Platycephalus laevigatus	Rock flathead	D	MS	PV
Platycephalus westraliae	Yellowtail flathead	D	ES	PV
Leviprora inops	Long-head flathead	D	MS	PV
Platycephalus speculator	Southern blue-spotted flathead	D	ES	PV
Amniataba caudavittata	Yellow-tail trumpeter	BP	ES	OP

Species name	Common name	Habitat group	Estuary usage/life history group	Feeding group
Pelates octolineatus	Western striped grunter	BP	MM	OV
Edelia vittata	Western pygmy perch	BP	FM	ZB
Ostorhinchus rueppelli	Gobbleguts	BP	ES	ZB
Siphamia cephalotes	Woods siphonfish	BP	MS	ZB
Perca fluviatilis	Redfin perch	BP	FM	PV
Sillago bassensis	Southern school whiting	D	MS	ZB
Sillago burrus	Western trumpeter whiting	D	MM	ZB
Sillaginodes punctata	King George whiting	D	MM	ZB
Sillago schomburgkii	Yellow-finned whiting	D	MM	ZB
Sillago vittata	Western school whiting	D	MM	ZB
Pomatomus saltatrix	Tailor	P	MM	PV
Trachurus novaezelandiae	Yellowtail scad	P	MS	ZB
Pseudocaranx dentex	Silver trevally	BP	MM	ZB
Pseudocaranx wrightii	Sand trevally	BP	MM	ZB
Arripis georgianus	Australian herring	P	MM	PV
Arripis esper	Southern Australian salmon	P	MS	PV
Gerres subfasciatus	Roach	BP	MM	ZB
Acanthopagrus butcheri	Black bream	BP	ES	OP
Rhabdosargus sarba	Tarwhine	BP	MM	ZB
Argyrosomus japonicus	Mulloway	BP	MM	PV
Upeneus tragula	Bartail goatfish	D	MS	ZB
Pampeneus spilurus	Black-saddled goatfish	D	MS	ZB
Upeneichthys vlamingii	Bluespotted goatfish	D	MS	ZB
Microcanthus strigatus	Stripey	BP	MS	ZB
Enoplosus armatus	Old wife	D	MS	ZB
Aldrichetta forsteri	Yellow-eye mullet	P	MM	OV
Mugil cephalus	Sea mullet	P	MM	DV
Sphyraena obtusata	Striped barracuda	P	MS	PV
Notolabrus parilus	Brownspotted wrasse	D	MS	ZB
Halichoeres brownfieldi	Brownfield's wrasse	D	MS	ZB
Haletta semifasciata	Blue weed whiting	D	MS	OV
Siphonognathus radiatus	Long-rayed weed whiting	D	MS	OV
Neoodax baltatus	Little weed whiting	D	MS	OV
Parapercis haackei	Wavy grubfish	D	MS	ZB
Lesueurina platycephala	Flathead sandfish	D	MS	ZB
Petroscirtes breviceps	Short-head sabre blenny	SB	MS	OV
Omobranchus germaini	Germain's blenny	SB	MS	ZB
Parablennius intermedius	Horned blenny	D	MS	ZB
Trinorfolkia incisa	Notched threefin	SB	MS	ZB
Cristiceps australis	Southern crested weedfish	D	MS	ZB
Favonigobius lateralis	Long-finned goby	SB	MM	ZB
Afurcagobius suppositus	Southwestern goby	SB	ES	ZB
Pseudogobius olorum	Blue-spot / Swan River goby	SB	ES	OV

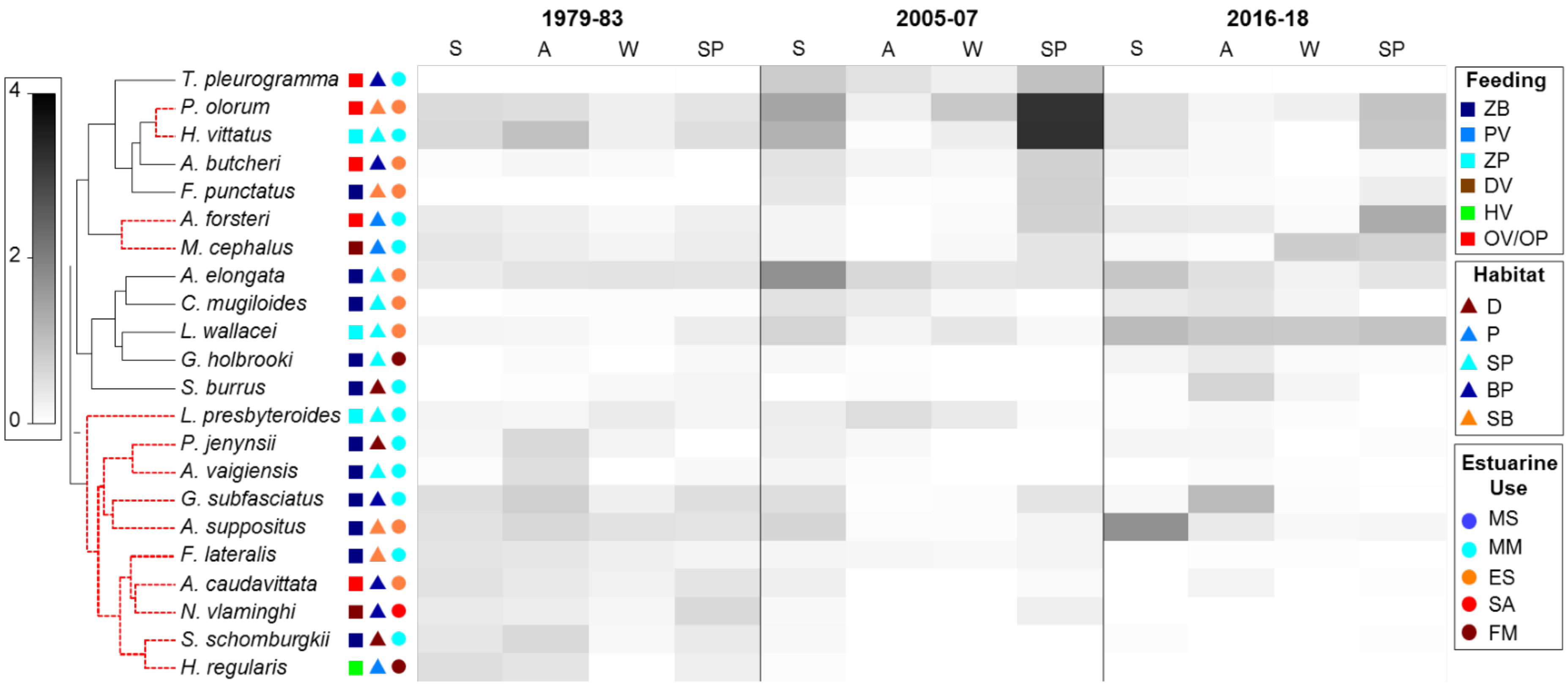
Species name	Common name	Habitat group	Estuary usage/life history group	Feeding group
Arenigobius bifrenatus	Bridled goby	SB	ES	ZB
Callogobius mucosus	Sculptured goby	SB	MS	ZB
Callogobius depressus	Flathead goby	SB	MS	ZB
Favonigobius punctatus	Yellow-spotted sandgoby	SB	ES	ZB
Pseudorhombus jenynsii	Small-toothed flounder	D	MM	ZB
Ammotretis rostratus	Longsnout flounder	D	MM	ZB
Ammotretis elongatus	Elongate flounder	D	MM	ZB
Acanthaluteres brownii	Spiny-tailed leatherjacket	D	MS	OV
Brachaluteres jacksonianus	Southern pygmy leatherjacket	D	MS	OV
Scobinichthys granulatus	Rough leatherjacket	D	MS	OV
Meuschenia freycineti	Sixspine leatherjacket	D	MM	OV
Monacanthus chinensis	Fanbellied leatherjacket	D	MM	OV
Acanthaluteres vittiger	Toothbrush leatherjacket	D	MS	OV
Acanthaluteres spilomelanurus	Bridled leatherjacket	D	MM	OV
Torquigener pleurogramma	Weeping toadfish / Blowfish	BP	MM	OP
Contusus brevicaudus	Prickly toadfish	BP	MS	OP
Kyphosus sydneyanus	Silver drummer	BP	MM	HV
Girella tricuspidata	Luderick	BP	MS	ZP

S9.2. Environmental variables derived from the estuary response models (Chapters 3 and 4) that were related to observed Fish Community Index grades from 1979-2018 using GAMs (see section 9.3.2) to identify key environmental drivers of estuary condition. NB: all environmental variables were defined at two spatial scales, (i) a site scale, i.e. averaged environmental values across all model cells within a 100 m radius of each shallow fish sampling site (constrained to a maximum water depth of 1 m) and within a 250 m radius of deeper fish sampling sites (not constrained by water depth), and (ii) region scale, i.e. averaged environmental values across all model cells within the sampling region to which a site was assigned (see Fig. 9.2).

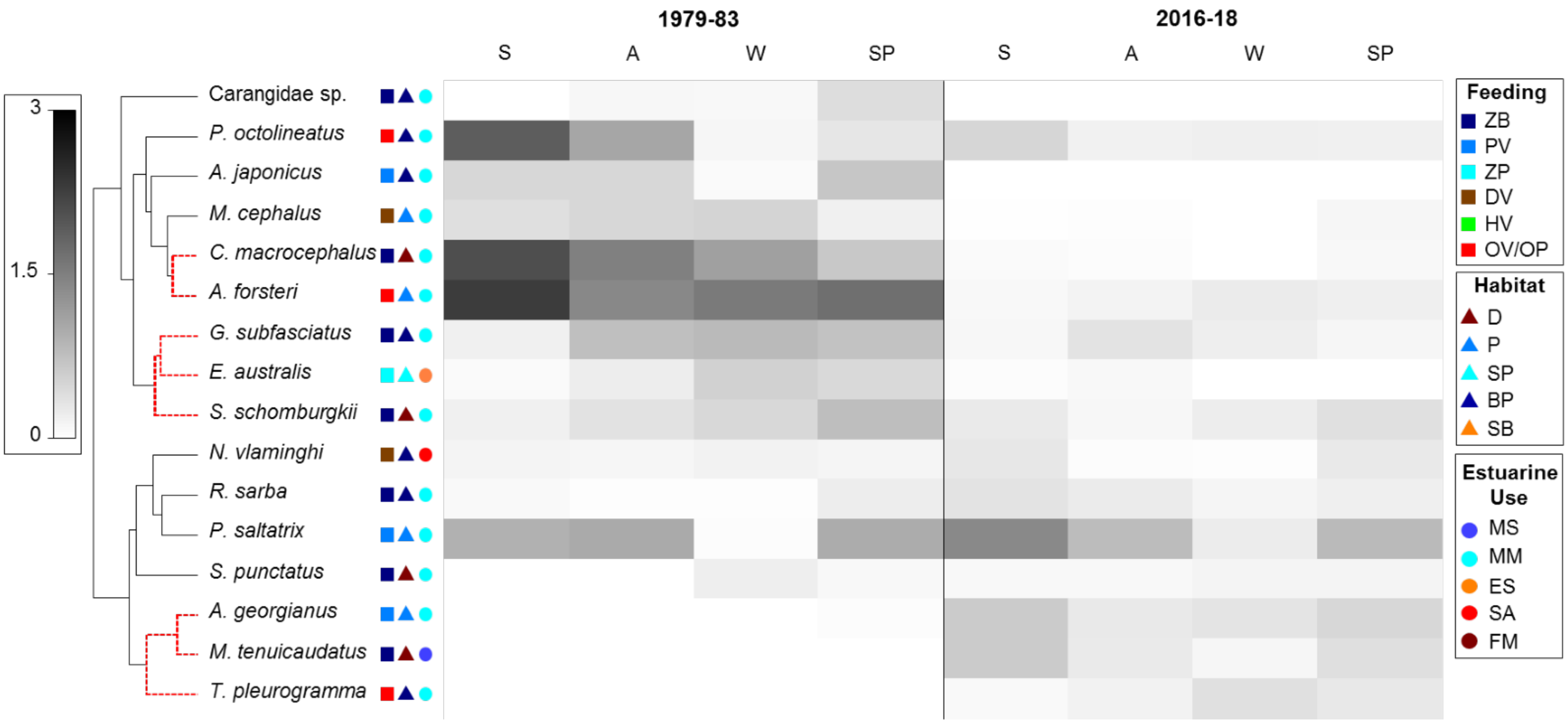
Environmental variable	**Definition**
Age_surface	Average age of surface water on the sampling day
Age_bottom	Average age of bottom water on the sampling day
Oxygen_surface	Average dissolved oxygen concentration (mg/L) of surface water on the sampling day
Oxygen_bottom	Average dissolved oxygen concentration (mg/L) of bottom water on the sampling day
Ammonium_surface	Average ammonium concentration (mg/L) of surface water at the site on the sampling day
Ammonium_bottom	Average ammonium concentration (mg/L) of bottom water at the site on the sampling day
Salinity stratification_average	Average difference between bottom and surface salinities on the sampling day
Salinity stratification_area	Areal footprint (%) of the model polygon with (bottom salinity−surface salinity) >6 on the sampling day
Low oxygen_area	Areal footprint (%) of the bottom cells in the model polygon for which dissolved oxygen was <4 mg/L on the sampling day
Hypoxia_area	Areal footprint (%) of the bottom cells in the model polygon for which dissolved oxygen was <2 mg/L on the sampling day
Temperature_surface_average	Average temperature of surface water on the sampling day
Temperature_surface_max	Maximum temperature of surface water on the sampling day
Chlorophyll a	Average Chlorophyll a concentration at the site on the sampling day



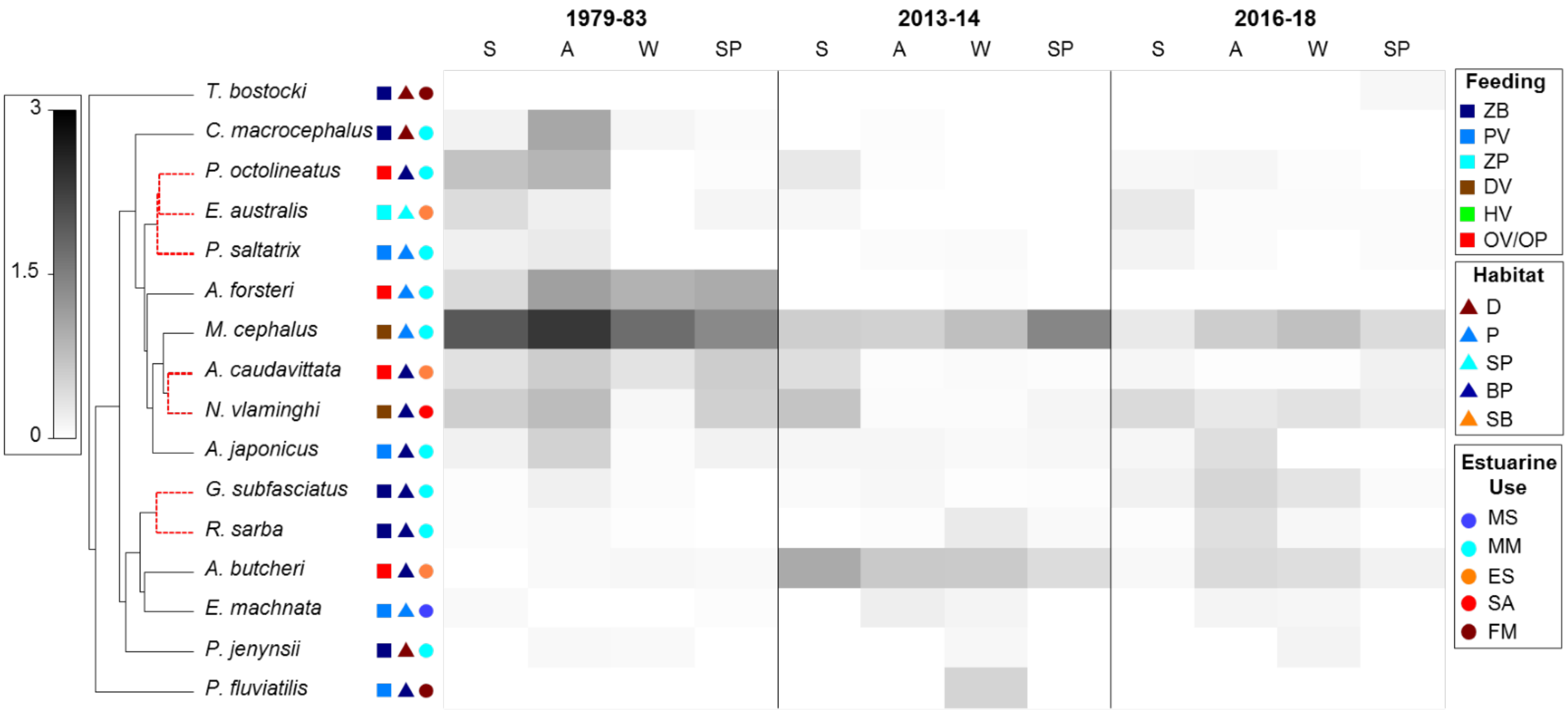
S9.3. Shadeplot of the average abundance of the most prevalent fish species recorded in the shallow waters of the basins in each sampling period and season (S, summer; A, autumn; W, winter; SP, spring). Each fish species has been coded for its feeding, habitat and estuary usage group (see Supplementary Material S9.1 for explanation of codes). Abundance is shown on a grey scale from most abundant (black) to absent (white) and has been plotted from pretreated not raw data.



S9.4. Shadeplot of the average abundance of the most prevalent fish species recorded in the shallow waters of the rivers in each sampling period and season (S, summer; A, autumn; W, winter; SP, spring). Each fish species has been coded for its feeding, habitat and estuary usage group (see Supplementary Material S9.1 for explanation of codes). Abundance is shown on a grey scale from most abundant (black) to absent (white) and has been plotted from pretreated not raw data.



S9.5. Shadeplot of the average abundance of the most prevalent fish species recorded in the deeper waters of the basins in each sampling period and season (S, summer; A, autumn; W, winter; SP, spring). Each fish species has been coded for its feeding, habitat and estuary usage group (see Supplementary Material S9.1 for explanation of codes). Abundance is shown on a grey scale from most abundant (black) to absent (white) and has been plotted from pretreated not raw data.



S9.6. Shadeplot of the average abundance of the most prevalent fish species recorded in the deeper waters of the rivers in each sampling period and season (S, summer; A, autumn; W, winter; SP, spring). Each fish species has been coded for its feeding, habitat and estuary usage group (see Supplementary Material S9.1 for explanation of codes). Abundance is shown on a grey scale from most abundant (black) to absent (white) and has been plotted from pretreated not raw data.

S9.7. The best-fit GAM model for each major estuarine region and water depth. See Supplementary Material S9.2 for full definitions of environmental variables.

Region and depth	Best-fit model	Deviance explained
Rivers, deeper waters	FCI score ~ bottom water age + bottom salinity + bottom DO + sampling period	38.8%
Basins, deeper waters	No significant correlation	0%
Rivers, shallow waters	FCI score ~ bottom salinity + hypoxia area + sampling period	12.4%
Basins, shallow waters	FCI score ~ bottom salinity + hypoxia area + sampling period	18.7%

10. Understanding local economic competitiveness for the Peel-Harvey: Identifying key and strategic industries, 2006-2016

S10.1. Australian and New Zealand Standard Industrial Classification (ANZSIC).

ANZSIC Classification	Mnemonic
Accommodation & food services	AAF
Arts & recreation services	AAR
Administrative & support services	AAS
Agriculture, forestry & fishing	AGR
Construction	CON
Education & training	EAT
Electricity, gas, water & waste services	EGW
Financial & insurance services	FAI
Health care & social assistance	HAS
Information media & telecommunications	IMT
Inadequately described/Not stated	INS
Manufacturing	MAN
Mining	MIN
Other services	OTS
Public administration & safety	PAS
Professional, scientific & technical services	PST
Retail trade	RET
Rental, hiring & real estate services	RHR
Transport, postal & warehousing	TPW
Wholesale trade	WHO

S10.2. Formulae for calculating local economic growth rates and specialization.

1. *Relative Growth Rates:*

Let $E_{ir,t}$ define the number of persons employed in industry i in region r at time t. It follows that the local growth rate g_{ir} can be defined as:

$$g_r = \frac{E_{ir,t+1}}{E_{ir,t}} - 1$$

Similarly, the average growth rate across the benchmark economy, in this instance Western Australia, g_{iWA}, can be defined as:

$$g_{iWA} = \frac{E_{iWA,t+1}}{E_{iWA,t}} - 1$$

It follows that the relative local economic performance, A_{ir}, in terms of job creation is defined as:

$$A_{ir} = g_{ir} - g_{iWA}$$

If $A_{ir} > 0$ then industry i in region r is performing better than the same industry in the benchmark economy. Conversely, if $A_r < 0$ then industry i in region r is performing worst than in the benchmark economy.

2. *Local Specialization and the Economic Base:*

Conventionally, basic sector employment is assumed to include Agriculture, Mining, Tourism, State/Federal Government and manufacturing (partially) whereas non-basic economic activities include retailing, commercial banking, local government, local public schools, services. However, this rule-of-thumb can be augmented with a more objective measure of local specialization, the location quotient. An employment location quotient (LQ_{ir}) is used to define the relative specialization of an industry i in a region r relative to the employment in the same industry in a benchmark economy:

$$LQ_{ir} = \frac{E_{ir}/E_r}{E_{iWA}/E_{WA}}$$

Where, E_{iWA} is the level of employment in industry i, in the benchmark economy and E_{WA} is the total employment in the benchmark economy, in this instance Western Australia.

Where local economic data on trade flows does not exist regional trade patterns need to be imputed from measures of local economic structure. Specifically, it is assumed that the patterns of trade can be imputed from the patterns of industrial specialization.

In general,

(a) the greater is the LQ_{ir} above unity, the larger will be the regions net sectoral exports

(b) the greater is the LQ_{ir} below unity, the larger will be the regions net sectoral imports

(c) for an LQ_{ir} of unity, the region is neither a net exporter nor a net importer.

From which it is possible to calculate the level of base sector employment in a local economy:

$$E_{ir}^{B} = (1 - 1/LQ_{ir})E_{ir} = \left(\frac{E_{ir}}{E_{iWA}} - \frac{E_{r}}{E_{WA}}\right)E_{iWA}, \quad \forall LQ_{ir} > 1$$

The first term on the righthand side of this equation can be considered as a proxy for the local economy's share of the total production, or quantity supplied, of the products of industry *i* for the base economy WA. Similarly, the second term can be considered a proxy for the region's share of the 'base' economy's consumption, or quantity demanded. If the difference is positive (i.e. a LQ_{ir} > 1) then the local economy produces a greater share of the 'base' economy's production than it consumes and the excess is assumed to be exported. As a corollary, this equation can be used to calculate net export employment, that is the local economic base by aggregating across all industries, $E_{r}^{B} = \sum_{i=1}^{n} E_{ir}^{B}$.

11. Estuarine and societal health trade-offs for the Peel-Harvey under 2050 scenarios

S11.1. Survey provided to Peel stakeholders during June 2018 workshop to determine key values and 2050 scenarios of interest.

2050 Scenarios for the Peel

Stakeholder views

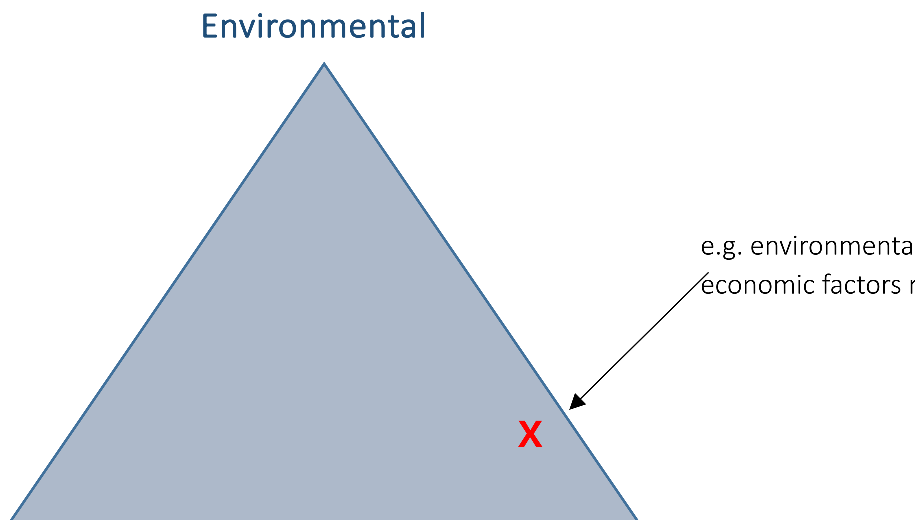
ARC Linkage Project *Balancing estuarine and societal health in a changing environment*

Environmental (estuary focus)	Rk

Social (regional focus)	Rk

Q1b. What is the relative importance of environmental, social and economic factors in shaping the future of the Peel?

Place a cross on the triangle opposite.



blowfish. Swimming in the estuary is limited to accidental "man overboard" instances as boat owners travel out to sea to fish and swim. In general, the community see the e
and picnic near the beach instead.

Narrative 1:

Narrative 2:

Narrative 3:

- *Maps are provided at the end of this survey if you would like to depict scenarios spatially. Please write the scenario rank number on each map.*
- *Please prioritise catchment or sub-catchment scales rather than highly localised scales.*
- *Projected 2050 climate conditions will be incorporated into all scenarios.*

Land-use and/or management practice scenario	Rank

Dissolved oxygen levels throughout the estuary will remain sufficiently high to not cause major fish kill events

Harmful algal blooms will not occur in any part of the estuary

The overall ecological health of the estuary, reflected by its fish and invertebrate fauna, consistently scores a grade of B (good) or higher (A, excellent)

The estuary maintains its Ramsar status

Riparian buffer zones are prioritised above all other land-uses along key waterway margins, including drainage networks

All relevant industries or operators will comply with mandatory nutrient testing programs for soil or waste-water (e.g. agriculture, wastewater treatment)

Total annual nutrient inflows to the estuary (total nitrogen and phosphorous) are at least half of current levels

Recycled water will provide the majority of the regions' industrial and urban water requirements

Water sensitive urban design is mandatory for all new urban developments and retrofitted to existing urban areas where possible

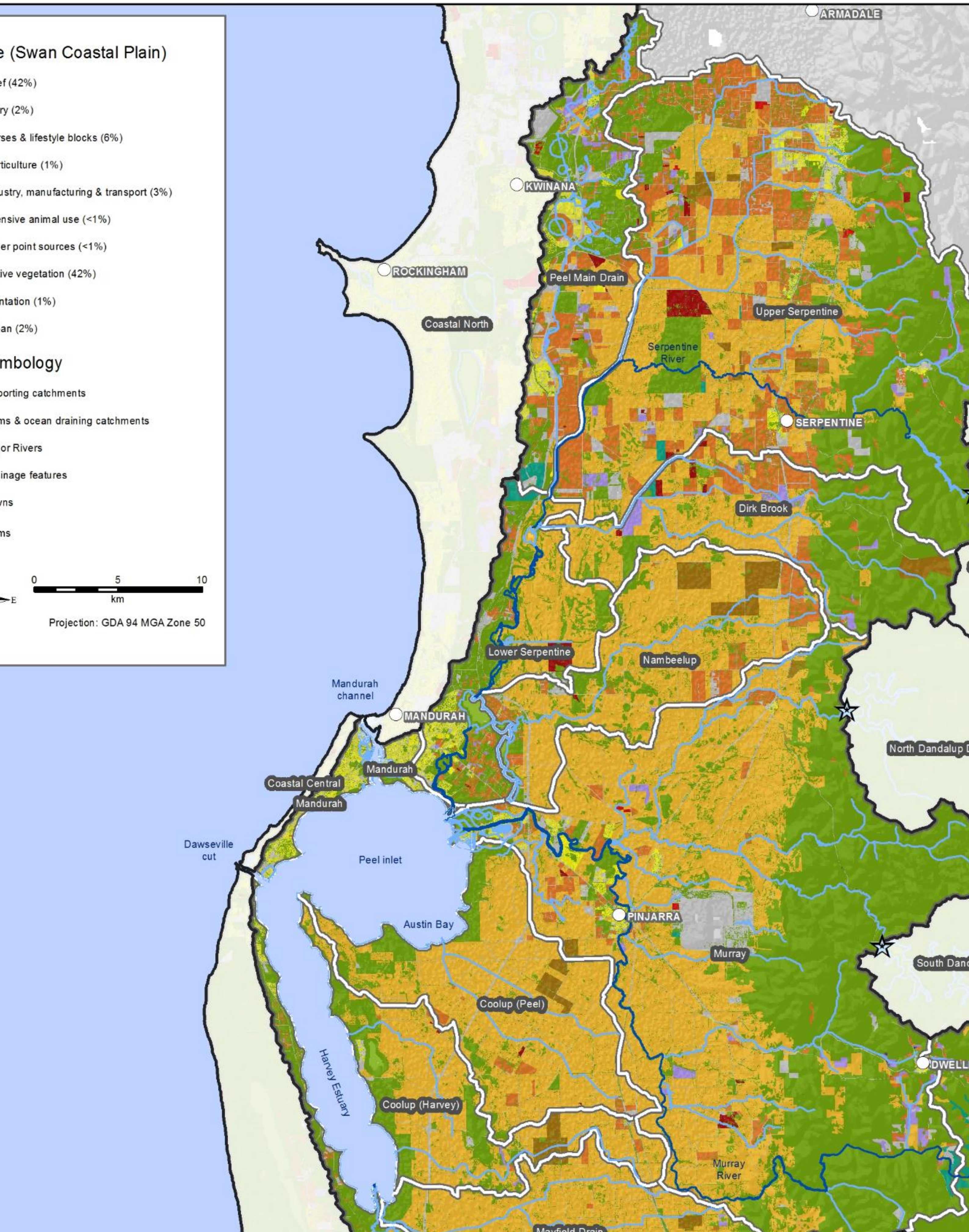
Peel's rate of employment will exceed the WA average

Peel's income per capita will exceed the WA average

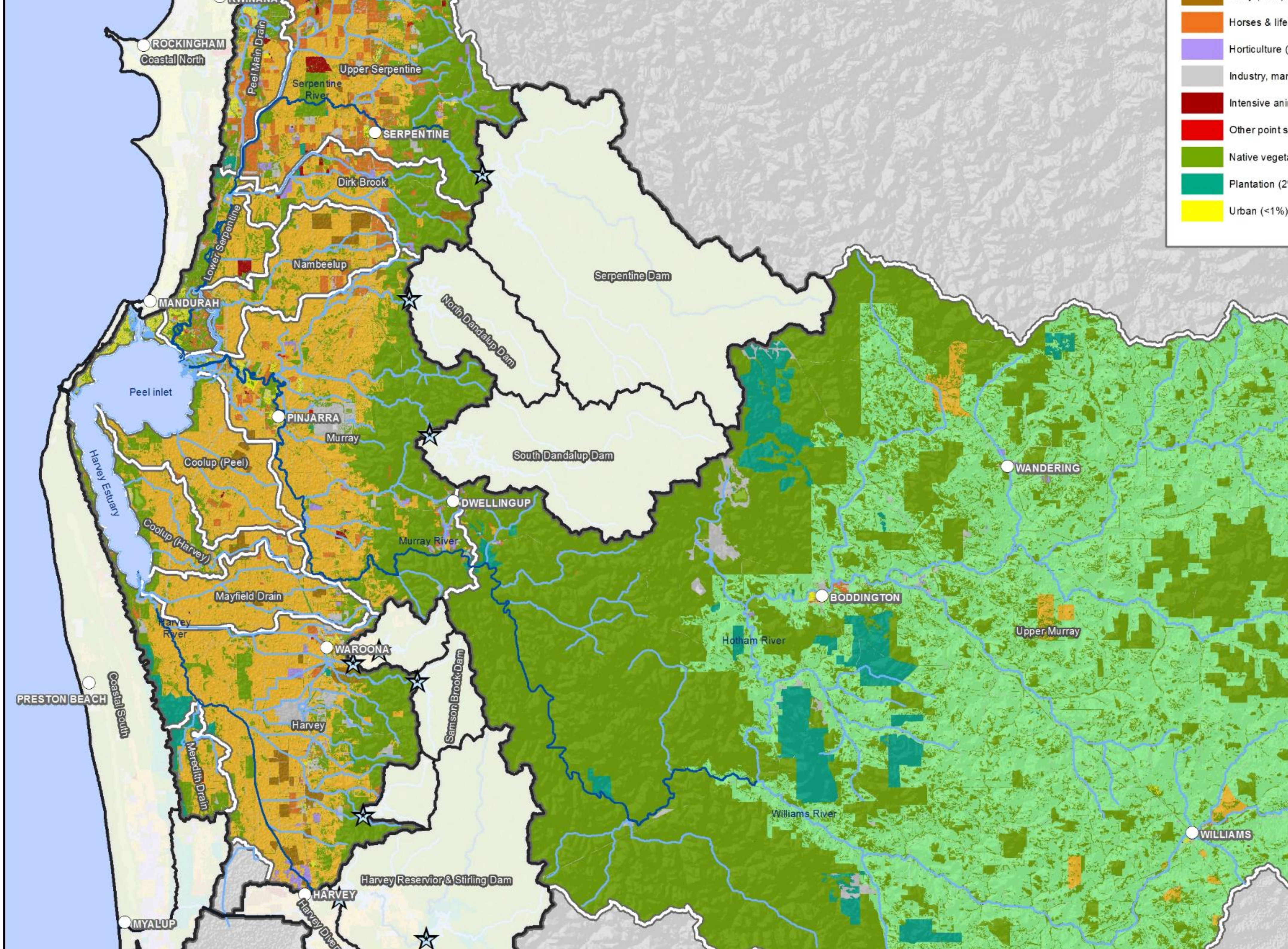
The proportion of people employed in important growth industries (high employment growth, specialisation and export value) and emerging industries (high employment export demand) is significantly greater than current levels

The employment growth and export potential of Peel's agricultural and horticultural industries will be significantly greater than current levels

Q7. Which future estuary condition states are most important to explore and why? (e.g. a certain environmental threshold, health status of ecos



e (Swan Coastal Plain)
ef (42%)
ry (2%)
rses & lifestyle blocks (6%)
rticulture (1%)
ustry, manufacturing & transport (3%)
ensive animal use (<1%)
er point sources (<1%)
ive vegetation (42%)
ntation (1%)
an (2%)
mbology
porting catchments
ms & ocean draining catchments
or Rivers
inage features
vns
ms
0
5
10
km
E
Projection: GDA 94 MGA Zone 50
ARMADALE
KWINANA
ROCKINGHAM
Peel Main Drain
Upper Serpentine
Coastal North
Serpentine River
SERPENTINE
Dirk Brook
Nambeelup
Lower Serpentine
Mandurah channel
MANDURAH
North Dandalup D
Mandurah
Coastal Central
Mandurah
Dawseville cut
Peel inlet
PINJARRA
Austin Bay
Murray
South Danc
Coolup (Peel)
DWELL
Harvey Estuary
Coolup (Harvey)
Murray River
Mayfield Drain



Horses & life
Horticulture (
Industry, man
Intensive ani
Other point s
Native veget
Plantation (2
Urban (<1%)
ROCKINGHAM
Coastal North
Peel Main Drain
Serpentine River
Upper Serpentine
SERPENTINE
Dirk Brook
Lower Serpentine
Nambeelup
Serpentine Dam
MANDURAH
North Dandalup Dam
Peel inlet
PINJARRA
Murray
South Dandalup Dam
Coolup (Peel)
Harvey Estuary
WANDERING
DWELLINGUP
Coolup (Harvey)
Murray River
Mayfield Drain
BODDINGTON
Harvey River
Upper Murray
Hotham River
WAROONA
Samson Brook Dam
PRESTON BEACH
Coastal South
Harvey
Meredith Drain
Williams River
WILLIAMS
Harvey Reservior & Stirling Dam
HARVEY
MYALUP

S11.2. Summary of water quality and ecosystem indicators computed for scenario comparison.

Water Quality		
Seasonal changes	$\bar{\tau}$, $\bar{S}$, $\overline{DO_{bot}}$	Used to explore spatial patterns in water quality attributes
Regional-scale or estuary-scale changes	$\bar{\bar{\tau}}$, $\bar{\bar{S}}$, $\overline{\overline{DO_{bot}}}$	Used to summarise and compare average conditions
Relative change (delta) between two periods	$\overline{\Delta\tau}$, $\overline{\Delta S}$, $\overline{\Delta DO}$, $\overline{\Delta TN}$, $\overline{\Delta TP}$, $\overline{\Delta TCHLA}$	Used to compare spatial differences between specific scenarios
Ecosystem Indicators		
NEA *Nutrient Export & Assimilation*	$\overline{\overline{N_{ret}}}$, $\overline{\overline{P_{ret}}}$	Time-averaged and estuary-scale retention of nutrients
IWQ *Composite Index of Water Quality*	$\overline{IWQ}$ $\overline{\overline{A^{A}_{IWQ}}}$	Time-averaged water quality index Area of estuary considered A grade quality
HYP *Hypoxia Likelihood*	$P(DO \vert DO<DO_{crit})$ $\overline{A_{hypoxia}}$	Probability of dissolved oxygen below a critical value (4mg/L); Average area of estuary with low DO
TUR *Water clarity*	$\overline{C_T}$, $\overline{\overline{C_T}}$	
HAB *Harmful Algal Bloom Likelihood*	$\overline{HAB^{\text{salinity}}_{cyano}}$ $\overline{HAB_{dino}}$ $\overline{\overline{HAB_{dino}}}$ $\overline{A^{\text{dino}}_{HAB}}$	Time-averaged Harmful Algal Bloom index for cyanobacteria, salinity factor; Time-averaged Harmful Algal Bloom index for dinoflagellate, overall; Time & space averaged dinoflagellate index area of suitable habitat dinoflagellate blooms
CHI *Crab Habitat Suitability*	$\overline{CHI^{\text{salinity}}_{juv}}$ $\overline{\overline{CHI_{juv}}}$ $\overline{A^{\text{juv}}_{CHI}}$	Time-averaged Crab Habitat Index (CHI) for juvenile life-stage, for salinity; Time & space averaged juvenile crab habitat suitability; Area of suitable habitat for juvenile crabs
FCI *Fish Community Index*	$\overline{FCI}$ $\overline{\overline{FCI}}$ $\overline{A^{A}_{FCI}}$	