Marine and Freshwater Research, 2021, **72**, 904–921.
https://doi.org/10.1071/MF20196

Supplementary Materials

Identifying physiological and environmental influences on otolith chemistry in a coastal fishery species

Jasmin C. Martino[A,C,D], *Zoë A. Doubleday*[A,C], *Anthony J. Fowler*[B] *and Bronwyn M. Gillanders*[A]

[A]Southern Seas Ecology Laboratories, School of Biological Sciences,

The University of Adelaide, SA 5005, Australia.

[B]South Australian Research and Development Institute (Aquatic Sciences),

West Beach, SA 5024, Australia.

[C]Present Address: Future Industries Institute, University of South Australia, SA 5095, Australia.

[D]Corresponding author. Email: jasmin.martino@unisa.edu.au

Table S1. Model parameter estimates and test statistics of best ranked model describing random effects, fixed effects and extrinsic predictors of isotope variation in snapper otoliths

Estimates are included for carbon isotopes ($\delta^{13}C$), oxygen isotopes ($\delta^{18}O$), magnesium (Mg : Ca), strontium (Sr : Ca), barium (Ba : Ca) manganese (Mn : Ca) and lithium (Li : Ca). Presence of values indicate that inclusion of the variable improved the model fit. For fixed effects, strong effect sizes are indicated by *t* being higher than 2 or lower than -2 (-2>*t*>2), while Est indicates magnitude and direction of the effect. R^2 metrics explain model fit with R^2 (marginal) describing the proportion of variance of fixed effects and R^2 (conditional) describing the variance explained by both fixed and random effects. Environmental predictors are included but indicate separate models with either sea surface temperature (linear, SST; quadratic, SST + SST^2) or chlorophyll-*a* (linear, Chl-*a*; quadratic, Chl-*a* + Chl-a^2)

	$\delta^{13}C$			$\delta^{18}O$			Mg : Ca			Sr : Ca			Ba : Ca			Mn : Ca			Li : Ca		
Random effects	Var	s.d.	Corr	Var	s.d.	Corr	Var	s.d.	Corr	Var	s.d.	Corr	Var	s.d.	Corr	Var	s.d.	Corr	Var	s.d.	Corr
Fish ID	0.19	0.44		0.13	0.37		0.02	0.15		0.012	0.11		0.11	0.33		0.014	0.12		0.031	0.18	
Age|Fish ID							0.02	0.14	-0.19	0.016	0.13	0.31	0.06	0.25	0.36	0.065	0.25	0.03	0.005	0.07	0.20
Season																0.002	0.05				
Region																					
Cohort																					
Residual	2.12	1.46		1.59	1.26		0.032	0.19		0.009	0.095		0.030	0.17		0.016	0.13		0.026	0.16	
Fixed effects	Est	s.e.	*t*	Est	s.e.	*t*	Est	s.e.	*t*	Est	s.e.	*t*	Est	s.e.	*t*	Est	s.e.	*t*	Est	s.e.	*t*
Intercept	-3.86	0.26	-14.9	1.67	0.27	6.2	3.95	0.05	75.21	8.15	0.03	325.2	0.88	0.07	12.71	0.18	0.026	6.973	1.412	0.040	34.6
Age	0.16	0.03	5.41	0.07	0.04	1.78	0.02	0.04	-0.45	0.16	0.03	5.8	-0.04	0.05	-0.82	-0.23	0.054	-4.26	-0.06	0.02	-3.33
Sex (male)	0.20	0.33	0.59	0.42	0.32	1.31	-0.18	0.07	-2.59												
Otolith Growth Rate							0.04	0.01	3.01												
Fish Length	-0.001	0.002	-0.78							-0.16	0.085	-1.89							-0.23	0.16	-1.48
Fish Length × Sex	0.004	0.002	1.72																		
Otolith Growth Rate × Sex																					
Model fit																					
R^2 (marginal)	0.23			0.13			0.17			0.34			0.01			0.45			0.14		
R^2 (conditional)	0.26			0.17			0.53			0.69			0.78			0.73			0.59		
Environmental predictors	Est	s.e.	*t*	Est	s.e.	t	Est	s.e.	*t*	Est	s.e.	*t*	Est	s.e.	*t*	Est	s.e.	*T*	Est	s.e.	*t*
SST				-0.09	0.2	-0.45	-0.002	0.003	-0.57												
SST + SST^2	-0.55	0.3	-1.8																		
Chl-*a*	-0.49	0.24	-2.01	-0.17	0.19	-0.88															
Chl-*a* + Chl-a^2																					

Table S2. Selection of optimal random effects structures in lifetime carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotopes in snapper otoliths

Random slope term designated with *x* | *y*

	Δ*AICc*	
Random effects	$\delta^{13}C$	$\delta^{18}O$
1|FishID	0.00	0.00
Age|FishID	1.72	2.88
1|FishID + 1|Cohort	2.22	2.37
Age|FishID2 + 1|Cohort	4.01	5.35
1|FishID + Age|Cohort	6.76	2.36
Age|FishID + Age|Cohort	8.67	5.30
1|FishID + 1|Region	1.85	2.36
Age|FishID2 + 1|Region	3.77	5.30
1|FishID2 + Age|Region	3.68	4.78
Age|FishID2 + Age|Region	7.01	7.84
1|FishID2 + 1|Region + 1|Cohort	4.10	2.37
Age|FishID + 1|Region + 1|Cohort	6.00	5.35

Table S3. Selection of optimal random effects structures (highlighted in bold) in lifetime magnesium (Mg : Ca), strontium (Sr : Ca) and barium (Ba : Ca) concentrations in snapper otoliths

Random slope term designated with *x* | *y*. If there were errors in the optimum model (i.e. Singular Fit), AICc comparison tests were rerun without models with errors

	Δ*AICc*				
Random effects	Mg : Ca	Sr : Ca	Ba : Ca	Mn : Ca	Li : Ca
1|FishID	90.1	203.2	308.5	304.80	16.46
Age|FishID	**0.0**	**0.0**	**0.0**	6.80	**0.00**
1|FishID + 1|iSeason	82.5	194.0	310.5	303.80	18.51
sAge|FishID + 1|Season	19.9	14.7	2.1	**0.0**	2.06
1|FishID + 1|Region	92.0	205.3	310.5	306.30	18.51
sAge|FishID2 + 1|Region	2.1	20.5	3.7	51.78	6.07
1|FishID +sAge|Region	34.3	16.7	1.2	47.78	2.06
sAge|FishID + sAge|Region	92.4	209.3	296.6	307.40	21.70
1|FishID + 1|iSeason + 1|Region	84.4	196.1	312.5	305.50	20.57
sAge|FishID + 1|iSeason + 1|Region	22.0	2.1	3.3	40.99	4.13
1|FishID2 + sAge|iSeason + 1|Region	59.6	190.4	286.2	253.90	24.57
sAge|FishID2 + sAge|iSeason + 1|Region	32.2	4.4	5.4	38.92	7.80
1|FishID + 1|iSeason + sAge|Region	72.3	198.6	298.6	301.60	23.79
sAge|FishID2 + 1|iSeason + sAge|Region	24.9	5.6	5.8	44.91	8.15
1|FishID + 1|iSeason + sAge|Region + sAge|Region	78.1	204.8	304.9	307.80	30.01
sAge|FishID + sAge|iSeason + sAge|Region	50.2	7.9	3.4	45.72	11.87

Table S4. Selection of optimal fixed effects models (highlighted in bold) for carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotopes, magnesium (Mg : Ca), strontium (Sr : Ca), barium (Ba : Ca), manganese (Mn : Ca) and lithium (Li : Ca) in snapper otoliths

				$\Delta AICc$			
Fixed effects	$\delta^{13}C$	$\delta^{18}O$	Mg : Ca	Sr : Ca	Ba : Ca	Mn : Ca	Li : Ca
Base Model	220.38	155.98	375.8	1.1	**0.000**	**0.00**	6.10
Fish length	222.37	158.1	377.4	**0.0**	5.876	2.35	5.41
Otolith growth	222.44	158.05	375.43	9.0	2.565	3.11	0.20
Sex	0.81	**0.00**	5.20	363.9	27.42	60.66	109.98
Otolith growth, Fish length	224.38	160.22	377.02	7.8	3.483	2.74	**0.00**
Otolith growth, Sex	2.93	2.26	**0.00**	371.7	29.09	67.19	107.32
Sex, Fish length	1.35	1.52	7.23	362.8	26.69	57.59	110.39
Otolith growth, Sex, Fish length	3.20	3.69	2.01	370.4	28.24	64.26	108.11
Fish length × Sex	**0.00**	3.32	9.11	365.3	26.48	59.2	112.28
Otolith growth × Sex	2.37	2.83	2.04	373.7	29.23	69.22	109.24
CFL × Sex, Otolith growth	1.86	5.55	3.90	373.1	27.72	65.9	109.81
Otolith growth × Sex, CFL	2.84	4.52	3.97	373.5	28.34	66.3	109.93

Table S5. Selection of optimal environmental models (highlighted in bold) in lifetime carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotopes, magnesium (Mg : Ca), strontium (Sr : Ca) and barium (Ba : Ca) in snapper otoliths

Environmental predictors assessed include linear sea surface temperature (SST) and curvilinear sea surface temperature (SST + SST^2). Base model indicates that an environmental term did not improve fit

				$\Delta AICc$			
Environmental predictors	$\delta^{13}C$	$\delta^{18}O$	Mg : Ca	Sr : Ca	Ba : Ca	Mn : Ca	Li : Ca
Base model	153.49	101.7	39.86	**0.0**	**0.00**	**0.00**	**0.0**
SST	1.86	0.0	10.44	353.4	23.32	306.04	160.1
SST + SST^2	0.30	1.002	12.51	355.4	25.17	306.95	169.1
SST (lagged)	1.56	1.088	0.00	366.7	32.45	340.54	169.1
SST (lagged) + SST^2 (lagged)	**0.00**	1.088	1.874	366.7	34.46	341.07	162.1

Table S6. Selection of optimal environmental structures (highlighted in bold) in lifetime carbon ($\delta^{13}C$) and oxygen ($\delta^{18}O$) isotopes, magnesium (Mg : Ca), strontium (Sr : Ca) and barium (Ba : Ca) in snapper otoliths

Environmental predictors assessed include linear chlorophyll-*a* (Chl-*a*) and curvilinear chlorophyll-*a* (Chl-*a* + Chl-a^2). Base model indicates that an environmental term did not improve fit

				$\Delta AICc$			
Environmental predictors	$\delta^{13}C$	$\delta^{18}O$	Mg : Ca	Sr : Ca	Ba : Ca	Mn : Ca	Li : Ca
Base model	293.88	183.7	**0.000**	**0.0**	**0.0**	**0.00**	**0.0**
Chl-*a*	**0.00**	**0.00**	107.6599	1039.8	312.7	690.79	418.4
Chl-*a* + Chl-a^2	0.94	2.082	109.4785	1041.4	308.2	691.21	419.5
Chl-*a* (lagged)	0.31	1.911	142.7463	1054.5	317.4	656.32	431.9
Chl-*a* (lagged) + Chl-a^2 (lagged)	1.07	1.911	144.8599	1054.5	313.7	657.27	431.9

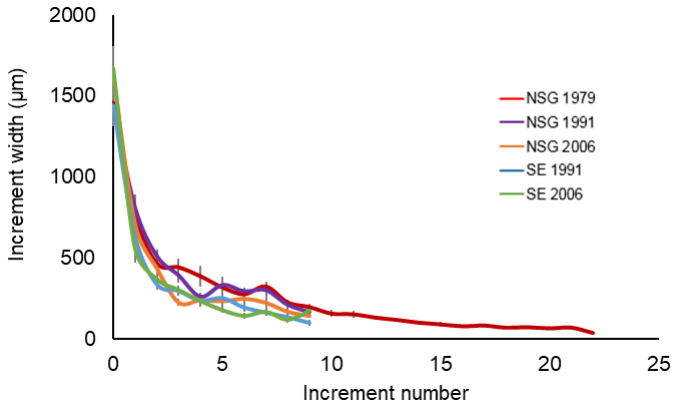

Fig. S1. Mean (+ standard errors) otolith increment widths along axis 1 (Fig. 2) in snapper from two regions and three cohorts in South Australia.

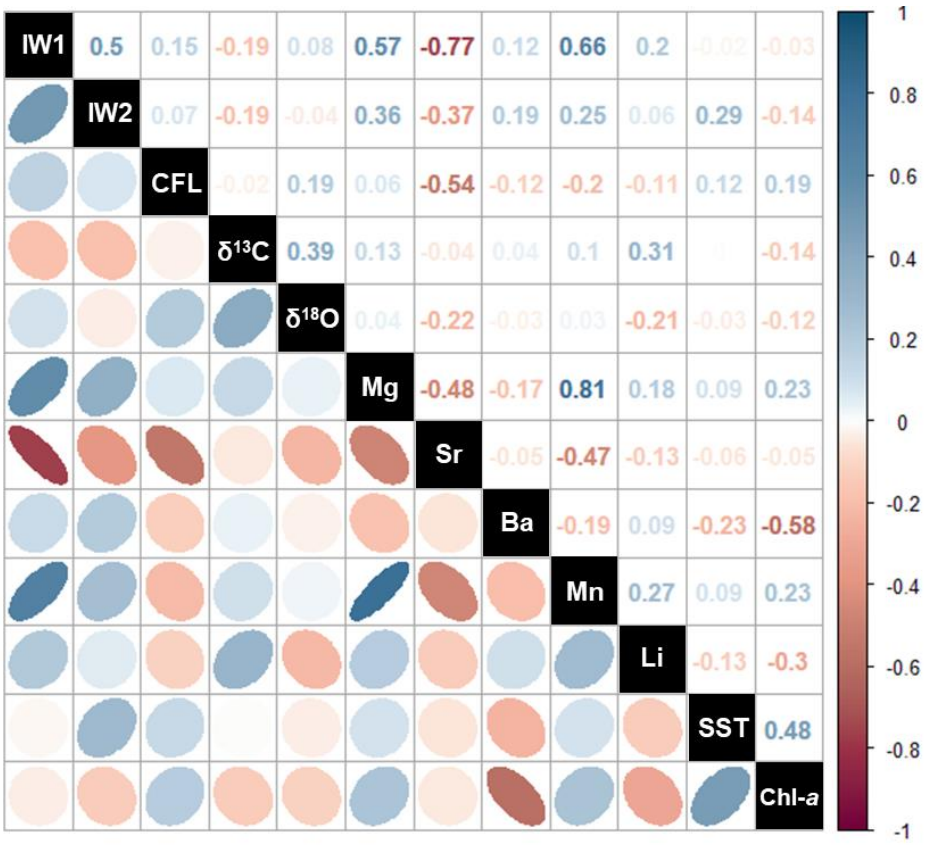

Fig. S2. Annual relationships in snapper otoliths between Axis 1 Increment Width (IW1; Fig. 5.3), Axis 2 Increment Width (IW2; Fig. 5.3), carbon isotopes ($\delta^{13}C$), oxygen isotopes ($\delta^{18}O$), magnesium (Mg), Strontium (Sr), Barium (Ba), Manganese (Mn), Lithium (Li), and extrinsic factors sea surface temperature (SST) and chlorophyll-*a* (Chl-*a*). Isotopes were analysed on the same axis as IW1 and elements were analysed on the same axis as IW2. Elements shown are ratioed to calcium. Spread of data and best fit line are indicated by the bottom panel, with narrower ellipses indicating stronger relationships. The top panel provides Pearson's correlation coefficients indicating the extent of correlation between the two variables. Correlation matrix were created using package *corrplot* in R.

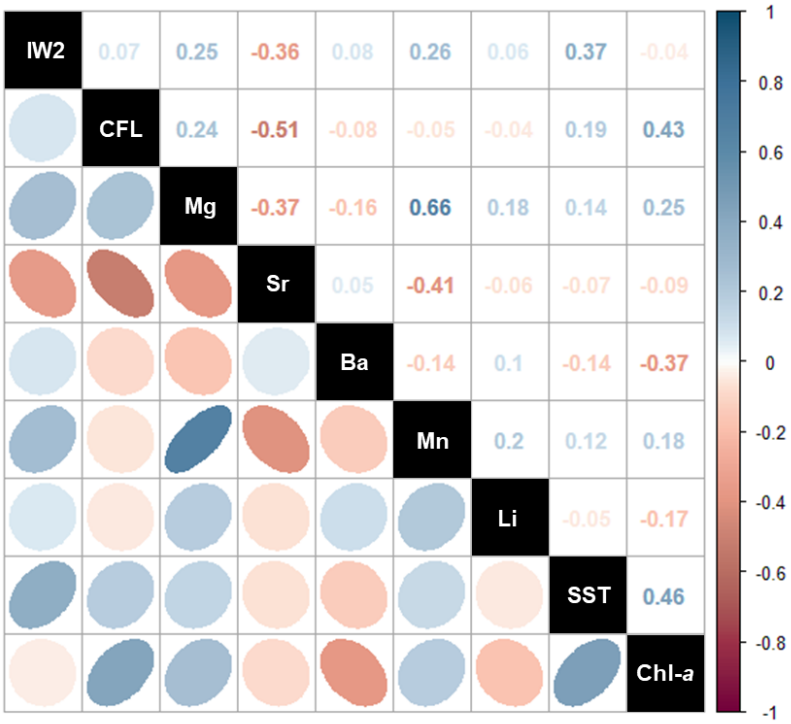

Fig. S3. Seasonal relationships in snapper otoliths between Axis 2 Increment Width (IW2; Fig. 5.3), caudal fork length (CFL), magnesium (Mg), Strontium (Sr), Barium (Ba), Manganese (Mn), Lithium (Li), and extrinsic variables of sea surface temperature (SST) and chlorophyll-*a* (Chl-*a*). Elements shown are ratioed to calcium. Spread of data and best fit line are indicated by the bottom panel, with narrower ellipses indicating stronger relationships. The top panel provides Pearson's correlation coefficients indicating the extent of correlation between the two variables. Correlation matrix were created using package *corrplot* in R.

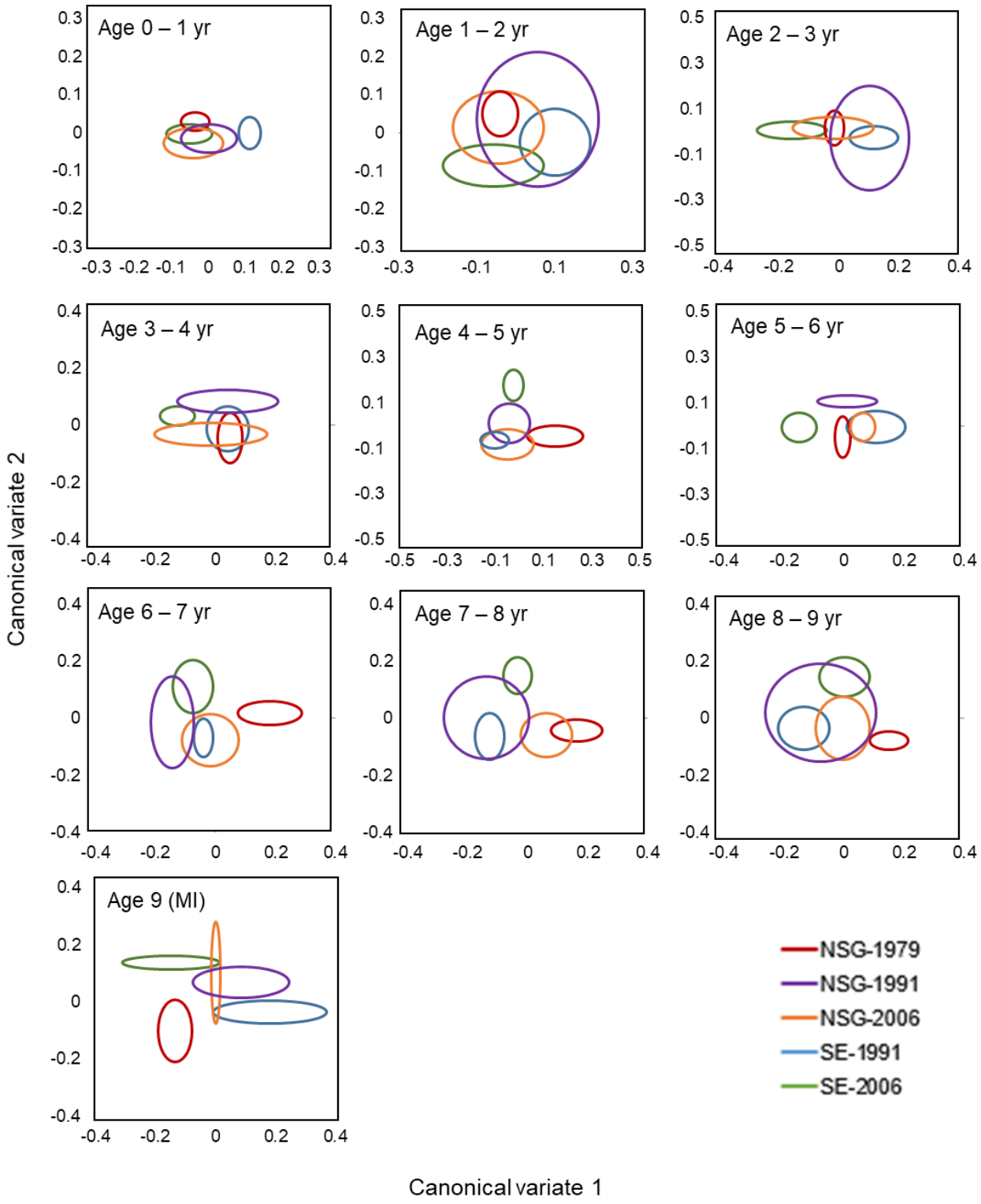

Fig. S4. Canonical analysis of principle coordinates (CAP) plot showing variation in chemical signatures in snapper otoliths for Northern Spencer Gulf (NSG) and South East (SE) regions and 3 cohorts (1979, 1991, 2006) in South Australia. Ellipses represent 95% confidence around group means. Vector diagrams show the direction and weight of individual chemical markers to sample distribution.