

Supplementary tables

Table 1. Ecopath model diet composition matrix. Numbers represent biomass fractions (out of 1.00) of food ingested.

	Prey \ Predator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Large mysticetes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Small mysticetes	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Odontocetes	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	Pinnipeds	0	0	0.05	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	Penguins	0	0	0.08	0.01	0	0.01	0	0	0	0	0	0	0	0	0	0	0
6	Flying seabirds	0	0	0	0	0	0.01	0	0	0	0	0	0	0	0	0	0	0
7	Large demersals	0	0	0.15	0.04	0	0.02	0.01	0	0	0	0	0	0	0	0	0	0
8	Small demersals	0	0	0.13	0.15	0.05	0.03	0.26	0.02	0	0.06	0	0	0	0	0	0	0
9	Small pelagics	0.05	0.1	0.25	0.25	0.33	0.35	0.11	0.03	0	0.23	0	0	0	0	0	0	0
10	Cephalopods	0.02	0.02	0.32	0.2	0.13	0.15	0.03	0.05	0	0.2	0	0	0	0	0	0	0
11	Carn. zooplankton	0.02	0.02	0	0	0	0.01	0.05	0.19	0.4	0.05	0	0.03	0	0	0	0	0.01
12	Krill	0.8	0.8	0.02	0.35	0.5	0.4	0.21	0.25	0.16	0.05	0	0	0	0	0	0	0.01
13	Salps	0.01	0.01	0	0	0	0.01	0.02	0.02	0.04	0.25	0.05	0	0	0	0	0	0
14	Copepods	0.1	0.05	0	0	0	0.02	0.05	0.19	0.4	0.02	0.65	0.03	0.05	0	0	0	0.01
15	Microzooplankton	0	0	0	0	0	0	0	0	0	0	0.1	0.35	0.15	0.35	0.1	0	0.15
16	Bacterioplankton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.2	0	0
17	Benthos	0	0	0	0	0	0	0.26	0.25	0	0.15	0.1	0	0	0	0	0	0.02
18	Producers	0	0	0	0	0	0	0	0	0	0	0	0.5	0.7	0.63	0.7	0	0.6
19	Detritus	0	0	0	0	0	0	0	0	0	0	0.1	0.1	0.1	0.02	0	1	0.2

Table 2. Values and sources for the parameters of the pre-whaling (1900) and post-whaling (2008) Southern Ocean Ecopath models.

Group	Model				Model			Both models											
	1900		2008		1900	2008		P/B			Q/B			P/Q			Fe content ²⁰		
	Input biomass (t wet w.km ⁻²)				EE			(y ⁻¹)	(y ⁻¹)	(y ⁻¹)	Fe content ²⁰ (kg Fe. t ⁻¹ wet weight)			L	H	source			
source	source	source	source	source	source	source	source	source	source	source	source	source	source	source	source	source	source		
Large mysticetes	2.159	1	0.039	1	0.06	0.93	4	0.030	6	3.75	6	0.008	4	0.012	0.229	11			
Small mysticetes	0.263	1	0.187	1	0.51	0.55	4	0.050	6	5.00	6	0.012	4	0.012	0.229	11			
Odontocetes	1.000	2	0.178	3	0.60	0.60	4	0.040	7	7.20	7	0.008	4	0.012	0.229	11			
Pinnipeds	0.025	2	0.155	3	0.81	0.98	4	0.150	2	15.00	2	0.027	4	0.012	0.229	11			
Penguins	0.040	2	0.255	3	0.87	0.77	4	0.250	2	60.00	2	0.010	4	0.068	0.163	11			
Flying seabirds	0.020	2	0.062	3	0.70	0.69	4	0.100	2	100.00	2	0.008	4	0.068	0.163	11			
Large demersals	1.000	5	0.474	3	0.77	0.97	4	0.550	5	3.30	5	0.167	4	0.073	0.324	12			
Small demersals	1.400	5	2.018	3	0.96	1.00	4	0.800	5	4.20	5	0.357	4	0.073	0.324	12			
Small pelagics	3.000	2	10.248	3	0.98	0.60	4	1.500	2	5.00	2	0.400	4	0.073	0.324	12			
Cephalopods	1.000	5, 6	2.588	3	0.98	0.98	4	0.950	6	2.50	6	0.667	4	0.121	0.245	12			
Carn. zooplankton	3.360	7	5.769	3	0.88	0.79	4	4.900	7	19.00	7	0.395	4	0.025	0.070	13			
Krill	14.000	6	12.007	3	0.64	0.89	4	1.500	6	33.00	6	0.076	4	0.003	0.040	14			
Salps	8.000	5	2.221	3	0.23	0.92	4	6.500	5	250.00	5	0.026	4	0.180	0.500	15			
Copepods	11.200	7	12.236	3	0.97	0.85	4	8.600	7	34.00	7	0.441	4	0.006	0.050	16			
Microzooplankton	40.000	7	28.767	3	0.81	0.90	4	47.000	7	160.00	7	0.294	4	0.007	0.013	17			
Bacterioplankton	No input	4	No input	4	0.98	0.98	8	87.400	8	380.00	4	0.230	8	0.017	0.370	18			
Benthos	28.800	7	13.701	3	0.07	0.18	4	0.540	7	2.20	7	0.7500	4	0.353	0.415	12			
Producers	120.000	9	50.255	10	0.78	0.70	4	75.000	6	N/A	N/A	N/A	4	0.004	0.022	17			
Detritus	80.000	4	48.879	3	1.00	0.87	4	N/A	N/A	N/A	N/A	N/A	4						
													<i>Detritus 1900</i>			0.051	0.221	19	
													<i>Detritus 2008</i>			0.032	0.207	19	

Sources

- 1.** Surplus production model (Surma et al. 2014); **2.** All Ecopath models listed in Methods; **3.** Ecosim (bottom-up 1) run (Surma et al. 2014);
4. Estimated by Ecopath; **5.** Bredesen 2003; **6.** Hoover et al. 2012; **7.** Hill et al. 2012; **8.** Bradford-Grieve et al. 2003;
9. Cornejo-Donoso and Antezana 2008; **10.** Arrigo et al. 2008; **11.** Honda et al. 1987; **12.** Moreno and Haffa 2014;
13. amphipods: Rainbow and Moore 1986, Masuzawa et al. 1988, Bargagli 2001; chaetognaths: Masuzawa et al. 1988; jellyfish: Shiber 1981, Moreno and Haffa, 2014;
14. Honda et al. 1987, Ratnarajah et al. 2014, Barbante et al. 2000, Fowler et al. 1977; **15.** Strohal et al. 1969; **16.** Honda et al. 1987, Chen et al. 2011;
17. Twining et al. 2004; **18.** Granger and Price 1999; **19.** these numbers (1900/2008) were calculated as weighted averages (see methods for details)
20. see further details in the *Materials and methods*

Table 5. Calculated percentage contribution of each prey item to the total Fe ration of each consumer in the post-whaling (2008) Southern Ocean mass-balanced ecosystem model. For these calculations we used the low Fe content estimates of each functional group.

LOW Fe: % Fe ration from prey																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Large mysticetes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Small mysticetes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odontocetes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinnipeds	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Penguins	0	0	6	1	0	1	0	0	0	0	0	0	0	0	0	0	0
Flying seabirds	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Large demersals	0	0	13	5	0	3	1	0	0	0	0	0	0	0	0	0	0
Small demersals	0	0	11	19	8	4	15	1	0	3	0	0	0	0	0	0	0
Small pelagics	33	51	22	32	54	50	6	2	0	11	0	0	0	0	0	0	0
Cephalopods	22	17	47	42	35	35	3	6	0	17	0	0	0	0	0	0	0
Carn. zooplankton	5	4	0	0	0	0	1	4	50	1	0	7	0	0	0	0	1
Krill	19	14	0	2	3	2	0	1	2	0	0	0	0	0	0	0	0
Salps	16	12	0	0	0	4	3	3	36	31	17	0	0	0	0	0	0
Copepods	5	2	0	0	0	0	0	1	12	0	7	2	4	0	0	0	0
Microzooplankton	0	0	0	0	0	0	0	0	0	0	1	29	14	43	10	0	6
Bacterioplankton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	47	0	0
Benthos	0	0	0	0	0	0	71	82	0	37	68	0	0	0	0	0	40
Producers	0	0	0	0	0	0	0	0	0	0	0	25	40	46	43	0	15
Detritus	0	0	0	0	0	0	0	0	0	0	6	37	42	11	0	100	36

Table 6. Calculated percentage contribution of each prey item to the total Fe ration of each consumer in the post-whaling (2008) Southern Ocean mass-balanced ecosystem model. For these calculations we used the high Fe content estimates of each functional group.

HIGH Fe: % Fe ration from prey																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Large mysticetes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Small mysticetes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Odontocetes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pinnipeds	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Penguins	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Flying seabirds	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Large demersals	0	0	18	6	0	3	1	0	0	0	0	0	0	0	0	0	0
Small demersals	0	0	15	23	9	5	32	4	0	5	0	0	0	0	0	0	0
Small pelagics	25	41	29	39	61	59	14	6	0	22	0	0	0	0	0	0	0
Cephalopods	8	6	28	24	18	19	3	7	0	15	0	0	0	0	0	0	0
Carn. zooplankton	2	2	0	0	0	0	1	8	38	1	0	4	0	0	0	0	1
Krill	50	41	0	7	12	8	3	6	9	1	0	0	0	0	0	0	1
Salps	8	6	0	0	0	3	4	6	27	37	21	0	0	0	0	0	0
Copepods	8	3	0	0	0	1	1	5	27	0	27	3	6	0	0	0	1
Microzooplankton	0	0	0	0	0	0	0	0	0	0	1	12	5	20	1	0	3
Bacterioplankton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	82	0	0
Benthos	0	0	0	0	0	0	41	59	0	19	34	0	0	0	0	0	12
Producers	0	0	0	0	0	0	0	0	0	0	0	28	38	61	17	0	20
Detritus	0	0	0	0	0	0	0	0	0	0	17	53	51	18	0	100	62

Table 7. Functional group biomass density ratio between the model balanced for Fe and the model balanced for biomass for the pre-whaling (1900) and post-whaling (2008) Southern Ocean ecosystem. L, model run using the low Fe content (kg Fe.t⁻¹wet weight) for each functional group; H, model run using the high Fe content (kg Fe.t⁻¹wet weight) for each functional group (see Suppl. 2, 3, 4, and Table 3 and 4). For further details on the calculations, see the *Materials and methods* section.

Biomass density ratio: balanced for Fe / balanced for biomass				
	2008 L	2008 H	1900 L	1900 H
Large mysticetes	1.03	1.00	1.00	1.00
Small mysticetes	1.00	1.00	0.99	1.00
Odontocetes	1.00	1.00	1.01	1.00
Pinnipeds	0.99	1.00	1.01	1.00
Penguins	1.00	1.08	1.00	1.23
Flying seabirds	0.99	1.00	1.00	1.00
Large demersals	1.00	1.00	1.00	1.00
Small demersals	1.00	1.00	1.00	1.00
Small pelagics	1.00	1.00	1.00	1.00
Cephalopods	1.00	1.00	1.00	1.00
Carn. zooplankton	2.73	3.48	3.77	3.48
Krill	28.85	5.73	25.38	4.50
Salps	1.27	1.27	1.00	1.00
Copepods	15.00	5.70	22.40	7.19
Microzooplankton	14.68	23.35	15.41	20.19
Bacterioplankton	6.27	1.29	6.46	1.00
Benthos	1.00	1.00	1.00	1.00
Producers	18.09	9.72	24.62	10.98
Detritus	1.00	1.00	1.00	1.00

Table 8. Permutations of post-whaling (2008) Southern Ocean biomass-balanced ecosystem model, by randomly selecting low or high Fe content values (kg Fe.t⁻¹ wet weight) for each functional group. The annual Fe released associated with prey consumption (kg Fe.km⁻².y⁻¹) was then calculated for each functional group. In permutation 3 and 5, the Fe content of the functional groups is the same, except for the micrograzers, whose Fe content was increased 4 times from 0.013 to 0.05 kg Fe.t⁻¹ wet weight. For further details on the calculations, see the *Materials and methods* section.

2008	Permutation	1			2			3			4			5		
		Fe content	Fe released	% T releas.	Fe content	Fe released	% T releas.	Fe content	Fe released	% T releas.	Fe content	Fe released	% T releas.	Fe content	Fe released	% T releas.
		kg Fe. t ⁻¹ w.w.	kgFe. km ⁻² .y ⁻¹		kg Fe. t ⁻¹ w.w.	kg Fe. km ⁻² .y ⁻¹		kg Fe.t ⁻¹ w.w.	kg Fe. km ⁻² .y ⁻¹		kg Fe. t ⁻¹ w.w.	kg Fe. km ⁻² .y ⁻¹		kg Fe.t ⁻¹ w.w.	kg Fe. km ⁻² .y ⁻¹	
	Balanced for biomass															
	Large mysticetes	0.229	0.021	0.079	0.012	0.013	0.007	0.012	0.018	0.008	0.229	0.005	0.003	0.012	0.018	0.008
	Small mysticetes	0.012	0.059	0.225	0.012	0.037	0.020	0.012	0.044	0.020	0.012	0.016	0.009	0.012	0.044	0.020
	Odontocetes	0.229	0.165	0.624	0.229	0.254	0.139	0.012	0.162	0.074	0.012	0.198	0.111	0.012	0.162	0.075
	Pinnipeds	0.229	0.245	0.928	0.012	0.312	0.171	0.229	0.174	0.080	0.012	0.282	0.158	0.229	0.174	0.081
	Penguins	0.068	2.182	8.271	0.163	2.107	1.153	0.068	1.182	0.540	0.163	1.346	0.755	0.068	1.182	0.546
	Flying seabirds	0.068	0.782	2.962	0.068	0.848	0.464	0.163	0.460	0.210	0.068	0.484	0.271	0.163	0.460	0.212
	Large demersals	0.073	0.392	1.487	0.324	0.332	0.182	0.324	0.285	0.130	0.073	0.533	0.299	0.324	0.285	0.131
	Small demersals	0.073	0.884	3.351	0.073	1.135	0.621	0.073	0.976	0.446	0.324	0.166	0.093	0.073	0.976	0.451
	Small pelagics	0.234	-4.645		0.234	-3.138		0.073	0.501	0.229	0.073	-0.467		0.073	0.501	0.231
	Cephalopods	0.121	1.879	7.121	0.245	1.389	0.760	0.121	1.600	0.731	0.245	0.297	0.166	0.121	1.600	0.739
	Carnivorous zooplankton	0.025	6.543	24.797	0.070	9.204	5.036	0.025	8.041	3.673	0.025	6.055	3.395	0.025	8.534	3.941
	Krill	0.040	2.895	10.971	0.003	8.216	4.495	0.040	9.902	4.523	0.003	6.625	3.715	0.040	15.347	7.087
	Salps	0.500	-1.630		0.500	2.507	1.372	0.500	7.153	3.267	0.180	4.362	2.446	0.500	9.931	4.586
	Copepods	0.006	1.238	4.690	0.050	-4.249		0.006	6.155	2.811	0.006	2.157	1.209	0.006	10.612	4.900
	Microzooplankton	0.007	10.731	40.670	0.013	156.408	85.581	0.013	182.280	83.258	0.013	155.820	87.370	0.050	166.740	76.992
	Bacterioplankton	0.017	-0.747		0.370	-144.041		0.370	-143.389		0.370	-146.230		0.370	-142.293	
	Benthos	0.353	-33.379		0.415	-37.638		0.415	-36.129		0.415	-38.231		0.415	-35.149	
	Producers	0.004			0.004			0.022			0.004			0.022		
	Detritus	0.048			0.112			0.117			0.096			0.125		
	sum Fe released		28.015			182.761			218.934			178.345			216.567	

References of Supplementary Tables

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