The following supplement accompanies the article

Variation in the diet of killer whales *Orcinus orca* at Marion Island, Southern Ocean

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Supplementary methods – prey sample collection and preparation

We used $\delta^{13}C$ and $\delta^{15}N$ values for all prey species recorded in the diet of Marion Island killer whales and all species were sampled at or near (in the case of Patagonian toothfish) Marion Island (Table 2 and Supplementary Tables S1–S3). While we attempted to match killer whale and prey samples closely in time, this was not always possible. Prey samples were collected in four years, and in seven calendar months (November-May). Marked inter- or intra-annual variation in prey foraging behaviour or oceanographic conditions could thus influence our representation of the killer whale prey field. Blood samples were collected from eight king penguins, five macaroni penguins and seven rockhopper penguins (Supplementary Table S1). Blood samples were centrifuged to separate red blood cells from plasma and then stored at -20°C without preservatives. Red blood cells where oven-dried prior to transport and we weighed 0.35–0.45 mg into tin capsules for stable isotope analysis. Whole blood samples were collected from 13 lactating, adult female Subantarctic fur seals during a satellite tagging study at Marion Island (Supplementary Table S2) (Wege 2013). Samples were stored without any preservatives at -20° C and we lyophilized samples for 24 hours before they were transported. We analysed two aliquots of 0.35–0.45 mg each. Whole blood samples were also collected from 35 adult female Antarctic fur seals at Marion Island; these samples were analysed and reported in Walters (2014). The mean $\delta^{13}C$ value was -21.7 ± 0.5‰ and the mean $\delta^{15}N$ value was 11.2 ± 0.3‰. In mammals and birds, whole blood and red blood cells integrate a temporal window of several weeks (Dalerum and Angerbjörn 2005); turnover is faster in birds than in mammals, and faster in whole blood than in red blood cells (Boecklen et al. 2011).

Skin and hair samples were collected from 25 actively moulting southern elephant seals at Marion Island (Supplementary Table S2). Elephant seals were individually tagged near weaning and their ages and identities are thus known (de Bruyn et al. 2008, Bester et al. 2011). Five samples were collected from animals in each of the following categories: adult males, adult females, subadults, one year olds, and underyearlings (< 1 year old). Samples were stored in paper envelopes at room temperature. We cleaned the hair, still attached to skin, following the method of Lewis et al. (2006).

We rinsed samples in running purified water and then placed them in glass test tubes with ~150 ml of purified water and sonicated them for 20 minutes. We then discarded the water, added ~150 ml chlroform:methanol solution (2:1 volume:volume) and sonicated the samples for 20 minutes. We discarded the solution and again added ~150 ml of chloroform:methanol and sonicated the samples for 20 minutes. Next we rinsed the samples in purified water and sonicated them in purified water for 20 minutes. Finally we rinsed the samples in running purified water and air dried them. We cut hair from the skin samples and we weighed two 035–0.45 mg aliquots into tin capsules for stable isotope analysis. Southern elephant seals replace their pelage annually (November-March) when they haul out on land and undergo a 'catastrophic' moult. Thereafter, the hair follicle enters a resting stage until the next moult. The hair follicle is active for ~12 weeks, and most hair synthesis occurs during the 4-6 week moulting haul out period (Ling 2012). Hair collected in a given year thus represents the individual's dietary resources just prior to moult (i.e., austral summer) in the previous year with a temporal integration period similar or shorter to that in muscle and whole blood (cf. Dalerum and Angerbjörn 2005).

Patagonian toothfish white muscle samples were collected from 10 individuals caught by the longline fishing vessel *Koryo Maru No. 11* (Supplementary Table S3). These fish were caught on 2013/11/09, approximately 160 km NNE of Marion Island (at 45° 27.59' S, 35° 23.85' E). Samples were stored at -20°C. We rinsed the samples in distilled water and then oven-dried them at 70°C overnight. Three aliquots of each sample were analysed: two were lipid extracted (and we averaged these two values for further analysis), while the third aliquot was not lipid extracted. We extracted lipids using a 1:2 chloroform:ethanol solution (Logan et al. 2008); samples were washed three times for 20 minutes each in an ultrasonic bath, before rinsing and drying as above. We weighed 0.8–1.0 mg of tissue into tin cups for analysis. As for killer whale samples, lipid extraction affected $\delta^{15}N$ values as well as $\delta^{13}C$ values (see Results in main text); we therefore used lipid extracted $\delta^{13}C$ values with non lipid extracted $\delta^{15}N$ value for further analysis.

Supplementary results – prey

There were significant differences among prey $\delta^{13}C$ values (ANOVA, $F = 23.2$, df = 9, $p < 0.001$) and among prey $\delta^{15}N$ values (ANOVA, $F = 67.0$, df = 9, $p < 0.001$), the latter showing greater segregation (Figure 3). A post-hoc multiple comparisons using adjusted values (Tukey's HSD) is shown in Supplementary Table S4. $\delta^{13}C$ values were similar among penguin species. $\delta^{15}N$ values for macaroni and rockhopper penguins were similar (9.2 ± 0.3‰ and 8.5 ± 0.6‰, respectively), but those for king penguins were significantly higher (mean = 10.5 ± 0.3‰) (Supplementary Table S1; Supplementary Table S4). Among seals, $\delta^{13}C$ values were significantly different only between elephant seal adult males and juveniles, and Subantarctic fur seals and elephant seal underyearlings (Supplementary

Table S4). Elephant seal adult males had the highest δ^{15}N values among seals (12.7 ± 0.6‰), followed by Subantarctic fur seal adult females (12.1 ± 0.3 ‰), elephant seals of all other age-sex classes (combined: 11.4 ± 0.5 ‰), and Antarctic fur seal adult females (11.9 ± 0.3‰) (Supplementary Table S2). Elephant seal adult females, subadults and yearlings had significantly lower δ^{15}N values than elephant seal adult males and Subantarctic fur seals, but elephant seal underyearlings did not (Supplementary Table S4). Mean $\delta^{15}N_{NLE}$ for Patagonian toothfish was 12.7 ± 0.6‰ – higher than adult male elephant seals, but not significantly so –while mean $\delta^{13}C_{LE}$ was -20.2 ± 0.6‰ (Table 2; Supplementary Table S3). δ^{13}C values were only significantly different from those for penguins and elephant seal underyearlings (Supplementary Table S4). δ^{13}C values were not significantly different among penguins (Supplementary Table S4, Figure 3).

Supplementary results – lipid extraction of killer whale samples

Lipid extraction decreased C:N ratios. Mean atomic C:N in NLE skin was 4.5 ± 0.7; that in LE skin was 3.5 ± 0.1 (Table 1). δ^{13}C was negatively related to atomic C:N ratio, but δ^{15}N showed no such relationship (Supplementary Figure S1). Lipid extraction changed δ^{13}C values and, to a lesser extent, δ^{15}N values. δ^{13}C values in skin were significantly higher and less variable following lipid extraction (mean $\delta^{13}C_{NLE}$ = -20.4 ± 0.9‰, $\delta^{13}C_{LE}$ = -18.6 ± 0.4‰; paired t-test, $t = -9.24$, df = 29, $p < 0.001$) (Table 1). δ^{15}N values were also significantly higher after lipid extraction from skin ($\delta^{15}N_{NLE}$ = 12.3 ± 0.6‰, $\delta^{15}N_{LE}$ = 12.8 ± 0.7‰; paired t-test, $t = -4.83$, df = 29, $p < 0.001$) (Table 1), but the differences were smaller and variability was similar (Supplementary Figure S1).

Supplementary discussion — prey trophic structure

Penguins foraged at similar latitudes (judged by δ^{13}C values) but at different trophic levels. Macaroni and rockhopper penguins had similar δ^{15}N values, affirming their similar diet. Both species feed primarily on crustaceans, particularly the benthic shrimp *Nauticaris marionis* which is abundant on the shallow shelf between Marion and Prince Edward Island. They include more fishes, mainly pelagic myctophids, and some cephalopods (mainly *Kondokovia longimana*) later in their chick-rearing phase as they are able to forage farther afield (Brown & Klages 1987, Crawford et al. 2003). King penguins, in contrast, prey mainly on myctophid fishes and small cephalopods (juvenile *K. longimana*) (Adams & Klages 1987) and this is reflected in their higher δ^{15}N values.

The diet of Subantarctic fur seals at Marion Island is dominated by myctophid fishes. Fishes occurred in 98.1% of faecal samples, while cephalopods were found in only 1.4% of samples (Makhado et al. 2013). Fishes—mostly myctophids—also dominated the diet of Antarctic fur seals at Marion, occurring in 96.1% of faecal samples, while shrimp (*Nauticaris marionis*) and cephalopods occurred in only 2.7 and 1.2% of samples (Makhado et al. 2008). More recently, Walters (2014) used stable isotope analysis to document seasonal dietary shifts, which included increased foraging on krill (euphausiids) during winter. The trophic level similarity between these two species is supported by δ^{15}N values (0.2 ‰ difference in mean values), but δ^{13}C values indicate different foraging areas (1.6 ‰ difference in mean values). Satellite tracking studies show that Subantarctic fur seals usually feed at lower latitudes (reflected in our results by higher δ^{13}C values) than Antarctic fur seals (de Bruyn et al. 2009, Wege 2013, Walters 2014).

No studies have investigated the diet of elephant seals at Marion Island, but studies elsewhere report varying combinations of fishes and cephalopods (e.g., Green & Burton 1993, van den Hoff et al. 2003, Daneri et al. 2004, van den Hoff 2004, Field et al. 2006). We show that adult male elephant seals have higher δ^{15}N values, and thus feed at a higher trophic level than other age-sex classes, but that they forage in approximately the same habitats (as judged by δ^{13}C values). An increase in trophic level with age has been shown for male elephant seals elsewhere (Bailleul et al. 2010, Chaigne et al. 2012), but adult females show more variation (Hückstädt et al. 2012, Chaigne et al. 2012; although see Lewis et al. 2006). Adult female, subadult and juvenile elephant seals in our study had δ^{15}N values between those of fur seals and king penguins, all of which feed primarily on myctophid fishes. It is thus possible that these elephant seals, like adult females at Kerguelen (Cherel et al. 2008), feed primarily on mesopelagic fishes as opposed to toothfish and cephalopods. Males at Marion, which have δ^{15}N values almost as high as killer whales, probably take larger/higher trophic level fishes and cephalopods.

Adult Patagonian toothfish are opportunistic carnivores, feeding on any locally abundant prey of a suitable size, which may include fishes, cephalopods and crustaceans (Collins et al. 2010). In 118 Patagonian toothfish stomachs from near Marion Island, the most important prey (by mass) were the cephalopods *Moroteuthis* sp. (47.5%) and *K. longimana* (12.0%) and the fish *Gymnoscopelus* sp. (family Myctophidae) (11.2%) and *Stomias boa boa* (family Stomiidae) (8.7%) (Pakhomov et al. 2006). The high proportions of such cephalopods would explain the high δ^{15}N values for toothfish (see Cherel & Hobson 2005, Guerreiro et al. 2015).

Supplementary tables

Table S1. $\delta^{13}C$ and $\delta^{15}N$ (‰) values of red blood cells collected from three penguin species at Marion Island. C:N is the atomic carbon:nitrogen ratio. Adjusted values are corrected to represent muscle tissue (refer to Table 3 the main text).

Species	Date	$\delta^{13}C$	$\delta^{15}N$	C:N	Adjusted $\delta^{13}C$	Adjusted $\delta^{15}N$
Aptenodytes patagonicus	2011/05/01	-22.6	10.5	3.8	-22.2	10.6
Aptenodytes patagonicus	2011/05/01	-22.6	10.7	3.8	-22.2	10.8
Aptenodytes patagonicus	2011/05/01	-22.8	11.0	4.0	-22.4	11.1
Aptenodytes patagonicus	2011/05/01	-22.6	10.1	3.9	-22.2	10.2
Aptenodytes patagonicus	2011/05/01	-22.9	10.6	3.9	-22.5	10.7
Aptenodytes patagonicus	2011/05/01	-22.7	10.4	3.9	-22.3	10.5
Aptenodytes patagonicus	2011/05/01	-22.8	10.1	3.9	-22.4	10.2
Aptenodytes patagonicus	2011/05/01	-22.7	10.0	3.8	-22.3	10.1
n = 8						
Mean		-22.7	10.4	3.9	-22.3	10.5
SD		0.1	0.3	0.1	0.1	0.3
Eudyptes chrysolophus	2011/04/14	-23.0	9.0	3.9	-22.6	9.1
Eudyptes chrysolophus	2011/04/16	-22.8	8.7	3.9	-22.4	8.8
Eudyptes chrysolophus	2011/04/16	-22.9	9.0	3.8	-22.5	9.1
Eudyptes chrysolophus	2011/04/16	-22.8	9.5	3.9	-22.4	9.6
Eudyptes chrysolophus	2011/04/16	-23.1	9.4	3.8	-22.7	9.5
n = 5						
Mean		-22.9	9.1	3.8	-22.5	9.2
SD		0.1	0.3	0.0	0.1	0.3
Eudyptes chrysocome filholi	2011/04/17	-23.0	8.7	3.9	-22.6	8.8
Eudyptes chrysocome filholi	2011/04/17	-22.4	8.1	3.8	-22.0	8.2
Eudyptes chrysocome filholi	2011/04/17	-22.9	8.5	3.9	-22.5	8.6
Eudyptes chrysocome filholi	2011/04/17	-22.9	7.5	4.1	-22.5	7.6
Eudyptes chrysocome filholi	2011/04/17	-22.9	8.1	4.4	-22.5	8.2
Eudyptes chrysocome filholi	2011/04/17	-23.0	9.3	3.9	-22.6	9.4
Eudyptes chrysocome filholi	2011/04/17	-23.8	8.8	4.3	-22.4	8.9
n = 7						
Mean		-23.0	8.4	4.0	-22.6	8.5
SD		0.4	0.6	0.2	0.4	0.6

Table S2. δ^{13}C and δ^{15}N values (‰) of whole blood (*A. tropicalis*) and hair (*M. leonina*) collected from two seal species at Marion Island. C:N is the atomic carbon:nitrogen ratio. Adjusted values are corrected to represent muscle tissue (refer to Table 3 in the main text). [a] For elephant seals, class represent the age class when hair was synthesised. [b] Underyearling elephant seals are recently weaned and therefore have higher δ^{15}N values than adult females, but lower δ^{13}C values, reflecting their milk diet.

Species	Tissue	Date	Individual	Sex	Class [a]	Age (years)	δ^{13}C	δ^{15}N	C:N	Adjusted δ^{13}C	Adjusted δ^{15}N
Arctocephalus tropicalis	Whole blood	2011/03/24	A202	F	Adult	-	-20.4	11.6	4.0	-20.8	12.3
Arctocephalus tropicalis	Whole blood	2011/03/24	A204	F	Adult	-	-20.7	11.6	4.0	-21.1	12.3
Arctocephalus tropicalis	Whole blood	2011/05/13	A310	F	Adult	-	-20.4	11.6	4.0	-20.8	12.3
Arctocephalus tropicalis	Whole blood	2012/03/08	A333	F	Adult	-	-20.0	11.6	4.0	-20.4	12.3
Arctocephalus tropicalis	Whole blood	2011/03/24	A142	F	Adult	-	-20.6	11.1	4.1	-21.0	11.8
Arctocephalus tropicalis	Whole blood	2013/03/03	A153	F	Adult	-	-20.2	11.4	4.0	-20.6	12.1
Arctocephalus tropicalis	Whole blood	2011/03/13	LB160	F	Adult	-	-20.1	11.2	4.0	-20.5	11.9
Arctocephalus tropicalis	Whole blood	2012/12/24	A602	F	Adult	-	-19.3	11.7	3.9	-19.7	12.4
Arctocephalus tropicalis	Whole blood	2013/03/16	A611	F	Adult	-	-20.4	11.1	4.0	-20.8	11.8
Arctocephalus tropicalis	Whole blood	2011/12/27	GW503	F	Adult	-	-19.6	11.4	4.0	-20.00	12.1
Arctocephalus tropicalis	Whole blood	2011/04/29	LB491	F	Adult	-	-20.2	11.1	4.0	-20.6	11.8
Arctocephalus tropicalis	Whole blood	2012/12/23	LB504	F	Adult	-	-19.1	12.0	4.0	-19.5	12.7
Arctocephalus tropicalis	Whole blood	2011/04/29	OO440	F	Adult	-	-20.3	11.2	3.9	-20.7	11.9
n = 13											
Mean							-20.1	11.4	4.0	-20.5	12.1
SD							0.5	0.3	0.0	0.5	0.3
Mirounga leonina	Hair	2010/11/21	OB054	M	Underyearling [b]	1	-19.5	12.3	3.6	-21.0	11.7
Mirounga leonina	Hair	2010/11/26	OB069	F	Underyearling [b]	1	-20.0	12.6	3.7	-21.5	12.0
Mirounga leonina	Hair	2010/11/26	OB229	F	Underyearling [b]	1	-20.4	12.4	3.6	-21.9	11.8
Mirounga leonina	Hair	2010/11/26	OB003	F	Underyearling [b]	1	-20.3	12.6	3.7	-21.8	12.0
Mirounga leonina	Hair	2010/11/21	OB202	M	Underyearling [b]	1	-19.8	12.7	3.7	-21.3	12.1
n = 5											
Mean							-20.0	12.5	3.7	-21.5	11.9
SD							0.4	0.2	0.1	0.4	0.2

Species	Tissue	Date	Individual	Sex	Class [a]	Age (years)	δ^{13}C	δ^{15}N	C:N	Adjusted δ^{13}C	Adjusted δ^{15}N
Mirounga leonina	Hair	2010/12/16	FB026	F	Yearling	2	-20.2	11.8	3.7	-21.7	11.2
Mirounga leonina	Hair	2010/12/08	FB137	F	Yearling	2	-19.7	11.3	3.5	-21.2	10.7
Mirounga leonina	Hair	2010/12/01	FB160	M	Yearling	2	-19.1	12.6	3.6	-20.6	12.0
Mirounga leonina	Hair	2010/12/01	FB213	M	Yearling	2	-20.5	12.0	3.8	-22.0	11.4
Mirounga leonina	Hair	2010/12/11	FB253	F	Yearling	2	-18.7	11.8	3.5	-20.2	11.2
n = 5											
Mean							-19.6	11.9	3.6	-21.1	11.3
SD							0.7	0.5	0.1	0.7	0.5
Mirounga leonina	Hair	2011/01/08	LB276	F	Subadult	3	-19.1	11.5	3.6	-20.6	10.9
Mirounga leonina	Hair	2010/12/30	LB306	F	Subadult	3	-19.4	11.9	3.4	-20.9	11.3
Mirounga leonina	Hair	2010/11/22	LB092	M	Subadult	3	-19.4	11.4	3.4	-20.9	10.8
Mirounga leonina	Hair	2011/03/05	RR400	M	Subadult	6	-18.8	11.9	3.6	-20.3	11.3
Mirounga leonina	Hair	2011/02/07	RR408	M	Subadult	6	-18.6	12.1	3.6	-20.1	11.5
n = 5											
Mean							-19.1	11.8	3.5	-20.6	11.2
SD							0.4	0.3	0.1	0.4	0.3
Mirounga leonina	Hair	2010/12/30	GW160	F	Adult	4	-19.2	11.6	3.6	-20.7	11.0
Mirounga leonina	Hair	2011/01/25	GW283	F	Adult	4	-20.1	11.5	3.6	-21.6	10.9
Mirounga leonina	Hair	2011/01/14	RR364	F	Adult	6	-18.3	11.1	3.6	-19.9	10.5
Mirounga leonina	Hair	2011/01/13	WW061	F	Adult	10	-18.7	12.6	3.6	-20.2	12.0
Mirounga leonina	Hair	2011/01/14	WB103	F	Adult	16	-18.1	11.7	3.5	-19.6	11.1
n = 5											
Mean							-18.9	11.7	3.6	-20.4	11.1
SD							0.8	0.6	0.0	0.8	0.6
Mirounga leonina	Hair	2013/03/25	PP129	M	Adult	7	-16.8	13.5	3.6	-18.3	12.9
Mirounga leonina	Hair	2011/04/07	WW185	M	Adult	10	-19.6	12.4	3.6	-21.1	11.8
Mirounga leonina	Hair	2013/02/24	OO016	M	Adult	11	-18.3	12.8	3.6	-19.8	12.2
Mirounga leonina	Hair	2011/02/13	PO225	M	Adult	12	-18.1	13.7	3.5	-19.6	13.1
Mirounga leonina	Hair	2013/02/26	GG045	M	Adult	13	-18.6	13.9	3.7	-20.1	13.3
n = 5											
Mean							-18.3	13.3	3.59	-19.8	12.7
SD							1.0	0.6	0.07	1.0	0.6

Table S3. $\delta^{13}C$ and $\delta^{15}N$ values (‰) of white muscle collected from Patagonian toothfish caught near Marion Island. C:N is the atomic carbon:nitrogen ratio.

Sample	Not lipid extracted			Lipid extracted		
	$\delta^{13}C$	$\delta^{15}N$	C:N	$\delta^{13}C$	$\delta^{15}N$	C:N
PTF01	-19.9	13.7	4.7	-18.8	15.3	4.0
PTF02	-21.0	11.8	4.9	-20.7	12.3	4.0
PTF03	-21.9	12.6	6.1	-20.4	12.4	3.9
PTF04	-21.8	12.5	6.2	-20.3	13.9	3.9
PTF05	-22.6	12.8	5.3	-19.8	14.1	3.8
PTF06	-22.2	13.4	6.2	-20.3	14.0	4.1
PTF07	-23.2	12.5	7.8	-20.2	11.7	4.0
PTF08	-23.7	12.0	9.5	-20.6	12.2	3.9
PTF09	-22.0	12.9	6.4	-20.1	13.6	4.0
PTF10	-23.0	13.2	6.8	-21.1	13.8	4.1
n = 10						
Mean	-22.1	12.7	6.4	-20.2	13.3	4.0
SD	1.1	0.6	1.4	0.6	1.1	0.1

Table S4. Mean δ differences among prey groups (‰). $\delta^{13}C$ is shown below the diagonal, $\delta^{15}N$ above. Cells are shaded by *p*-values from multiple comparisons using Tukey's Honest Significant Differences. Prey abbreviations: PT – Patagonian toothfish; KP – king penguin; MP – macaroni penguin; RP – rockhopper penguin; SES – southern elephant seal (UY – underyearling, Y – yearling, SA – subadult, AF – adult female, AM – adult male); SFS – Subantarctic fur seal. Published Antarctic fur seal mean ± SD values (Walters 2014) are not included.

	PT	KP	MP	RP	SES UY	SES Y	SES SA	SES AF	SES AM	SFS
PT	-	2.2	3.5	4.2	0.8	1.4	1.6	1.6	0.1	0.6
KP	2.1	-	1.3	2.0	1.4	0.8	0.6	0.6	2.1	1.6
MP	2.3	0.2	-	0.7	2.7	2.1	2.0	1.9	3.4	2.9
RP	2.4	0.3	0.1	-	3.4	2.8	2.7	2.6	4.1	3.6
SES UY	1.3	0.8	1.0	1.1	-	0.6	0.7	0.8	0.7	0.2
SES Y	0.9	1.2	1.4	1.5	0.3	-	0.1	0.2	1.4	0.8
SES SA	0.3	1.7	1.9	2.0	0.9	0.6	-	0.1	1.5	0.9
SES AF	0.2	1.9	2.1	2.2	1.1	0.8	0.2	-	1.5	1.0
SES AM	0.4	2.5	2.7	2.8	1.7	1.3	0.8	0.6	-	0.5
SFS	0.3	1.8	2.0	2.1	1.0	0.6	0.1	0.1	0.7	-

p-values:

<0.001

<0.01

<0.05

Table S5. Mean skin $\delta^{15}N_{NLE}$ differences among killer whale social units. Cells are shaded by p-values from multiple comparisons using Tukey's Honest Significant Differences. U – unknown individuals.

	A	B	C	D	E	F	G	H	U	U
A		0.5	0.3	0.9	0.1	0.4	1.3	0.2	0.1	0.1
B			0.8	0.4	0.6	0.9	0.8	0.7	0.6	0.4
C				1.2	0.2	0.1	1.6	0.1	0.2	0.4
D					1	1.4	0.3	1.2	1.1	0.9
E						0.3	1.4	0.1	0	0.2
F							1.7	0.2	0.3	0.5
G								1.5	1.4	1.2
H									0.1	0.3
U										0.2
U										

p-values:

<0.001

<0.01

<0.05

Supplementary figure

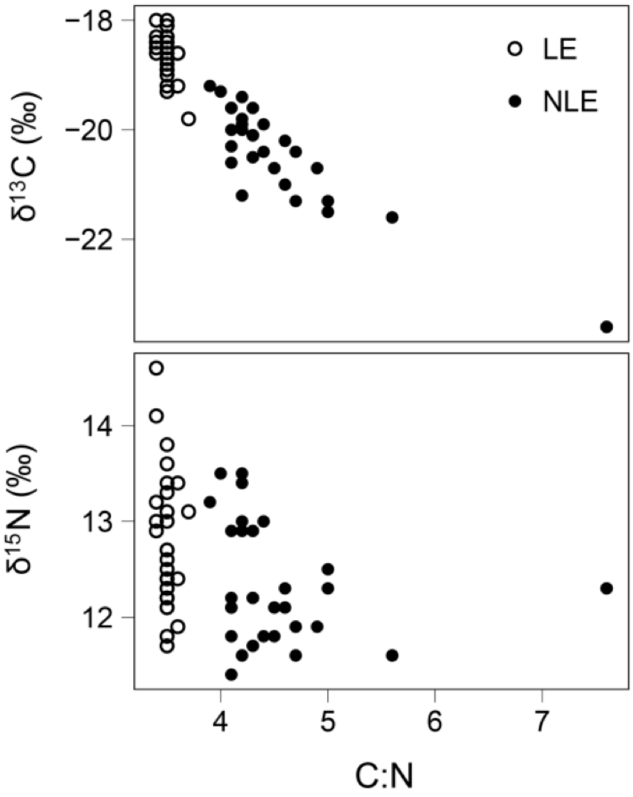

Figure S1. $\delta^{13}C$ and $\delta^{15}N$ values of lipid extracted (LE; open circles) and non lipid extracted (NLE; filled circles) killer whale skin, plotted against atomic C:N ratio.

LITERATURE CITED

Adams NJ, Klages NT (1987) Seasonal variation in the diet of the king penguin (*Aptenodytes patagonicus*) at sub-Antarctic Marion Island. J Zool 212:303–324

Bailleul F, Authier M, Ducatez S, Roquet F, Charrassin JB, Cherel Y, Guinet C (2010) Looking at the unseen: combining animal bio-logging and stable isotopes to reveal a shift in the ecological niche of a deep diving predator. Ecography 33:709–719

Boecklen WJ, Yarnes CT, Cook BA, James AC (2011) On the use of stable isotopes in trophic ecology. Annu Rev Ecol Evol Syst 42:411–440

Bester MN, de Bruyn PJN, Oosthuizen WC, Tosh CA, McIntyre T, Reisinger RR, Postma M, van der Merwe D, Wege M (2011) The Marine Mammal Programme at the Prince Edward Islands: 38 years of research. African J Mar Sci 33:511–521

Brown CR, Klages NT (1987) Seasonal and annual variation in diets of Macaroni (*Eudyptes chrysolophus chrysolophus*) and Southern rockhopper (*E. chrysocome chrysocome*) penguins at sub-Antarctic Marion Island. J Zool 212:7–28

Chaigne A, Authier M, Richard P, Cherel Y, Guinet C (2012) Shift in foraging grounds and diet broadening during ontogeny in southern elephant seals from Kerguelen Islands. Mar Biol 160:977–986

Cherel Y, Ducatez S, Fontaine C, Richard P, Guinet C (2008) Stable isotopes reveal the trophic position and mesopelagic fish diet of female southern elephant seals breeding on the Kerguelen Islands. Mar Ecol Prog Ser 370:239–247

Cherel Y, Hobson KA (2005) Stable isotopes, beaks and predators: a new tool to study the trophic ecology of cephalopods, including giant and colossal squids. Proc Biol Sci 272:1601–7

Collins MA, Brickle P, Brown J, Belchier M (2010) The Patagonian toothfish: biology, ecology and fishery. Adv Mar Biol 58:227–300

Crawford RJM, Cooper J, Dyer BM (2003) Population of the macaroni penguin *Eudyptes chrysolophus* at Marion Island, 1994/95–2002/03, with information on breeding and diet. African J Mar Sci 25:475–486

Dalerum F, Angerbjörn A (2005) Resolving temporal variation in vertebrate diets using naturally occurring stable isotopes. Oecologia 144:647–58

Daneri GA, Carlini AR, Rodhouse PGK (2004) Cephalopod diet of the southern elephant seal, *Mirounga leonina*, at King George Island, South Shetland Islands. Antarct Sci 12:76–79

De Bruyn PJN, Tosh CA, Oosthuizen WC, Bester MN, Arnould JPY (2009) Bathymetry and frontal system interactions influence seasonal foraging movements of lactating subantarctic fur seals from Marion Island. Mar Ecol Prog Ser 394:263–276

De Bruyn PJN, Tosh CA, Oosthuizen WC, Phalanndwa MV, Bester MN (2008) Temporary marking of unweaned southern elephant seal (*Mirounga leonina* L.) pups. South African J Wildl Res 38:133–137

Field IC, Bradshaw CJA, van den Hoff J, Burton HR, Hindell MA (2006) Age-related shifts in the diet composition of southern elephant seals expand overall foraging niche. Mar Biol 150:1441–1452

Green K, Burton HR (1993) Comparision of the stomach contents of southern elephant seals, *Mirounga leonina*, at Macquarie and Heard Islands. Mar Mammal Sci 9:10–22

Guerreiro M, Phillips R, Cherel Y, Ceia F, Alvito P, Rosa R, Xavier J (2015) Habitat and trophic ecology of Southern Ocean cephalopods from stable isotope analyses. Mar Ecol Prog Ser 530:119–134

Hückstädt LA, Koch PL, McDonald BI, Goebel ME, Crocker DE, Costa DP (2012) Stable isotope analyses reveal individual variability in the trophic ecology of a top marine predator, the southern elephant seal. Oecologia 169:395–406

Lewis R, O'Connell TC, Lewis M, Campagna C, Hoelzel AR (2006) Sex-specific foraging strategies and resource partitioning in the southern elephant seal (*Mirounga leonina*). Proc R Soc B Biol Sci 273:2901–2907

Ling JK (2012) The skin and hair of the southern elephant seal, *Mirounga leonina* (Linn.). IV. Annual cycle of pelage follicle activity and moult. Aus J Zool 60:259–271.

Logan JM, Jardine TD, Miller TJ, Bunn SE, Cunjak RA, Lutcavage ME (2008) Lipid corrections in carbon and nitrogen stable isotope analyses: comparison of chemical extraction and modelling methods. J Anim Ecol 77:838–46

Makhado AB, Bester MN, Kirkman SP, Pistorius PA, Ferguson JWH, Klages NTW (2008) Prey of the Antarctic fur seal *Arctocephalus gazella* at Marion Island. Polar Biol 31:575–581

Makhado AB, Bester MN, Somhlaba S, Crawford RJM (2013) The diet of the subantarctic fur seal *Arctocephalus tropicalis* at Marion Island. Polar Biol 36:1609–1617

Pakhomov EA, Bushula T, Kaehler S, Watkins BP, Leslie RW (2006) Structure and distribution of the slope fish community in the vicinity of the sub-Antarctic Prince Edward Archipelago. J Fish Biol 68:1834–1866

Van den Hoff J (2004) A comparative study of the cephalopod prey of Patagonian toothfish (Dissostichus eleginoides) and southern elephant seals (*Mirounga leonina*) near Macquarie Island. Polar Biol 27:604–612

Van den Hoff J, Burton H, Davies R (2003) Diet of male southern elephant seals (*Mirounga leonina* L.) hauled out at Vincennes Bay , East Antarctica. Polar Biol 26:27–31

Walters A (2014) Quantifying the trophic linkage of Antarctic marine predators. PhD thesis, University of Tasmania, Hobart

Wege M (2103) Maternal foraging behaviour of subantarctic fur seals from Marion Island. MSc thesis, University of Pretoria, Pretoria, 154 pp.