

Proximate composition and energy density of nototheniid and myctophid fish in McMurdo Sound and the Ross Sea, Antarctica

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Received: 18 August 2011 / Revised: 25 September 2011 / Accepted: 11 October 2011 / Published online: 11 November 2011
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Abstract Nototheniid and myctophid fish are primary prey for marine piscivores, yet little is known about their nutritional value. In this study, we characterized the proximate composition [PC: water, fat (neutral lipids), crude protein (CP) and ash] and energy density (ED; kJ g^{-1}) of fifteen fish species from McMurdo Sound and the Ross Sea, Antarctica. We assayed the entire fish for all species except for the large Antarctic toothfish, *Dissostichus mawsoni* (muscle tissue only). On a wet mass basis (WM), fish were variable in composition: moisture content ranged from 64.9 to 87.3% WM, fat from 0.5 to 17.4% WM, CP from 7.7 to 16.7% WM, ash from 11.2 to 21.0% FFDM (fat-free dry mass), and ED from 2.9 to 10.3 kJ g^{-1} . Myctophids and pelagic nototheniids such as *Pleuragramma antarcticum* and *D. mawsoni* were high in fat content (7–17% WM), while a bathylagid and benthic nototheniids including most *Trematomus* spp. and *Lepidonotothen squamifrons* were low in fat (0.5–4% WM). The epibenthic *Trematomus* species (*T. eulepidotus* and *T. lepidorhinus*) were intermediate. Energy density tracked fat content, with highest values in myctophids and pelagic nototheniids. The variation in nutrient and energy density confirms that prey composition must be taken into account when modelling energy and nutrient fluxes within the Antarctic ecosystem. Further

analyses of prey collected over a number of different locations and seasons are needed in order to determine how the nutritional value of certain species might affect annual or decadal variation in reproductive success or population size of top predators.

Keywords *Dissostichus mawsoni* · Proximate composition · Nototheniid · Diet · Ross Sea · Weddell seal

Introduction

Compared with temperate and tropical regions, piscivores in the Southern Ocean have access to relatively low prey species diversity. Benthic fish species, and especially those of the perciform suborder Notothenioidei, predominate in the fish fauna of the Antarctic continental shelf and upper slope (Eastman 2005). In the Ross Sea, notothenioids account for 76% of fish species diversity, 91% of species abundance and 92% of biomass, respectively (Eastman and Hubold 1999). Notothenioids are the most important food source for marine birds and mammals foraging on the continental shelf (La Mesa et al. 2004; Smith et al. 2007). Among notothenioids, the family Nototheniidae is particularly speciose, with many benthic as well as benthopelagic or pelagic (e.g., silversides, *Pleuragramma antarcticum*; subadult and adult Antarctic toothfish, *Dissostichus mawsoni*) and cryopelagic (bald notothen or “borchs”, *Pagothenia borchgrevinki*) species. In the Ross Sea, seals, birds and whales feed heavily on nototheniids, and a single species, *P. antarcticum*, can contribute a substantial portion to their diet (Ainley et al. 1984, 1998; Burns et al. 1998; Cherel and Kooyman 1998; Ichii et al. 1998; Lauriano et al. 2007). For example, some studies suggest that Weddell seals

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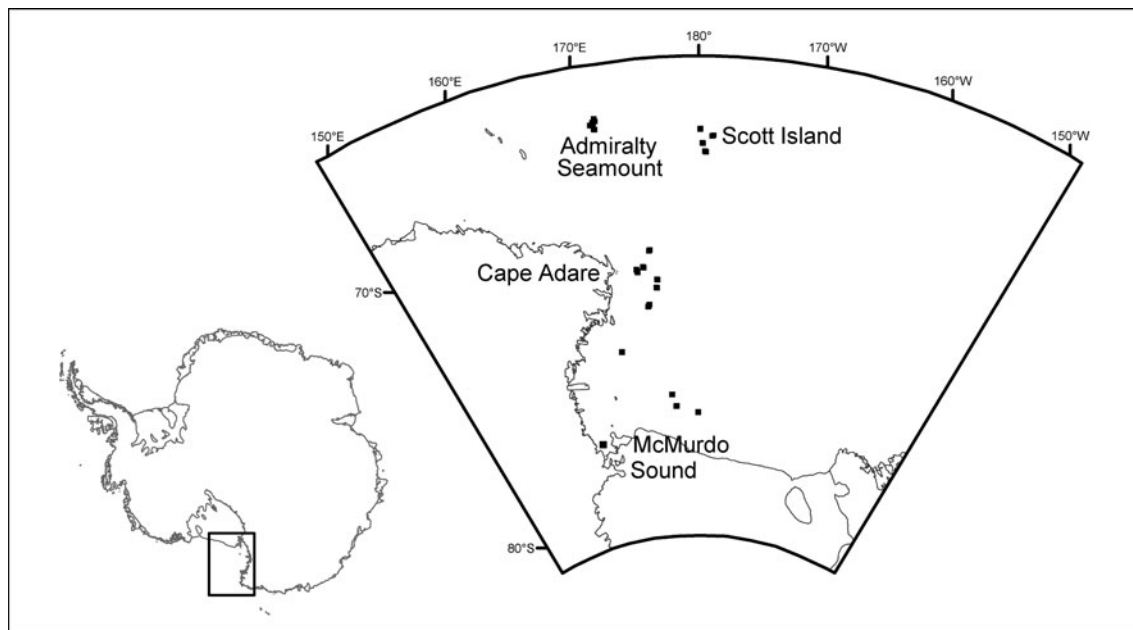


Fig. 1 Map showing the locations (black dots) of fish collected in the Ross Sea and McMurdo Sound

(*Leptonychotes weddellii*) in the Ross Sea feed predominantly on *P. antarcticum*, while others indicate greater diversity or emphasize the potential importance of other prey such as cephalopods and in particular the large Antarctic toothfish, *D. mawsoni* (Dearborn 1965; Calhaem and Christoffel 1969; Burns et al. 1998; Ainley and Siniff 2009).

Given the nutritional importance of notothenioids in seabird and marine mammal diets, surprisingly little information is available on the nutrient composition of these fish. Lipid content of notothenioid tissues has been examined with regard to fish feeding ecology and buoyancy (Friedrich and Hagen 1994; Hagen et al. 2000) but it is whole-body lipid content that is important to piscivores that consume entire prey. As part of a study of the nutrition and reproductive energetics of Weddell seals, we had opportunity to obtain a wide array of fish species from within McMurdo Sound and from the Ross Sea, including benthic, pelagic and cryopelagic notothenioids (Nototheniidae), as well as lanternfishes (Myctophidae) and a deepsea smelt (Bathylagidae). In this study, we present data on the proximate composition [PC: water, fat (neutral lipids), crude protein (CP) and ash] and energy density (ED; kJ g^{-1}) of these fish to address the current knowledge gap about prey composition.

Materials and methods

Fish from various locations within McMurdo Sound were captured during the austral spring (October–December) in 2006 and 2007 during research projects of Dr. Gretchen

Hofmann (University of California at Santa Barbara, CA), Dr. Art DeVries (University of Illinois, Urbana-Champaign, IL), and Dr. Victoria Metcalf (Lincoln University, Christchurch, New Zealand) (Fig. 1). Fish were caught using hook and line and snap-frozen whole in liquid nitrogen. Dr. Matt Pinkerton (National Institute of Water and Atmospheric Research, Wellington, New Zealand) provided samples collected during New Zealand's IPY—Census of Antarctic Marine Life (CAML) survey in the Ross Sea (between 65° – 75° S and 170° E– 175° W; Fig. 1) aboard the RV *Tangaroa* in the summer (February–March) of 2008. For details of collection procedures, see Hanchet (2008). All samples were collected in accordance with relevant collection and animal ethics permits issued to the collector in each instance. All samples were of whole fish except *D. mawsoni*, for which we were provided a sample of dorsal trunk musculature dissected posterior to the pectoral fins. We considered this an appropriate sample for this prey species as Weddell seals do not consume the entire fish but rather remove and consume muscle and viscera (Ainley and Siniff 2009).

In the laboratory, frozen specimens were partially thawed, blotted dry and weighed to the nearest 0.1 g to determine wet mass (WM); total length (TL) was measured to the nearest 0.1 cm (Table 1). Fish of <100 g WM were pooled ($n = 2$ –30 fish, depending on prey size) to obtain sufficient mass for all analyses reported herein and biomarker and trace element data to be published elsewhere. While still partially frozen, individuals or pooled specimens were homogenized whole (or after being cut into small

Table 1 Proximate composition (% moisture, fat, crude protein, ash) and energy density (ED) of fish species collected from McMurdo Sound (MS) and the Ross Sea (RS). Fish were assayed individually (I) or as pooled samples (P)

Species	n	Method	Collection area	Length (cm)	Mass (g)	Water (% WM)	Fat (%WM)	Crude protein (%WM)	Ash (%FFDM)	ED (kJ g ⁻¹ WM)
Nototheniidae										
<i>Dissostichus mawsoni</i> ^a	1	I ^a	MS	NA	983.2	68.6	15.1	15.4	–	9.4
<i>Lepidotothen squamifrons</i>	5	P	RS	22.4 ± 31.7	291.0 ± 102.0	81.3	2.3	10.5	15.8	4.0
<i>Pagothenia borchgrevinki</i> 2006	2	P	MS	18.2 ± 0.3	88.7 ± 0.1	77.2	5.6	16.4	12.8	5.6
<i>Pagothenia borchgrevinki</i> 2006	4	I	MS	20.5 ± 2.6	125 ± 24.9	77.6 ± 3.1	4.8 ± 3.2	14.9 ± 2.4	13.1 ± 0.3	5.3 ± 1.3
<i>Pagothenia borchgrevinki</i> 2007	4	I	MS	23.5 ± 2.7	162.6 ± 18.1	76.0 ± 2.5	5.2 ± 2.9	13.9 ± 1.8	11.2 ± 0.1	5.7 ± 1.1
<i>Pleuragramma antarcticum</i>	15	P	RS	13.4 ± 2.1	23.7 ± 15.2	82.1	7.2	8.3	13.1	5.0
<i>Trematomus bernacchii</i> 2006	6	P	MS	14.6 ± 1.8	48.7 ± 6.1	78.3	2.9	14.5	14.4	4.7
<i>Trematomus bernacchii</i> 2007	7	P	MS	16.4 ± 2.5	77.1 ± 53.4	77.4	2.8	16.7	13.6	5.0
<i>Trematomus bernacchii</i> 2007	4	I	MS	18.9 ± 2.2	114.7 ± 23.3	76.2 ± 3.0	4.1 ± 3.3	15.2 ± 3.4	14.2 ± 0.3	5.5 ± 1.3
<i>Trematomus eulepidotus</i>	5	P	RS	19.6 ± 3.1	121.8 ± 59.9	75.6	4.6	15.1	12.1	5.7
<i>Trematomus hansonii</i>	7	I	MS	21.1 ± 26.2	148.0 ± 53.2	76.7 ± 2.0	3.7 ± 2.5	15.4 ± 1.5	12.8 ± 0.1	5.4 ± 0.9
<i>Trematomus lepidorhinus</i>	5	P	RS	27.4 ± 5.6	217.0 ± 102.4	71.3	9.4	15.1	12.4	7.7
<i>Trematomus pennelli</i>	2	P	MS	14.1 ± 1.6	46.1 ± 4.4	78.3	2.6	14.2	15.7	4.6
<i>Trematomus scotti</i>	5	P	RS	12.9 ± 0.7	13.4 ± 2.1	78.5	0.5	14.8	22.0	4.0
Myctophidae										
<i>Electrona antarctica</i>	30	P	RS	8.1 ± 1.0	7.4 ± 2.5	69.6	15.2	12.2	15.8	9.0
<i>Electrona carlsbergi</i>	15	P	RS	7.2 ± 0.6	5.5 ± 1.6	73.9	7.6	13.9	15.1	6.1
<i>Gymnoscopelus braueri</i>	5	P	RS	10.1 ± 0.7	9.0 ± 1.9	68.5	14.9	13.7	15.7	9.3
<i>Gymnoscopelus nicholsi</i>	5	P	RS	14.9 ± 0.7	37.0 ± 3.4	64.9	17.4	14.3	12.4	10.3
Bathylagidae										
<i>Bathylagus antarcticus</i>	5	P	RS	15.1 ± 2.0	38.6 ± 18.2	87.3	2.6	7.7	16.8	2.9

Values are mean ± SEM, expressed on the basis of wet mass (% WM). Ash was calculated as a proportion of fat-free dry mass (% FFDM)

^a Values are for a fillet of white muscle

pieces) with distilled water (added 1:1 m/m) in a commercial food blender (model MX1000, Waring Commercial, Torrington, CT, USA). The wet homogenate was subsampled into aluminum pans, dried overnight in a forced convection oven at 56°C and ground using an electric kitchen grinder to a uniform consistency before being subsampled for all subsequent assays. The blender and grinder were cleaned and dried between samples.

Pooled and individual species were analyzed in triplicate for each assay. *Water* content was determined by mass loss when separate 1-g subsamples of wet homogenate were dried overnight in a forced convection oven at 56°C, and then for a further 2 h at 100°C. *Fat* or neutral lipid was determined by overnight extraction (ca. 16–18 h) of 1.0 g dried, ground homogenate using petroleum ether in a Soxhlet fat extraction apparatus. *Crude protein* content [total nitrogen (TN) \times 6.25] was determined by both CHN gas analysis and macro-Kjeldahl methods. For CHN gas analysis, 3–5 mg dried homogenate was dried at 56°C overnight and combusted at 950°C in a CHN elemental gas analyzer (Model 2400, series 2, Perkin Elmer Co., Norwalk, CT, USA.) with supplemental oxygen boosts of 2 s. To validate the CHN method, a subset of samples ($n = 23$ of 34 samples) was also assayed using a conventional macro-Kjeldahl method. Subsamples of dried, ground homogenate (0.5–0.7 g) were digested with 30 ml concentrated sulfuric acid (H_2SO_4) and catalyst (FisherTab™ CT-50 Kjeldahl tablets); the digests were rendered basic with sodium hydroxide (NaOH) and steam-distilled. Ammonia in distillates was titrated with hydrochloric acid (0.1 M HCl) to determine total nitrogen content of the sample. *Ash* was determined by combusting 0.5–1.0 g dried homogenate in porcelain crucibles in a muffle furnace (model FA17301, Thermolyne Sybron Corp, Dubuque, IA, USA). Temperatures were ramped up slowly from 100°C to 400°C, and then set at 550°C for 5 h. *Gross energy* density was determined for 0.4–0.6 g dried homogenate using an adiabatic bomb calorimeter (Model 1241, Parr Instruments, Moline, IL, USA) calibrated with pre-weighed benzoic acid tablets. Corrections were made for the energy equivalents of fuse wire combustion and acid production. Percent fat, CP, and ED are expressed per unit wet mass (% WM) unless otherwise stated. Ash is expressed as a proportion of fat-free dry mass (% FFDM).

Interspecies statistical comparisons of PC and ED were limited to three fish species, which were analyzed individually (*Trematomus hansonii* collected in 2007, *Trematomus bernacchii* in 2007 and *P. borchgrevinkii* in 2006 and 2007). A generalized linear mixed effects model was used to detect differences in PC and ED using the statistical package ‘R’ (version 2.10.1), using Tukey’s test for *post ex facto* comparison ($\alpha = 0.05$) between groups.

Results

Within-sample coefficients of variation for the analyses were as follows ($n = 34$): moisture ($0.5 \pm 0.7\%$, range 0.1–3.6%), fat ($0.8 \pm 0.9\%$, range 0.03–3.1%), CP (2.0 ± 2.3 , range 0.2–5.8%), ash (0.8 ± 0.5 , range 0.1–2.8%) and ED (0.5 ± 0.6 , range 0.1–3.3%).

Compositional data were obtained for 15 fish species from three families, including six species of *Trematomus*, single species of four other nototheniid genera, four species in two genera of myctophids, and a bathylagid (Table 1). The nototheniids were equally divided between McMurdo Sound and the open Ross Sea; the myctophids and bathylagid were collected near the Admiralty Seamounts, abyssal plain and Scott Seamounts in the Ross Sea.

Data were obtained from both pooled and individually analyzed fish, with the latter representing a larger size class (individual mass >100 g). No compositional differences were apparent between the pooled or individually analyzed fish on a wet or dry mass basis in those species for which this could be compared (Table 1). Interspecies statistical comparisons of *T. hansonii*, *T. bernacchii* and *P. borchgrevinkii* from McMurdo Sound showed that they did not differ in fat ($P = 0.630$), CP ($P = 0.277$) or ED ($P = 0.987$), but there were significant differences in ash content expressed as a proportion of FFDM ($F_{2,19} = 11.2$, $P < 0.001$). *T. bernacchii* had a significantly higher ash content (14.2% FFDM) than *P. borchgrevinkii* (12.6% FFDM, $P < 0.001$) and *T. hansonii* (12.8% FFDM, $P = 0.015$).

Moisture content of whole fish was variable, ranging from a low of 64.9% WM (*Gymnoscopelus nicholsii*) to 87.3% WM (*Bathylagus antarcticus*, Table 1). Fat content was also variable, ranging from 0.5% WM (*Trematomus scottii*) to 17.4% WM (*Gymnoscopelus braueri*). Myctophids were particularly high in fat, while benthic *Trematomus* spp. were low in fat. Among nototheniids, *Trematomus lepidorhinus* and *D. mawsonii* muscle had particularly high fat contents. Our sample of *D. mawsonii* consisted of 900 g of white muscle from the only toothfish caught in McMurdo Sound in 2007 (A. DeVries, personal communication). Among the nototheniids from McMurdo Sound, the sample of *D. mawsonii* muscle was highest in fat (15.1% WM) while *Trematomus pennellii* was lowest in fat content (2.6% WM).

Total nitrogen content estimated for the same samples by CHN and macro-Kjeldahl methods did not differ (paired *t* test: $t = 2.07$, $P = 0.766$, $df = 22$); we report CP results from our larger CHN dataset. CP content was relatively low for *P. antarcticum* (8.3% WM) and *B. antarcticus* (7.7% WM) while benthic *Trematomus* species (e.g., *T. bernacchii*) were high in CP (Table 1). Among the nototheniids, pooled *T. bernacchii* from 2007 was highest in CP. Ash content (% FFDM) was high in myctophids and the benthic

T. scotti, and low for pelagic species such as *P. antarcticum*. Among nototheniids, the epibenthic species *Trematomus eulepidotus* and *T. lepidorhinus* were lowest in ash content on a FFDM basis (Table 1).

ED of whole fish varied more than threefold, from 2.9 kJ g⁻¹ WM (*B. antarcticus*) to 10.3 kJ g⁻¹ WM (*G. nicholsi*). Fat content was the primary determinant of energy content and explained 90% of variation of ED between samples (Pearson correlation $r = 0.96$, $P < 0.001$). Myctophids were high in ED, as was *D. mawsoni* muscle. Among the nototheniids caught in McMurdo Sound, *T. pennellii* was lowest in ED (4.6 kJ g⁻¹, Table 1).

Discussion

This research provides important new information about the nutritional value of a range of known and potential prey species available to marine piscivores in McMurdo Sound and the Ross Sea. As we only obtained fish from the austral spring (McMurdo Sound) and austral summer (Ross Sea), our data provide a snapshot of nutrient composition at these times; it is not known whether any of these species undergo changes in fat and energy content in response to seasonal changes in productivity or as a function of reproductive effort or migratory pattern. One limitation is that pooled samples may disguise variation among individual fish associated with sex, reproductive status, body condition, age and body size. Tierney et al. (2002) found that smaller individuals tended to have higher energy content while other studies report the opposite (Van de Putte et al. 2010). Lawson et al. (1998) found that energy density differed with size in some (e.g., halibut) but not all (e.g., Atlantic cod) species in the Northwest Atlantic. Despite two to threefold differences in mass of individual fish for two species (bald notothen, *P. borchgrevinki*, and emerald notothen, *T. bernacchii*) for which we had both individual and pooled results, there was no apparent difference in energy density (Table 1).

Our results represent the first broad study of the nutrient composition and energy density of fish in the Ross Sea. Published data are available on the water, lipid and/or energy contents of the four myctophids of the genera *Electrona* and *Gymnoscopelus* at other locations: Bird Island (Clarke and Prince 1980), Croker Passage (Reinhardt and Van Vleet 1986), Kerguelen Plateau (Lea et al. 2002b; Connan et al. 2010), Macquarie Ridge (Lea et al. 2002b; Tierney et al. 2002), the Lazarev Sea (Van de Putte et al. 2006) and the Cosmonaut Sea (Van de Putte et al. 2010). These studies agree with our findings (for fish of similar size class) in that these myctophids are high in fat (12–19% vs. 8–17% WM in our study) and energy (7–13 kJ g⁻¹ vs. 6–10 kJ g⁻¹ WM), although Tierney et al. (2002) reported a

somewhat lower energy density (5.4 kJ g⁻¹) for *E. carlsbergi* at Macquarie Ridge. Other myctophid species in the Southern Ocean also have high fat and energy contents, with the possible exception of *Protomyctophium* spp. that contain 4–10% WM fat and 4–7 kJ g⁻¹ (Donnelly et al. 1990; Lea et al. 2002b; Tierney et al. 2002; Connan et al. 2010). In general, myctophids are lipid- and energy-rich prey, due to accumulation of triacylglycerols (e.g., *E. carlsbergi*, *G. nicholsi*) or wax esters (e.g., *E. antarcticus*, *G. braueri*) (Phleger et al. 1997, 1999; Connan et al. 2010). It is not known if myctophid species high in wax esters are more difficult to digest (Place 1992), although some seabirds and whales appear to have compensatory mechanisms to allow wax ester utilization (Place 1992; Nordoy 1995).

Unfortunately there is little published data on nototheniids. Lipid content of *P. antarcticum* is reported as 10.4% WM and 38–48% DM in the Weddell/Lazarev Sea and Croker Passage (Reinhardt and Van Vleet 1986; Friedrich and Hagen 1994; Hagen et al. 2000) as compared to our values of 7.2% WM and 41.6% DM. This species has an energy density of 26 kJ g⁻¹ dry mass in the Cosmonaut Sea (Van de Putte et al. 2010); we measured 28 kJ g⁻¹. In the Weddell/Lazarev Sea *T. lepidorhinus* has been found to contain 5.2% lipid on a WM basis and 21–23% lipid on a DM basis (Friedrich and Hagen 1994; Hagen et al. 2000), compared to 9.4 and 32.9% in this study. The single *D. mawsoni* muscle fillet that we analyzed was high in lipid and energy (Table 1), presumably due to deposition of triacylglycerols; nototheniids do not deposit wax esters in significant amounts (Eastman 1985b, 1993). The fat content reported here is within the range (6.6–23.0% WM) reported by Clarke et al. (1984) for white muscle of *D. mawsoni* caught in McMurdo Sound.

The bathylagid *B. antarcticus* has been reported to contain as little as 0.9% WM lipid in one study (Donnelly et al. 1990), but we found more than twice this amount (2.6% WM, equivalent to 21% DM). Reinhardt and Van Vleet (1986) reported 23% DM lipid in this species. The energy density of *B. antarcticus* has been reported as 2.9–3.9 kJ g⁻¹ WM (Tierney et al. 2002; Van de Putte et al. 2006), similar to our measurement of 3.0 kJ g⁻¹ WM. Thus, available published data are in reasonable agreement with our results for fish similar in length, although the comparisons are confounded by differences in analytical methodology. We assayed neutral lipids by ether extraction, whereas other investigators have typically used modified Bligh and Dyer and Folch procedures. Both methods extract polar lipids in addition to neutral lipids, but do not necessarily achieve complete extraction, especially at high lipid concentrations (Iverson et al. 2001).

Our results suggest an effect of both phylogeny and life history on fish proximate composition in the Antarctic. On the one hand, myctophids were high in fat and energy both

in our study and in prior reports from the Southern Ocean. Myctophids are also high in fat and energy in the subarctic Pacific, but not in the tropical Pacific (Seo et al. 1996; Saito and Murata 1998). Nototheniids were much more variable in composition, which may relate to habitat use. Benthic species examined in this study (*Lepidonotothen squamifrons*, *T. bernacchii*, *T. hansonii*, *T. pennellii*, and *T. scotti*) had particularly low lipid (0.5–4.1% WM) and energy densities (4.0–5.5 kJ g⁻¹ WM) among the nototheniids that were analyzed (Table 1). This is not surprising, given that benthic species should have negative buoyancy and fat causes an increase in buoyancy. Benthic nototheniids typically have a higher proportion of body mass as skeleton which is high in ash (Eastman 1993) and whole-body ash was high (14–21% FFDM) in the benthic species we examined. *Trematomus* species also tend to be generalist predators that feed mainly on low-energy benthic organisms (Montgomery et al. 1993; Vacchi et al. 1994), and thus their fat intake may be limited.

Notothenioids radiated from a benthic habitat when invading Antarctic waters, which accounts for their lack of swim bladders, even in pelagic nototheniid species such as silversides, *P. antarcticum*, and Antarctic toothfish, *D. mawsoni* (Eastman 1993, 2005). These species are thought to achieve near neutral buoyancy by various morphological features, including accumulation of lipids in tissues (Eastman 1985b). High lipid accumulation is apparent in *D. mawsoni* (Table 1; Clarke et al. 1984) and to a lesser extent in *P. antarcticum* (Table 1) which has subcutaneous lipid sacs along the sides of the body (Eastman 1985b). The cryopelagic *P. borchgrevinkii* that associates with the underside of sea ice is not particularly high in lipids (4.8–5.6% WM), but it is considered more buoyant than benthic notothenioids (Eastman and DeVries 1982, Eastman 1985b). It is intriguing that *T. lepidorhinus* contained 9.4% lipids on a wet mass basis. This is consistent with evidence that *T. lepidorhinus* feeds away from the bottom, especially on pelagic amphipods (DeWitt et al. 1990), and thus may need to be more buoyant than other strictly benthic *Trematomus* species. However, Friedrich and Hagen (1994) and Hagen et al. (2000) reported somewhat lower lipid levels for this species.

High lipid, high energy foods may be beneficial to seabirds and marine mammals, especially when recovering from periods of fasting or during reproduction (Boness and Bowen 1996). For large predators, *D. mawsoni* appears to be the highest quality fish prey item by virtue of its large size and high energy content, and is consumed both by Weddell seals and some killer whales, *Orcinus orca* (Calhaem and Christoffel 1969; Lauriano et al. 2007; Ainley and Siniff 2009). Although subadult and adult toothfish are too large for avian and many other predators, the smaller *P. antarcticum* is both abundant and relatively rich

in lipids compared with other nototheniids. *P. antarcticum* occupies a critical role in the food web of the Ross Sea. It is the main fish prey for emperor and Adélie penguins (Ainley et al. 1998; Cherel and Kooyman 1998) as well seabirds (Ainley et al. 1984). It is thought to be predominant in the diet of Weddell seals and is also a major food source for toothfish (Eastman 1985a). The predominance of *P. antarcticum* in predator diets is undoubtedly related to its abundance (DeWitt 1970) and occurrence as a clustered resource, as *P. antarcticum* is a schooling fish (Fuiman et al. 2002). A large number of individuals of this species ($n > 200$) may be consumed by individual Weddell seals in a single feeding bout (Plötz et al. 2001).

The combination of low-energy content, small-medium body size and scattered distribution in solitary or small aggregations (Bill Davison, University of Canterbury, personal communication) implies that benthic *Trematomus* species may not be optimal prey resources for avian or mammalian piscivores in the Ross Sea, even though *Trematomus* remains have been found in stomach and/or scat samples from Weddell seals (Burns et al. 1998) and emperor penguins (Cherel and Kooyman 1998), and may represent a significant component to Weddell seal diets in the Weddell Sea at least in some years (Plötz et al. 1991). By contrast, the high lipid and energy content of myctophids suggest that these fish could have greater dietary importance in the Ross Sea than currently recognized. However, diet data for marine piscivores is limited outside of McMurdo Sound and myctophids are mesopelagic in waters of the continental slope and beyond (Eastman and Hubold 1999). Certainly, myctophid species are an important diet component for Weddell seals inhabiting sub-Antarctic islands (Casaux et al. 1997, 2006) as well as for southern elephant seals (Cherel et al. 2008), Antarctic fur seals (Green et al. 1991; Lea et al. 2002a; Staniland et al. 2010), penguins (Hindell 1989; Hull 1999) and seabirds (Connan et al. 2008).

In conclusion, our results indicate that there are large differences in the quality of prey potentially available to piscivores in the Ross Sea. More research is needed on seasonal, reproductive, geographic, body size and other factors that may affect nutrient composition of Antarctic prey, and also to expand coverage to include other unique Antarctic fish taxa, such as plunderfishes (Artedidraconidae), dragonfishes (Bathydraconidae), and icefishes (Channichthyidae). It may also be important to focus sampling at different locations and seasons and at various seal and penguin breeding colonies (e.g., Terra Nova Bay, Cape Adare).

Acknowledgments We would like to thank Dr. Gretchen Hofmann (University of California Santa Barbara, Santa Barbara, CA), Dr. Art DeVries (University of Illinois, Urbana-Champaign, IL), and Dr. Matt Pinkerton (National Institute of Water and Atmospheric Research, Wellington, New Zealand) for providing samples. Specimens and data

collected by and made available through the New Zealand International Polar Year–Census of Antarctic Marine Life Project are gratefully acknowledged. We would also like to thank Michael Jakubasz (Smithsonian National Zoological Park) for his help with all of the assays, Luis Apiolaza (University of Canterbury) for statistical advice and David Ainley and Graham Worthy for their comments on an earlier version of this manuscript. This manuscript was greatly improved by comments from three anonymous reviewers. This work was supported by the National Science Foundation, Office of Polar Programs grant 0538592 to Oftedal, Eisert and DJ Boness.

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