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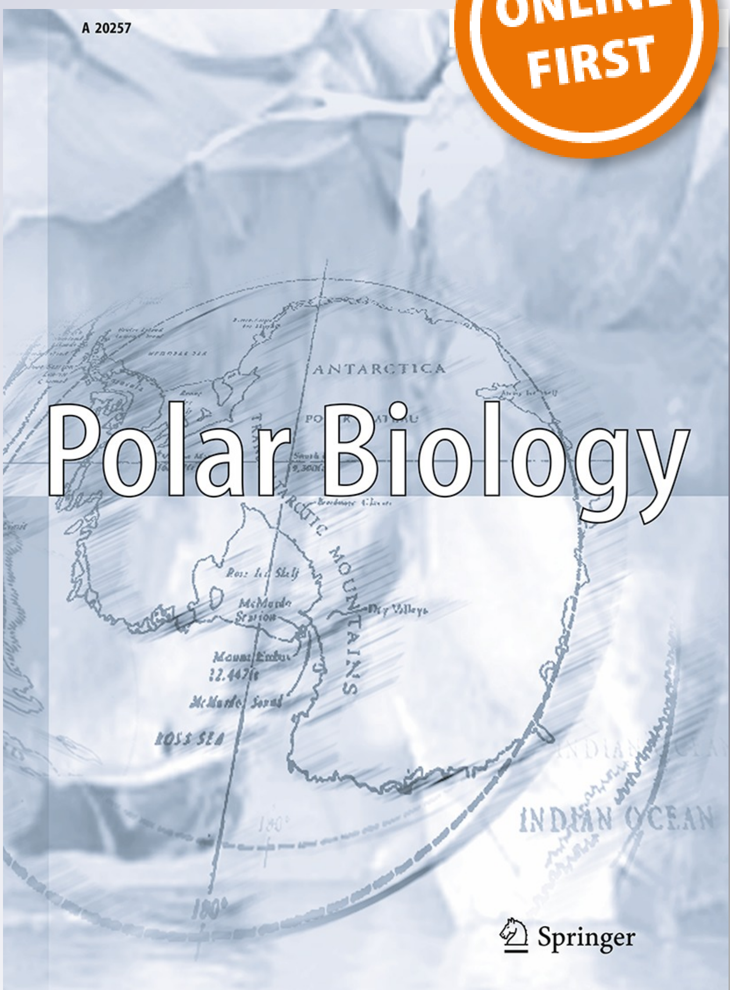

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SHORT NOTE

The cephalopod prey of the Weddell seal, *Leptonychotes weddellii*, a biological sampler of the Antarctic marine ecosystem

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Abstract Weddell seals, *Leptonychotes weddellii*, are important apex predators in the food web of the Antarctic marine ecosystem. However, detailed information on their trophic relationships with cephalopods is scarce. Moreover, cephalopods play a key role in the marine environment, but knowledge of their feeding habits is limited by lack of data. Here, we have combined the use of this seal as a biological sampler together with measurements of the stable isotopic signature of the beaks of their cephalopod prey. Thus, the aims of the present study were: (1) to examine in detail the cephalopod portion of the diet of Weddell seals by means of scat analysis and (2) to assess the habitat use and trophic level of the different cephalopod prey taxa identified. From January to February 2009, a total of 48 faecal droppings were collected at Hope Bay, Antarctic Peninsula. Cephalopods were mainly represented by beaks ($n = 83$) which were identified to the lowest possible taxonomic level. Furthermore, subsamples of beaks were separated for further isotopic analysis. Relative abundance of stable isotopes of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) was determined by continuous-flow isotope-ratio mass spectrometry. Cephalopods were represented uniquely by octopods of the subfamily Eledoninae. *Pareledone turqueti* was the dominant prey species followed by the papillated *Pareledone* species group and *Adelieledone polymorpha*. We conclude that Weddell seals preyed primarily on benthic prey resources. Furthermore, the relatively similar $\delta^{13}C$ and $\delta^{15}N$ values in beaks of the three octopod prey taxa suggest that these share the same type of habitat and occupy similar trophic level positions.

Keywords Antarctica · *Leptonychotes weddellii* · Diet · Cephalopods · Stable isotopes

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Introduction

Climate change has an impact on both the physical and biological components of ecosystems, and global climate models predict enhanced sensitivity in polar regions (Proffitt et al. 2007). Such context has raised concerns for Antarctic animal populations that may show direct responses to changes in sea-ice distribution and extent, sea surface temperature or indirect responses to changes in prey distribution and abundance (Atkinson et al. 2004; Forcada and Trathan 2009; Xavier et al. 2013). In this regard, the investigations of the feeding habits of Weddell seals *Leptonychotes weddellii* are of considerable importance to understand the role they play as top predators within the food web of the Antarctic marine ecosystem.

Weddell seals have a circumpolar range and inhabit the fast ice areas of the Antarctic continent and adjacent islands (e.g. South Orkneys, South Shetlands, South Georgia), though juveniles and non-reproducing seals may spend several years further off shore in pack ice habitats

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(Reeves et al. 1992). The unique hole-breathing behaviour of Weddell seals allows them to live under continuous sea ice. Moreover, combined with the ability to dive to depths of 700–800 m (Castellini et al. 1992; Testa 1994), Weddell seals are the only air-breathing predators capable of foraging in both benthic and pelagic habitats throughout the ice-covered oceans over the Antarctic continental shelf (Lake et al. 2003). This feeding behaviour makes them one of the most important marine predators in the food web of the Antarctic marine ecosystem and a potential environmental indicator of how the Southern Ocean is functioning.

In the last decades, top predators, such as seals, have been used as biological samplers in order to collect information on the cephalopod fauna of the Southern Ocean (Daneri et al. 1999, 2000; Cherel et al. 2004). For example, cephalopod eaters catch larger specimens and a greater diversity of species than sampling gear (Rodhouse 1990). Moreover, the increasing knowledge on the morphology of cephalopod beaks (chitinous hard structures that resist digestion) has allowed the identification to the species level of most of the accumulated items found in predator stomachs (Clarke 1986; Imber 1992; Lu and Ickeringill 2002; Xavier and Cherel 2009).

In addition a relatively recent tool has been applied to investigate the trophic structure of cephalopods by combining the use of their predators as biological samplers together with measurements of the stable isotopic signature of their beaks (hard structures that resist digestion). Combining these techniques applied to beaks found in the diet of Weddell seals can provide useful information about the composition, distribution, abundance and ecology of cephalopods occurring within Weddell seals foraging ranges (Cherel and Hobson 2005).

To date, most dietary studies of Weddell seals, mainly based on scat or stomach content analysis, have indicated that fish, cephalopods and crustaceans are their dominant prey taxa: the relative contribution of each of these food items to the overall diet of seals is highly variable, both temporally and spatially (e.g. Dearborn 1965; Lipinski and Woyciechowski 1981; Plötz 1986; Green and Burton 1987; Plötz et al. 1991; Castellini et al. 1992; Casaux et al. 1997; Burns et al. 1998; Lake et al. 2003; Zhao et al. 2004; Casaux et al. 2009; Daneri et al. 2012). However, few studies have focused on the cephalopod portion of their diet in detail (Clarke and MacLeod 1982; Daneri et al. 2012). Thus the aims of the present study applied to Weddell seals from Antarctic Peninsula were: (1) to examine in detail the composition of the cephalopod component of their diet by means of scat analysis and (2) to assess the habitat use and trophic level of the different cephalopod prey taxa identified by measuring the stable isotopic signature of the cephalopod beaks found in their diet.

Materials and methods

From mid-January to February 2009, a total of 48 faecal droppings were collected at Hope Bay (Lat, 63°24 S; Long. 57°00 W), Antarctic Peninsula, next to the Argentinian scientific station Esperanza, and kept frozen at −20 °C. Once in the laboratory, these were thawed and then sieved (mesh size 1 mm.) through running water, and prey remains sorted under a binocular microscope. All the lower beaks were identified to the lowest possible taxonomical level using reference collections and appropriate guides (Lipinski and Woyciechowski 1981; Clarke 1986; Xavier and Cherel 2009). Mantle length and mass of the different cephalopod species were estimated from the lower hood length of beaks, using previously published length to mass regression equations (Clarke 1986; Xavier and Cherel 2009). Furthermore, subsamples of beaks were separated, cleaned and kept in 70 % ethanol for further isotopic analysis. For each species, up to ten random lower beaks in good condition were selected following Cherel and Hobson (2005). Prior to the analysis, the beaks were dried at 60 °C and ground into a fine powder; 0.30–0.55 mg of each beak sample was placed in a tin capsule, and the relative abundance of C and N isotopes was determined with a continuous-flow mass spectrometer (Thermo Scientific Delta V Advantage) coupled to an elemental analyser (Thermo Scientific Flash EA 1112). Results are presented in the δ notation relative to Vienna PeeDee Belemnite and atmospheric N_2 for $\delta^{13}C$ and $\delta^{15}N$, respectively. Replicate measurements of internal laboratory standards (acetanilide) indicate measurement errors <0.10 ‰ for both $\delta^{13}C$ and $\delta^{15}N$ values.

Results

The analysis of scats containing prey remains ($n = 46$) indicated that fish was the most frequent prey group of seals, occurring in 100 % of samples, followed by cephalopods, which were present in 37 % of scats. The occurrence of crustacean remains was negligible. A total of 83 cephalopod beaks (34 upper and 49 lower) were removed from scats. This prey taxon was represented only by octopods of the subfamily Eledoninae. The dominant prey species was *Pareledone turqueti*, which occurred in almost 70 % of scats containing cephalopod remains and represented over 40 % in terms of numerical abundance and 60.5 % in mass of cephalopods consumed. This species was followed by the papillated *Pareledone* species group and *Adelieledone polymorpha* (Table 1).

Table 1 Taxonomic composition of the cephalopod prey of Weddell seals, *L. weddellii*, at Hope Bay, expressed as the frequency of occurrence (*f*), per cent frequency of occurrence (*%f*), number of lower beaks (*n*), percentage of the total number (*%n*), reconstituted mass (in grams) and percentage of total reconstituted mass (*%m*) (from the 15 scats containing cephalopod remains)

Species	*f*	*%f*	*n*	*% n*	*m*	*%m*
Papillated *Paraledone* species group	6	50	19	38.8	1340	29.3
Pareledone turqueti	8	66.7	21	42.9	2773	60.5
Adelieledone polymorpha	5	41.7	9	18.4	468	10.2

Table 2 Lower hood length and δ^{13}C and δ^{15}N values of lower beaks of the three octopodid prey of *L. weddellii*

Species	*n*	Lower hood length (mm)	δ^{13}C (‰)	δ^{15}N (‰)
Adelieledone polymorpha	9	2.4 ± 0.4 (1.6–2.9)	−18.8 ± 0.7 (−19.8 to 17.6)	7.3 ± 0.4 (6.8–8.0)
Pareledone turqueti	10	6.4 ± 1.2 (4.0–8.1)	−19.1 ± 0.7 (−20.2 to 17.9)	7.7 ± 0.7 (6.8–8.8)
Papillated *Pareledone* species group	10	4.2 ± 1.0 (3.1–6.4)	−19.0 ± 1.9 (−23.1 to 17.5)	6.3 ± 0.5 (5.5–7.3)

Values are mean ± SD with ranges in parentheses

δ^{13}C values in beaks of these three octopod taxa were not significantly different (ANOVA $F = 0.17$, $P = 0.841$) (Table 2).

Discussion

In relation to the papillated group, it is worth emphasizing that, until recently, all papillated specimens of *Pareledone* from the Antarctic Peninsula were ascribed to the species *Pareledone charcoti*. A re-examination of the papillated-type material of *Pareledone*, however, has led to the identification of at least eight new species of papillated *Pareledone* from the Antarctic Peninsula region (Allcock 2005; Allcock et al. 2007). These are distinguished by subtle taxonomic characters, such as the morphology and placement of their papillae, whereas traditional features, such as beak morphology, fail to separate them as they all show a strong resemblance to *P. charcoti* (Allcock 2005).

The papillated *Pareledone* species group had a higher range and standard deviation, presumably due to the fact that it is precisely "a group" and thus includes several octopod species (Fig. 1). The overlapping and relatively positive δ^{13}C values indicate that the three octopod taxa share the same, most likely benthic, type of habitats. Indeed, the octopod δ^{13}C values fit well with those of Antarctic benthic fishes (Cherel et al. 2011), but not with the much more negative δ^{13}C value of the control pelagic species, the squid *Psychroteuthis glacialis* (Fig. 1) (Cherel and Hobson 2005). This squid is an endemic teuthid species in the Southern Ocean and extremely abundant in the high Antarctic (Gröger et al. 2000; Collins and Rodhouse 2006). In contrast to δ^{13}C, beak δ^{15}N values were overall statistically different with *Pareledone* spp. having lower values than *Pareledone turqueti* and *A. polymorpha* (ANOVA $F = 14.74$, $P < 0.0001$). The diet of the papillated *Pareledone* species group thus merits further investigation to better understand trophic partitioning among Antarctic octopods.

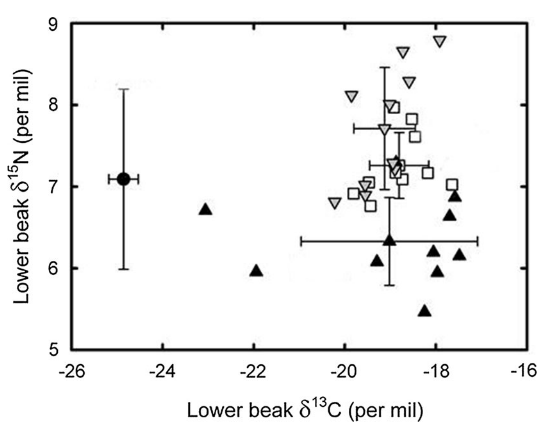

Fig. 1 Individual and mean (±SD) δ^{13}C and δ^{15}N values of lower beaks from the three octopodid prey taxa of *L. weddellii,* namely *A. polymorpha* (*white squares*), *P. turqueti* (*grey triangles down*) and papillated *Pareledone* species group (*black triangles up*), *P. glacialis* (*black circle*)

Based on the cephalopod prey identified from seal scats in this study, it is suggested that during the summer season of 2009, Weddell seals preyed primarily on benthic prey resources. This finding coincided with the high abundance of benthic fish prey of the families Nototheniidae and Channichthyidae in the diet of seals during the same time period, both families constituting over 78 % in number and almost 90 % in mass of the fish predated (Daneri and Negri unpublished data). Monitoring the diet of *L. weddellii* for a longer period of time at different seasons of the year and therefore at different stages of its annual cycle, i.e. reproductive/moulting phase, will be essential to gain adequate knowledge of its trophodynamics and its ecological role as a top predator of the Antarctic marine ecosystem. Moreover, the stable isotopic signature of beaks removed from predators scats may reveal new and/or unexpected trophic relationships among poorly known cephalopod species and families in the area of the Antarctic Peninsula.

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