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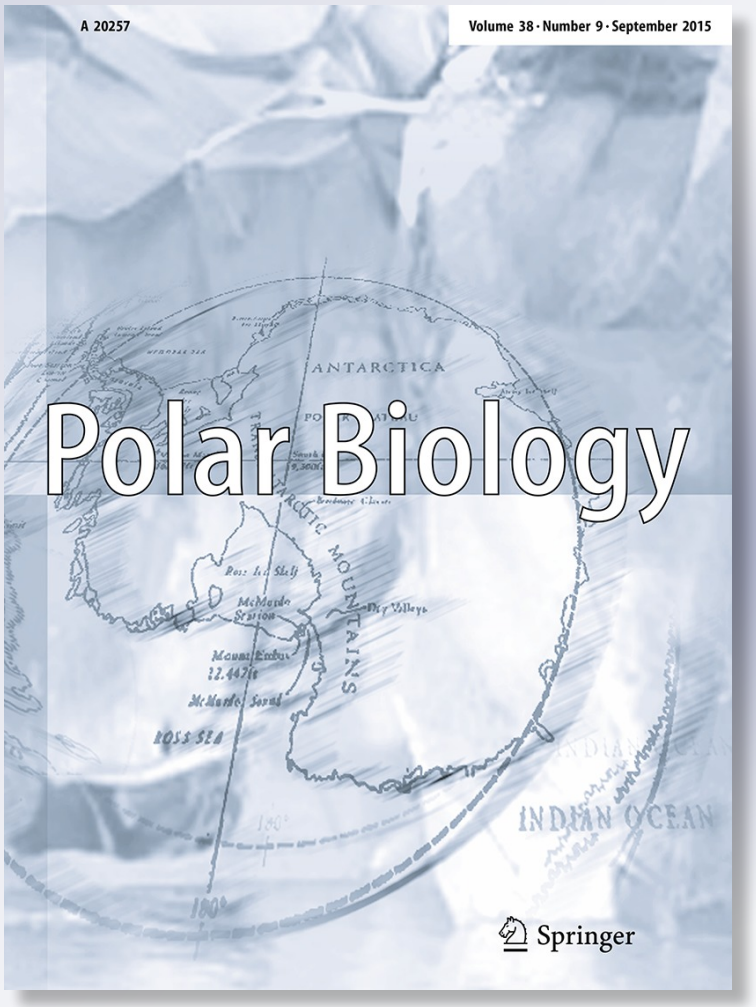

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SHORT NOTE

Cephalopod remains in scats of Weddell seals (*Leptonychotes weddellii*) at Cape Shirreff, South Shetland Islands, Antarctica

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Abstract The diet of Weddell seals (*Leptonychotes weddellii*) varies regionally, and fish and cephalopods are thought to be the most important food source. However, there is limited information on the cephalopod component of the Weddell seal's diet in the South Shetland Islands. We investigated cephalopod remains in the diet of Weddell seals by analysing 21 scats collected on three beaches at Cape Shirreff, Livingston Island, Antarctica, from 1 to 20 February 1999. Although the number of scats is small and collected from only 1 month a long time ago, fish and cephalopods were present in 21 and 16 of the scats, respectively. Only cephalopods of the order Octopoda were represented. *Thaumeledone* sp. was the most abundant prey species in terms of numbers, followed by *Pareledone charcoti* and *P. turqueti*. The latter two species showed the highest frequency of occurrence in scats (10 and 9, respectively). *Graneledone macrotyla*, *Opistoteuthis* sp., *Argonauta* sp., *Haliphron* sp. and *Thaumeledone* sp. are new species identified in the diet of Weddell seals in the present study, but all made a negligible contribution to their diet at Cape Shirreff. Our findings agree with previous dietary studies of Weddell seals at other localities in the South Shetland Islands and the Antarctic Peninsula, which showed a relatively greater contribution of octopods to the diet compared with squid in summer.

Keywords Cephalopods · Octopoda · Weddell seal · Cape Shirreff · Antarctica

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Introduction

The Weddell seal, *Leptonychotes weddellii* (Lesson 1826), is an important top-level predator that forages in Antarctic coastal ecosystems. The ability to dive below 700 m allows Weddell seals to forage in both benthic and pelagic habitats over the Antarctic continental shelf (Testa 1994; Lake et al. 2003). The diet of Weddell seals has been studied in East Antarctica (Green and Burton 1987; Green et al. 1995; Lake et al. 2003), the Antarctic Peninsula (Casaux et al. 2006; Daneri et al. 2012), the Weddell Sea (Plötz 1986; Plötz et al. 1991), the Ross Sea (Dearborn 1965; Calhaem and Christoffel 1969; Davis et al. 1982; Castellini et al. 1984; Testa et al. 1985; Green and Burton 1987; Burns et al. 1998) and the South Shetland Islands (Lipinski and Woyciechowski 1981; Clarke and MacLeod 1982; Cassaux et al. 1997). The diet has been reported to consist of notothenid fishes, cephalopods, prawns and other small invertebrates. In general, fish are considered the most important prey in the diet. However, studies of the Weddell seal diet have shown regional variation, with pelagic fish predominant in the diet in McMurdo Sound (e.g. Testa et al. 1985; Burns et al. 1998; Lake et al. 2003) and cephalopods predominant in the South Shetland Islands and near Mawson Station (e.g. Lipinski and Woyciechowski 1981; Clarke and MacLeod 1982; Green and Burton 1987; Cassaux et al. 1997).

It is widely acknowledged that cephalopods play a key role in global marine ecosystems. They occupy a wide range of habitats (Clarke 1996, Daneri et al. 2012) and constitute an important food resource for top predators (e.g. Lipinski and David 1990; Imber 1992; Rodhouse et al. 1992; Cherel et al. 1996; Clarke 1996; Klages 1996; Santos and Haimovici 1998). However, information on the cephalopod component of the diet of Weddell seals is scarce in the region of the Scotia Arc, with only three studies (Lipinski and Woyciechowski 1981; Clarke and MacLeod 1982; Daneri et al. 2012). The aims of the present study were to investigate the cephalopod component of the diet and to assess the contribution, estimated size and wet mass of this prey taxon ingested by Weddell seals at Cape Shirreff in the South Shetland Islands.

Materials and methods

Study site

A total of 21 scats from animals of unknown age were collected in February 1999 at Cape Shirreff, located south of the Drake Passage and on the northern coast of Livingston Island, the second largest of the South Shetland group (62°27′30″S, 60°47′17″W; Fig. 1). This unique scat collection of Weddell seals was part of the fieldwork of the Chilean Antarctic Institute project 018 (INACH 018; Ecological studies on the Antarctic fur seal, *Arctocephalus gazella*). Antarctic Specially Protected Area (ASPA) No. 149 at Cape Shirreff and San Telmo Islets hosts the largest breeding population of Antarctic fur seals in the South Shetland Islands (Aguayo-Lobo 1978; Bengtson et al. 1988; Torres 1995; Hucke-Gaete et al. 2004). The Cape also hosts a few individuals of three true Antarctic seal species, Weddell seals, crabeater seals (*Lobodon carcinophaga*) and leopard seals (*Hydrurga leptonyx*) and one true sub-Antarctic seal species, the southern elephant seal (*Mirounga leonina*) that breed and moult on some of the beaches during summer.

Scat analysis

The scat collection was carried out around groups of adult and/or subadult seals of both sexes hauled out on the snow. The samples were individually washed through a series of sieves of different mesh, and the remains of fish and cephalopods were separately stored in vials with 70 % alcohol. Fish bones were collected in all scats, but due the few identifiable otoliths collected that were in suitable condition for specific identification, the fish component was not included in the analysis. The most common cephalopod remains were mandibles (upper and lower beaks), but only lower beaks were used for identification

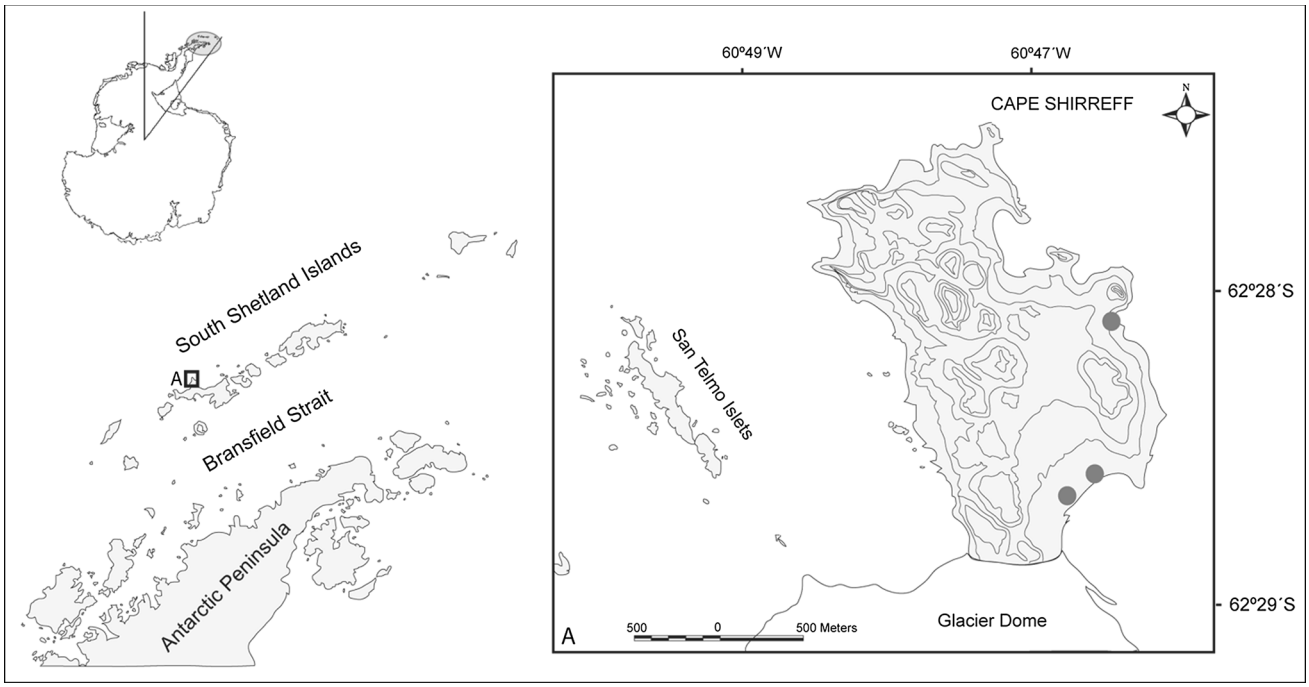

Fig. 1 Map showing the location of Antarctic Specially Protected Area (ASPA) No. 149 Cape Shirreff and San Telmo Islets, located on the northern coast of Livingston Island, South Shetland Islands, and the specific locations where the scats were collected (*dark grey circle*)

purposes. The lower beaks were identified under a stereoscopical microscope to the lowest taxonomic level possible at the Laboratory of Malacology of the National Museum of Natural History (MNHN) in Santiago, Chile. Identification was performed by comparison with a reference collection deposited at the MNHN (Vega et al. 2001), and using published descriptions and taxonomic criteria (Lipinski and Woyciechowski 1981; Wolff 1984; Roper et al. 1988; Clarke 1996; Xavier and Cherel 2009).

Lower beak lengths (LHL) were measured using vernier callipers to the nearest 0.05 mm. From these measurements, the dorsal mantle length (ML) and wet mass (W) were estimated using allometric equations from Rodhouse et al. (1992) and Xavier and Cherel (2009) for the genus *Pareledone*. Several unidentified beaks (referred to here as Sp. 1 and Sp. 2) were similar in form to the genus *Pareledone* and were considered as *P. charcoti* for mass estimation purposes. Allometric equations developed by Clarke (1996) for another species of the family Octopodidae were used to estimate dorsal MLs and mass from LHL. The dorsal MLs were averaged to obtain an estimate of the sizes of cephalopods. The total wet mass of cephalopods consumed was calculated as the sum of the estimated mass of each beak present in the scats.

Results

All scats were brown in colour and composed of fish ($n = 21$ scats) and cephalopods ($n = 16$ scats). A total of 344 beaks (169 lower and 175 upper) were removed from 16 scats that contained cephalopod remains, with an average of 22 beaks (range 16–25) per scat. The maximum number of cephalopod taxa identified in a single scat was five. From 132 of the lower beaks, eight species representing four families of the order Octopoda were identified. Another 37 beaks could not be identified to the species level, but 27 were representatives of the family Octopodidae (Sp. 1 and Sp. 2; Table 1). The family Octopodidae was the most important cephalopod family consumed by Weddell seals at Cape Shirreff, present in the 16 scats containing cephalopod remains. *Thaumeledone* sp. was the most abundant prey species in terms of numbers of cephalopods consumed, followed by *Pareledone charcoti* and *P. turqueti*. However, the latter two species showed the highest frequency of occurrence in scats (10 and 9 samples, respectively). The LHL of the different prey species of the family Octopodidae ranged from 1.75 to 11.05 mm. These LHL represented specimens with MLs of 25.1–314.2 mm and wet mass of 107–216 g (Table 2). The total wet mass of cephalopods estimated from the 16 scats that contained beaks represented 24,921 g biomass consumed.

Table 1 Cephalopod composition of the diet of Weddell seals at Cape Shirreff, Livingston Island, during February 1999, based on lower beaks found in 16 scats, expressed as the number of lower beaks (n) and number of occurrence in scats (Nscat)

Family	Species	n	Nscat
Opisthoteuthidae	*Opisthoteuthis sp.*	2	2
Octopodidae	*Pareledone charcoti*	34	10
	Pareledone turqueti	32	9
	Sp. 1	14	6
	Sp. 2	13	4
	Graneledone macrotyla	5	3
	Thaumeledone sp.	51	8
	Megaleledone setebos (*senoi*)	5	2
Argonautidae	*Argonauta* sp.	1	1
Alloposidae	*Haliphron* sp.	2	1
Unidentified		10	5
Total		169	16

Discussion

While fish are the most important prey item of Weddell seals, cephalopods are also important prey items in the diet of this seals (e.g. Bertram 1940; Dearborn 1965; Davis et al. 1982; Testa et al. 1985; Plötz 1986; Casaux et al. 2006, 2009). Despite the low number of scats collected from only 1 month a long time ago at Cape Shirreff, the order Octopoda accounted for 100 % of the cephalopod component. According to previous dietary studies at several locations in the Southern Ocean, the relative contribution of octopods and squid (teuthoids) to the diet of Weddell seals seems to be highly variable. Dietary studies carried out in the Scotia Arc, including the present work, indicate a relatively greater contribution of octopods than squids to the Weddell seal diet compared with reports from the Weddell Sea area and East Antarctica. Lipinski and Woyciechowski (1981) found that cephalopods, mainly represented by octopods, were as important as fish in the diet of Weddell seals in Admiralty Bay, King George Island. At Nelson Island, octopods were again the main component of the cephalopod diet of Weddell seals (Cassaux et al. 1997). Casaux et al. (2009) also analysed the diet of Weddell seals during two periods at Laurie Island in the South Orkney Islands, and although octopods were present in more than 60 % of the scats collected, their contribution in terms of numbers and mass differed between the collection periods. In all three previous studies conducted in the Scotia Arc and in the present study, squid in the diet was negligible or absent. Conversely, Clarke and MacLeod (1982) found cephalopod remains in the stomach contents of eight Weddell seals killed at Deception Island,

Table 2 Number of lower beaks, estimated size (mm), wet mass (g) and total wet mass (g) of octopods ingested by Weddell seals at Cape Shirreff

Prey species	*n*	LHL		ML		W		Wt
		Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	
Pareledone charcoti[a]	34	3.1 ± 0.8	1.8–5.4	35.0 ± 7.1	24.7–54.7	133.5 ± 12.2	110.4–158.1	4539
Pareledone turqueti[b]	32	3.4 ± 1.9	2.4–11.7	63.7 ± 25.6	49.7–174.3	127.2 ± 19.4	107.0–193.9	4070
Sp. 1[a]	14	3.6 ± 0.9	1.9–5.4	39.5 ± 7.8	25.1–54.7	140.4 ± 12.5	111.9–158.1	1966
Sp. 2[a]	13	4.4 ± 1.6	2.2–7.4	46.2 ± 13.8	27.7–71.6	147.2 ± 14.6	119.9–168.7	1913
Graneledone macrotyla[c]	5	6.1 ± 1.9	3.3–8.7	165.7 ± 51.1	91.1–234.5	189.3 ± 16.1	162.5–205.9	946
Thaumeledone sp.[c]	51	10.0 ± 1.1	8.4–11.7	269.7 ± 28.2	226.6–314.2	210.7 ± 3.7	204.7–216.2	10,748
Megaleledone setebos[c]	5	2.75 ± 0.87	1.7–4.1	76.3 ± 23.1	48.5–112.3	147.5 ± 20.9	116.1–174.1	737

LHL lower beak length, *ML* mantle length, *W* wet mass, *Wt* total wet mass

[a] Allometric equations from Rodhouse et al. (1992)

[b] Allometric equations from Xavier and Cherel (2009)

[c] Allometric equations from Clarke (1996)

but teuthoids contributed substantially to the diet (60 % in terms of numerical abundance), followed by octopods, probably *Pareledone* sp. However, there also was a seasonal variation with squid predominant in the diet in March and April and octopods predominant in the cephalopod fraction in July. The only two previous dietary studies carried out on the Antarctic Peninsula show different contributions of cephalopods in terms of numbers and mass. In Weddell seals from the Danco Coast, teuthoids were more abundant in the diet than octopods (Casaux et al. 2006), while in seals from Hope Bay, octopods were the principal prey item (Daneri et al. 2012).

The octopods, *Pareledone charcoti*, *P. turqueti* and *Megaleledone setebos* (=*M. senoi*), were previously reported in the diet of Weddell seals in the Scotia Arc and Antarctic Peninsula, with *P. charcoti* and *P. turqueti* as the main prey species (Lipinski and Woyciechowski 1981; Clarke and MacLeod 1982; Cassaux et al. 1997; Casaux et al. 2006, 2009; Daneri et al. 2012). The genus *Pareledone* also occurred in the diet of Weddell seals in East Antarctica (Lake et al. 2003). *Pareledone* is the most speciose, abundant and widespread genus of octopods in the Southern Ocean, and the species *P. charcoti* and *P. turqueti* are extremely abundant in shallow waters around the islands of the Scotia Ridge and in West Antarctica. However, as noted by Allcock (2005), until recently all papillated specimens of *Pareledone* were ascribed to the species *P. charcoti*, but a detailed examination of material from the Antarctic Peninsula region revealed seven new species. The beaks identified as Sp. 1 and Sp. 2 may correspond to some of the new species of *Pareledone* (*P. albimaculata, P. aurata, P. cornuta, P. panchroma, P. serperastrata, P. subtilis* and *P. aequipapillae*) from around the South Shetland Islands as described by Allcock (2005), or *Adelieledone polymorpha* from the west Antarctic Peninsula (Collins and Rodhouse 2006; Daneri et al. 2012), but we could not achieve positive identification.

The presence of *Megaleledone setebos* in the diet of Weddell seals has been previously reported by Lipinski and Woyciechowski (1981), who identified it as the main prey species of seals in Admiralty Bay, King George Island. This octopod is the largest in the Southern Ocean and has a circum-Antarctic distribution, but does not extend as far north as the sub-Antarctic islands (Allcock et al. 2003; Collins and Rodhouse 2006). Conversely, *Graneledone macrotyla*, *Opistoteuthis* sp., *Argonauta* sp., *Haliphron* sp. and *Thaumeledone* sp. are new species identified in the diet of Weddell seals in the present study. However, all except *Thaumeledone* sp. contributed negligibly to the diet. This last genus includes three Southern Ocean deepwater species. *T. gunteri* is found only at South Georgia (Yau et al. 2002; Allcock et al. 2004; Collins et al. 2004), *T. rotunda* has a circum-Antarctic distribution, and *T. peninsulae* was described from the Antarctic Peninsula (Allcock et al. 2004). The presence of *T. brevis* was reported in Admiralty Bay, King George Island (Lipinski and Woyciechowski 1981), but Allcock et al. (2004) showed them to be misidentified, with *T. brevis* localized only off Montevideo, Uruguay. Therefore, the genus *Thaumeledone* in the diet of Weddell seals at Cape Shirreff is most likely represented by two species, *T. rotunda* and/or *T. peninsulae*.

The analysis of scats can underestimate the number of prey ingested and may not accurately represent the overall diet. Nonetheless, based on our findings, the species composition of cephalopods consumed by Weddell seals at Cape Shirreff suggests that seals do not prefer octopods of a specific species, but will consume all octopods encountered. The particular cephalopod component of the diet of Weddell

seals at Cape Shirreff during the summer season suggests that these animals foraged close to the coast in inshore waters when octopods would be predominant, as found by Green and Burton (1987) near Davis Station (East Antarctica) in spring–summer seasons. Cape Shirreff and San Telmo Islet, in the present study, host the largest breeding population of Antarctic fur seals in the South Shetland Islands, and both seals species could compete for food resources such as fish and cephalopods. However, Antarctic fur seals preferred Antarctic krill (*Euphausia superba*), the most commonly encountered prey item (58–86 % of scats), during five consecutive years (1997–2001), followed by fish (12–55 % of scats). The very low occurrence of squid remains and penguins (0–10 %) indicated that these are no fundamental prey of *A. gazella* at Cape Shirreff (Osman et al. 2004). Therefore, the absence of squid remains in the scats of Weddell seals, at least in summer, is not related to an effect of interspecific competition. Although the fish component was not included in the present study, both seals may compete for this prey given that *Electrona antarctica*, *E. carlsbergi* and *Gymnoscopelus nicholsi* constituted the main fish species in the scats of *A. gazella* at Cape Shirreff (Osman et al. 2004), as well as the most commonly encountered prey in scats of *L. weddelli* at Harmony Point, South Shetland Islands (Cassaux et al. 1997).

Although no new scats were collected in subsequent years, our findings agree with those of others for Weddell seals in the South Shetland Islands and the Antarctic Peninsula where, in the cephalopod fraction, octopods contributed relatively more to the diet as compared to squid in the summer seasons.

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