



Fish prey of Weddell seals, *Leptonychotes weddellii*, at Hope Bay, Antarctic Peninsula, during the late summer

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Abstract

The study of the feeding habits of Weddell seals, *Leptonychotes weddellii*, in the area of west Antarctic Peninsula is essential to understand the role they play in the marine food webs, especially considering that this is one of the regions most affected by climate change. With the aim of detecting temporal changes in the fish predation pattern of seals, a total of 217 scats were collected at Hope Bay, during three consecutive summers (2003, 2004 and 2005). The family Nototheniidae comprised over 80% in numbers of fish preyed by seals. The Antarctic silverfish, *Pleuragramma antarctica*, was, by far, the most frequent and abundant prey species with a mean percentage frequency of occurrence of 48.7% and representing in average 52.1% in numbers of the fish consumed by seals. Other fish species of lesser importance were the nototheniids *Trematomus newnesi*, *Lepidonotothen larseni*, *Gobionotothen gibberifrons* and the channichthyid *Chionodraco rastrospinosus*. Temporal variation was observed not only in the relative proportions of the different fish prey taxa but also in the sizes of the dominant prey, *P. antarctica*. Given the high trophic vulnerability of this species to changes in abiotic factors and food web structure and dynamics, a possible influence of El Niño Southern Oscillation events of 2002–2003 and 2004–2005 should not be discarded. Moreover, special attention should be addressed to its population status, distribution and spatial/temporal availability as prey resource of upper trophic level consumers such as *L. weddellii* which largely depend on *P. antarctica*.

Keywords *Leptonychotes* · Fish · Diet · *Pleuragramma* · Antarctic Peninsula · ENSO

Introduction

Weddell seals, *Leptonychotes weddellii*, are important top predators in the Antarctic coastal marine ecosystem. To date, most dietary studies of this phocid seal have indicated that fish, cephalopods, and crustaceans constitute the main prey taxa; their relative contribution to the overall diet being highly variable both temporally and spatially (Plötz et al.

1991; Burns et al. 1998; Lake et al. 2003; Zhao et al. 2004; Casaux et al. 2006; Negri et al. 2015 among others). A detailed study on the cephalopod prey of Weddell seals was previously reported for Hope Bay by Daneri et al. (2012). That study also indicated that the two main food items of seals were fish and cephalopods, which occurred respectively in an average of 94.5 and 45.6% of scats containing prey remains, the presence of crustaceans being of minor importance (7.8%). Therefore, the aims of the present study were to examine in detail the fish component of the diet of this Weddell seal population during three consecutive summers (2003, 2004, 2005) and how this varied interannually. Furthermore, an assessment of the temporal variation in the sizes of the dominant fish prey, *P. antarctica*, was performed.

Materials and methods

The sampling site is located along the coasts of Hut Cove, Hope Bay (63°24'S, 57°00'W), Antarctic Peninsula, where 217 scats were collected from mid-February to mid-March

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2003 ($n = 51$), 2004 ($n = 87$), and 2005 ($n = 79$) (Daneri et al. 2012; see Fig. 1). The collection was carried out, on a weekly basis, around groups of up to 20 adult and/or sub adult seals of both sexes resting on the beach. Scats were kept frozen at -20° and further processed using the method described in Daneri et al. (2012). Otoliths were identified to the lowest possible taxonomic level by comparison with reference collections and using published otolith guides (Hecht 1987; Williams and McEldowney 1990; Reid 1996). The length of otoliths with little or no sign of erosion was measured with a digital calliper to the nearest 0.01 mm. and then corrected to account for erosion in the digestive process using a correction factor following Burns et al. (1998). Fish standard length was predicted from the corrected otolith lengths using the regression equations given by Hecht (1987), Williams and McEldowney (1990) and Reid (1996).

To test for interannual differences in the sizes of *P. antarctica*, a nested ANOVA design was applied, considering the scat as a random factor nested in the year. The analysis provides exact tests for the null hypothesis of no differences between years (Sokal and Rohlf 1994). The relative importance of each fish prey taxon was evaluated in terms of frequency of occurrence, numerical abundance, and reconstituted mass. Also the index of relative importance (IRI) was estimated following Pinkas et al. (1971) but in a modified version where the original term by volume was replaced by wet weight (Daneri et al. 2015).

In order to make the interpretation of the IRI easier, this index was expressed on a percent basis (% IRI) following Cortes (1997).

Results

Of the 217 faecal samples collected during the study period, 14 contained no prey remains and were therefore excluded from further analysis. Fish occurred in over 90% of the scats examined ($n = 203$).

A total of 584 otoliths (2003, $n = 29$; 2004, $n = 344$; 2005, $n = 211$) were removed from scats, from which 17 fish species were identified, including 9 species of nototheniid fish (Table 1). Regarding exclusively those scats containing otoliths, these were recovered at a rate of 2.8 otoliths per scat in 2003 in comparison with 7.8 and 5.1 otoliths per scat in 2004 and 2005, respectively.

The family Nototheniidae dominated the fish diet followed by the family Channichthyidae, each constituting, in average, 83.1 and 8.6% in numbers, respectively, of all the fish identified. The Antarctic silverfish, *P. antarctica*, was by far the most frequent and abundant fish prey species throughout the study period with a mean percentage frequency of occurrence of 48.7% (range 30–79.5) and representing in average 52.1% in numerical abundance of the fish consumed by seals (range 37.9–77.0). However, in terms of biomass this species was the main contributor only in the 2004 season, whereas the Channichthyid *Chionodraco rastrispinosus* and the nototheniid *Trematomus newnesi* were in 2003 and 2005, respectively. The main fish species preyed upon by seals, according to the Index of relative importance, were *P. antarctica*, *T. newnesi*, *Lepidonotothen larseni*, *Gobionotothen gibberifrons*, and *C. rastrispinosus* (Table 1). Their estimated standard lengths are shown in Table 2. There were significant interannual differences in the mean sizes of *P. antarctica* preyed upon by Weddell seals (Nested Anova $F(2,305) = 52.3$ $p < 0.0001$), the difference lying exclusively in the 2005 season (Tukey test $p < 0.0001$), with a progressive decrease in size through years (Fig. 1).

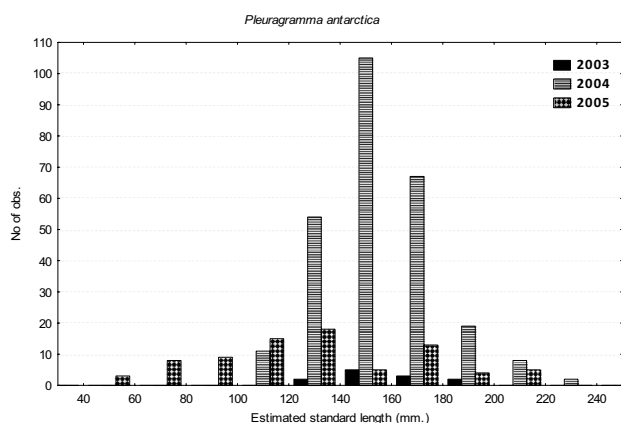


Fig. 1 The estimated standard length frequency distribution of *Pleuragramma antarctica* preyed on by Weddell seals, *L. weddellii*, at Hope Bay during three consecutive summers (2003, 2004 and 2005)

Discussion

The taxonomic composition of the fish component of the diet of Weddell seals showed diverse prey species of both pelagic and benthic-demersal habitat. Nototheniid fish were by far the dominant prey, with *P. antarctica* as the main contributor to the diet. Almost all the fish taxa here identified were also reported as common prey of Weddell seals at other localities of their distributional range (Plotz et al. 1991; Burns et al. 1998; Lake et al. 2003; Casaux et al. 2006). However, the contribution of *P. antarctica* to the diet of *L. weddellii* is highly variable, depending on the different localities and seasons studied. For instance, at

Table 1 Composition of the fish remains (otoliths, $n = 584$) recovered from scats ($n = 203$) of *L. weddellii* at Hope Bay expressed as percent frequency of occurrence (% F), percentage of total number (% N), percentage of total reconstituted mass (% M) and percent of Index of Relative Importance (% IRI)

Fish taxon	Summer 2003				Summer 2004				Summer 2005			
	% F	% N	% M	% IRI	% F	% N	% M	% IRI	% F	% N	% M	% IRI
Myctophidae												
<i>Electrona antarctica</i>	10.0	6.9	0.9	2.3								
<i>Gymnoscopelus nicholsi</i>	10.0	3.4	6.1	2.7	2.3	0.3	0.4	0.0				
Channichthyidae												
<i>Pagetopsis macropterus</i>	10.0	3.4	7.7	3.2	9.1	1.7	1.9	0.3	2.4	0.5	1.1	0.1
<i>Chionodraco rastrospinosus</i>	10.0	3.4	40.1	12.6	9.1	2.0	6.6	0.7	7.3	1.4	4.6	1.0
<i>Chionodraco myersi</i>					4.5	0.6	3.0	0.1	4.9	1.4	2.9	0.5
<i>Chaenodraco wilsoni</i>					6.8	1.5	2.3	0.2	4.9	0.9	2.9	0.4
<i>Dacodraco hunteri</i>					2.3	0.3	0.8	0.0				
<i>Cryodraco antarcticus</i>					2.3	0.3	2.6	0.1				
Channichthyidae indet.	10.0	3.4			13.6	4.9						
Nototheniidae												
<i>Pleuragramma antarctica</i>	30.0	41.4	19.1	52.3	79.5	77.0	61.1	96.9	36.6	37.9	16.1	45.6
<i>Lepidonotothen nudifrons</i>					2.3	0.3	0.2	0.0	4.9	0.9	2.2	0.3
<i>Lepidonotothen larseni</i>					6.8	1.2	1.7	0.2	19.5	11.8	19.0	13.9
<i>Lepidonotothen kempfi</i>									4.9	0.9	2.7	0.4
<i>Lepidonotothen squamifrons</i>					2.3	0.6	1.1	0.0	4.9	1.4	2.9	0.5
<i>Gobionotothen gibberifrons</i>	20.0	20.7	26.1	27.0	4.5	0.6	1.9	0.1	9.8	3.3	13.3	3.7
<i>Trematomus newnesi</i>					4.5	1.5	10.9	0.5	29.3	18.5	29.7	32.6
<i>Trematomus hansonii</i>					4.5	0.9	0.5	0.1				
<i>Trematomus eulepidotus</i>					9.1	5.2	5.2	0.8	7.3	2.4	2.7	0.9
<i>Trematomus/Pagothenia</i> spp.					2.3	0.3			7.3	1.9		
Nototheniidae indet.	20.0	10.3			2.3	0.6			17.1	9.5		
Artedidraconidae												
Artedidraconidae indet.									2.4	0.5		
Unidentified	20.0	6.9			2.3	0.3			7.3	6.6		
Number of scats analysed	43				82				78			
Number of otoliths	29				344				211			

lower latitudes of the Southern Ocean, (e.g. Islands of the Scotia Arc), this fish taxon was completely absent in their diet (Casaux et al. 1997; Casaux et al. 2009). In contrast, it was reported as a dominant prey, at least in the summer season, at higher latitudes such as West Antarctic Peninsula (Casaux et al. 2006); Weddell sea (Plotz 1986), East Antarctica and Ross sea (Green and Burton 1987; Burns et al. 1998; Lake et al. 2003; among others). Moreover, studies on foraging behaviour of *L. weddellii* indicate that it is an opportunistic feeder capable of chasing prey in different parts of the water column during a single dive, performing benthic and pelagic dives and primarily exploiting pelagic prey such as *P. antarctica* (Plotz et al. 2001; Fuiman et al. 2002; Heerah et al. 2013). This is in line with our findings which indicate that *P. antarctica* was the dominant fish prey of seals during the study period, though its relative contribution to the diet varied through years

(Table 1). *P. antarctica* has a circumantarctic distribution and constitutes the food resource of so many species of marine mammals, fishes and seabirds that it is considered a keystone species in the food web of the high Antarctic zone (Cherel and Kooyman 1998; Fuiman et al. 2002). The interannual differences in the size frequency distribution of *P. antarctica* ingested by seals suggest a temporal variation in their pattern of predation (Fig. 1). This fish species attains sexual maturity at ca. 125–140 mm (Gon and Heemstra 1990; Burns et al. 1998). Therefore, according to the estimated sizes from the corrected otolith lengths, *L. weddellii* preyed predominantly upon adult forms of *P. antarctica* in 2003 and 2004 whereas in 2005 did so on immature juvenile stages. The vertical spatial segregation pattern of *P. antarctica* is well known, with larvae being more abundant in the upper water layers (~ 200 m), juveniles up to 400 m and adults reaching more than 700 m

Table 2 Mean length (mm), standard deviation (SD) and size range of the fish represented by the otoliths found in scats of *L. weddellii* collected at Hope Bay, Antarctic Peninsula during the summers of 2003, 2004 and 2005

Fish taxon	<i>n</i>	Season	Mean (SD)	Range
<i>Pleuragramma antarctica</i>	12	2003	156.9 (20.0)	121.7–188.1
	265	2004	154.9 (21.3)	105.0–232.1
	80	2005	128.8 (42.5)	46.4–216.5
<i>Trematomus newnesi</i>	–	2003	–	–
	5	2004	242.4 (58.6)	174.2–298.3
	39	2005	167.8 (20.4)	137.1–226.8
<i>Lepidonotothen larseni</i>	–	2003	–	–
	4	2004	156.6 (26.8)	121.3–185.1
	25	2005	189.4 (34.2)	108.1–244.5
<i>Gobionotothen gibberifrons</i>	2	2003	274.3 (115.2)	193.0–356.0
	2	2004	228 (62.7)	183.7–272.3
	7	2005	262.5 (67.5)	191.4–393.3
<i>Chionodraco rastrospinus</i>	–	2003	–	–
	7	2004	214.4 (24.1)	173.6–250.3
	3	2005	236.9 (30.4)	202.3–259.4

depth (Fischer and Hureau 1985; Gon and Hemstra 1990; Granata et al. 2009). This size-dependent vertical distribution probably constitutes an important feature to avoid intraspecific competition ensuring the survival of the species (Hubold 1985). The difference in sizes of *P. antarctica* preyed upon by seals between years, particularly in the summer of 2005, might have reflected temporal changes either in the vertical foraging range of seals or in the availability of the different age classes of this nototheniid species. Moreover, the second and third prey species in terms of relative importance (% IRI) in 2005, *T. newnesi* and *L. larseni*, were absent or of minor relevance in the diet of seals in the two previous years.

The reproductive cycle and feeding dynamics of this species seem to be closely related to seasonal sea ice dynamics, and early stages depend on the temporal and spatial match with the seasonal zooplankton production (La Mesa and Eastman 2012). Indirect evidence from abundance and distribution of *P. antarctica* larvae and juveniles suggest that these stages have limited ability to tolerate changes in temperature and salinity (Granata et al. 2002; Mintenbeck et al. 2012).

During the study period, two El Niño Southern Oscillation (ENSO) events occurred, the first from May 2002 to February 2003 and the second from July 2004 to January 2005 (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml).

The ENSO is the largest climatic cycle on decadal and sub-decadal time scales and it has a profound effect not only on the weather and oceanic conditions across the

tropical Pacific, where it has its origins, but also in regions far removed from the Pacific basin (Turner 2004). ENSO signals can be identified in the physical and biological environment of the Antarctic. The most pronounced signals are found over the southeast Pacific as a result of a climatological Rossby wave train (known as the Pacific South American Association) that gives positive (and negative) height anomalies over the Amundsen–Bellingshausen Sea during El Niño (La Niña) events (Turner et al. 2009). The strong connections between sea ice and ENSO variability across the southwest Atlantic region of the Southern Ocean result in correlations between ENSO variation and krill recruitment and abundance and also predator population dynamics (Fraser and Hofmann 2003; Murphy et al. 2007). Periods of reduced top predator breeding performance (e.g. seals, penguins) are the consequence of low prey availability, usually of krill and krill-dependent fish species (Croxall et al. 1988; Turner et al. 2009). The vulnerability of a particular species to changes in food web structure and dynamics depends on its ability to cope with both ‘bottom-up’ and ‘top-down’ effects (O’Gorman and Emmerson 2010; Melian et al. 2011). In this sense, the relative trophic vulnerability index, a quantitative measure which serves as an indicator of a consumer species risk to be negatively affected by these changes is highest for the plankton feeder *P. antarctica* (Mintenbeck et al. 2012).

During the three consecutive summers of 2003, 2004 and 2005, *P. antarctica* was the most important fish prey of Weddell seals at Hope Bay. However, its contribution fluctuated through years not only in terms of abundance but also in the size (age) classes preyed upon by seals. Moreover, it would not be surprising that the decrease in size of *P. antarctica* individuals preyed on by seals in 2005 might be a consequence of reduced krill availability related to the previously mentioned ENSO (2002–2003, 2004–2005), especially taken into account that *Euphausia superba* is the main food item of adult stages of this nototheniid species in the area of Antarctic Peninsula and Weddell sea. Given the vulnerability of *P. antarctica* to changes in abiotic factors and food web structure and dynamics as a consequence of oceanographic and climatological changes such as ENSO, special attention should be addressed to its population status, distribution, and spatial/temporal availability as prey resource of upper trophic level consumers. In this regard, and based on our findings, that *P. antarctica* makes up a substantial contribution to the diet of Weddell seals, it is strongly recommended to continue with the monitoring of the diet of *L. weddellii* in the area of Hope Bay for a longer period of time (minimally a decade). This will permit to detect temporal changes in the feeding patterns of this phocid species as a response to an eventual decrease in the availability of one of its main fish prey.

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