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The diet of the Weddell Seal *Leptonychotes weddellii* at the Danco Coast, Antarctic Peninsula

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Abstract The diet of the Weddell Seal *Leptonychotes weddellii* at the Danco Coast, Antarctic Peninsula, was investigated by the analysis of 105 and 39 faeces collected at beaches surrounding Cierva Point during January–March 1998 and 2000, respectively. The diet was diverse and composed of both pelagic and benthic-demersal organisms. Fish, followed by cephalopods, constituted the bulk of the diet by number and mass. Among fish, *Pleuragramma antarcticum*, *Chaenodraco wilsoni* and *Gobionotothen gibberifrons* were the dominant fish by mass in 1998, whereas *Chionodraco rastrospinosus*, *P. antarcticum* and *C. wilsoni* predominated by mass in 2000. The contribution of channichthyid species to the diet of seals at the Danco Coast was higher than previously reported. Besides those species, the myctophid *Electrona antarctica* was also an important prey by number in the diet of seals in both summer seasons. The results are compared with information from other study areas and the possibility of using information on the diet of this seal as a gross indicator of fish availability/distribution is considered.

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Introduction

The study of the diet of top predators is of considerable importance not only to understand on the predator–prey interactions and on prey distribution but also, under certain conditions, to monitor trends in prey populations (Casaux 2003; Casaux et al. 2003a) and/or to assess in the management of exploited prey stocks by enhancing the accuracy of predictions of yield and of the evaluation of the ecological effects of exploiting particular prey species (Lindstrøm et al. 1998).

The Weddell Seal *Leptonychotes weddellii* is a generalised circum-Antarctic top predator that forages on both pelagic and benthic-demersal species to depths of 741 m (Testa 1994). The diet of this seal was studied at the East Antarctica (Green and Burton 1987; Green et al. 1995), the Weddell Sea (Plötz 1986; Plötz et al. 1991), the Ross Sea (Dearborn 1965; Castellini et al. 1984, 1992; 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; Casaux et al. 1997). Almost all of these studies reported that fish (mainly *Pleuragramma antarcticum*), followed by cephalopods or prawns, were the most important prey to the Weddell Seal (but see Casaux et al. 1997). Among fish, several species of current or potential commercial interest (such as *P. antarcticum*, Myctophids, *Gobionotothen gibberifrons* and *Dissostichus mawsoni*) were reported as prey of *L. weddellii*.

Although *L. weddellii* is well distributed throughout the Antarctic Peninsula, there is no information available from this area on the diet of this seal. Thus, the aim of this study is to provide information on the diet of the Weddell Seal from an unstudied area such as the Danco Coast, Antarctic Peninsula, giving a particular importance to fish as prey.

Materials and methods

A total of 105 and 39 faeces of the Weddell Seal *L. weddellii* were collected from January to March 1998 and 2000, respectively, around groups of juvenile and adult specimens of both sexes resting at beaches surrounding Cierva Point (64°09′S; 60°57′W), Danco Coast, Antarctic Peninsula (Fig. 1). Given that before the collection of the samples, the beaches to be surveyed were cleaned from old faeces, all the samples analysed were produced by seals during the study periods.

The samples were individually washed through sieves (minimum mesh 0.54 mm) and the prey remains were sorted to the lowest taxonomic level possible. In order to estimate the approximate number of individuals of the Antarctic krill *Euphausia superba* present in each sample, we considered the number of eyes and telsons or the dry weight of the total of the carapaces present in the sample according to the technique described by Casaux et al. (1998). The highest of these three estimations was considered as the minimum number of krill specimens present per sample. The mass of the individuals was estimated by comparing with entire specimens recovered from the study area. Isopods, amphipods and decapods were represented by exoskeletons remains and their mass were estimated by comparing with entire specimens collected in the study area.

Cephalopods were identified using reference materials and the illustrations and descriptions in Clarke (1980), Lipinski and Woyciechowski (1981), Okutani and Clarke (1985) and Fischer and Hureau (1988). The number of individuals represented in the samples was estimated by the number of upper and lower beaks or eye lenses. The lower hood length of octopod beaks (identified as *Pareledone* sp.) were measured to 0.01 mm with vernier callipers and the mass of the individuals was estimated using the relationships in Rodhouse et al. (1992). Almost all the squids represented in the samples were tentatively identified as *Psychroteuthis glacialis* and the mass of the individuals was estimated considering the rostral length of the lower beak and applying the relationship described in Gröger et al. (2000). The beak from one specimen remained unidentified; for the aim of the study the mass of that specimen was assumed to be the mean mass estimated for *P. glacialis*. The number of gastropods and bivalves represented in the scats was estimated considering the number of valves present in the samples and the mass was estimated by comparing with entire specimens recovered from the study area.

Bones, otoliths and eye lenses indicated the presence of fish in the scat samples. The sagittal otoliths were identified to species level, where possible, using our own reference collection and illustrations and descriptions in Hecht (1987), Williams and McEldowney (1990) and Reid (1996). The otoliths belonging to specimens of each species were sorted into right or left and the most abundant of these was considered as the number of fish present in each sample. The otolith length was measured

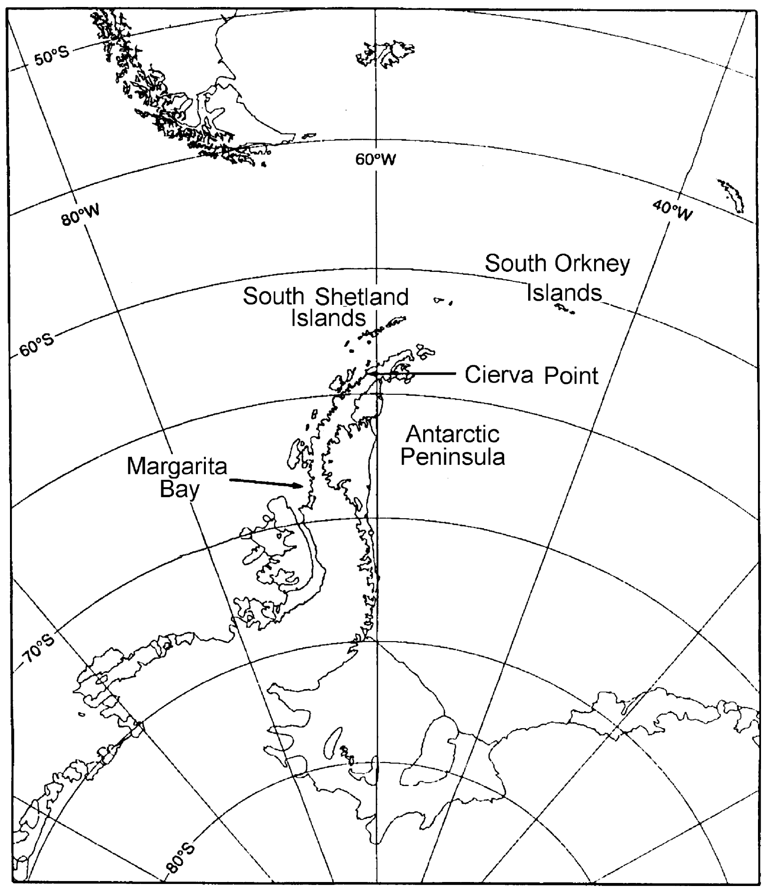

Fig. 1 Map showing the location of Cierva Point at the Danco Coast, Antarctic Peninsula

to 0.01 mm and the fish body length and mass estimated using the equations of Hecht (1987), Williams and McEldowney (1990) and those obtained by Casaux et al. (2003b) from fish caught in the study area. The mass of the specimens that remained unidentified in each season was assumed to be similar to the mean mass estimated for specimens identified in the corresponding season.

Since the estimates of the number and mass of prey species represented in scats usually give biased results (see Clarke and MacLeod 1982; da Silva and Neilson 1985; Green and Burton 1987; Murie 1987; Casaux et al. 1997; among others), the estimated mass of the different alimentary items does not necessarily represent their real contribution to the diet. However, these values were included because they provide information not reflected by the frequencies of occurrence.

Results

The total mean mass represented in a sample was 678.4 g (SD 1247.9; range 6.3–6567.0 g) in 1998 and 737.1 g (SD 110.9; range 3.4–4257.3 g) in 2000, whereas the mean number of prey per sample was 41.7 (SD 78.5; range 1–422) and 27.3 (SD 37.9; range 1–161) in both summer seasons respectively. There were no statistically significant differences between seasons in the number of preys and mass represented in the samples (Mann–Whitney *U* test, not significant).

The composition of the diet was diverse and both pelagic and benthic-demersal species were represented in the samples. Fish, followed by molluscs (mainly cephalopods) and crustaceans, were the most frequent and numerous preys and constituted the bulk of the diet in both summer seasons (Table 1). The mean mass estimated for the octopod specimens was 53.5 g ($n=42$, SD 25.3, range 5.4–107.3 g) in 1998 and 64.6 g ($n=12$, SD 23.8, range 27.6–101.7 g) in 2000 and the differences between years were not statistically significant. The mean mass estimated for the squids represented in the scats was 39.0 g ($n=103$, SD 63.2, range 0.9–237.2 g) in 1998 and 74.1 g ($n=14$, sd 65.5, range 2.1–199.9 g) in 2000; the differences between years were statistically significant (Mann–Whitney *U* test, $P<0.05$).

In both summer seasons, eye lenses (3,521 in 1998 and 595 in 2000) represented a number of fish larger than those represented by otoliths. A total of 616 and 326 otoliths was recovered from the samples in both summer seasons, respectively, and represented 493 and 291 fish, respectively; 399 and 205 of them were assigned to species. The otoliths representing 18.7 and 30.2% of the fish in both the summer seasons were not assigned to species since they were broken or too eroded to be identified. Among fish, the species belonging to the families Nototheniidae and Channichthyidae dominated in the samples, whereas those belonging to Myctophidae and Paralepididae were scarcely represented (Table 2). *Pleuragramma antarcticum*, *Chaenodraco wilsoni* and *G. gibberifrons* were the dominant fishes in 1998, whereas *Chionodraco rastrospinosus*, *P. antarcticum* and *C. wilsoni* predominated in 2000. *Electrona antarctica* and *C. wilsoni* were the smallest and largest fishes represented in the samples in both summer seasons and the estimated

Table 1 The composition of the diet of the Weddell Seal *Leptonychotes weddellii* at the Danco Coast, Antarctic Peninsula, as reflected by the analysis of scats collected during the 1997/1998 and 1999/2000 summer seasons

	1998 ($n=105$)			2000 ($n=39$)		
	F (%)	*N* (%)	*M* (%)	*F* (%)	*N* (%)	*M* (%)
Fish	97.1	92.4	90.6	97.4	92.3	94.0
Crustaceans						
Euphausia superba	5.7	0.2	0.0	18.0	0.9	0.0
Decapods	1.0	0.1	0.1	–	–	–
Amphipods						
Gammarids	2.9	0.1	0.0	2.6	0.1	0.0
Isopods						
Glyptonotus antarcticus	1.0	0.0	0.0	5.1	0.2	0.1
Serolis sp.	1.9	0.1	0.0	–	–	–
Others	16.2	0.7	–	7.7	0.4	0.0
Molluscs						
Cephalopods						
Octopods						
Pareledone sp.	19.1	1.1	3.5	18.0	1.5	2.8
Teuthoids						
Psychroteutis glacialis	39.1	2.6	5.7	33.3	1.7	3.0
Other	1.0	0.0	0.1	–	–	–
Gastropods						
Nacella concinna	2.9	0.1	0.0	2.6	0.1	0.0
Others	3.8	0.1	0.0	–	–	–
Bivalves	19.1	2.4	0.1	7.7	2.8	0.1
Polychaetes	0.1	0.0	0.0	–	–	–

F frequencies of occurrence, *N* importance by number, *M* importance by mass; sample sizes in parentheses

Table 2 Fish represented by the otoliths found in scats of the Weddell Seal *Leptonychotes weddellii* collected at the Danco Coast, Antarctic Peninsula, during the 1997/98 and 1999/00 summer seasons

	1998 ($n=105$)			2000 ($n=39$)		
	F (%)	*N* (%)	*M* (%)	*F* (%)	*N* (%)	*M* (%)
Myctophidae						
Electrona antarctica	14.3	12.6	2.5	25.0	11.7	1.3
Gymnoscopelus braueri	1.9	0.4	0.1	–	–	–
Gymnoscopelus nicholsi	7.6	4.1	5.5	11.1	2.4	2.4
Protomyctophum normani	1.9	0.4	0.1	–	–	–
Channichthyidae						
Chaenodraco wilsoni	2.9	10.2	30.6	11.1	6.2	25.0
Chionodraco rastrospinosus	2.9	0.6	4.0	11.1	10.0	33.4
Cryodraco antarcticus	–	–	–	8.4	2.8	3.9
Pagetopsis macropterus	–	–	–	2.8	1.0	1.7
Pseudochaenichthys georgianus	–	–	–	2.8	0.3	1.1
Nototheniidae						
Gobionotothen gibberifrons	9.5	2.4	15.6	2.8	0.7	1.4
Lepidonotothen nudifrons	1.9	0.8	1.4	–	–	–
Pleuragramma antarcticum	25.7	46.6	31.4	13.9	33.7	29.7
Trematomus bernacchii	2.9	1.0	4.8	5.6	0.7	0.2
Trematomus scotti	4.8	1.8	4.0	–	–	–
Paralipididae						
Notolepis coatsi	0.1	0.2	0.1	2.8	0.3	0.1
Unidentified	24.8	18.7	–	33.3	30.2	–

F frequencies of occurrence, *N* importance by number, *M* importance by mass; sample sizes in parentheses

fish prey size ranges were 3.2–29.4 cm in 1998 and 4.0–28.4 cm in 2000 (Table 3). The overall fish length varied between the seasons (Mann–Whitney *U* test, $P<0.0001$). Within species there were also significant differences between the seasons in the length of the specimens of *C. wilsoni* (Mann–Whitney *U* test, $P<0.01$) and *P. antarcticum* ($P<0.0001$). The length of the *E. antarctica* specimens represented in both summer seasons did not differ statistically, whereas, due to the scarce number of individuals represented in the samples, the remaining species were not tested.

Discussion

As observed in other study areas (Green and Burton 1987; Plötz et al. 1991; Casaux et al. 1997; Burns et al. 1998; among others), the diet of the Weddell Seal at the

Table 3 Total length (mean in cm, standard deviation and range) of the fish represented in scats of the Weddell Seal *Leptonychotes weddellii* collected at the Danco Coast, Antarctic Peninsula, during the 1997/1998 and 1999/2000 summer seasons; sample sizes in parentheses

	1998 ($n=105$)			2000 ($n=39$)		
	Mean	SD	Range	Mean	SD	Range
Myctophidae						
Electrona antarctica	5.7	0.9	3.2–7.4	5.9	1.0	4.0–8.0
Gymnoscopelus braueri	7.0	2.8	5.0–8.9	–	–	–
Gymnoscopelus nicholsi	13.3	3.3	7.6–17.9	16.1	1.3	14.1–18.0
Protomyctophum normani	6.7	0.3	6.4–6.9	–	–	–
Channichthyidae						
Chaenodraco wilsoni	15.3	3.5	9.5–29.4	20.5	5.6	13.1–28.4
Chionodraco rastrospinosus	19.0	3.4	15.5–22.3	19.0	3.7	13.4–24.8
Cryodraco antarcticus	–	–	–	19.3	4.7	13.2–25.0
Pagetopsis macropterus	–	–	–	20.4	0.9	19.4–21.0
Pseudochaenichthys georgianus	–	–	–	26.2	–	–
Nototheniidae						
Gobionotothen gibberifrons	19.8	5.7	11.6–28.4	18.4	0.5	18.0–18.7
Lepidonotothen nudifrons	10.9	6.6	5.2–17.5	–	–	–
Pleuragramma antarcticum	10.6	1.8	7.5–22.7	15.1	1.9	8.4–19.1
Trematomus bernacchii	18.1	3.0	13.7–21.6	10.1	1.9	8.8–11.4
Trematomus scotti	11.6	1.9	6.8–13.0	–	–	–
Paralipididae						
Notolepis coatsi	18.5	–	–	16.8	–	–
Overall	11.0	4.0	3.2–29.4	14.6	5.2	4.0–28.4

Danco Coast was diverse and composed of both pelagic and benthic-demersal organisms (Table 1). Several authors suggested that seals foraged on pelagic or on benthic-demersal resources according to the prey availability or to the foraging areas/depths exploited (Green and Burton 1987; Plötz et al. 1991, 2001; Green et al. 1992; Casaux et al. 1997). Burns et al. (1998) commented that stable isotope and dive data analyses carried out at McMurdo Sound indicated that while most seals foraged predominantly on pelagic fish and squids, some juvenile concentrated on shallow benthic preys. Given the age range of the individuals observed at the study area (see above), this last finding also helps to explain the diverse composition of the diet observed in seals at the Danco Coast.

Previous studies carried out at East Antarctica, the Weddell Sea and the Ross Sea have indicated that fish largely constituted the main component in the diet of the Weddell Seal (Dearborn 1965; Øritsland 1977; Weiner et al. 1981; Plötz 1986; Plötz et al. 1991; Green and Burton 1987; Green et al. 1995; among others) or, at least, of similar importance to octopods (Bertram 1940). Casaux et al. (1997) observed that although fish were the most frequent and numerous preys, octopods constituted the bulk of the diet of seals at Harmony Point, South Shetland Islands. Although in that study the contribution of fish to the diet of seals might have been underestimated (Casaux et al. 1997), the importance of octopods as prey was also indicated for other localities of the South Shetland Islands (Lipinski and Woyciechowski 1981; Clarke and MacLeod 1982). Our results from the Antarctic Peninsula indicate that fish largely predominated in the diet, whereas, except cephalopods, the remaining preys were scarcely represented, thus resembling the foraging habits reported for East Antarctica, the Weddell Sea and the Ross Sea.

Regarding fish, most of the studies carried out at East Antarctica, the Weddell Sea (but see Plötz et al. 1991) and the Ross Sea (Plötz 1986; Green and Burton 1987; Green et al. 1995; Burns et al. 1998; among others) indicated that *P. antarcticum* was the most important prey for Weddell seals. Other nototheniid species and channichthyids were secondary fish preys at those areas, except at the Weddell Sea during the spring of 1986 when, due to the low abundance of *P. antarcticum* at seals foraging areas, those fish constituted the bulk of the diet (Plötz et al. 1991). *Pleuragramma antarcticum* was also absent in the diet of Weddell seals during the summer of 1996 at Harmony Point, South Shetland Islands, whereas myctophids (mainly *Gymnoscopelus nicholsi*) followed by other nototheniid species were the dominant fish prey (Casaux et al. 1997). Although in the present study *P. antarcticum* was one of the most important fish prey, the contribution of channichthyids to the diet of this seal was higher than previously reported.

A similar pattern of fish consumption reported here for the Weddell seal was observed in the Antarctic fur seal *Arctocephalus gazella* also at the Danco Coast during the summers of 1998 and 2000 (Casaux et al. 2003c). Although the Antarctic fur seal preyed more intensively than the Weddell seal on the Antarctic krill, a strong competition for the fish resources between both species seems to occur at this area. Similarly, although there was no overlap in the main non-fish prey consumed by Weddell seals (mainly cephalopods) and Antarctic fur seals (mainly Antarctic krill) during the 1996-1997 summer season at Nelson Island, South Shetland Islands, both seals preyed intensively on myctophids (mainly *G. nicholsi* and *E. antarctica*), which represented 88.9 and 97.6% of the fish mass consumed by both species respectively (see Casaux et al. 1997, 1998). As observed, at least at the South Shetland Islands and the Antarctic Peninsula, Weddell and Antarctic fur seals share water column fish resources. This pattern of niche overlap between both seals was never reported in the literature and concurrent studies on the diet and diving behaviour of these species are required to understand on this matter.

Among water column fish prey, the relative contribution of *P. antarcticum* and myctophids to the diet of Weddell seals at the Antarctic Peninsula (this study) and the South Shetland Islands (Casaux et al. 1997) was similar to the observed in the Antarctic fur seal at both areas (Casaux et al. 1998, 2003a, c, 2004). These studies support the suggestion of Casaux et al. (1997) indicating that myctophids occupy the role of *P. antarcticum* in waters around the South Shetland Islands. Interestingly, the overall agreement within areas in the pattern of fish consumption between Weddell seals and Antarctic fur seals at the Danco Coast and at Harmony Point, South Shetland Islands evidences the opportunistic foraging behaviour of these seals, perhaps reflecting the fish availability at the feeding areas. This fact encourages the possibility of using, after calibration studies, the composition of the diet of these seals as a gross indicator of fish distribution/availability.

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