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Geographical variation in the diet of the Antarctic fur seal *Arctocephalus gazella*

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Abstract The diet of non-breeding male Antarctic fur seals *Arctocephalus gazella* was investigated at different localities of the Antarctic Peninsula (Cierva Point and Hope Bay), South Shetland Islands (Deception Island and Potter Peninsula) and the South Orkney Islands (Laurie Island), by the analysis of 438 scats collected from January to March 2000. The composition of the diet was diverse, with both pelagic and benthic-demersal prey represented in the samples. Antarctic krill *Euphausia superba* was the most frequent and numerous prey at all the study sites except at Cierva Point, followed by fish, penguins and cephalopods. Antarctic krill also predominated by mass, followed by either fish or penguins. Fish were the second most important prey by mass at the Antarctic Peninsula whereas penguins were the second most important prey by mass at the South Shetland and South Orkney Islands. Among fish, *Pleuragramma antarcticum* was the most important species in the diet of the Antarctic fur seals at the Antarctic Peninsula whereas *Gymnoscopelus nicholsi* predominated at the South Shetland and South Orkney Islands. The results are compared with previous studies, and the possibility of implementing monitoring studies on the distribution/abundance of myctophids and *P. antarcticum* based on the analysis of the diet of the Antarctic fur seal is considered.

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Introduction

Top predators or key species of the ecosystem are increasingly being used as monitoring vehicles for the marine environment. It was observed that the monitoring of reproductive, populational or alimentary parameters of target species reflects changes in the ecosystem (see references in Furness and Greenwood 1993). Moreover, Montevecchi (1993) proposed that behavioural and reproductive buffers are highly responsive to environmental contingencies and can often generate useful environmental information including indication of the conditions of fish stocks.

Despite the extensive information on the macroscale distribution, mechanisms governing the distribution of Antarctic fish, mainly *Pleuragramma antarcticum* and myctophids, are still poorly understood (Kock 1992), and the relationship between fish distribution and environmental factors for the Southern Ocean can still only be described in very general terms (Nast et al. 1988). Information on fish abundance and distribution is of particular importance for the understanding and management of the Antarctic ecosystem and the administration of current or potential fish resources.

The Antarctic fur seal *Arctocephalus gazella* has a widespread distribution in the Southern Ocean (see Fischer and Hureau 1988; J. Bengtson, personal communication, quoted in Whitehouse and Veit 1994), and is a top predator that preys heavily on fish (e.g. Green et al. 1991; Reid 1995; Cherel et al. 1997; Casaux et al. 1998a, 2003; Klages and Bester 1998). Based on marked differences between seasons or localities in the contribution of different fish species to the diet of *A. gazella*, Casaux et al. (2003) suggested that the long-term study of concurrent information on the diet of the Antarctic fur seal from different localities may help to describe the patterns of distribution/abundance of *P. antarcticum* and myctophids. This kind of study could also help us to understand the processes determining the decrease in the contribution of *P. antarcticum* to the diet of several *P. antarcticum*-feeders at the South Shetland Islands during the last decade (see Casaux et al. 2003).

We present here information on the diet of non-breeding male Antarctic fur seals obtained at five localities of the Antarctic Peninsula (Cierva Point and Hope Bay), South Shetland Islands (Deception Island and Potter Peninsula) and the South Orkney Islands (Laurie Island) from January to March 2000. Additionally, this is the first study reporting on the diet of Antarctic fur seals at two previously unstudied localities: Hope Bay, at the tip of the Antarctic Peninsula, and Deception Island.

Materials and methods

A total of 438 scats of non-breeding male Antarctic fur seals was collected simultaneously at beaches surrounding Cierva Point (64°09′S, 60°57′W; $n=149$) and Hope Bay (63°24′S, 57°00′W; $n=33$), both at the Antarctic Peninsula; Deception Island (62°59′S, 60°41′W; $n=101$) and Potter Peninsula (62°14′S, 58°40′W; $n=62$), King George Island, both at the South Shetland Islands; and Laurie Island (60°44′S, 44°44′W; $n=93$), in the South Orkney Islands (Fig. 1), from January to March 2000.

The samples were washed individually through sieves (minimum mesh 0.54 mm). For the identification of the prey remains represented in the samples and the estimation of their contribution to the diet of seals by mass, we followed the methodology applied by Casaux et al. (2003).

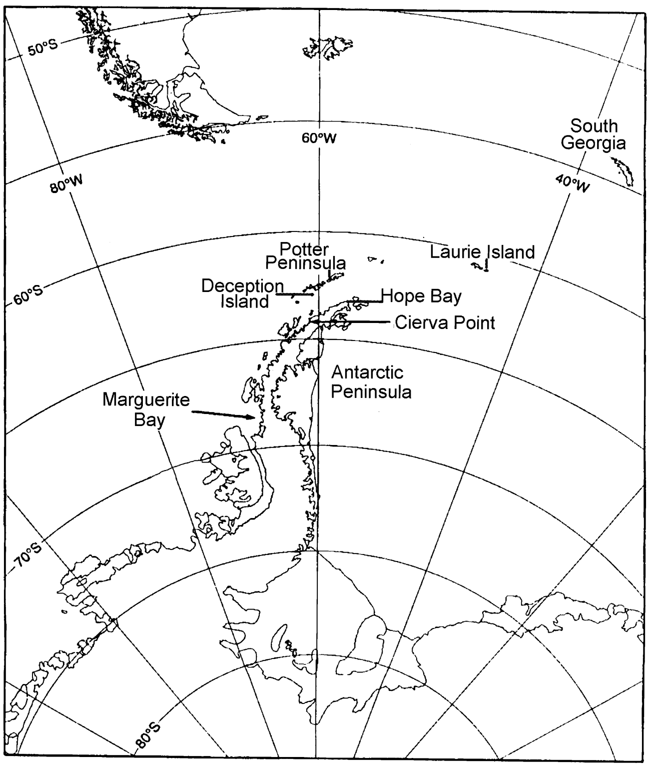

Fig. 1 Map showing the location of study sites at the Antarctic Peninsula, South Shetland Islands and South Orkney Islands

Since the estimates of the number and mass of prey species represented in scats usually gives biased results (see, for example, Clarke and MacLeod 1982; da Silva and Neilson 1985; Green and Burton 1987; Murie 1987; Casaux et al. 1997), the mass estimated of the different alimentary items do 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 and because, given that this is a comparative study, the results from the different study areas are similarly biased and so will not invalidate the conclusions.

Results

Of the samples collected at Cierva Point, Hope Bay, Deception Island, Potter Peninsula and Laurie Island, 100% (149 scats), 100% (33 scats), 100% (101 scats), 95.2% (59 scats) and 67.7% (63 scats) of the scats respectively, contained prey remains. The frequencies of occurrence presented below are referred to the number of samples containing prey remains.

The Antarctic krill *Euphausia superba* was the most frequent (except at Cierva Point) and numerous prey at all the study sites, being followed by fish, penguins and cephalopods (Table 1). Antarctic krill also predominated by mass (together with fish at Hope Bay), being followed by fish or penguins. Fish were the second most important prey by mass at the Antarctic Peninsula whereas penguins were the second most important prey by mass at the South Shetland and South Orkney islands.

The otoliths found in the scats represented 1212, 192, 1862, 25 and 339 fish at Cierva Point, Hope Bay, Deception Island, Potter Peninsula and Laurie Island, respectively, and 955, 172, 1723, 25 and 325 of them were identified as belonging to the families Bathylagidae, Paralepididae, Myctophidae, Nototheniidae, Bathydraconidae and Channichthyidae (Table 2). The otoliths from the remaining specimens were unidentifiable to species because they were broken or strongly eroded. Pelagic species predominated in the diet, and among them, *Electrona antarctica* was the most frequent fish prey at Cierva Point (followed by *P. antarcticum*), Deception Island (followed by *Gymnoscopelus nicholsi*) and Potter Peninsula (followed by *G. nicholsi*) whereas *P. antarcticum* (followed by *Chaenodraco wilsoni*) and *G. nicholsi* (followed by *E. antarctica*) were the most frequent fish prey at Hope Bay and Laurie Island, respectively. *Electrona antarctica* also predominated by number at Cierva Point and Potter Peninsula, with *P. antarcticum* the most numerous fish prey at Hope Bay and *G. nicholsi* at Deception and Laurie islands. *Pleuragramma antarcticum* was the fish species that most contributed to the diet of the Antarctic fur seals at the Antarctic Peninsula whereas *G. nicholsi* predominated at the South Shetland and South Orkney Islands.

Except for *P. antarcticum*, nototheniid species contributed little to the diet of Antarctic fur seals. The contribution by mass of channichthyids to the diet of seals was high at Cierva Point and tended to decrease to the north; the importance by mass of *C. wilsoni* at

Table 1 The composition of the diet of non-breeding male Antarctic fur seals at different localities of the Antarctic Peninsula, South Shetland Islands and South Orkney Islands, as reflected by the analysis of scats collected during the 1999/2000 summer season. Percentage frequencies of occurrence (*F*%), number (*N*%) and mass (*M*%), sampling size in parentheses

	Cierva Point (149)			Hope Bay (33)			Deception Island (101)			Potter Peninsula (62)			Laurie Island (63)		
	F%	*N*%	*M*%	*F*%	*N*%	*M*%	*F*%	*N*%	*M*%	*F*%	*N*%	*M*%	*F*%	*N*%	*M*%
Poriferans	0.7	0.0	0.0	–	–	–	–	–	–	–	–	–	–	–	–
Crustaceans															
Krill	85.2	97.8	60.6	54.6	91.6	40.7	91.1	98.4	47.5	100	99.9	76.6	85.7	99.2	58.6
Isopods	0.7	0.0	0.0	–	–	–	–	–	–	–	–	–	–	–	–
Pycnogonids	–	–	–	–	–	–	–	–	–	–	–	–	1.6	0.0	0.0
Molluscs															
Cephalopods															
Octopods															
Pareledone sp.	0.7	0.0	0.3	3.0	0.0	3.8	–	–	–	–	–	–	–	–	–
Squids															
P. glacialis	14.1	0.0	3.0	–	–	–	6.9	0.0	0.3	1.0	0.0	0.0	3.2	0.0	1.2
Gastropods															
Nacella concinna	0.7	0.0	0.0	–	–	–	–	–	–	–	–	–	3.6	0.0	0.0
Others	1.3	0.0	0.0	–	–	–	–	–	–	1.9	0.0	0.0	1.6	0.0	0.0
Bivalves	1.3	0.0	0.0	–	–	–	–	–	–	–	–	–	–	–	–
Fish	90.6	2.2	30.9	54.6	8.4	40.0	72.3	1.6	13.5	7.8	0.0	0.4	41.3	0.8	15.3
Penguins	1.3	0.0	5.2	3.0	0.0	15.5	31.7	0.0	38.7	8.5	0.0	23.0	9.5	0.0	24.8

Table 2 Fish represented by the otoliths found in scats of non-breeding male Antarctic fur seals collected at different localities of the Antarctic Peninsula, South Shetland Islands and South Orkney Islands, during the 1999/2000 summer season. Percentage frequencies of occurrence (*F*%), number (*N*%) and mass (*M*%), sampling size in parentheses

	Cierva Point (149)			Hope Bay (33)			Deception Island (101)			Potter Peninsula (62)			Laurie Island (93)		
	F%	*N*%	*M*%	*F*%	*N*%	*M*%	*F*%	*N*%	*M*%	*F*%	*N*%	*M*%	*F*%	*N*%	*M*%
Bathylagidae															
Bathylagus antarcticus	0.7	0.1	0.0	–	–	–	–	–	–	–	–	–	–	–	–
Paralepididae															
Notolepis coatsi	–	–	–	–	–	–	1.0	0.1	0.2	–	–	–	–	–	–
Myctophidae															
Electrona antarctica	61.1	33.3	5.3	–	–	–	60.4	44.2	11.1	8.5	64.0	20.2	15.9	10.6	1.6
Electrona carlsbergi	2.7	0.6	0.3	–	–	–	–	–	–	–	–	–	–	–	–
Gymnoscopelus braueri	5.4	0.7	0.2	–	–	–	4.0	0.3	0.2	–	–	–	–	–	–
Gymnoscopelus fraseri	–	–	–	–	–	–	1.0	0.1	0.0	–	–	–	–	–	–
Gymnoscopelus nicholsi	19.5	14.2	15.5	–	–	–	59.4	46.2	84.1	3.8	32.0	61.5	36.5	82.6	88.8
Krefftichthys anderssoni	–	–	–	–	–	–	1.0	0.1	0.0	–	–	–	–	–	–
Protomyctophum sp.	1.3	0.3	0.1	–	–	–	1.0	0.1	0.0	–	–	–	–	–	–
Nototheniidae															
Lepidonotothen kempi	–	–	–	3.0	0.5	1.1	–	–	–	–	–	–	–	–	–
Lepidonotothen nudifrons	0.7	0.1	0.1	–	–	–	2.0	0.1	0.1	–	–	–	–	–	–
Nototheniops larseni	1.3	0.2	0.1	–	–	–	–	–	–	–	–	–	4.8	1.5	2.0
Pagothenia bernacchii	0.7	0.1	0.0	–	–	–	–	–	–	–	–	–	–	–	–
Pleuragramma antarcticum	48.3	17.6	27.6	39.4	83.9	86.6	8.9	1.2	2.9	–	–	–	1.6	0.3	0.7
Trematomus newnesi	4.0	0.7	0.7	–	–	–	–	–	–	–	–	–	–	–	–
Bathydraconidae															
Parachaenichthys charcoti	0.7	0.1	0.4	–	–	–	–	–	–	–	–	–	–	–	–
Channichthyidae															
Chaenocephalus aceratus	–	–	–	–	–	–	–	–	–	–	–	–	1.6	0.3	3.9
Chaenodraco wilsoni	12.1	3.6	20.5	9.1	2.1	5.8	0.1	0.1	0.2	1.0	4.0	18.3	–	–	–
Chionodraco rastrospinosus	15.4	4.9	22.3	3.0	3.1	6.5	3.0	0.3	1.2	–	–	–	–	–	–
Cryodraco antarcticus	8.7	2.2	5.6	–	–	–	–	–	–	–	–	–	1.6	0.6	3.1
Pagetopsis macropterus	2.7	0.3	1.2	–	–	–	–	–	–	–	–	–	–	–	–
Unidentified	43.6	21.2	–	21.2	10.4	–	30.7	7.5	–	–	–	–	11.1	4.1	–

Potter Peninsula is an artefact given that, due to the scarce number of samples containing fish remains, a single specimen of this species represented 18.3% of the diet.

The estimated total length of the fish represented in the samples ranged from 3.5 cm (*E. antarctica*) to 36.4 cm (*Chaenocephalus aceratus*) (Table 3). The length of the fish consumed varied in the different areas

Table 3 Mean length ($\bar{x}$, in cm), standard deviation (*sd*) and size range of the fish represented by the otoliths found in scats of non-breeding male Antarctic fur seals collected at different localities of the Antarctic Peninsula, South Shetland Islands and South Orkney Islands, during the 1999/2000 summer season

	Cierva Point			Hope Bay			Deception I.			Potter P.			Laurie I.		
	$\bar{x}$	sd	Range	$\bar{x}$	sd	Range	$\bar{x}$	sd	Range	$\bar{x}$	sd	Range	$\bar{x}$	sd	Range
Bathylagidae															
Bathylagus antarcticus	9.4	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Paralepididae															
Notolepis coatsi	–	–	–	–	–	–	25.7	1.0	25.0–26.4	–	–	–	–	–	–
Myctophidae															
Electrona antarctica	6.0	0.9	3.5–8.2	–	–	–	5.9	0.9	3.5–8.3	6.4	0.7	4.7–7.1	6.2	0.7	4.6–7.3
Electrona carlsbergi	7.9	1.1	5.7–8.9	–	–	–	–	–	–	–	–	–	–	–	–
Gymnoscopelus braueri	8.3	1.2	5.6–9.2	–	–	–	8.3	0.9	7.0–9.2	–	–	–	–	–	–
Gymnoscopelus fraseri	–	–	–	–	–	–	5.6	–	–	–	–	–	–	–	–
Gymnoscopelus nicholsi	14.6	2.0	7.8–19.2	–	–	–	14.6	2.3	6.5–19.9	14.9	2.0	10.2–16.0	15.4	1.7	8.2–19.1
Krefftichthys anderssoni	–	–	–	–	–	–	8.4	–	–	–	–	–	–	–	–
Protomyctophum sp.	7.6	0.1	7.5–7.7	–	–	–	7.4	–	–	–	–	–	–	–	–
Nototheniidae															
Lepidonotothen kempi	–	–	–	15.0	–	–	–	–	–	–	–	–	–	–	–
Lepidonotothen nudifrons	10.6	–	–	–	–	–	11.2	0.6	10.8–11.7	–	–	–	–	–	–
Nototheniops larseni	10.8	0.7	10.4–11.3	–	–	–	–	–	–	–	–	–	14.6	1.5	12.7–16.2
Pagothenia bernacchii	8.8	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Pleuragramma antarcticum	16.5	2.0	9.0–20.6	15.9	1.7	12.5–23.9	15.9	2.9	6.9–20.8	–	–	–	19.4	–	–
Trematomus newnesi	9.7	0.9	8.3–10.7	–	–	–	–	–	–	–	–	–	–	–	–
Bathydraconidae															
Parachaenichthys charcoti	17.1	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Channichthyidae															
Chaenocephalus aceratus	–	–	–	–	–	–	–	–	–	–	–	–	36.4	–	–
Chaenodraco wilsoni	21.2	4.1	13.4–33.1	18.7	4.7	13.7–24.9	17.6	–	–	17.8	–	–	–	–	–
Chionodraco rastrospinosus	19.4	2.6	12.6–25.2	16.4	2.0	14.3–20.1	16.1	2.5	13.1–18.5	–	–	–	–	–	–
Cryodraco antarcticus	20.8	3.7	12.8–27.6	–	–	–	–	–	–	–	–	–	27.0	0.1	26.4–27.7
Pagetopsis macropterus	22.3	4.8	17.1–28.7	–	–	–	–	–	–	–	–	–	–	–	–
Overall	12.0	5.9	3.5–33.1	16.0	1.9	12.5–24.9	10.5	4.7	1.3–26.4	9.6	4.5	4.7–17.8	14.3	3.6	4.6–36.4

(ANOVA, $F_{4,3200} = 35.2$, $P < 0.00001$). The largest fish were ingested at Hope Bay (Newman-Keuls, $P < 0.001$, compared to the remaining areas) whereas the smallest ones were ingested at Potter Peninsula (Newman-Keuls, $P < 0.05$, compared to Cierva Point, Hope Bay and Laurie Island). The overall size of the fish ingested at the different study sites was positively correlated (Spearman test, $r = 0.90$, $P < 0.05$) with the importance of fish by mass in the diet of seals at those sites. Within species, there were also significant differences between localities in the length of the specimens of *Chionodraco rastrospinosus* ($F_{2,70} = 7.5$, $P < 0.01$), *E. antarctica* ($F_{3,1279} = 2.9$, $P < 0.05$), *G. nicholsi* ($F_{3,1320} = 4.7$, $P < 0.01$) and *P. antarcticum* ($F_{2,396} = 3.6$, $P < 0.05$). The largest specimens of *C. rastrospinosus* (Newman-Keuls, $P < 0.05$) and *P. antarcticum* (Newman-Keuls, $P < 0.05$) were ingested at Cierva Point whereas the largest *E. antarctica* (Newman-Keuls, ns) and *G. nicholsi* (Newman-Keuls, $P < 0.05$) were ingested at Potter Peninsula and Laurie Island, respectively.

Discussion

The diet of the Antarctic fur seal was extensively studied throughout its distribution range. Previous studies developed out of the study area were based on breeding individuals (North et al. 1983; Green et al. 1990; Reid and Arnould 1996; Kirkman et al. 2000; among others) or on non-breeding individuals during autumn and winter (Green et al. 1991; Reid 1995; North 1996). Due to the differences in the reproductive status of the individuals studied or in the sampling period, our results are not comparable with those obtained at other localities.

As previously reported for the study area (Daneri and Coria 1992; Daneri 1996; Daneri and Carlini 1999; Casaux et al. 2002, 2003), the analysis of the scats collected at the different localities considered in this study indicated that krill and fish were the most frequent and numerous prey of non-breeding male Antarctic fur seals during summer. Krill was also the prey that most contributed to the diet by mass. Fish were the second most important prey by mass at the Antarctic Peninsula whereas penguins were the second most important prey by mass at the South Shetland and South Orkney Islands. The importance of penguins as prey of the Antarctic fur seal at these two archipelagos was previously reported by Daneri and Coria (1992) and Casaux et al. (1998a, 2002). The relatively low contribution of penguins to the diet of seals at the Antarctic Peninsula might be related to their lower abundance in this area compared to that reported for the South Shetland and South Orkney Islands (see Casaux et al. 2003). The consumption of penguins at Hope Bay, the tip of the Antarctic Peninsula, reflects the local availability of these birds (120,000 pairs, A. Carlini, unpublished data) at that locality.

The overall size of the fish ingested at the different study sites was positively correlated with the importance of fish by mass in the diet of seals at those sites. Among other possibilities, this might be indicating a positive selection of larger fish by seals. Regarding fish, the most interesting point is the relative contribution of *P. antarcticum* and myctophids (mainly *E. antarctica* and *G. nicholsi*) to the diet of seals from the different areas considered here. Whereas *P. antarcticum* was the most important fish prey by mass at the Antarctic Peninsula, *G. nicholsi* predominated at the South Shetland and South Orkney Islands. Coincidentally with this pattern, the frequency of occurrence of *P. antarcticum* in the samples increased to the south, and the overall contribution of myctophids to the diet by mass was relatively low at Cierva Point (21.4%); these fish were absent in the samples from Hope Bay at the tip of the Antarctic Peninsula, and ranged from 81.7% to 95.4% by mass at the South Shetland and South Orkney Islands. This pattern of fish consumption might be reflecting the fish availability within the seals' foraging areas at the different localities. The absence of recent comparative studies on the abundance of these fish throughout the study area prevents further analysis.

Previous information from the study area indicated that: (1) myctophids were the most numerous fish prey (96.3%) and that *P. antarcticum* was absent in samples from the South Orkney Islands (Daneri and Coria 1993); (2) during the last decade the importance of myctophids and *P. antarcticum* in the diet of the Antarctic fur seal at the South Shetland Islands has increased and decreased respectively, to the point that myctophids were the most important fish prey in samples from recent years (Daneri 1996; Casaux et al. 1998a, 2002; Daneri and Carlini 1999); and (3) *P. antarcticum* was the third most important prey by mass whereas myctophids were poorly represented (except *G. nicholsi*) in the diet of seals at the Antarctic Peninsula (Casaux et al. 2003). Our results agree with the patterns of fish consumption described in previous studies for the Antarctic Peninsula and South Orkney Islands and with those observed in recent years at the South Shetland Islands.

Top predators or key species of the ecosystem are increasingly being used as monitoring vehicles for the marine environment. Montevecchi (1993) proposed that behavioural and reproductive buffers are highly responsive to environmental contingencies and can often generate useful environmental information, including indication of the conditions of fish stocks. Casaux et al. (2003) suggested that co-ordinated long-term studies on the diet of the Antarctic fur seal from different localities may help to provide advice on the patterns of distribution/abundance of *P. antarcticum* and myctophids, which is of particular importance for the administration of these current or potential fish resources and for the management of the Antarctic ecosystem. The fact that our results are consistent with previous information on the diet of the Antarctic fur seal from the study area, and that the pattern of fish consumption observed in *A. gazella* during the last decade at the South Shetland Islands (see above) was also reflected in the analysis of the diet of other potential *P. antarcticum*-feeders such as Cape petrels (*Daption capense*), Weddell seals (*Leptonychotes weddelli*) and Antarctic terns (*Sterna vittata*) (Casaux et al. 1997, 1998b; R. Casaux, unpublished data), encourages the implementation of such monitoring programmes.

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