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ORIGINAL PAPER

Interannual variation in the diet of non-breeding male Antarctic fur seals, *Arctocephalus gazella*, at Isla 25 de Mayo/King George Island

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Abstract The diet of non-breeding male Antarctic fur seals, *Arctocephalus gazella*, was investigated at Stranger Point, King George Island, through the analysis of scats during three consecutive summer seasons (1996, 1997, 1998). Overall, fish and krill were the most frequent prey occurring, respectively, in an average of 82.9% and 78.8% of samples ($n = 131$), followed by penguins (22.8%) and cephalopods (17.8%). Myctophids constituted almost 90% of the fish predated, with *Electrona antarctica* and *Gymnoscopelus nicholsi* being the most abundant and frequent species consumed. All fish taxa identified were krill feeding species suggesting that seals foraged mainly on a krill and a fish community associated with krill aggregations. However, a seasonal change was observed in the relative proportions of the different prey taxa, with a progressive decrease with time in the occurrence of krill and a concomitant increase of fish, penguins and squid. Possible influence of the strong 1997/98 ENSO event is discussed.

Keywords Diet · *Arctocephalus gazella* · ENSO · South Shetland Islands

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Introduction

The Antarctic fur seal, *Arctocephalus gazella*, is widely distributed in the Southern Ocean with most of their breeding colonies occurring mainly on Islands south of the Antarctic Convergence, e.g. South Georgia, South Orkney, South Shetland, Heard, Kerguelen Islands and a few, Prince Edward, Marion, Crozet and Macquarie Islands lying north of it (Reeves et al. 1992). A considerable number of dietary studies of this species at different localities over its distributional range have been performed during the last two decades. Most of them, which have been based on scat analysis, reported that krill and fish constituted the bulk of their diet though the relative proportions of the different prey taxa varied according to sex, age, locality and season (Reid and Arnould 1996; Kirkman et al. 2000; Daneri et al. 2005a, among others). The abundance and spatial distribution of krill in the South Shetland Islands area are clearly dependent on different oceanographic and biological features and events operating both in the Scotia Sea area and the Antarctic Peninsula region (Priddle et al. 1988). These may result in local changes in prey availability, and therefore, contribute to inter or intra annual changes in the composition of fur seals diet (Reid and Arnould 1996; Ciaputa and Sicinski 2006). At Stranger Point, King George Island, every year from the end of January, there is an influx of non breeding male Antarctic fur seals reaching peak numbers between March and April. The aim of the present study was

to analyze the diet of juvenile/sub-adult male fur seals hauled out at Stranger Point during three consecutive summer seasons (1996, 1997,1998) and to detect whether or not there existed inter annual changes in the contribution of the different prey taxa to their diet.

Materials and methods

A total of 133 fresh fur seal scats were collected at Stranger Point (62° 14′ S; 58° 40′ W), Isla 25 de Mayo/King George Island, South Shetland Islands, from February to mid-March of three consecutive years ($n = 55$ in 1996, $n = 53$ in 1997, $n = 25$ in 1998). During these collection periods the maximum number of fur seals counted ashore in each year was 440, 239 and 73, respectively (G. Moreira, S. Poljak, R. Montiel, pers. com.). Two scats from 1998 season contained no prey remains and, therefore, excluded from further analysis. Where possible, the different prey taxa were identified to the lowest possible taxonomical level. Fish otoliths were identified by comparison with a reference collection stored at the Instituto Antártico Argentino and published otolith guides (Hecht 1987; Williams and McEldowney 1990; Reid 1996). Otoliths were assigned to three categories in increasing order of erosion: (1) good: little or no erosion with intact margins and medial relief; (2) some signs of smoothing of margins and medial relief; and (3) heavily eroded: with no medial relief and margins generally rounded. A correction factor was applied to compensate for this erosion (10% for group 1 and 20% for group 2) after Reid (1995). The length of otoliths in these two groups were measured to the nearest 0.01 mm. Heavily eroded specimens were considered unidentified and discarded. Fish size and mass were calculated from the corrected otolith length using regression equations given by Williams and McEldowney (1990) and Reid (1996). Cephalopod beaks were identified following Clarke (1986) and by comparison with a reference collection kept at the Instituto Antártico Argentino. Allometric equations were taken from Clarke (1986) to relate the lower rostral length (LRL) of beaks to dorsal mantle length (ML, in mm) and wet mass (M, in g). Given the unusually low occurrence of krill remains in those scats collected in 1998, random samples of at least 20 carapaces were removed and measured for carapace length (RCL) and carapace width (RCW). Following Staniland (2002) carapaces smaller than 13 mm were assigned as juveniles. Only for those carapaces of RCL > 13 mm, a linear discriminant function was applied to determine the sex of krill specimens after Reid and Measures (1998). For juvenile specimens, krill total length was then estimated using the formula given by Staniland (2002), while for adult specimens these were estimated using separate regression equations for males and females (Reid and Measures 1998).

Results

Fish was the most frequent prey item, occurring on average, in 82.9% (range through years 67.3–94.3) of scats during the overall study period, followed by krill, which occurred in 78.8% (range 60.9–96.4). Of lesser importance were penguins and cephalopods which occurred, respectively, in 22.8% (range 5.5–47.8) and 17.8% (range 7.3–34.8) of scats, respectively. The presence of other prey taxa was negligible (Table 1; Fig. 1). There were significant differences in the frequency of occurrence of these 4 taxa between years ($X^2_6 = 27.1$; $P < 0.01$). Considering only the two major prey items during the whole period of study, krill and fish co-occurred in 64.9% of samples ($n = 85$), krill occurred alone in 18.3% ($n = 24$) and fish alone in 16.8% ($n = 22$). There were significant differences between years in the proportion of scats containing krill and/or fish either alone or combined ($X^2_4 = 25.9$; $P < 0.01$). The estimated mean total length of krill predated was 43.1 ± 3.2 mm (range 30.4–53.9 mm) and the modal size taken was 44.2 mm (Fig. 2). Sixty-one percent of the krill specimens analyzed corresponded to juvenile stages. The remainder (39%) were sexed. Of these, 84.7% were males and 15.3% were females.

Table 1 Percentage frequency of occurrence of remains in scats of *A. gazella* at Stranger Point

Taxon	1996	1997	1998
Krill	96.4	79.2	60.9
Fish	67.3	94.3	87.0
Cephalopods	7.3	11.3	34.8
Penguins	5.5	15.1	47.8
Nematodes	5.5	13.2	43.5
Acantocephalans	1.8	1.9	0.0
Algae	18.2	3.8	43.5
Gastropods	1.8	1.9	0.0
Bivalves	3.6	0.0	0.0
Total scats	55	53	25 (2)

Value in brackets refer to empty scats excluded from analysis

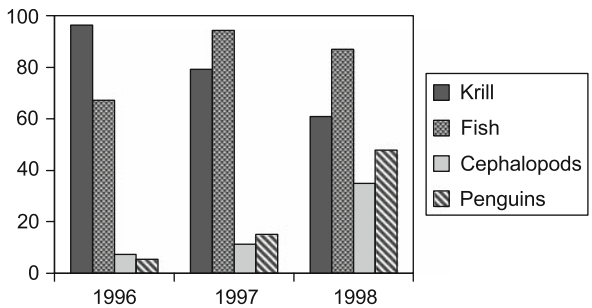

Fig. 1 Percent frequency of occurrence of the four main prey items recovered from scats of *A. gazella* at King George Island

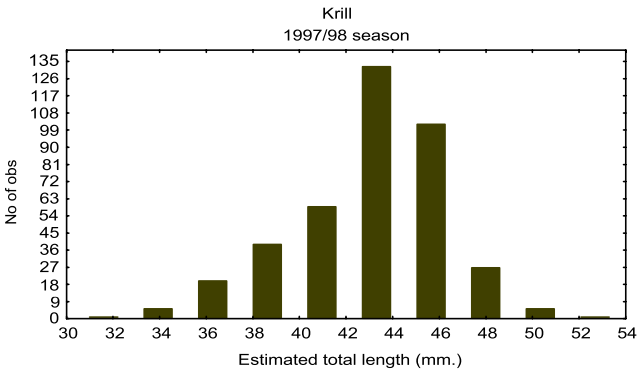

Fig. 2 Estimated length frequency distribution of krill preyed on by seals during the 1997/98 season

Fish were represented by a total of 2,493 otoliths during the whole study period at a rate of 9.3 otoliths per scat in 1996; 38.3 in 1997 and 12.5 in 1998. Myctophids dominated the fish portion of the diet of fur seals representing over 90% of the otoliths removed. In all seasons, *E. antarctica* and *G. nicholsi* were the most frequent and dominant prey species constituting together, on average, almost 85% of the fish predated both in terms of number and mass. Of the remaining fish taxa, the paralepidid *Notolepis coatsi* was the only one that occurred, on average, in more than 10% of scats, contributing 10.1% by mass to the fish diet of the seals in the overall study period. Nototheniids were uniquely represented by the Antarctic silverfish, *Pleuragramma antarcticum* the presence of which was negligible overall, although its contribution in numbers and mass apparently increased in 1998. Finally, channichthyid fish were either scarcely represented (1996 and 1997), or completely absent (1998) (Table 2). The estimated size of the fish ingested ranged from 46.7 mm standard length (*E. antarctica*) to 465.7 mm total length (*Notolepis coatsi*). There were significant inter annual differences in the mean sizes of *E. antarctica* preyed upon by fur seals (mean 86.4 ± 9.7 mm in 1996; mean 83.9 ± 8.6 mm in 1997; mean 85.0 ± 10.3 mm in 1998) (Nested Anova $P < 0.01$), the difference lying between the 1996 and 1997 seasons exclusively (Tukey test $P < 0.01$). For *G. nicholsi,* there were also significant inter annual differences in the mean sizes taken (mean $143.3 \text{ mm} \pm 14.7$ in 1996; mean $143.1 \text{ mm} \pm 11.9$ in 1997; mean $150.1 \text{ mm} \pm 10.1$ in 1998) (Nested Anova $P < 0.01$). In this case, the 1998 season differed from the others (Tukey test <0.01). Furthermore, for both species, there was not a clear trend with time in the modal size class preyed upon by seals (Figs. 3, 4).

Table 2 Composition of the fish remains recovered from scats of Antarctic fur seals on King George Island expressed as percent frequency of occurrence (%F), percentage numerical abundance (%N) and percentage of total mass (%M)

Fish prey taxon	Summer 1996						Summer 1997						Summer 1998					
	F	%F	N	%N	M	%M	F	%F	N	%N	M	%M	F	%F	N	%N	M	%M
Myctophidae																		
Electrona antarctica	30	85.7	137	41.9	619.7	19.1	48	96	1022	53.4	4000.1	24.5	8	40	57	22.7	231.5	17.1
Gymnoscopelus nicholsi	19	54.3	132	40.4	2205.6	67.9	36	72	716	37.4	9638.2	59.1	13	65	136	54.2	911.6	67.3
Gymnoscopelus braueri	2	5.7	2	0.6	7.4	0.2	5	10	5	0.3	19.0	0.1	1	5	1	0.4	5.1	0.4
Protomyctophum tenisoni	1	2.9	1	0.3	1.8	0.1	4	8	8	0.4	14.8	0.1						
Krefftichthys anderssoni	1	2.9	1	0.3	2.3	0.1	14	28	19	1.0	45.7	0.3	1	5	1	0.4	9.5	0.7
Protomyctophum choriodon	2	5.7	2	0.6	10.9	0.3												
Protomyctophum sp							3	6	5	0.3			2	10	3	1.2		
Myctophidae indet.	1	2.9	2	0.6			4	8	9	0.5			3	15	7	2.8		
Channichthyidae																		
Chaenodraco wilsoni	2	5.7	3	0.9	114.9	3.5												
Chionodraco rastrospinosus	1	2.9	1	0.3	86.5	2.7	4	8	10	0.5	435.1	2.7						
Chionodraco sp.	2	5.7	7	2.1			2	4	4	0.2								
Pagetopsis sp.							2	4	4	0.2								
Cryodraco antarcticus							2	4	3	0.2	198.4	1.2						
Channichthyidae indet.	4	11.4	14	4.3			10	20	35	1.8								
Nototheniidae																		
Pleuragramma antarcticum	2	5.7	2	0.6	30.9	1.0	1	2	1	0.1	11.2	0.1	1	5	37	14.7	171.4	12.6
Paralepididae																		
Notolepis coatsi	4	11.4	5	1.5	169.8	5.2	14	28	67	3.5	1933.1	11.9	1	5	1	0.4	26.1	1.9
Unidentified	5	14.3	18	5.5			6	12	7	0.4			5	25	8	3.2		
Total			327	100.0	3249.8	100.0			1915	100.0	16296	100.0			251	100.00	1355	100.0

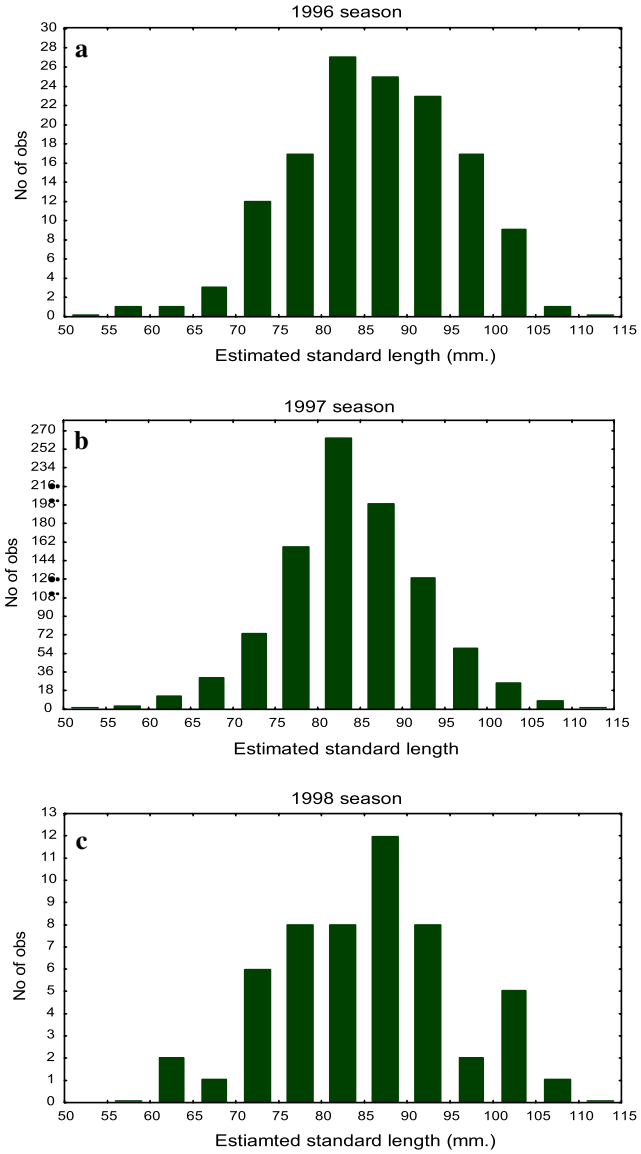

Fig. 3 **a**–**c** The estimated length frequency distribution of *Electrona antarctica* in (**a**) 1996, (**b**) 1997, (**c**) 1998

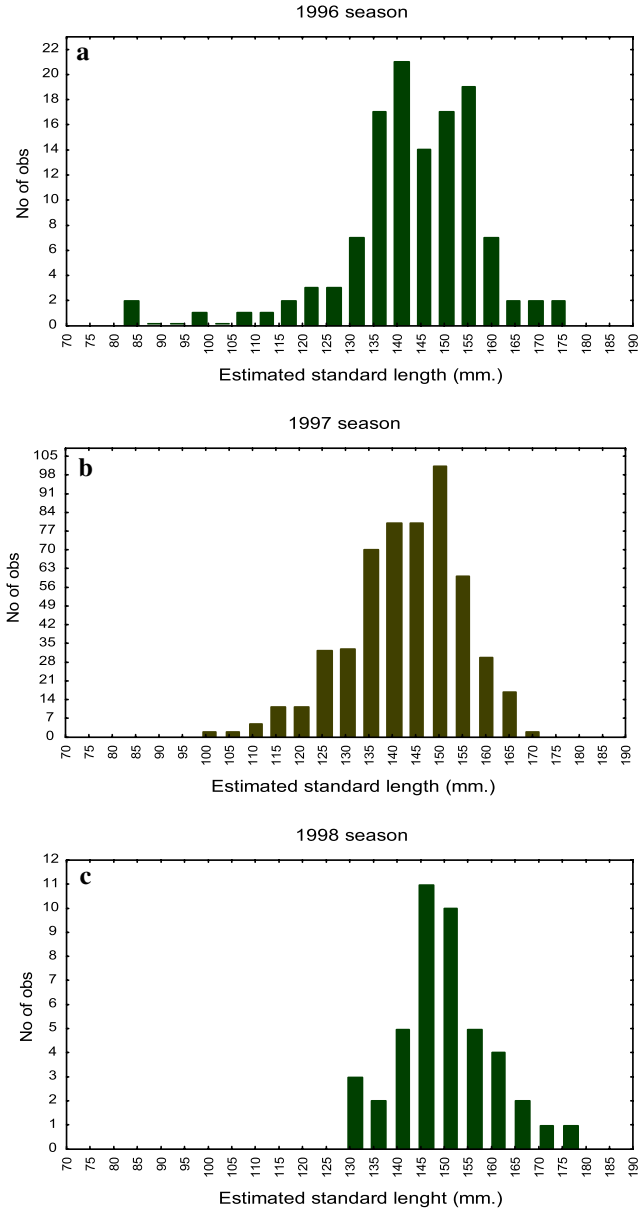

Fig. 4 **a**–**c** The estimated length frequency distribution of *Gymnoscopelus nicholsi* in (**a**) 1996, (**b**) 1997, (**c**) 1998

Cephalopods were represented, in total, by 36 beaks (19 upper and 17 lower) and 13 eye lenses which were removed from 18 of the 131 scats analysed. Identification of lower beaks showed that *Slozarsykowia circumantarctica* was the only squid prey species with a LRL ranging from 2 to 3.3 mm, representing specimens of 56.7–81.9 mm ML and 4.6–9.1 g wet mass.

Discussion

Fish and krill were the most frequent prey occurring in average in 82.9 and 78.8% of scats, respectively, during the total study period. The proportion of scats containing krill alone was highest in 1996 (32.7%) while that containing only fish was highest in 1998 (39.1%). In this regard Reid (1995) and Casaux et al. (1998), studying the diet of *A. gazella* reported that krill and fish co-occurred together in most of fur seal faeces analyzed at South Georgia and Nelson Island, respectively. The number of scats containing a single prey item was higher if this item was fish rather than krill. Our study showed a similar pattern with the exception of the 1996 season where scats containing krill alone were higher than those containing only fish (32.7 vs. 2.6%).

The mean size of krill ingested by fur seals in 1998 was higher than that reported by Osman et al. (2004) for *A. gazella* at Cape Shirreff, Livingston Island, in the same season (43.1 ± 3.2 vs. 40.9 ± 0.2 mm). Furthermore, these authors

indicated that the proportions of juvenile, male and female krill found in fur seal scats across the whole study period (1998–2001) changed significantly over time with increasing proportion of females and a reduction in juvenile stages. Specifically for the 1998 season almost 70% of krill predated were juvenile forms. This agrees with our results which showed that juvenile stages comprised more than 60% of the krill predated. Additionally, the male and female component of the older stages of krill were represented by relatively similar proportions in both studies (ca. 90 vs. 10%, respectively). It is known that the different developmental stages of krill have a characteristic spatial segregation with juveniles inhabiting shelf waters of the Antarctic peninsula and South Shetland Archipelago and adult stages mainly occurring over the continental slope and in the open ocean (Jazdzewski et al. 1978; Siegel 2000). Hence, we surmise that in the 1998 season fur seals centered their foraging activity in inshore zones. This is supported by the fact that, in that year, the myctophid *G. nicholsi* was the dominant fish prey species of *A. gazella* at Stranger Point, accounting for 54.2% in numbers and 67.3% in mass of the total fish predated. Although this species leads a pelagic existence, it commonly occurs in shelf areas (Williams and McEldowney 1990).

Myctophids were the most frequent fish prey representing, on average, over 85% of the total fish predated both in numbers and mass, with *E. antarctica* and *G. nicholsi* the dominant species. These two taxa showed a clear and uniform dominance throughout the whole study period though the latter, as stated before, became more important in 1998 in comparison with the former one, showing a marked increase in terms of occurrence and abundance (Table 2). Osman et al. (2004) also found that these same myctophid species dominated the fish diet of *A. gazella* at Cape Shirreff. In addition, based on their estimated sizes and through the analysis of the relationship between standard length and sexual maturity (Hulley 1990) they concluded that fur seals preyed upon immature stages of *G. nicholsi* and both mature and immature *E. antarctica*. In this study, the size frequency distribution of both species indicated that *A. gazella* preyed upon both ontogenetic stages of these fish species, but with a clear predominance of mature *E. antarctica* (SL > 74 mm) and immature *G. nicholsi* (SL < 160 mm) (Figs. 3, 4). Almost all the fish taxa identified in this study are krill feeding species usually associated with krill swarms (Williams 1985) thus suggesting that seals targeted their foraging on a krill and a fish community associated with krill aggregations.

Regarding cephalopods, there should be caution when assessing the actual contribution of this prey taxon to the diet of seals. Several authors had pointed out that cephalopod flesh is digested more rapidly than fish muscle, but beaks are indigestible and usually retained in the stomach rugae of seals. Furthermore, accumulation of beaks may occasionally block the pyloric sphincter and provoke natural spewings (e.g. Pitcher 1980; Santos et al. 2001). This may lead to either an overestimation of these hard parts in stomachs or in an underrepresentation in the seal faeces (Bigg and Fawcett 1985). However, during the total sampling period no natural regurgitations from fur seals were observed in the field. Moreover, the examination of 2 complete stomachs of recently dead young fur seals found on the beach near Stranger Point and stomach lavages applied to 12 young male individuals at the same location in the 1996 and 1997 seasons showed no evidence of squid remains (Daneri and Carlini, unpublished data). Therefore, in the present study, the low occurrence of cephalopods in seals scats (13.4%) would reinforce previous suggestions that they do not usually constitute an important dietary item of *A.gazella* at least for this study area (Daneri et al. 1999, 2005a). Nevertheless, an increase in the occurrence of squid remains was observed in the 1998 season. It is remarkable that the single presence of the brachioteuthid squid *Slozarsykowia circumantarctica,* originally assigned, in previous studies, to the species *Brachioteuthis ?picta* (Daneri et al. 1999, 2005a). For more details of the taxonomical status of brachioteuthid squids see Lipinski (2001). This is a small-sized squid which is usually found at or near the surface (Rodhouse et al. 1992) and thus within the depth range of the shallow diving fur seals (Kooyman et al. 1986). Ciaputa and Sicinski (2006) also found that cephalopods were taken in small numbers by *A. gazella* at Admiralty bay, King George Island. However, the dominant squid prey species was *Alluroteuthis antarcticus* in contrast to the present study, comprising ca. 95% in numbers of cephalopods predated whereas Brachioteuthid squids were only represented by two beaks. *A. Antarcticus* has not been cited to date as prey of *A. gazella* at Stranger Point. Instead, at this same locality, this squid species is a relatively common prey of both female and male Southern elephant seals, *Mirounga leonina* (Daneri et al. 2000, 2005b).

As regards penguin remains, these were present, on average, in 22.8% of scats with a peak of occurrence in the 1998 season (47.8%) which coincided with a substantial decrease in the occurrence of krill. According to previous studies, the presence of penguins in the diet of non-breeding male fur seals is variable. Daneri and Coria (1992) found that penguin remains occurred in 22.7% of scats collected at Laurie Island in the summer season of 1988. On the other hand, Casaux et al. (2004) reported that penguins, represented in scats by skin or feathers, were a frequent prey item of fur seals in different summer seasons at Harmony Point, Nelson Island, ranging from 31.9 to 45.1% of scats and contributing up to 75% by mass to the diet of seals. Additionally, at different localities of the Scotia Arc and Antarctic Peninsula the frequency of occurrence of penguins

in the diet of fur seals ranged from 1.3% (Cierva Point, Antarctic Peninsula) to 31.7% (Deception Island, Scotia Arc), with an estimated contribution by mass of 5.2 and 38.7%, respectively (Casaux et al. 2003). From these findings, the aforementioned authors suggested that penguins should be considered as a dietary item of fur seals, as did Bonner and Hunter (1982) and Hofmeyr and Bester (1993) who also observed penguins being attacked by both adult or subadult male Antarctic fur seals. However, not all the attacks ended with the ingestion of the bird and, on many occasions, penguin hunting was commonly abandoned in favour of interacting with other seals, suggesting that this was probably an extension of play activities. Hence, scats containing penguin remains such as feathers and/or skin do not necessarily indicate that the bird was ingested. As the study area is located within an Antarctic Special Protected Area (ASPA N° 132) where breeding colonies of three penguin species *Pygoscelis adeliae, Pygoscelis papua* and *Pygoscelis antarctica* occur (7,741; 2,191 and 75 breeding pairs, respectively, in the 1996/97 season, N. R. Coria, A. R. Carlini unpublished data), a higher occurrence of penguin remains in seal scats might have been expected in each of the three consecutive seasons. However, this was not the case in the present study since this taxon just became important in terms of occurrence in the 1998 season only (47.8%), coinciding with a substantial decrease in the occurrence of krill (60.9%). Therefore, we suggest that penguins might become an alternative and, eventually, important prey item of fur seals at this locality in years of low availability of krill and/or fish. It is conceivable that when the energetic cost involved in searching for krill is higher than usual to meet the predator energy expenditure (e.g. when krill swarms are dispersed or less predictable) penguins could be energetically a more highly profitable target prey, provided that they are abundant and readily available in the area.

Regarding the 3 years of the study period as a whole, our results are in line with previous dietary reports at this locality and others of the Scotia Arc, i.e., fur seals based their foraging activity mainly on a krill and fish community associated with krill (Daneri and Carlini 1999; Casaux et al. 2003; Osman et al. 2004; Daneri et al. 2005a; Ciaputa and Sicinski 2006). However, examining the composition of their diet by year, the 1998 season presents some particular features that differentiates it from the previous ones; these are the following (Table 1; Fig. 1):

a) a substantial decrease in the occurrence of krill
b) a relatively higher occurrence of cephalopods
c) a marked increase in the occurrence of penguin remains
d) a high frequency of occurrence of fish (87%) but in low numbers, especially in comparison with the 1997 season (otoliths, $n = 251$, 1998 vs. 1915, 1997; rate of otoliths per scat 12.5, 1998 vs. 38.3, 1997)
e) the lowest peak in seal numbers ashore during the total sampling period (see "Materials and methods").

Similar temporal fluctuations in the diet composition as well as in foraging behavior of female Antarctic fur seals have been reported from South Georgia (Reid and Arnould 1996; McCafferty et al. 1998). In general, these studies showed that in years when krill was less common in the diet of seals, the incidence of fish and or squid became more important. Also for this same locality, Croxall et al. (1988) pointed out, that the 1977/78 and 1983/84 austral summers were seasons of particularly poor reproductive performance by many species of seabirds and seals (e.g. Antarctic fur seals) and that there was circumstantial evidence relating this to reduced krill availability. They speculated that these two seasons were each 1 year after strong El Niño Southern Oscillation (ENSO) events. More recently, Forcada et al. (2005) reported that sea surface temperature (SST) anomalies at South Georgia were preceded or cross-correlated with frequent El Niño–La Niña events between 1987 and 1998. Positive anomalies, preceded approximately by an El niño event 2.5 years earlier, explained the extreme reduction in fur seal pup production over 20 years of study and were likely associated with low availability of krill.

In this study, the 1998 season coincided with one of the strongest El Niño ENSO events for the twentieth century (McPhaden 1999). The lowest occurrence of krill in the diet of male fur seals was recorded, not only in comparison with the two previous years but also with previous dietary studies at this locality. This scarcity of krill, together with the low availability of fish, as reflected by the low number of otoliths retrieved, might have induced fur seals to search for alternative food resources such as squid and especially penguins and also to travel greater distances than usual to their foraging grounds from Stranger Point. This, in turn, would partially explain the low number of seals recorded ashore. The nearest breeding population of *A. gazella* to Stranger Point is located at Cape Shirreff (62° 28′ S, 60° 48′ W) and Telmo Islets (2 km west of Cape Shirreff) both comprising ca. 20,000 animals (Hucke-Gaete et al. 2004). The overall population growth at these rookeries had always been positive, except during the breeding season of 1997/98, when 14% fewer pups than the previous year were counted, resulting in a 16% decline in total population numbers (Hucke-Gaete et al. 2004). Whether this lower reproductive performance of fur seals from Livingston Island, as well as the abrupt change in the composition of the diet of subadult male fur seals at Stranger Point were related to some extent with the 1997/98 ENSO events remains uncertain. However, Vergani and Stanganelli (1990) suggested that the decline observed in the female

component of the southern elephant population in 1982 at Stranger Point as well as that of the male component in 1987 were possibly influenced by the El Niño events of 1982/83 and 1986/87, respectively. Moreover, Vergani et al. (2001) stated that weaning mass of elephant seals at King George was higher during "La Niña" and lower during "El Niño" years. All these findings, in addition to the results of our study would suggest a link between environmental conditions at the Tropical Pacific El Niño region and the Western Antarctic Peninsula area which would occur at a different temporal scale, i.e. not with a delay of ca. 2.5 years, as reported for South Georgia. This would not be surprising if we consider that White and Peterson (1996) stated that the ocean circulation could play an important role in the transmissions of ENSO signals to high southern latitudes via the Antarctic circumpolar wave (ACW). These authors suggested that the ACW in sea-surface temperature originated in the western subtropical Pacific and then spread south and east into the Southern Ocean. A subsequent eastward propagation took place via the Antarctic Circumpolar Current. Moreover, Turner (2004), stated that the most pronounced signals of ENSO are found over the southeast Pacific as a result of a climatological Rossby wave train that gives positive (and negative) height anomalies over the Amundsen–Bellingshausen Sea during El Niño (La Niña) events. Hence, we consider of high priority an integrated study on diet and reproductive performance of seals and sea birds as well as on physical factors such as sea surface temperature, sea ice fluctuations and hydrological conditions in the area of King George for a period of at least five consecutive years in order to corroborate or refute this hypothesis.

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