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Original Paper

The diet of the Antarctic fur seal *Arctocephalus gazella* at Harmony Point, South Shetland Islands: evidence of opportunistic foraging on penguins?

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Abstract The analysis of 523 scats collected at Harmony Point, Nelson Island, South Shetland Islands, from January to March in 2001 and 2002, indicated that the diet of non-breeding male Antarctic fur seals *Arctocephalus gazella* was diverse and composed of both pelagic and benthic-demersal prey. Overall, the Antarctic krill *Euphausia superba* and fish were the most frequent and numerous prey, followed by penguins, cephalopods (mainly squid) and gastropods. Myctophids represented 86.5% and 65.8% of the fish mass in 2001 and 2002 respectively, with *Gymnoscopelus nicholsi* being the main prey. Interestingly, penguin remains were present in 39.0% and 31.9% of the samples in 2001 and 2002, respectively and these birds were the main prey by reconstituted mass (74.0% and 76.1% in both seasons). The occurrence of penguins in the diet of *A. gazella* at Harmony Point is discussed in terms of the foraging strategy employed by seals and the temporal availability of prey.

Introduction

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). The diet of this seal was extensively studied and, depending on the study area, reproductive status or season, the Antarctic krill *Euphausia superba* or fish were reported as the main prey of *A. gazella* (see Green et al. 1989; Reid and Arnould 1996; Cherel et al. 1997; Casaux et al. 1998, 2003; Klages and Bester 1998; Kirkman et al. 2000, among others).

Several studies reported penguin remains in food samples of the Antarctic fur seal (e.g. Bonner 1968; Bonner and Hunter 1982; Laws 1985; Green et al. 1989, 1990; Hofmeyr and Bester 1993; Casaux et al. 1998). Whereas it is suggested that *A. gazella* frequently kill but do not eat penguins (Fischer and Hureau 1988) or that most of the penguins caught are not ingested (Bonner and Hunter 1982), other studies reported that seals frequently kill and eat penguins (Laws 1985; Hofmeyr and Bester 1993; Casaux et al. 1998). Antarctic fur seal-penguin interaction is of particular interest to better understand the foraging behaviour of the Antarctic fur seal and its influence on penguins population dynamics, in particular if the expansion of the Antarctic fur-seal population (Bengtson et al. 1990) continues.

While collecting scat samples to monitor inter-annual changes in the diet of the Antarctic fur seal at Harmony Point during the 2000/2001 summer season, we observed a temporal increase in the consumption of penguins, these birds being the main prey by mass. Thus, during the 2001/2002 summer season, we replicated the study and analysed the incidence of these birds in the diet of seals. The aim of this study is to provide new information on the diet of the Antarctic fur seal at the South Shetland Islands, paying particular attention to penguins as prey and to temporal variations in its consumption rate.

Materials and methods

A total of 523 scats of non-breeding male Antarctic fur seals was collected at Harmony Point (62°18′S, 59°14′W), Nelson Island, South Shetland Islands, from January to March in 2001 (n=272) and 2002 (n=251). The samples were obtained by collecting all faeces found along 3 sectors of the coast (Harmony Cove, 62 and 63 scats in 2001 and 2002, respectively; Nelson Strait, 55 and 54 scats; Drake Passage, 155 and 134 scats; Fig. 1) from the arrival of the seals in the area during January to the end of the field season (5 and 13 March in 2001 and 2002, respectively).

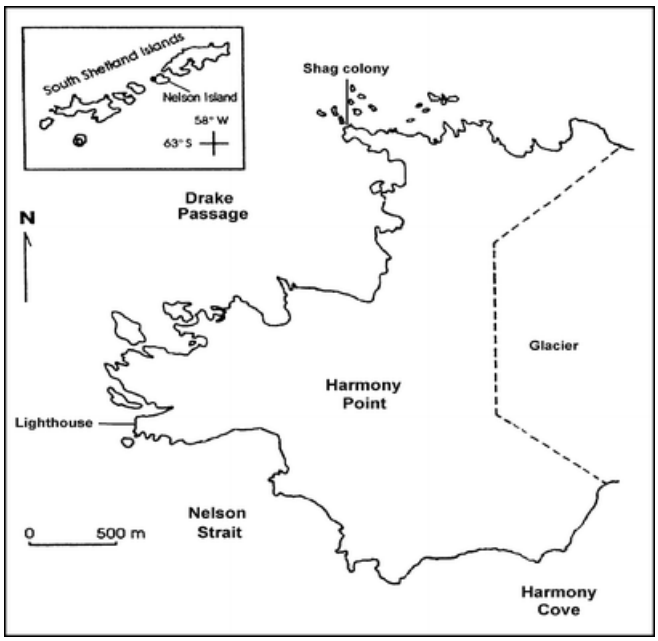

Fig. 1 Map showing the location of Nelson Island in the South Shetland Islands and the sampling areas at Harmony Point

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The samples were washed individually through sieves (minimum mesh 0.54 mm). Overall, 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). Differently to that study, the mass of krill individuals was estimated by measuring entire exoskeletons present in the samples and applying the length-weight relationship described in Morris et al. (1988), and the mass of the squid individuals was estimated using the rostral length of the lower beak and applying the relationship described in Clarke (1986).

Since the estimates of the number and mass of prey species represented in scats usually gives 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 masses 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.

To analyse if the variance in numbers of Antarctic fur seals at Harmony Point corresponded to the penguin availability, from 24 February to 5 March 2001 we carried out four censuses counting the number of seals present at three sectors of Harmony Point: Harmony Cove (area: 173,700 m^2), Nelson Strait (268,200 m^2) and Drake Passage (170,100 m^2). During the 2001/2002 summer season, the coast of Harmony Point was surveyed every 6 days. Due to the difficult access to many beaches on Drake Passage, the beaches located between the lighthouse and the shag colony (Fig. 1) were only occasionally visited; thus that information was not included in the study. The beaches on

Drake Passage between the shag colony and the glacier were visited during all of the censuses. The maximum area occupied by Antarctic fur seals in the three study sectors (see above) was estimated using a Global Positioning System (GPS) equipment (TRIMBLE Ensign, Trimble Navigation, Sunnyvale, Calif.).

Results

Of the samples collected in 2001 and 2002, 98.5% (268 scats) and 92.4% (232) respectively, contained prey remains. The frequencies of occurrence presented below are referred to the number of samples containing prey remains.

Overall, krill (mean total length 52.7 mm, SD 10.2, n=45) was the most frequent and numerous prey in both seasons, followed by fish and penguins (Table 1). Cephalopods (mainly squid) and gastropods were rarely represented. When the samples obtained at the different sectors at Harmony Point (Fig. 1) were analysed separately, we observed the same pattern, except for the beaches of Drake Passage in 2001 where penguins were the second most frequent prey instead of fish (47.7%, Table 1), and at Harmony Cove in 2002, where fish were the most frequent prey. Penguins were the most important prey by mass in both seasons followed by krill and fish (Table 1). The importance of penguins by mass in the scats collected at the 3 different sampling areas was positively (but non-significantly) correlated (Spearman test, r=0.99, ns, in 2001 and r=0.77, ns, in 2002) with the number of *Pygoscelis antarctica* breeding at those areas (Harmony Cove: 1,783 pairs; Nelson Strait: 21,639 pairs; Drake Passage: 66,263 pairs; Silva et al. 1998).

[Table 1 will appear here. See end of document.]

The otoliths found in the scats represented 1,326 and 1,592 fish in 2001 and 2002, respectively, of which 1,278 and 1,269 respectively were identified as belonging to the families Bathylagidae, Paralepididae, Myctophidae, Nototheniidae, Harpagiferidae, 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, *Gymnoscopelus nicholsi* was the most important fish prey in both seasons, followed by *Notolepis coatsi* and *Electrona antarctica* in 2001, and by *Gobionotothen gibberifrons* and *Chionodraco rastrospinosus* in 2002. The estimated total length of the fish represented in the samples ranged from 3.5 cm (*E. antarctica*) to 40.1 cm (*N. coatsi*).

[Table 2 will appear here. See end of document.]

In both seasons, the frequency of occurrence of penguin remains in the samples was low at the beginning of the study, reached a peak by late February (46.4% in 2001 and 55.9% in 2002), and then slightly decreased (Fig. 2). The end of the field season did not allow us to follow the evolution of those trends. During the first part of the study in 2001, penguin remains co-occurred with remains of other prey in scats, but from 16 February, these birds were the sole prey represented in almost all samples where they occurred (Fig. 2). In 2002, penguins were the only prey in 52.2% of the scats where they occurred.

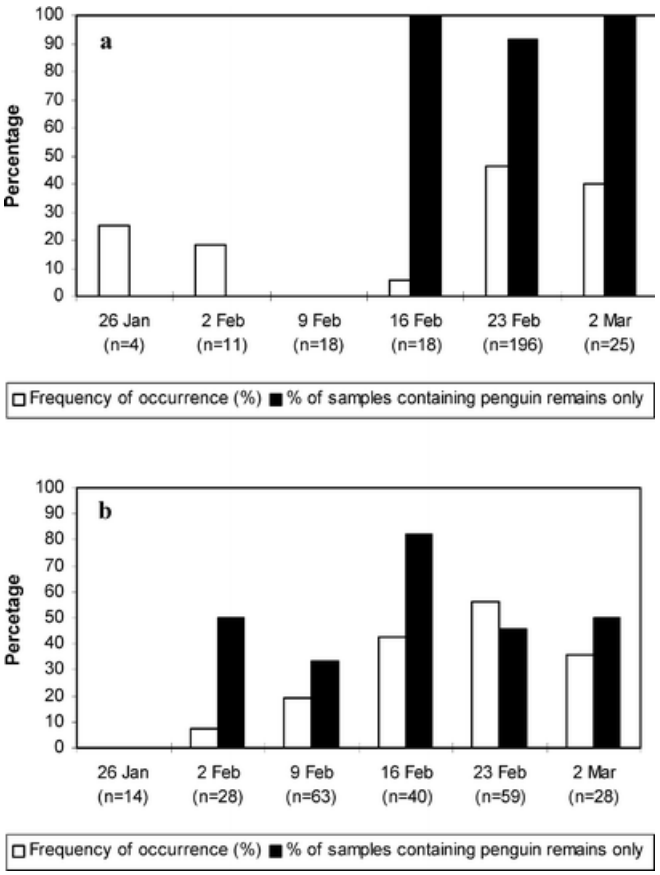

Fig. 2a,b Variation in the frequency of occurrence (%) of penguins in the diet of the Antarctic fur seal and in the percentage of scats containing only penguin remains in relation to those where this prey was represented, as reflected by the samples collected at Harmony Point during January/March 2001 (**a**) and 2002 (**b**)

During November and December 2001 and 2002, Antarctic fur seals were only occasionally observed at Harmony Point, and the number of individuals started to increase from mid-January in both seasons. By the end of January 2001, only 23 specimens were observed in the area, and the number of seals present at Harmony Point reached a peak by 24 February and then decreased (Table 3). During the 2001/2002 summer season, the abundance of seals at Harmony Point peaked in early February and early March (Fig. 3). Given that no censuses were carried out from late

January to 24 February, perhaps the peak of early February was missed in the data from 2001. The number of *A. gazella* on the different beaches of Harmony Point was positively (but non-significantly) correlated (Spearman test, r=0.87, ns, in 2001 and r=0.93, ns, in 2002) with the number of *P. antarctica* breeding pairs (see Silva et al. 1998), but was weakly (r=0.26, ns) and inversely (r=−0.58, ns) correlated in both seasons, respectively, with the area used by seals in those sectors.

[Table 3 will appear here. See end of document.]

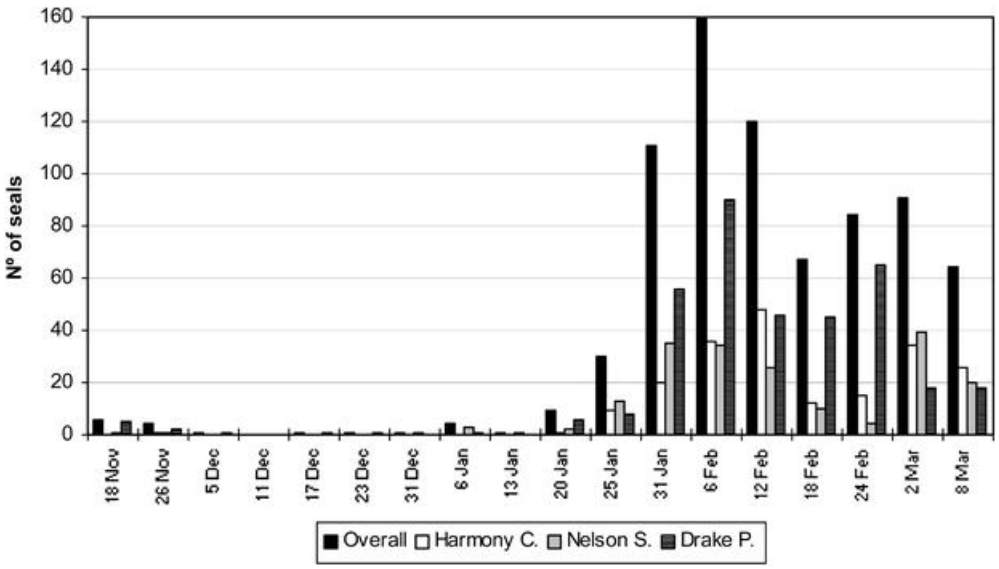

Fig. 3 Number of Antarctic fur seals observed during the censuses carried out within different sectors of Harmony Point during the summer 2001/2002

Discussion

As reported for other study sites (Daneri and Coria 1992; Reid 1995; Daneri 1996; Casaux et al. 2003) and for this locality in a previous season (Casaux et al. 1998), krill and fish were the most frequent and numerous prey of non-breeding male Antarctic fur seals hauling out at Harmony Point. As observed for Antarctic fur seals during summer (Reid 1995; Reid and Arnould 1996; Casaux et al. 1998), cephalopods were scarcely represented in the samples. Daneri and Coria (1992) proposed that cephalopods might be an important component of the diet during autumn, which seems to be supported by the results of Green et al. (1991). Interestingly, this is the first study indicating that penguins are the main prey by mass of non-breeding male Antarctic fur seals during summer.

It has been suggested that non-breeding male Antarctic fur seals frequently kill but do not eat penguins (Fischer and Hureau 1988) or that most of the penguins caught are not ingested (Bonner and Hunter 1982). It was proposed that predation on penguins by Antarctic fur seals is a probable extension of play behaviour (Bonner and Hunter 1982), which is supported by the scarcity or absence of remains of these birds in samples collected at several localities (e.g. Green et al. 1991; Reid 1995; Reid and Arnould 1996; Cherel et al. 1997). Conversely, other studies reported that seals frequently kill and eat penguins (Laws 1985; Hofmeyr and Bester 1993), penguin remains being present in 23% of the samples collected at the South Orkney Islands (Daneri and Coria 1992). Based on that observation and on the occurrence of penguin remains in 45% of the scats collected at Harmony Point during the 1995/1996 and 1996/1997 summer seasons, Casaux et al. (1998) also indicated that penguins are an important food item of the Antarctic fur seal. Interestingly, Kirkman et al. (2000) suggested that a source of error in prey-consumption estimates for *A. gazella* is the exclusion of penguins as prey from the analysis. In the present study, penguins were the main prey by mass, and seals seemed to be distributed according to penguin availability rather than to the area available to haul out; a seal was seen eating three *P. antarctica* chicks consecutively, which confirms the importance of penguin as prey of *A. gazella*. Whereas remains of macaroni (*Eudyptes chrysolophus*), gentoo and King (*Aptenodytes patagonicus*) penguins were observed in food samples of the Antarctic fur seal (Bonner 1968; Bonner and Hunter 1982; Laws 1985; Green et al. 1989, 1990; Hofmeyr and Bester 1993), this is the first study reporting chinstrap penguins as prey of Antarctic fur seals.

If penguins are an alimentary item of *Arctocephalus gazella*, the low occurrence or the absence of their remains in the food samples analysed in other studies could be due to a number of different reasons. Given that *Arctocephalus gazella* is an opportunistic feeder, we might expect that penguins will be preyed upon more intensively at those localities where they are abundant. Scats containing penguin remains (usually feathers) only present scarce agglutinating material, and in frequent strong winds they can quickly break up. Thus, as the inter-sampling time increases, the probability of finding scats containing penguin remains might decrease. The predation on penguins by the Antarctic fur seal might be associated with a specific period of the reproductive cycle of both predator or prey; if the scats are not collected during that specific period, the occurrence of penguins in the samples will be low. Finally, several of the previous studies were concentrated on females, which are much smaller than males and may therefore be unable to take penguins because of morphological constraints.

Some 89,685 pairs of *P. antarctica* and 3,347 pairs of *Pygoscelis papua* breed at Harmony Point (Silva et al. 1998) and, thus, the availability of penguins at this locality could be considered as high. Given that the scats were collected every 2–5 days, the probability that the samples containing penguin remains were detached was low. Although we have no conclusive evidence, the peak of abundance of Antarctic fur seals at Harmony Point (Table 3, Fig. 3) and the peak in penguin remains in the scats (Fig. 2) suggest that, at this locality, the consumption of penguins by *Arctocephalus gazella* might be associated with the end of the fledging period of these birds (approximately from 10 February for *P. papua* and from 18 February for *P. antarctica* in 2001, N. Coria, personal communication; and from 2 and 15 February, respectively in 2002, M. Favero, personal communication). Thus, the sampling was concurrent with the postulated period of high penguin consumption. This study was focused on non-breeding males for whom morphological constraints to take penguins are not expected. These four factors, separately or in conjunction, might explain the high occurrence of penguin remains in the scats collected at Harmony Point during the 2000/2001 and 2001/2002 summer seasons. Given that in waters close to Harmony Point, Antarctic krill is commercially exploited, the alternative consumption of penguins due to a temporal interference of the fisheries within the foraging areas of *Arctocephalus gazella* (see Croll and Tershy 1998) should also be considered in future studies.

The fact that the peaks in the abundance of the Antarctic fur seal and in the occurrence of penguin remains in the scats at Harmony Point were concurrent with the end of the fledging period of *P. antarctica* and *P. papua* suggest that *Arctocephalus gazella* might have preyed mainly on chicks. However, although the high occurrence of penguins in the samples from late January and early February 2001 could be an artefact related to the small number of scats collected, adult birds also seem to be ingested. The consumption of penguin chicks could be related to their high temporal availability, to their high energy content and to their inexperience at swimming, which make them highly vulnerable to predation. This vulnerability, coupled with the high energy return of penguin, makes them a highly profitable prey, especially when considered that they are caught close to the shore.

Future studies should determine if the foraging strategy observed in the Antarctic fur seal at Harmony Point is a local and/or an occasional phenomenon, or if it is a frequent and widespread strategy that was not previously documented. Understanding of this matter will help to improve the knowledge on the foraging behaviour of this seal and on the population dynamics of *P. antarctica* and *P. papua*.

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Table 1 The composition of the diet of non-breeding male Antarctic fur seals at Harmony Point as reflected by the analysis of scats collected during January-March 2001 and 2002. Percentage frequencies of occurrence (*F*%), number (*N*%) and mass (*M*%)

	Overall						Drake Passage						Harmony Cove						Nelson Strait					
	2000			2001			2000			2001			2000			2001			2000			2001		
	F%	*N*%	*M*%	*F*%	*N*%	*M*%	*F*%	*N*%	*M*%	*F*%	*N*%	*M*%	*F*%	*N*%	*M*%	*F*%	*N*%	*M*%	*F*%	*N*%	*M*%	*F*%	*N*%	*M*%
Krill	75.0	97.8	16.8	69.8	94.8	12.2	69.0	97.5	11.8	75.8	96.1	11.9	85.5	98.0	26.5	52.7	92.0	12.1	80.0	98.2	25.6	73.5	94.5	13.1
Cephalopods																								
Octopods	0.4	0.0	0.2	2.2	0.0	0.2	0.7	0.0	0.3	0.8	0.0	0.0	-	-	-	1.8	0.0	0.1	-	-	-	6.1	0.1	0.6
Squids	10.3	0.1	0.5	8.6	0.1	0.5	5.2	0.1	0.2	10.2	0.1	0.6	11.3	0.0	0.2	5.5	0.1	0.2	27.3	0.1	2.1	8.2	0.1	0.2
Gastropods	1.8	0.0	0.0	-	-	-	1.9	0.0	0.0	-	-	-	-	-	-	-	-	-	3.6	0.0	0.0	-	-	-
Fish	48.5	2.0	8.5	63.8	4.9	11.0	40.0	2.2	6.9	54.7	3.6	8.2	61.3	1.9	13.1	72.7	7.7	21.3	58.2	1.6	9.2	67.4	5.2	7.9
Penguins	39.0	0.1	74.1	31.9	0.2	76.2	47.7	0.2	80.8	35.2	0.2	79.2	29.0	0.1	60.2	25.5	0.2	66.3	23.6	0.1	63.1	30.6	0.2	78.3

Table 2 Fish represented by the otoliths found in scats of non-breeding male Antarctic fur seals collected at Harmony Point during January/March 2001 and 2002. Percentage frequencies of occurrence (*F%*), number (*N%*) and mass (*M%*)

	Overall						Drake Passage						Harmony Cove						Nelson Strait					
	2001			2002			2001			2002			2001			2002			2001			2002		
	F%	*N%*	*M%*	*F%*	*N%*	*M%*	*F%*	*N%*	*M%*	*F%*	*N%*	*M%*	*F%*	*N%*	*M%*	*F%*	*N%*	*M%*	*F%*	*N%*	*M%*	*F%*	*N%*	*M%*
Bathylagidae																								
Bathylagus antarcticus	-	-	-	0.4	0.1	0.7	-	-	-	-	-	-	-	-	-	1.8	0.2	1.7	-	-	-	-	-	-
Paralepididae																								
Notolepis coatsi	3.3	1.0	4.4	2.6	1.2	1.3	2.6	0.6	4.1	1.6	1.9	2.3	4.8	0.9	1.3	3.6	0.4	0.3	5.5	1.9	4.5	6.1	0.9	1.4
Myctophidae																								
Electrona antarctica	21.0	17.7	2.9	20.7	22.9	4.2	11.6	13.7	2.0	16.4	9.8	1.8	32.3	22.0	3.8	30.9	24.2	4.2	32.7	21.3	4.1	20.4	49.6	11.8
Ecanlebergi	-	-	-	1.3	1.4	0.5	-	-	-	2.3	3.0	1.2	-	-	-	-	-	-	-	-	-	-	-	-
Gymnoscopelus braueri	7.0	4.3	2.0	1.7	0.4	0.2	3.9	1.9	0.8	3.1	0.8	0.5	11.3	2.3	1.1	-	-	-	10.9	16.1	8.1	-	-	-
G.nicholsi	20.6	69.5	81.5	22.8	42.4	60.6	14.5	74.6	81.9	17.2	36.6	53.1	24.2	69.5	88.3	34.6	58.5	66.8	30.9	52.6	66.4	24.5	29.6	65.7
Gymnoscopelus	-	-	-	0.4	0.1	0.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.0	0.3	1.0
Krefftichthys andersoni	0.4	0.1	0.0	-	-	-	0.7	0.2	0.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Protomyctophum sp.	-	-	-	1.3	0.3	0.1	-	-	-	-	-	-	-	-	-	7.3	0.9	0.1	-	-	-	-	-	-
Nototheniidae																								
Gobionotothen gibberifrons	-	-	-	1.3	0.4	10.2	-	-	-	-	-	-	-	-	-	3.6	0.9	19.1	-	-	-	2.0	0.3	15.3
Lepidonotothen mudifrons	0.7	0.2	0.3	0.9	0.1	0.1	1.3	0.4	0.6	-	-	-	-	-	-	3.6	0.4	0.2	-	-	-	-	-	-
Notothenia coriiceps	1.1	0.2	1.3	0.9	0.1	1.5	1.3	0.3	1.1	1.6	0.3	3.5	-	-	-	-	-	-	1.8	0.5	4.9	-	-	-
Notothenia larseni	1.1	0.3	0.3	1.3	0.2	0.1	1.9	0.6	0.5	2.3	0.4	0.3	-	-	-	-	-	-	-	-	-	-	-	-

	Overall						Drake Passage						Harmony Cove						Nelson Strait					
	2001			2002			2001			2002			2001			2002			2001			2002		
	F%	*N*%	*M*%	*F*%	*N*%	*M*%	*F*%	*N*%	*M*%	*F*%	*N*%	*M*%	*F*%	*N*%	*M*%	*F*%	*N*%	*M*%	*F*%	*N*%	*M*%	*F*%	*N*%	*M*%
Pogothenia bernacchii	1.1	0.3	0.8	-	-	-	1.9	0.6	1.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Paragamma antarcticum	1.8	0.5	1.1	2.6	7.2	2.3	1.3	0.4	0.8	1.6	15.3	4.3	-	-	-	7.3	0.8	0.9	5.5	1.9	4.5	-	-	-
Harpagiferidae																								
Harpagifer antarcticus	2.6	1.4	0.6	2.6	0.9	0.6	2.6	1.6	0.7	1.6	0.7	0.4	3.2	1.6	0.7	5.5	1.7	0.8	1.8	0.5	0.1	2.0	0.3	0.3
Bathydraconidae																								
Racovitzia charcoti	-	-	-	0.4	0.1	0.5	-	-	-	0.8	0.1	1.1	-	-	-	-	-	-	-	-	-	-	-	-
Channichthyidae																								
Chaenocephalus aceratus	0.4	0.1	0.6	0.4	0.1	2.4	0.7	0.2	1.0	0.8	0.2	5.5	-	-	-	-	-	-	-	-	-	-	-	-
Chionodraco wilsoni	0.7	0.2	1.0	0.9	0.2	0.3	1.3	0.4	2.7	0.8	0.3	0.3	-	-	-	-	-	-	-	-	-	2.0	0.3	0.8
Champsocephalus gunnari	-	-	-	1.7	0.4	4.1	-	-	-	3.1	0.8	9.4	-	-	-	-	-	-	-	-	-	-	-	-
Chionodraco rastrospinosus	1.5	0.3	1.4	3.9	0.9	9.1	0.7	0.2	1.2	3.9	1.2	14.5	4.8	0.7	2.3	5.5	0.8	5.2	-	-	-	2.0	0.3	3.7
Cryodraco antarcticus	1.8	0.4	1.8	0.4	0.1	0.4	1.3	0.3	1.1	0.8	0.1	1.0	3.2	0.5	2.6	-	-	-	-	-	-	-	-	-
Pagetopsis macropterus	-	-	-	2.2	0.4	0.7	-	-	-	2.3	0.6	1.0	-	-	-	3.6	0.4	0.6	-	-	-	-	-	-
Unidentified	10.3	3.6	-	15.5	20.3	-	8.4	4.1	-	14.1	27.9	-	16.1	2.5	-	21.8	10.9	-	10.9	4.7	-	12.2	18.5	-

Table 3 Number of Antarctic fur seals observed during the censuses carried out within different sectors of Harmony Point, Nelson Island, South Shetland Islands, during February and March 2001

	Drake Passage[a]	Nelson Strait	Harmony Cove	Overall
24 February	104	116	34	254
28 February	42	12	20	74
3 March	30	26	10	66
5 March	21	12	3	36
Overall	197	166	67	

[a]Only beaches located between the shag colony and the glacier (see Fig. 1).