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Fish in the diet of the Antarctic shag at four colonies on the Danco Coast, Antarctic Peninsula

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Abstract: The diet of breeding Antarctic shags (*Phalacrocorax bransfieldensis*) was investigated at four colonies on the Danco Coast, Antarctic Peninsula, by the analysis of 616 pellets (regurgitated casts) collected from December 1997 to February 1998. Overall, demersal-benthic fish were the most frequent and important prey at all the colonies, followed by octopods and gastropods. Amongst fish, *Notothenia coriiceps* was the main prey in all of the sampling sites, followed in similar importance by *Gobionotothen gibberifrons* at Cape Herschel, Primavera Island and Midas Island and in less importance by *Harpagifer antarcticus* at Py Point. There were marked differences among colonies in the size of the fish consumed. The largest and the smallest specimens were eaten by shags from Midas Island and Py Point respectively. This was mainly influenced by the number of specimens of the smallest fish species, *H. antarcticus*, consumed at Py Point. The differences in the diet composition may be related to the different foraging areas used by the shags. Results from this study differ from previous studies around the Antarctic Peninsula. The shags at the Danco Coast preyed markedly more intensively than those at the South Shetland Islands on *G. gibberifrons*. This finding reflects the low abundance of this fish species in inshore waters (< 100 m depth) at the South Shetland Islands and supports the use of the Antarctic shags to monitor trends in local populations of coastal fish species.

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Introduction

The Antarctic shag *Phalacrocorax bransfieldensis* (previously known as blue-eyed shag *P. atriceps bransfieldensis*) breeds along the Antarctic Peninsula and the South Shetland Islands (Orta 1992) during summer in colonies ranging in size from two (e.g. Potter Peninsula, King George Island, 62°14'S 58°40'W; Alcock Island, Antarctic Peninsula, 64°14'S 61°06'W; R. Casaux, unpublished data) up to several hundreds of breeding pairs (Anvers Island, Antarctic Peninsula, 64°46'S 64°03'W; Bernstein & Maxson 1985). There is a little information on this species during the non-breeding period (April–September), mainly due to limitations in access to the colonies and to adverse environmental conditions. It is believed that during winter these birds remain in the proximity of the breeding sites (Holdgate 1963, Glass 1978). Interestingly, an Antarctic shag that had been ringed as a juvenile in 1989 at Harmony Point, South Shetland Islands (62°17'S 59°14'W), was found at Sao Salvador do Bahia, Brazil (12°58'S 38°31'W), in the winter of 1997 (M. Favero personal communication 1997), a distance of 5700 km.

Several studies have reported on the composition of the diet and the foraging behaviour of the Antarctic shag at the South Shetland Islands (Casaux & Barrera-Oro 1993, Barrera-Oro & Casaux 1996, Coria *et al.* 1995, Casaux *et al.* 1997a, Favero *et al.* 1998, Casaux *et al.* 2001). There, although members of the breeding pair alternate the time at sea, with females foraging mainly in the morning and males in the afternoon, both forage mainly on demersal-benthic fish with *Notothenia coriiceps* and *Harpagifer antarcticus* the most important prey species.

Despite the occurrence of a large number of breeding *P. bransfieldensis* in the Antarctic Peninsula (estimate of 10 000 pairs at 56 colonies, Croxall *et al.* 1984), only two studies, published two decades ago (Tomo 1970, Schlatter & Moreno 1976), have reported dietary data, giving only limited information on the importance of fish as prey. Thus, the aim of this work is to provide new information on the diet of *P. bransfieldensis* from the Danco Coast, an unstudied area of the Antarctic Peninsula, paying special attention to the significance of fish in the reconstructed diet.

Material and methods

On the basis of a weekly collection of *c.* 15 samples per colony, from 20 December 1997 (early to mid chick rearing) to 20 February 1998 (chick fledging to chick post fledging) we obtained a total of 616 pellets (regurgitated casts) of the Antarctic shag from four colonies on the Danco Coast, Antarctic

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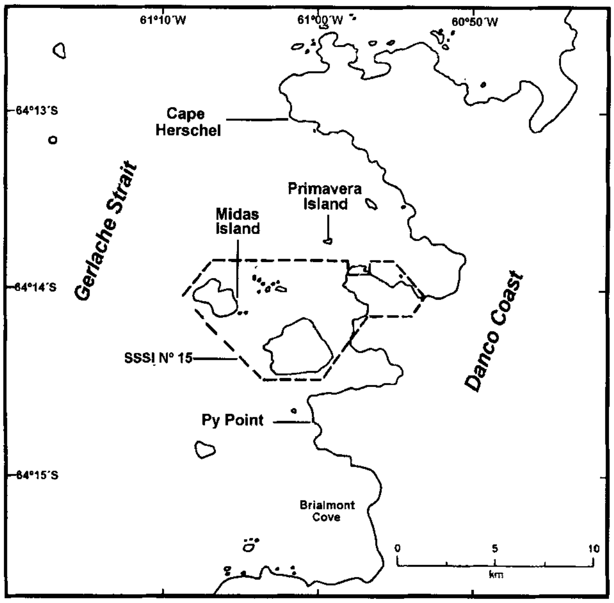

Fig. 1. Map showing the location of the colonies studied in the Danco Coast, Antarctic Peninsula, and the extension of the SCAR Site of Special Scientific Interest (SSSI) No 15.

Table I. Diet of the Antarctic shag from the Danco Coast, Antarctic Peninsula. Percentage frequencies of occurrence (*f*%) and number (*n*%).

	Primavera Is.		Midas Is.		Cape Herschel		Py Point	
	f%	*n*%	*f*%	*n*%	*f*%	*n*%	*f*%	*n*%
fish	100.0	94.2	100.0	89.3	100.0	95.6	100.0	82.8
octopods	17.2	2.6	24.9	3.4	12.6	1.2	28.2	8.1
gastropods	10.1	1.7	22.1	3.7	19.8	1.9	22.8	7.2
bivalves	6.6	0.7	9.7	2.0	5.3	0.4	5.4	0.3
amphipods	17.2	-	21.2	-	13.2	-	28.2	-
polychaetes	11.3	0.8	17.0	1.6	10.6	0.9	28.2	1.6
algae	62.3	-	81.2	-	91.4	-	67.8	-
stones	72.9	-	82.4	-	90.1	-	85.2	-

Peninsula: Cape Herschel (64°05'S 61°02'W, 30 breeding pairs, 151 pellets), Primavera Island (64°09'S 60°59'W, 9 breeding pairs, 151 pellets,), Midas Island (within Site of Special Scientific Interest 15, 64°10'S 61°05'W, 23 breeding pairs, 165 pellets) and Py Point (64°13'S 61°00'W, 22 breeding pairs, 149 pellets) (Fig. 1). The distance between Cape Herschel and Py Point, is 16.6 km.

The pellets were dried at 60°C and their contents sorted into prey classes using a binocular microscope. The otoliths present were identified, where possible, to species using descriptions and illustrations in Hecht (1987), Williams & McEldowney (1990)) and by comparison with our reference collection and with otoliths recovered from identifiable fish obtained from stomach contents of the shags under study (R. Casaux, unpublished data). The otoliths of each species were sorted into right and left and the most abundant was considered as the number of individuals per fish species present in the sample. The otoliths were measured to 0. 01 mm in length to estimate the size and mass of the individual fish applying the equations in Hecht (1987), Williams & McEldowney (1990), Casaux et al. (1998a) and those estimated from fish caught in the study areas (see Appendix A). Other hard fish remains found in the pellets (vertebrae, scales and eye-lenses) could not be identified to species level and were not considered in this study. Nomenclature for fish is Gon & Heemstra (1990)

Table II. Fish represented in the diet of the Antarctic shag from the Danco Coast, Antarctic Peninsula. Percentage frequencies of occurrence (*f*%), number (*n*%) and mass (M%).

	Primavera Is.			Midas Is.			Cape Herschel			Py Point		
	f%	*n*%	M%	*f*%	*n*%	M%	*f*%	*n*%	M%	*f*%	*n*%	M%
Nototheniidae												
Gobionotothen gibberifrons (Lönnberg)	50.3	17.1	30.9	58.8	20.8	38.3	49.7	16.1	33.6	24.8	3.8	8.0
Lepidonotothen larseni Lönnberg	5.3	0.9	1.2	1.2	0.2	0.1	2.6	0.4	0.3	2.0	0.1	0.1
Lepidonotothen nudifrons Lönnberg	60.3	19.3	8.8	60.6	18.3	6.2	35.8	8.8	3.2	48.3	9.8	5.9
Notothenia coriiceps Richardson	49.7	8.8	33.0	58.2	15.9	39.5	62.3	15.4	41.8	48.3	11.3	54.3
Notothenia rossii Richardson	0.7	0.1	1.7	-	-	-	-	-	-	0.7	0.1	1.7
Pagothenia borchgrevinki (Boulenger)	2.0	0.3	0.2	4.2	0.4	0.3	5.3	0.5	0.2	5.4	0.5	0.2
Trematomus bernacchii Boulenger	27.2	4.5	5.7	21.2	4.4	3.9	31.1	4.5	4.7	24.9	3.1	5.7
Trematomus newnesi Boulenger	53.0	14.9	11.4	58.8	20.6	10.2	52.3	18.7	10.7	38.3	7.0	6.5
Trematomus scotti (Boulenger)	3.3	0.2	0.3	0.6	0.1	0.1	0.7	0.1	0.0	0.7	0.0	0.0
Harpagiferidae												
Harpagifer antarcticus Nybelin	28.5	22.0	5.6	20.0	7.8	1.8	29.1	19.9	4.9	48.3	50.0	16.9
Bathydraconidae												
Parachaenichthys charcoti (Vaillant)	2.7	0.3	1.1	1.8	0.2	0.1	4.6	0.5	0.5	3.4	0.2	0.9
Channichthyidae												
Chaenodraco wilsoni Regan	0.7	0.1	0.1	-	-	-	-	-	-	-	-	-
Myctophidae												
Electrona antarctica Günther	0.7	0.1	0.0	-	-	-	-	-	-	-	-	-
Protomyctophum normani Tåning	-	-	-	-	-	-	0.7	0.1	0.0	-	-	-
Paralepididae												
Notolepis coatsi Dollo	-	-	-	0.6	0.1	0.0	-	-	-	0.7	0.0	0.0
Unidentified	60.9	11.4	-	52.1	11.3	-	70.2	15.2	-	72.5	14.0	-

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Table III. Mean total length, standard deviation and length range of the fish represented in the diet of the Antarctic shag at four colonies from the Danco Coast, Antarctic Peninsula.

	Primavera Is.			Midas Is.			Cape Herschel			Py Point		
	mean	s d	range	mean	s d	range	mean	s d	range	mean	s d	range
Nototheniidae												
Gobionotothen gibberifrons	13.9	6.6	3.7–36.9	15.8	7.8	5.0–36.6	15.3	7.5	4.6–34.4	13.0	6.8	4.6–34.4
Lepidonotothen larseni	14.8	4.4	9.2–22.7	11.7	0.9	10.7–13.0	14.7	1.3	12.7–16.4	13.8	0.8	13.1–14.6
Lepidonotothen nudifrons	9.5	1.8	4.2–17.2	9.8	1.7	3.3–14.0	9.3	1.5	3.7–13.0	9.5	1.9	4.7–14.6
Notothenia coriiceps	15.4	5.3	1.9–41.1	15.5	5.1	2.3–34.7	14.3	5.1	4.2–32.3	15.5	5.3	1.8–39.2
Notothenia rossii	30.0	2.5	28.2–31.7	-	-	-	-	-	-	29.8	1.7	28.6–31.0
Pagothenia borchgrevinki	9.1	2.8	4.0–12.7	9.3	4.8	5.5–19.9	7.5	3.7	2.1–13.7	6.9	1.7	4.5–10.3
Trematomus bernacchii	14.3	2.8	7.7–23.6	14.5	2.9	8.5–22.1	14.2	3.1	7.0–21.3	14.7	3.2	7.9–22.3
Trematomus newnesi	9.4	1.9	5.7–14.5	9.2	1.8	1.6–13.4	8.8	1.7	4.0–13.6	9.1	1.8	4.7–14.0
Trematomus scotti	11.8	1.9	9.4–13.8	13.0	-	-	5.8	-	-	5.3	-	-
Harpagiferidae												
Harpagifer antarcticus	6.5	1.3	4.6–9.8	7.8	0.7	6.3–9.8	7.2	0.7	4.8–8.7	6.7	1.3	4.2–9.2
Bathydraconidae												
Parachaenichthys charcoti	20.5	2.4	17.7–25.1	16.1	2.3	13.5–18.1	18.9	2.5	16.6–25.2	21.8	3.8	16.3–26.2
Channichthyidae												
Chaenodraco wilsoni	17.4	-	-	-	-	-	-	-	-	-	-	-
Myctophidae												
Electrona antarctica	5.4	-	-	-	-	-	-	-	-	-	-	-
Protomyctophum normani	-	-	-	-	-	-	5.2	-	-	-	-	-
Paralepididae												
Notolepis coatsi	-	-	-	19.1	-	-	-	-	-	-	-	-
Overall	10.5	4.9	1.9–41.1	12.1	5.6	1.6–36.6	11.0	5.3	2.1–34.4	9.0	4.4	1.7–39.2

and for the cormorants Orta (1992). Analysis of variance (ANOVA) was used to test for significant differences between colonies.

Results

Fish, then octopods and gastropods, were the most frequent and important prey by number at the four colonies sampled (Table I). The shags from Py Point preyed slightly less on fish and more frequently and intensively on octopods and gastropods than those from the other three colonies.

Among the fish prey, benthic-demersal species of the family Nototheniidae predominated in the diet. *Notothenia coriiceps* was the most important prey in the whole sampling area and, together with *Gobionotothen gibberifrons,* contributed with similar mass to the diet of shags from Cape Herschel, Primavera Island and Midas Island (Table II). At Py Point, *Harpagifer antarcticus* was the second most important prey, and *G. gibberifrons* was poorly represented.

Between colonies, the size of the fish ingested differed significantly ($F = 129.1$, df = 3, $P < 0.00001$). The shags from Midas Island and Py Point took the largest and the smallest fish, respectively (Table III). This was mainly influenced by the number of specimens of the smallest fish species, *H. antarcticus*, consumed at each colony. There were also differences between the colonies in the size of the fish eaten: *N. coriiceps* ($F = 3.5$, df = 3, $P < 0.05$), *H. antarcticus* ($F = 58.5$, df = 3, $P < 0.0001$), *Lepidonotothen nudifrons* ($F = 3.99$, df = 3, $P < 0.01$), *Trematomus newnesi* ($F = 5.7$, df = 3, $P < 0.001$), *G. gibberifrons* ($F = 6.5$, df = 3, $P < 0.001$) and *Parachaenichthys charcoti* ($F = 3.1$, df = 3, $P < 0.05$).

Discussion

Demersal-benthic fish were the main prey of *P. bransfieldensis* at the four colonies investigated in this study (Table I). As has been reported for other shag species from sub-Antarctic (*Phalacrocorax purpurascens* at Macquarie Island, Green *et al.* 1990a, Kato *et al.* 1996; *P. nivalis* at Heard Island, Green *et al.* 1990b; *P. melanogenis* at Crozet Island, Espitalier-Noel *et al.* 1988, Ridoux 1994; *P. georgianus* at South Georgia, Wanless & Harris 1993) and Antarctic (*P. georgianus* at the South Orkney Islands, Shaw 1984, Casaux *et al.* 1997b) areas.

Records of deep dives by *P. georgianus* for benthic foraging averaging 80–90 m and extending to 116 m (Croxall *et al.* 1991) for periods up to 6.5 min (Wanless *et al.* 1992) have been recorded for South Georgia. Similarly, for the closely related Antarctic shag, mean dives averaging 28 and 50 m for males and females respectively, to 113 m for periods up to 2.9 min have been recently recorded (Casaux *et al.* 2001).

Among fish, nototheniid species predominated in the diet samples with the families Harpagiferidae (except at Py Point), Channichthyidae, Bathydraconidae, Myctophidae and Paralepididae scarcely represented. *Notothenia coriiceps* was the main prey in all the sampling sites, followed in similar importance by *G. gibberifrons* in Cape Herschel, Primavera Island and Midas Island and in less importance by *H. antarcticus* in Py Point. Given that shags are opportunistic feeders (Craven & Lev 1987, Keller 1995), the differences in the composition of the diet may reflect a different prey availability around the study colonies. This hypothesis is supported by the fact that the shags from Primavera Island, Midas Island and Cape Herschel foraged mainly in open waters, close to the Gerlache Strait, whereas those from Py Point foraged mainly in inner waters at Brialmont Cove (RC, AB & EBO, unpublished data, Fig. 1). Data from trammel net catches obtained within the area showed that the abundance of *G. gibberifrons* increases with depth (Casaux *et al.* 2000). Our results may also suggest differences in the foraging depths used by the four colonies.

Our results differ from those presented in the only two previous studies on the diet of the Antarctic shag on the Antarctic Peninsula. According to Tomo (1970) the only prey species at Paradise Bay (64°53'S 62°53'W) during summer was *T. newnesi*, whereas in our study the food diversity is greater but also includes *T. newnesi*. Schlatter & Moreno (1976) reported that the fish remains found around the nests in the shag colony at Green Island, Antarctic Peninsula (65°20'S 64°10'W), belonged mainly to nototheniids but also to channichthyids (*Lepidonotothen kempi* (Norman) listed as *Notothenia kempi*: three individuals, and *Trematomus hansoni* (Boulenger): 1 individual, were the only two species identified). Based on these few data and on the size (up to 5 mm but predominantly between 2–3 mm) of unidentified otoliths found in a total of 64 pellets, they concluded that the Antarctic shag foraged mainly on pelagic juvenile *Notothenia* spp. and *Trematomus* spp. estimated to be 1–3 years old, 7.5–12.5 cm in length and 100–150 g in mass. These length and mass estimates were calculated using the relationship for otolith length/fish total length estimated by Hureau (1970) for *Notothenia cyanobrancha* Richardson, a fish species that is not taken by *P. bransfieldensis*. The hypothesis of exclusive predation on pelagic fish stages was erroneously based on a supposedly limited diving ability of the Antarctic shag. From the present study on the Danco Coast and from other recent studies at the South Shetland Islands (reviewed in Casaux *et al.* 1998b) it is now known that *P. bransfieldensis* prey on demersal-benthic fish frequently larger and heavier than those reported by Schlatter & Moreno (1976). For example, otoliths of 3 mm in length from frequent prey species such as *N. coriiceps*, *T. newnesi*, *T. bernacchii* and *Parachaenichthys charcoti*, which were concurrently sampled using trammel nets in the study area, represent fish of 22 to 29 cm in length and 169 to 273 g in mass (Casaux *et al.* 2000).

The comparison of our results with those given for *P. bransfieldensis* at the South Shetland Islands shows some quantitative differences in the composition of the diet. The importance of *G. gibberifrons* as prey of the Antarctic shag on the Danco Coast is markedly higher than that reported for the South Shetland Islands (Casaux & Barrera-Oro 1993, Coria *et al.* 1995, Barrera-Oro & Casaux 1996, Casaux *et al.* 1997a, Favero *et al.* 1998). The low predation on *G. gibberifrons* and *N. rossii* around the South Shetland Islands is related to the low occurrence of these two fish species in inshore waters (< 100 m depth) there (Casaux & Barrera-Oro 1993). The high incidence of *G. gibberifrons* in the diet of shags at the Danco Coast reflects a higher availability of this fish in an area remote from the main historical fishing grounds of the South Shetland Islands (Elephant Island and north of Livingston/King George islands) and the Antarctic Peninsula (Joinville Island) (see Kock 1992, for review). Recent data obtained directly from trammel net catches confirm the difference between both areas on the occurrence of *G. gibberifrons* around Antarctic shag colonies (Barrera-Oro *et al.* 2000, Casaux *et al.* 2000). The geographical distribution of *N. rossii* barely encroaches on the study area (DeWitt *et al.* 1990) supporting the low frequency in the diet.

The explanations given above support the hypothesis provided in Barrera-Oro & Marschoff (1991) and Barrera-Oro *et al.* (2000) that the most likely reason for the decrease in the inshore population of *G. gibberifrons* around the South Shetland Islands over the last seventeen years was the commercial fishing in the area at the end of the 1970s. Our findings are also consistent with the hypothesis of Casaux & Barrera-Oro (1993) where available in non-commercially exploited areas, *G. gibberifrons* can be an important component in the diet of the Antarctic shag. In conclusion, this study provides support for the suggestion that the analysis of the diet of this species reflects changes in the local availability of fish, one of the main assumptions that validate the use of shags to monitor trends in coastal fish populations.

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Appendix A. Equations for estimating fish length and mass from otolith length.

Notothenia coriiceps		
total length (cm) = -15.93 + otolith length (mm) * 13.03106	$n = 170$	$r = 0.89$
mass (g) = (0.008105 * total length (cm)$^{3.179846}$) + 1.750282	$n = 169$	$r = 0.99$
Gobionotothen gibberifrons		
total length (cm) = -6.27075 + otolith length (mm) * 5.211154	$n = 156$	$r = 0.91$
mass (g) = (0.000288 * total length (cm)$^{3.987669}$) + 15.92278	$n = 150$	$r = 0.99$
Trematomus bernacchii		
total length (cm) =-4.31225 + otolith length (mm) * 6.276656	$n = 36$	$r = 0.88$
mass (g) = (0.000222 * total length (cm)$^{4.2551}$) + 17.96915	$n = 34$	$r = 0.99$
Parachaenichthys charcoti		
total length (cm) = -13.2984 + otolith length (mm) * 14.13528	$n = 12$	$r = 0.97$
mass (g) = (0.000034 * total length (cm)$^{4.353528}$) + 17.53174	$n = 11$	$r = 0.98$

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