

## Original Paper

# The diet of the South Georgia shag *Phalacrocorax georgianus* at South Orkney Islands in five consecutive years

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**Abstract.** The diet of the South Georgia shag *Phalacrocorax georgianus* at Laurie Island, South Orkney Islands, was studied by the analysis of 420 pellets (regurgitated casts) collected from the 1995 to 1999 breeding seasons. Demersal-benthic fish were by far the main prey, followed by molluscs (mainly octopods and bivalves) and polychaetes. *Harpagifer antarcticus* (in 1995, 1998, 1999) and *Lepidonotothen nudifrons* (1996, 1997) were the most frequent prey, followed by *Gobionotothen gibberifrons* or *Trematomus newnesi*. *H. antarcticus*, followed by *L. nudifrons* or *T. newnesi*, was the most numerous prey in all of the seasons and predominated in mass in 1995 and 1996, followed by *Notothenia coriiceps* and *L. nudifrons*. In 1997 and 1999, *G. gibberifrons* and *N. coriiceps* were the species that most contributed to the diet whereas *N. coriiceps* and *H. antarcticus* contributed most in 1998. Our results differ from those reported for the South Orkney Islands in previous studies. These differences could be due to the use of different diet-analysis methods and to shags-related and/or fisheries-related changes in the food availability around the colonies. These alternative explanations are analysed and discussed.

## Introduction

The South Georgia shag (*Phalacrocorax georgianus*) breeds at South Georgia, Shag Rocks and at the South Sandwich and South Orkney Islands (Orta 1992). The total population estimated for this last archipelago is approximately 2,000 breeding pairs (N. Copley, unpublished work, quoted in Rootes 1988; N. Coria, unpublished data) distributed in colonies of up to 770 pairs.

Several studies carried out at South Georgia deal with the foraging behaviour of this shag. Wanless and Harris (1993) and Wanless et al. (1995) reported on the daily foraging activity and the extension of the foraging areas of breeding individuals. Croxall et al. (1991) and Wanless et al. (1992) considered the diving behaviour of this shag whereas Kato et al. (1992) analysed sexual differences in

diving patterns and performance. Despite this information, few authors have reported on the composition of the diet of the South Georgia shag. Wanless et al. (1992) and Wanless and Harris (1993) observed that *P. georgianus* at South Georgia forage mainly on bottom-living species, fish being the commonest prey, followed by octopods, polychaetes and crustaceans. However, these authors do not provide information on the species ingested. Few studies provided information on the diet of shags breeding at the South Orkney Islands (Conroy and Twelves 1973; Shaw 1984; Casaux et al. 1997a) and, although from occasional or few samples, all of them reported that the fish *Notothenia coriiceps* was the main prey.

Commercial fishing in the South Orkney Islands region (FAO Statistical Subarea 48.2) started in the 1977/1978 season. A total of 250,263 t of finfish was caught until the closure of the fisheries in the area in the 1990/1991 season, but most of the catches were fished during the first 3 years of exploitation (Kock 1992). *Champscephalus gunnari* constituted the bulk of the catches (187,898 t) whereas 2,888 t and 38,821 t of *N. rossii* and *Gobionotothen gibberifrons* were taken, respectively. However, as reported by Kock (1992), the catches of *Pisces nei* (approximately 9,691 t, excluding *Channichthyidae nei* and *Myctophidae nei*) probably consisted mostly of *G. gibberifrons*. As reported for Kerguelen Island (Duhamel 1990) and the South Shetland Islands (Barrera-Oro and Marschoff 1991), it is to be expected that the fisheries had affected the structure of the fish community around the South Orkney Islands, but there is not enough information available to corroborate this hypothesis and/or evaluate trends in fish populations.

Given that shags are opportunistic feeders (Craven and Lev 1987; Keller 1995) and that the fish represented in their pellets (regurgitated casts) agreed, even in relative numbers, with those regularly sampled by means of trammel-nets (Casaux and Barrera-Oro 1993), the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) considered that, among other parameters, the analysis of the diet of these birds could help to monitor trends in coastal-fish populations, mainly those of commercial interest such as *N. rossii* and *G. gibberifrons* (SC-CAMLR 1998). Thus, in this study, we provide new information on the fish species represented in the diet of the South Georgia shag, obtained from the analysis of pellets collected during five consecutive breeding seasons at Laurie Island, South Orkney Islands, to improve the knowledge of the foraging behaviour of this bird, and give advice on changes in the abundance of *N. rossii* and *G. gibberifrons* in the area.

## Materials and methods

The diet of the South Georgia shag (*P. georgianus*) at South Orkney Islands was studied by the analysis of 420 pellets (regurgitated casts) collected at Pirie Peninsula, close to Orcadas Station (60°42' S, 44°38' W) at Laurie Island, during the chick-rearing period of the 1995/1996 ( $n=24$ , hereafter 1995), 1996/1997 ( $n=226$ , 1996), 1997/1998 ( $n=54$ , 1997), 1998/1999 ( $n=77$ , 1998) and 1999/2000 ( $n=39$ , 1999) breeding seasons.

The pellets found in active nests were collected in separate polythene bags, and at the laboratory were dried at 60°C and sorted into prey classes, up to the lowest taxonomic level possible, using a binocular microscope. The otoliths present in the samples were identified, where possible, to species using descriptions and illustrations in Hecht (1987) and Williams and McEldowney (1990), and by comparison with our own reference collection. The otoliths belonging to each species were sorted into right and left, the most abundant being considered as the number of individuals from that species present in the sample. The otoliths were measured in length (to 0.01 mm), to calculate the size and mass of the specimens, applying the equations in Hecht (1987), Williams and McEldowney (1990) and Casaux et al. (1998). For the fish and shag species, we followed the nomenclature given in Gon and

Heemstra (1990) and Orta (1992), respectively.

## Results

The overall composition of the diet of the South Georgia shag was similar in all of the years considered. Fish were by far the main prey, followed by molluscs (mainly octopods and bivalves) and polychaetes (Table 1).

**Table 1.** Composition of the diet of the South Georgia shag *Phalacrocorax georgianus* as reflected by the analysis of 420 pellets collected in 5 consecutive breeding seasons at Laurie Island, South Orkney Islands. Diet is described by percentage frequencies of occurrence (*F%*) and number (*N%*). Sampling size *in parentheses*

	1995 (n=24)		1996 (n=226)		1997 (n=54)		1998 (n=77)		1999 (n=39)	
	<i>F%</i>	<i>N%</i>	<i>F%</i>	<i>N%</i>	<i>F%</i>	<i>N%</i>	<i>F%</i>	<i>N%</i>	<i>F%</i>	<i>N%</i>
Fish	100.0	96.8	100.0	93.2	100.0	92.5	100.0	93.2	100.0	91.3
Octopods	62.5	1.6	67.3	3.0	53.7	5.6	54.6	5.0	48.7	6.8
Bivalves	70.8	0.6	44.3	2.4	13.0	0.8	13.0	0.5	5.1	0.4
Limpets	8.3	0.1	2.1	0.0	-	-	-	-	-	-
Snails	70.8	0.1	29.7	0.5	1.9	0.1	6.5	0.2	15.4	1.1
Squids	-	-	0.4	0.0	-	-	1.3	0.0	-	-
Polychaetes	25.0	0.2	18.6	0.3	18.5	0.8	5.2	0.2	-	-
Brachiopods	-	-	4.0	0.5	3.7	0.3	7.8	0.9	5.1	0.4
Crustaceans	-	-	2.2	0.0	-	-	2.6	0.1	2.6	0.1
Algae	100.0	-	70.8	-	29.6	-	33.8	-	61.5	-

A total of 38,925 otoliths was found in the samples and represented 25,080 fish; 11,898 of them were identified to species; 52.6% of the fish represented in the samples (13,182 individuals) remained unidentified as the otoliths were broken or too eroded, but mainly due to the fact that most of them belonged to early stages of nototheniid species, presumably *Trematomus* spp.

Fish belonging to the families Nototheniidae and Harpagiferidae dominated in the diet whereas those from the families Channichthyidae, Bathydraconidae, Artedidraconidae and Myctophidae were scarcely represented. *Harpagifer antarcticus* (in 1995, 1998, 1999) and *Lepidonotothen nudifrons* (in 1996 and 1997) were the most frequent prey, followed by *G. gibberifrons* or *Trematomus newnesi* (Table 2). *H. antarcticus*, followed by *L. nudifrons* or *T. newnesi*, was the most numerous prey in all of the years and predominated in mass in 1995 and 1996, followed by *N. coriiceps* and *L. nudifrons*. In 1997 and 1999, *G. gibberifrons* and *N. coriiceps* were the species that most contributed to the diet by mass whereas *N. coriiceps* and *H. antarcticus* contributed most in 1998.

**Table 2.** Fish represented in the diet of the South Georgia shag *Phalacrocorax georgianus* as reflected by the analysis of 420 pellets collected in 5 consecutive breeding seasons at Laurie Island, South Orkney Islands. Diet is described by percentage frequencies of occurrence (*F%*), number (*N%*) and mass (*M%*). The number of fish represented in the pellets each year is presented *in parentheses*

	1995 (2924)			1996 (16725)			1997 (1713)			1998 (3030)			1999 (688)		
	F%	N%	M%	F%	N%	M%	F%	N%	M%	F%	N%	M%	F%	N%	M%
Nototheniidae															
<i>G. gibberifrons</i>	70.8	1.8	7.9	61.5	3.8	7.9	66.7	10.6	33.9	67.5	11.8	13.6	61.5	14.1	38.3
<i>L. larseni</i>	29.2	0.9	3.7	25.7	1.4	1.7	26.0	3.1	3.2	32.5	2.5	3.2	12.8	1.0	0.1
<i>L. nudifrons</i>	75.0	4.2	16.0	85.4	9.4	13.8	70.4	15.6	15.0	75.3	16.1	15.1	59.0	17.4	6.9
<i>L. squamifrons</i>	-	-	-	0.4	0.0	0.2	-	-	-	-	-	-	-	-	-
<i>N. coriiceps</i>	37.5	0.9	19.1	49.1	1.8	28.0	48.1	2.6	20.1	50.7	2.5	32.4	59.0	7.9	38.0
<i>N. rossii</i>	-	-	-	2.2	0.0	0.6	5.6	0.2	2.4	-	-	-	5.1	0.3	3.0
<i>T. bernacchii</i>	4.2	0.0	0.1	3.1	0.1	0.3	9.3	0.4	0.7	20.8	0.8	2.2	25.6	2.2	2.4
<i>T. eulepidotus</i>	4.2	0.0	0.4	-	-	-	-	-	-	-	-	-	-	-	-
<i>T. newnesi</i>	79.2	4.6	15.7	70.8	4.7	10.1	46.3	4.4	8.2	44.2	2.8	5.8	23.1	2.5	1.5
<i>T. scotti</i>	-	-	-	-	-	-	1.9	0.1	0.6	-	-	-	-	-	-
Harpagiferidae															
<i>H. antarcticus</i>	87.5	16.8	36.8	79.2	24.7	36.8	63.0	18.0	14.7	83.1	31.9	26.7	69.2	30.2	9.2
Channichthyidae															
<i>C. wilsoni</i>	-	-	-	-	-	-	1.9	0.1	0.3	-	-	-	-	-	-
<i>C. gunnari</i>	4.2	0.0	0.3	-	-	-	-	-	-	-	-	-	-	-	-
<i>C. rastrospinosus</i>	-	-	-	0.4	0.0	0.0	-	-	-	-	-	-	-	-	-
Bathydraconidae															
<i>P. charcoti</i>	-	-	-	1.3	0.0	0.3	1.9	0.1	0.6	6.1	0.2	2.2	-	-	-
Artedidraconidae															
<i>P. scotti</i>	-	-	-	-	-	-	1.9	0.1	0.1	-	-	-	-	-	-
Myctophidae															
<i>P. normani</i>	-	-	-	0.4	0.0	0.0	-	-	-	-	-	-	-	-	-
Unidentified	100.0	70.9	-	93.4	54.0	-	90.7	44.8	-	87.8	37.7	-	71.8	24.4	-

The length of the fish consumed varied in the different years (ANOVA,  $F_{4,12082}=185.2$ ,  $P<0.00001$ ). The largest fish were ingested in 1999 (Newman-Keuls,  $P<0.0001$ ) whereas the smallest ones were ingested in 1995 (Newman-Keuls,  $P<0.0001$ ) (Table 3). Within species, there were also significant differences in the length of the fish eaten in the different years; the largest specimens of *N. coriiceps* ( $F_{4,498}=7.4$ ,  $P<0.0001$ ), *H. antarcticus* ( $F_{4,6112}=95.6$ ,  $P<0.000001$ ), *G. gibberifrons* ( $F_{4,1325}=47.0$ ,  $P<0.00001$ ) and *Lepidonotothen larseni* ( $F_{4,414}=26.5$ ,  $P<0.000001$ ) were ingested in 1999 whereas the largest *L. nudifrons* ( $F_{4,2570}=15.6$ ,  $P<0.000001$ ) and *T. newnesi* ( $F_{4,1097}=101.0$ ,  $P<0.000001$ ) were ingested in 1995 and 1998, respectively.

**Table 3.** Total length (mean in centimetres, standard deviation and range) of the fish represented in the diet of the South Georgia shag *Phalacrocorax georgianus* as reflected by the analysis of 420 pellets collected in 5 consecutive breeding seasons at Laurie Island, South Orkney Islands. The number of fish considered each year is presented *in parentheses*

	1995 (851)			1996 (7694)			1997 (945)			1998 (2072)			1999 (520)		
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Nototheniidae															
<i>G. gibberifrons</i>	8.8	4.1	3.5-24.7	8.7	3.7	0.3-30.8	11.5	5.5	4.8-30.2	10.4	2.7	4.7-18.3	14.4	8.1	3.3-35.8
<i>L. larseni</i>	9.3	3.2	5.0-16.4	7.7	1.8	4.0-19.2	8.9	1.6	6.9-17.5	10.1	0.9	7.5-11.3	9.9	1.2	7.4-10.8
<i>L. nudifrons</i>	8.8	2.0	4.7-13.1	7.8	2.0	3.9-14.5	8.2	1.7	5.1-12.9	8.4	1.5	4.4-13.2	8.6	1.5	5.5-12.5
<i>L. squamifrons</i>	-	-	-	22.1	-	-	-	-	-	-	-	-	-	-	-
<i>N. coriiceps</i>	11.5	5.7	1.2-20.2	13.8	5.8	0.2-26.5	13.2	4.2	5.4-22.1	15.8	5.0	5.7-25.9	16.6	5.6	2.4-29.9
<i>N. rossii</i>	-	-	-	18.7	2.4	16.1-21.0	19.0	5.1	13.3-23.1	-	-	-	23.7	6.1	19.4-28.0
<i>T. bernacchii</i>	9.5	-	-	10.5	3.2	7.8-21.9	11.4	2.5	8.7-15.9	13.8	1.0	12.1-15.8	13.1	3.0	8.2-18.6
<i>T. eulepidotus</i>	11.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>T. newnesi</i>	6.4	1.3	4.7-11.2	7.1	1.0	4.8-12.0	8.5	0.9	6.7-11.9	8.7	1.2	6.2-10.6	8.0	1.3	6.1-10.6
<i>T. scotti</i>	-	-	-	-	-	-	13.1	0.0	13.1-13.1	-	-	-	-	-	-
Harpagiferidae															
<i>H. antarcticus</i>	6.1	0.6	4.8-8.8	6.5	0.6	4.2-10.1	6.9	0.6	5.3-8.6	6.9	0.5	5.8-8.8	6.9	0.5	5.7-8.1
Channichthyidae															
<i>C. wilsoni</i>	-	-	-	-	-	-	16.3	-	-	-	-	-	-	-	-
<i>C. gunnari</i>	17.6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>C. rastrispinosus</i>	-	-	-	12.7	-	-	-	-	-	-	-	-	-	-	-
Bathydraconidae															
<i>P. charcoti</i>	-	-	-	18.3	3.2	14.9-23.1	18.8	-	-	25.7	2.7	23.8-27.6	-	-	-
Arteidraconidae															
<i>P. scotti</i>	-	-	-	-	-	-	11.6	-	-	-	-	-	-	-	-
Myctophidae															
<i>P. normani</i>	-	-	-	5.4	0.1	5.3-5.5	-	-	-	-	-	-	-	-	-
Overall	7.0	2.3	1.2-24.7	7.4	2.5	0.2-30.8	8.8	3.5	4.8-30.2	8.5	2.9	4.4-27.6	10.04	5.4	2.4-35.8

## Discussion

As reported by Wanless et al. (1992) and Wanless and Harris (1993) for South Georgia, and by Shaw (1984) and Casaux et al. (1997a) also for the South Orkney Islands, demersal-benthic fish, followed by invertebrates such as octopods, polychaetes and crustaceans, were the main prey of the South Georgia shags considered in this study.

Conroy and Twelves (1973) reported that the only shag-stomach content sampled at the South Orkney Islands contained a single *N. coriiceps* specimen (formerly known as *Notothenia neglecta*), whereas by the analysis of 84 regurgitated food samples, Shaw (1984) observed that at this locality this fish was the main prey, followed by *Trematomus* spp. and *N. rossii*. Recently, Casaux et al. (1997a) provided new information on the diet of *P. georgianus* at the South Orkney Islands, based on the analysis of 29 stomach contents collected throughout the breeding season. These authors also observed that *N.*

*coriiceps* was the most important prey, followed by *T. newnesi* and *L. nudifrons*. Although in our study the analysis of pellets indicated that *N. coriiceps* was the main prey in 1998, *H. antarcticus* dominated in the diet in 1995 and 1996, and *G. gibberifrons* dominated in 1997 and 1999. Several hypotheses are suggested to explain the differences between our findings and those from previous studies: (1) analysis of different types of samples, (2) biased results in our study due to a large number of unidentified fish, (3) shags-related changes in the food availability around the colony, and (4) fisheries-related changes in the food availability.

Casaux et al. (1997b, 1998) and Casaux (1998) compared results from pellets with those from stomach contents and from stomach contents and regurgitated food samples collected simultaneously. It was reported that the food spectrum observed in pellets was slightly wider than those observed in stomach contents and regurgitated food samples. This may be explained by a higher number of foraging trips represented per pellet (four to seven foraging trips per pellet, Casaux et al. 1997b) compared with those represented in stomach contents or regurgitated food samples (one foraging trip per sample). There were also quantitative differences in the diet reflected by the different type of samples; e.g. the importance of *H. antarcticus* in the diet as reflected by the analysis of pellets is usually higher than when estimated by the analysis of stomach contents and/or regurgitated food samples. Thus, at least partially, hypothesis (1) probably explains the differences observed with previous studies. Mainly in 1995 and 1996, but also in the other years, a high number of the fish represented in the samples remained unidentified, chiefly due to the fact that the otoliths belonged to early stages of nototheniid species, presumably *Trematomus* spp. Hypothesis (2) does not explain the differences with previous studies since, if we consider the unidentified fish as *Trematomus* spp., the composition of the diet in this study remains markedly different from that reported previously. Considering that Casaux and Barrera-Oro (1999) observed experimentally that the structure of the population of a fish with a marked site fidelity like *N. coriiceps* (Barrera-Oro and Casaux 1996a) may be affected by a constant catch rate, it is probable that in subsequent years shags deplete the stocks of sedentary fish around the colonies (see also Birt et al. 1987; Leopold et al. 1998). Thus in order to perform a high prey catch rate it is probable that the shags forage proportionally on different prey species annually and/or alternate the feeding areas, which may explain the low importance of *N. coriiceps* in the diet mainly during 1995, but also during 1996, 1997, 1998 and 1999, when compared with previous studies. Finally, Duhamel (1990) and Barrera-Oro and Marschoff (1991) reported that the severe depletion of the offshore reproductive stocks of *N. rossii* and *G. gibberifrons* by the commercial fishery at Kerguelen and South Shetland Islands resulted in a marked diminution of the inshore stocks. After the closure of the fisheries, the continuous and/or incipient recovery of those inshore stocks are being observed (Duhamel 1990; Barrera-Oro et al. 2000). Given that shags are opportunistic inshore feeders (see also Craven and Lev 1987; Keller 1995), it is to be expected that the diet of the South Georgia shag reflects such trends in the inshore fish populations, if they also occur at the South Orkney Islands.

Shaw (1984) provided information on the diet of the South Georgia shag obtained during the 1979/1980 and 1980/1981 breeding seasons, after the first 2 years of commercial exploitation in the area when the bulk of the catches were already fished and the fisheries were considered not remunerative (see Kock 1992, for review). Shaw reported that *N. rossii* represented 13.4% by mass and that *G. gibberifrons* was absent from the diet of the South Georgia shag. Casaux et al. (1997a) reported that during the 1994/1995 breeding season, 4 years after the closure of the fisheries in the area, *N. rossii* was absent and *G. gibberifrons* was scarcely represented (1% by mass) in the samples analysed. Casaux et al. (1997a) suggested that the absence or low abundance of these two species in the diet of the South Georgia shag was probably related to a decrease in the abundance of these fish due to the fisheries in the area, a phenomenon also observed at South Georgia (Burchett and Ricketts, personal communication, quoted in North et al. 1983), Kerguelen Island (Duhamel 1990) and the South Shetland Islands (Barrera-Oro and Marschoff 1991). In our samples, *N. rossii* was only scarcely represented in 1996, 1997 and 1999 whereas the importance by number (Spearman test,  $r=0.97$ ,

$P < 0.01$ ) and mass ( $r = 0.87$ , n.s.) of *G. gibberifrons* in the diet tended to increase throughout the study period, being the most important prey by mass in 1997 (33.9%) and 1999 (38.3%). If it is assumed that the fish stocks were affected by the fisheries, and taking into account the historical data, our results seem to indicate a recovery of *G. gibberifrons* in inshore waters around the South Orkney Islands.

When our results were compared with those reported for the other shag species distributed in Antarctica, the Antarctic shag, *P. bransfieldensis*, quantitative differences in the contribution to the diet of the different fish species were observed. Interestingly, the importance of *N. coriiceps* and *G. gibberifrons* in the diet of the Antarctic shag at the South Shetland Islands (Casaux and Barrera-Oro 1993; Coria et al. 1995; Barrera-Oro and Casaux 1996b) was markedly higher and lower, respectively, than observed in this study. In contrast, the contribution of *G. gibberifrons* to the diet of the Antarctic shag at a locality far away from the main fishing grounds such as the Danco Coast, Antarctic Peninsula, was largely higher than that reported here (Casaux et al. 2002). These findings support the observations of Barrera-Oro et al. (2000) who reported that the present abundance of *G. gibberifrons* in inshore waters at the South Shetland Islands remains low, with the most likely reason for such populational decrease being the commercial fisheries around the archipelago at the end of the 1970s. Our results are also consistent with the suggestion of Casaux and Barrera-Oro (1993) that in non-commercially exploited areas and/or where available, *G. gibberifrons* could be an important component in the diet of these shags (i.e. the diet of this bird reflects changes in the food availability) (see also Casaux et al. 2002), one of the main assumptions supporting the use of shags to monitor coastal fish populations.

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