Antarctic Science 21 (3), 221–227 (2009) © Antarctic Science Ltd 2009 Printed in the UK doi:10.1017/S0954102009001746

The diet of post-breeding Antarctic shags *Phalacrocorax bransfieldensis* at the Danco Coast, Antarctic Peninsula

R. CASAUX[1,2]*, A. BARONI[3], A. RAMÓN[4], M. BERTOLIN[2] and C.Y. DI PRINZIO[2]

[1]*Instituto Antártico Argentino, Cerrito 1248, 1010 Buenos Aires, Argentina*
[2]*Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Av. Rivadavia 1917, (1033) Buenos Aires, Argentina*
[3]*Facultad de Farmacia y Bioquímica, Universidad de Buenos Aires, Junín 956, 1113 Buenos Aires, Argentina*
[4]*Subsecretaría de Medioambiente, Municipalidad de Esquel, Mitre 524, 9200 Esquel, Chubut, Argentina*
**Present address: Laboratorio de Investigaciones en Ecología y Sistemática Animal (LIESA), Universidad Nacional de la Patagonia San Juan Bosco, Ruta 259 km. 5, Planta de Aromáticas, 9200 Esquel, Chubut, Argentina*
**rcasaux@dna.gov.ar*

Abstract: The diet of post-breeding Antarctic shags *Phalacrocorax bransfieldensis* was investigated at four colonies at the Danco Coast, Antarctic Peninsula, by the analysis of 399 pellets (regurgitated casts) collected during February and March 1998 and 2000. Overall, demersal-benthic fish were the most frequent and important prey at all the colonies sampled, followed by octopods and gastropods. Amongst the fish, *Notothenia coriiceps* and *Gobionotothen gibberifrons* were the main prey in all of the sampling sites in both seasons. The composition of the diet of post-breeding shags differed from that observed in the previous breeding season. Post-breeders preyed on the same fish species consumed by breeders, although in different proportions and on larger specimens. The information provided here differs from that reported for post-breeding individuals belonging to other shag species and also for post-breeding Antarctic shags. Our results, as well as the differences with previous studies, are discussed in relation to differences in prey availability among localities and to the use of alternative foraging grounds at the end of the breeding period.

Received 18 September 2008, accepted 27 October 2008

Key words: Antarctica, *Gobionotothen*, *Notothenia*, post-breeding diet

Introduction

The Antarctic shag *Phalacrocorax bransfieldensis* Murphy breeds along the Antarctic Peninsula and at the South Shetland Islands (Orta 1992) during the summer in colonies of up to several hundred breeding pairs (Bernstein & Maxson 1985). Several studies deal with the foraging and reproductive behaviour and population trends of breeding Antarctic shags (see review in Casaux & Barrera-Oro 2006). However, due to limitations in logistic support as well as to adverse environmental conditions, little is known about this shag during the non-breeding period. It is believed that during winter these birds remain in the proximity of the breeding sites (Holdgate 1963, Tomo 1970, Glass 1978). Interestingly, an Antarctic shag which had been ringed as juvenile in 1989 at the South Shetland Islands, was found in the winter of 1997 at Sao Salvador do Bahia, Brazil (M. Favero personal communication 1998).

A steady declining trend in the number of breeding Antarctic shags has been reported for the last eighteen years at several colonies in the South Shetland Islands and the Antarctic Peninsula (Casaux & Barrera-Oro 2006). Whether individuals disperse or remain close to the colonies, the post-breeding foraging strategy is crucial to restore body condition in preparation for migration or for the harsher Antarctic winter conditions. An adequate foraging performance is essential to reduce post-breeding adult mortality and improve recruitment, both factors strongly related to the population trend of this bird.

Despite the importance of studying this aspect of the biology of the Antarctic shag, only one study, published almost four decades ago (Tomo 1970), reported on their post-breeding foraging behaviour. However, the information provided is very limited and there is not detail on the type and number of samples analysed and on the methodology followed. Thus, the aim of this study is to provide new information on the post-breeding diet of *P. bransfieldensis* from an unstudied area at the Antarctic Peninsula such as the Danco Coast.

Material and methods

A total of 399 pellets (regurgitated casts) of post-breeding Antarctic shags (adults and newly fledged chicks) were collected from 25 February–23 March 1998 (150 pellets) and from 16 February–29 March 2000 (249 pellets) at roosting areas surrounding four colonies in the Danco Coast, Antarctic Peninsula: Cape Herschel (64°05'S 61°02'W; surveyed only in 2000), Primavera Island (64°09'S 60°59'W; surveyed only in 1998), Midas Island (within the Antarctic Specially Protected Area No 134,

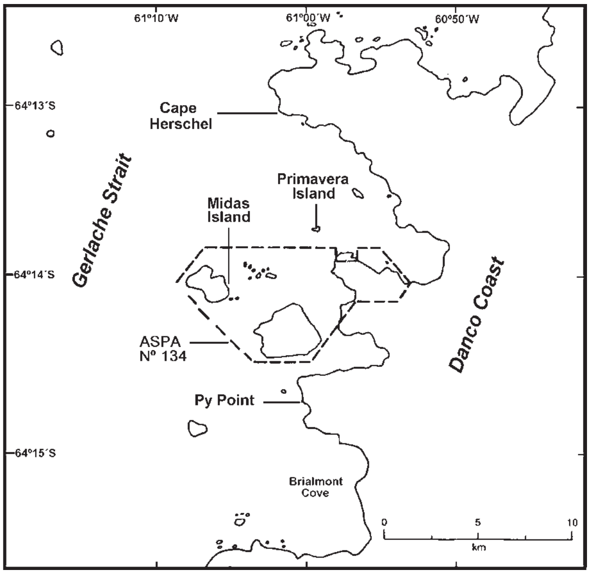

Fig. 1. Map showing the location of the colonies studied in the Danco Coast, Antarctic Peninsula, and the extension of the Antarctic Specially Protected Area (ASPA) No. 134.

64°10'S 61°05'W) and Py Point (64°13'S 61°00'W) (Fig. 1). During the 1997–98 breeding season all the breeding individuals and fledging chicks from the colonies located within the studied area were ringed. Given that during the 1998 post-breeding period only ringed specimens were observed at the roosting sites, we assumed that, at least for this season, the samples collected were produced by post-breeding individuals and not by juveniles or immature adults. For the analysis of the samples we followed the methods described in Casaux *et al.* (2002).

Results

In both seasons shags preyed almost exclusively on fish; invertebrates, mainly molluscs, were poorly represented in the samples (Table I). Amongst fish, benthic-demersal species of the family Nototheniidae largely predominated in the diet. *Notothenia coriiceps* Richardson or *Gobionotothen gibberifrons* (Lönnberg), depending on the colony and season, were the most important prey both by number and mass. Except for *Harpagifer antarcticus* Nybelin, fish from the remaining families represented in the samples (Bathydraconidae, Myctophidae and Paralepididae) contributed little to the diet (Table II). The differences in the composition of the diet between both post-reproductive seasons were statistically significant for Midas Island ($\chi^2_{14} = 150.9$; $P < 0.00001$) and Py Point ($\chi^2_{14} = 31.3$; $P < 0.01$) (Table II). Compared to the previous breeding season (see Casaux *et al.* 2002), post breeders from all the colonies considered in 1998 increased the consumption of *G. gibberifrons* and decreased the consumption of *N. coriiceps* and *H. antarcticus* which resulted in significant differences in the composition of the diet ($\chi^2_{13} > 28.0$; $P < 0.01$). The size of the fish ingested differed statistically between both post-breeding seasons (ANOVA, F = 4.77, df 1, $P < 0.05$). The fish ingested in 1998 (mean 11.9 ± 5.6 cm) were smaller than those ingested in 2000 (mean 12.4 ± 5.9 cm) (Table III). As observed in the 1997/98 breeding season, in the 1998 post-breeding period we observed marked differences in the size of the fish ingested at the different colonies (ANOVA, F = 21.6, df 2, $P < 0.0001$); shags from Py Point preyed **on** the smallest fish compared to Midas and Primavera islands (Newman-Keuls, $P < 0.0001$). This was mainly influenced by the number of specimens of the smallest fish species, *H. antarcticus*, consumed at Py Point. These differences among colonies in the size of the fish ingested were not observed in 2000. During the 1998 post-breeding period shags from Py Point and Primavera Island consumed fish larger than those consumed during the previous breeding season (Mann-Whitney, U > 306329, $P < 0.0001$). Post-breeders preyed on larger *Trematomus newnesi* Boulenger (Mann-Whitney, U = 1642, $P < 0.01$) and *H. antarcticus* specimens (U = 92701, $P < 0.00001$) at Py Point and on larger *N. coriiceps* (U = 3051, $P < 0.01$) and *H. antarcticus* (U = 3414, $P < 0.00001$) specimens at Primavera Island.

Table I. Diet of post-breeding Antarctic shags in the Danco Coast, Antarctic Peninsula, as reflected by the analysis of 399 pellets collected during February–March 1998 and 2000. Percentage frequencies of occurrence (F%) and number (N%). Number of pellets analysed in parenthesis.

	1998						2000					
	Midas Is. (50)		Py Point (50)		Primavera Is. (50)		Midas Is. (89)		Py Point (134)		Cape Herschel (26)	
	F%	N%	F%	N%	F%	N%	F%	N%	F%	N%	F%	N%
Fish	100.0	93.0	100.0	93.2	100.0	92.7	100.0	89.0	100.0	90.5	100.0	94.4
Octopods	18.0	2.4	14.0	1.5	20.0	3.5	28.1	6.0	13.4	3.4	7.7	1.3
Gastropods	12.0	2.1	12.0	2.2	28.0	2.6	14.5	1.9	13.9	3.3	11.5	1.3
Bivalves	8.0	1.3	10.0	1.6	6.0	0.9	1.1	0.2	2.2	1.2	3.9	0.4
Placophora	-	-	-	-	-	-	2.2	0.2	-	-	-	-
Amphipods	24.0	-	32.0	-	10.0	-	10.1	-	15.7	-	7.7	-
Polychaetes	14.0	1.3	16.0	1.4	4.0	0.3	15.7	2.7	9.0	1.6	19.2	2.6
Algae	86.0	-	82.0	-	80.0	-	55.1	-	56.0	-	80.8	-
Stones	80.0	-	72.0	-	84.0	-	42.7	-	36.6	-	73.1	-

Table II. Fish represented in 399 pellets of post-breeding Antarctic shags collected during February–March 1998 and 2000 at four colonies at the Danco Coast, Antarctic Peninsula. Percentage frequencies of occurrence (F%), number (N%) and mass (M%). Number of fish represented in the samples in parenthesis.

	1998									2000								
	Primavera Is. (607)			Midas Is. (637)			Py Point (579)			Midas Is. (721)			Py Point (986)			Cape Herschel (216)		
	F%	N%	M%	F%	N%	M%	F%	N%	M%	F%	N%	M%	F%	N%	M%	F%	N%	M%
Nototheniidae																		
Dissostichus mawsoni	-	-	-	-	-	-	-	-	-	-	-	-	0.7	0.1	0.5	-	-	-
Gobionotothen gibberifrons	50.0	29.0	48.0	84.0	25.9	63.9	30.0	8.6	21.5	21.4	4.4	18.3	20.2	5.6	13.8	42.3	13.9	46.1
Lepidonotothen nudifrons	52.0	20.4	8.3	92.0	39.1	13.2	30.0	7.8	4.7	52.8	30.5	11.0	32.1	15.8	6.1	30.8	7.4	1.8
Notothenia coriiceps	38.0	7.4	27.1	28.0	4.9	13.6	58.0	10.4	47.2	60.7	16.2	56.4	66.4	16.3	59.8	65.4	21.8	42.7
Notothenia rossii	2.0	0.2	3.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nototheniops nybelini	-	-	-	-	-	-	4.0	0.3	0.2	-	-	-	-	-	-	-	-	-
Pagothenia borchgrevinki	14.0	2.6	2.8	8.0	0.6	0.3	2.0	0.2	0.2	5.6	1.1	1.4	3.0	1.0	1.3	-	-	-
Pagothenia hansoni	-	-	-	-	-	-	-	-	-	1.1	0.1	0.1	0.8	0.2	0.3			
Trematomus bernacchii	22.0	3.5	3.7	30.0	4.9	4.2	24.0	5.5	7.0	15.7	4.2	3.7	20.9	8.0	8.4	11.5	3.2	0.8
Trematomus eulepidotus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.9	0.9	0.2
Trematomus newnesi	30.0	5.4	4.0	28.0	6.0	3.0	22.0	4.5	4.9	34.8	12.1	6.4	21.6	5.9	3.2	30.8	15.3	5.5
Trematomus scotti	8.0	1.0	1.5	6.0	0.9	1.0	4.0	0.5	1.0	-	-	-	1.5	0.2	0.0	3.9	0.5	0.0
Harpagiferidae																		
Harpagifer antarcticus	20.0	5.6	1.6	14.0	2.4	0.6	28.0	35.6	13.3	10.1	8.5	1.9	14.2	21.6	4.3	19.2	12.5	2.2
Bathydraconidae																		
Parachaenichthys charcoti	-	-	-	2.0	0.2	0.1	-	-	-	3.4	0.6	0.8	6.7	1.7	2.2	-	-	-
Myctophidae																		
Electrona antarctica	-	-	-	2.0	0.2	0.0	-	-	-	-	-	-	0.7	0.1	0.0	-	-	-
Electrona carlsbergi	-	-	-	-	-	-	-	-	-	-	-	-	1.5	0.2	0.1	3.9	1.4	0.5
Paralepididae																		
Notolepis coatsi	-	-	-	-	-	-	-	-	-	1.1	0.1	0.0	0.8	0.1	0.1	3.9	0.5	0.1
Unidentified	66.0	24.9	-	66.0	15.1	-	64.0	26.0	-	61.8	22.2	-	52.2	23.1	-	46.2	22.7	-

Table III. Mean total length, standard deviation and length range of the fish represented in 399 pellets of post-breeding Antarctic shags collected during February–March 1998 and 2000 at four colonies at the Danco Coast, Antarctic Peninsula.

	1998									2000								
	Primavera Is.			Midas Is.			Py Point			Midas Is.			Py Point			Cape Herschel		
	mean	sd	range	mean	sd	range	mean	sd	range	mean	sd	range	mean	sd	range	mean	sd	range
Nototheniidae																		
Dissostichus mawsoni	-	-	-	-	-	-	-	-	-	-	-	-	23.2	-	-	-	-	-
Gobionotothen gibberifrons	14.5	6.6	5.4–32.8	17.6	8.0	5.4–33.3	14.3	7.1	5.1–34.2	21.6	7.7	8.7–40.4	17.8	8.5	4.5–32.6	21.2	8.3	5.9–31.8
Lepidonotothen nudifrons	9.7	1.5	6.0–13.1	9.6	1.6	3.0–15.7	9.9	1.3	5.6–12.4	9.7	1.9	4.4–13.2	10.4	1.7	5.4–14.6	8.9	2.0	5.3–12.7
Notothenia coriiceps	17.2	4.7	4.8–28.0	15.2	6.1	5.8–29.0	16.3	4.5	8.2–26.3	17.4	5.5	5.3–27.7	19.0	4.7	6.4–30.7	14.7	4.7	5.6–25.4
Notothenia rossii	31.5	-	-	-	-	-				-	-	-	-	-	-	-	-	-
Nothothenios nybelini	-	-	-	-	-	-	11.9	1.3	10.9–12.8	-	-	-	-	-	-	-	-	-
Pagothenia borchgrevinki	11.2	3.7	2.0–16.3	9.1	3.6	5.0–13.3	10.8	-	-	12.9	2.9	10.6–19.2	13.6	1.9	11.7–17.9	-	-	-
Pagothenia hansoni	-	-	-	-	-	-	-	-	-	14.9	-	-	17.4	5.8	13.3–21.6	-	-	-
Trematomus bernacchii	14.3	2.8	9.1–18.6	13.9	3.1	7.8–20.2	13.4	3.0	6.9–21.4	13.7	3.2	8.6–21.5	15.1	3.2	8.4–24.8	10.4	1.7	8.2–13.1
Trematomus eulepidotus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11.0	0.4	10.8–11.3
Trematomus newnesi	9.9	1.9	7.2–13.7	9.0	1.6	6.1–14.3	10.2	2.1	4.7–13.6	9.4	1.2	6.2–12.6	9.7	1.5	5.6–14.3	8.3	0.8	6.9–9.8
Trematomus scotti	12.8	2.1	9.9–15.4	12.4	1.3	10.6–13.9	12.7	2.1	10.6–14.8	-	-	-	7.1	0.6	6.7–7.5	5.8	-	-
Harpagiferidae																		
Harpagifer antarcticus	7.8	0.6	6.0–8.8	7.9	0.6	6.7–8.9	7.4	0.8	4.9–9.3	7.3	0.8	6.2–10.2	7.2	0.7	5.5–8.9	7.2	0.5	6.0–8.4
Bathydraconidae																		
Parachaenichthys charcoti	-	-	-	17.9	-	-	-	-	-	20.8	5.7	16.0–28.1	21.3	4.6	11.8–28.5	-	-	-
Myctophidae																		
Electrona antarctica	-	-	-	5.4	-	-	-	-	-	-	-	-	4.1	-	-	-	-	-
Electrona carlsbergi	-	-	-	-	-	-	-	-	-	-	-	-	8.3	1.9	7.0–9.6	9.1	0.5	8.7–9.6
Paralepididae																		
Notolepis coatsi	-	-	-	-	-	-	-	-	-	16.5	-	-	24.4	-	-	18.8	-	-

Table IV. Summary of published information on diet composition of breeding Antarctic and sub-Antarctic *Phalacrocorax* species, with indication of the geographical area, the methodology used and the number of samples analysed (in parenthesis). Asterisks indicates those papers where strict identification of fish represented in shags diet is not provided, but it is assumed that fish prey were mainly demersal species. Modified from Casaux & Barrera-Oro 2006.

Species	Locality	Main prey	Secondary prey	Method of analysis	Source
P. bransfieldensis	Green Is., Antarctic Peninsula	demersal fish	octopods, crustaceans	pellets (64)	Schlatter & Moreno 1976*
P. bransfieldensis	Danco Coast, Antarctic Peninsula	demersal fish	octopods, gastropods, polychaetes	pellets (616)	Casaux *et al.* 2002
P. bransfieldensis	Nelson Is., South Shetland Is.	demersal fish	octopods, gastropods, gammarideans	pellets (50), stomach contents (40)	Casaux & Barrera-Oro 1993
P. bransfieldensis	Nelson Is., South Shetland Is.	demersal fish	octopods, polychaetes,		Coria *et al.* 1995
P. bransfieldensis	Half Moon Is., South Shetland Is.	demersal fish	gastropods, octopods, bivalves	pellets (38)	Barrera-Oro & Casaux 1996a
P. bransfieldensis	Nelson Is., South Shetland Is.	demersal fish	octopods, polychaetes	pellets (45), stomach contents (40)	Casaux *et al.* 1997b
P. bransfieldensis	Nelson Is., South Shetland Is.	demersal fish	octopods, gammarideans, euphausiids	stomach contents (139)	Favero *et al.* 1998
P. bransfieldensis	Nelson Is., South Shetland Is.	demersal fish	octopods, gammarideans, polychaetes	pellets (112), stomach contents (139)	Casaux *et al.* 1998
P. bransfieldensis	Nelson Is., South Shetland Is.	demersal fish	Gammarideans	stomach contents (84)	Casaux *et al.* 2001
P. bransfieldensis	Nelson Is., South Shetland Is.	demersal fish	polychaetes, gastropods, octopods	pellets (862)	Casaux 2003
P. georgianus	South Georgia	demersal fish	octopods, polychaetes, crustaceans	pellets (87)	Wanless & Harris 1993*
P. georgianus	South Georgia	demersal fish	octopods, polychaetes, crustaceans	pellets (48)	Wanless *et al.* 1992*
P. georgianus	Signy Is., South Orkney Is.	demersal fish	octopods, polychaetes, crustaceans	regurgitated samples (84)	Shaw 1986
P. georgianus	Laurie Is., South Orkney Is.	demersal fish	octopods, gammarideans, decapods	stomach contents (29)	Casaux *et al.* 1997a
P. georgianus	Laurie Is., South Orkney Is.	demersal fish	octopods, bivalves, polychaetes	pellets (420)	Casaux & Ramón 2002
P. melanogenis	Marion Is.	demersal fish	crustaceans, polychaetes, salps	pellets (2), stomach contents (1)	Blankley 1981
P. melanogenis	Marion Is.	demersal fish	crustaceans, octopods, polychaetes	pellets (50), stomach contents (47)	Espitalier Noel *et al.* 1988
P. melanogenis	Iles Crozet	demersal fish	crustaceans	stomach contents (19)	Derenne *et al.* 1976*
P. melanogenis	Iles Crozet	demersal fish	bivalves, crustaceans, polychaetes	stomach contents (129)	Ridoux 1994
P. melanogenis	Possession I.	demersal fish	crustaceans, annelids, octopods	stomach contents (11)	Tremblay *et al.* 2005
P. nivalis	Heard Is.	demersal fish	polychaetes, gastropods,	pellets (430)	Green *et al.* 1990a
P. nivalis	Heard Is.	demersal fish	polychaetes	pellets (210)	Green & Williams 1997
P. purpurascens	Macquarie Is.	demersal fish	-	stomach contents (47)	Brothers 1985
P. purpurascens	Macquarie Is.	demersal fish	crustaceans, gastropods, polychaetes	pellets (64)	Green *et al.* 1990b
P. purpurascens	Macquarie Is.	demersal fish	crustaceans, gastropods, bivalves	regurgitated samples (77), pellets (42)	Kato *et al.* 1996

Discussion

As has been reported for breeding individuals belonging to other shag species distributed in sub-Antarctic and Antarctic areas, and also for the Antarctic shag at the South Shetland Islands and the Antarctic Peninsula (Table IV), demersal-benthic fish were the main prey of post-breeding *Phalacrocorax bransfieldensis* at the four colonies investigated in this study (Table I). The only other study that provided information on the diet of post-breeding Antarctic shags surprisingly indicated that from autumn to spring this bird foraged solely on macroalgae (Tomo 1970). Although in our study macroalgae were frequently represented in the samples (Table I), we only found very small fragments which were always associated with fish remains. Thus, we consider that macroalgae are an indirect alimentary item (i.e. the macroalgae remains come from the stomachs of the fish consumed instead of being directly ingested by shags). This hypothesis is supported by the fact that during the study period algae were a frequent alimentary item of fish at the Danco Coast and constituted the bulk of the diet of *N. coriiceps* (Casaux *et al.* 2003), one of the main fish preys of the Antarctic shag. Unfortunately, Tomo (1970) did not provided information on the number and type of samples collected or on the methods used to analyse the samples, preventing further discussion on the differences in the results obtained.

Regarding other shag species, Espitalier-Noel *et al.* (1988) reported for *Phalacrocorax melanogenis* (Blyth) at Marion Island that from April to July invertebrates constituted 50% of the diet by mass. Green *et al.* (1990b) commented that at Heard Island non-breeding *P. nivalis* Falla foraged predominantly on polychaetes. These last authors also indicated that at the end of the breeding season breeders (whose main prey are fish) and newly fledged birds join non-breeders at roosting sites where they probably change their diet, also preying predominantly on polychaetes. In the present case, fish and not polychaetes constitute the main part of the diet. In this perspective, these differences between localities in post-breeding diet would represent differences in resource availability between sites. Green *et al.* (1990b) indicated that the high occurrence of polychaetes in the diet suggest that this prey must occur in very high numbers at Heard Island. We consider that a relatively higher fish availability at the Danco Coast might explain why post-breeding Antarctic shags do not change their feeding strategy to forage on less profitable resources such as invertebrates.

Amongst fish, nototheniid species predominated in the diet, whereas those from the families Harpagiferidae (except at Py Point), Channichthyidae, Bathydraconidae, Myctophidae and Paralepididae were scarcely represented (Table II). *Gobionotothen gibberifrons and N. coriiceps* were the two main prey at all the colonies in both seasons. Except for the markedly higher contribution of *G. gibberifrons* to the diet, the pattern of fish consumption observed in this study is similar to that reported for breeding Antarctic shags at the South Shetland Islands (see Casaux & Barrera-Oro 2006). The high importance of *G. gibberifrons* as prey of shags at the Danco Coast reflects the higher availability of this fish observed in trammel-net catches (Barrera-Oro *et al.* 2000, Casaux *et al.* 2003) in a site that is far away 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 also Casaux *et al.* 2002).

Although most of the fish prey co-occurred in both periods, the composition of the diet observed at the Danco Coast during the 1997/98 breeding season (Casaux *et al.* 2002) and during the following post-breeding period (this study) was markedly different. This was mainly related to an increase in the consumption of *G. gibberifrons* as well as to a decrease in the consumption of *N. coriiceps* and *H. antarcticus* during the post-breeding period. Casaux & Barrera-Oro (2002) observed that the structure of the populations of fish with marked site fidelity, like *N. coriiceps* and *H. antarcticus* (Everson 1970, Barrera-Oro & Casaux 1996b, North 1996), may be affected by a constant catch rate. Based on that finding, and as it was also reported for other seabirds (Birt *et al.* 1987, Leopold *et al.* 1998), Casaux *et al.* (2001) suggested that the Antarctic shag can deplete fish stocks in waters close to their colonies. We suggest that during the non-breeding season when birds are not constrained in time by the food for chick provisioning, shags might exploit more frequently areas further away or deeper waters than during the breeding season. This would preserve the feeding grounds close to the colonies and perhaps even improve feeding performance. This hypothesis is supported by 1) as reported by Green *et al.* (1990b) for *P. nivalis*, post-breeders abandoned the colonies and moved to roosting sites, 2) data from trammel-net catches obtained at the area studied showed that the abundance of *G. gibberifrons* increases with depth (Casaux *et al.* 2003), 3) Casaux & Barrera-Oro (2002) reported that one of the effects of a constant catch rate is a continuous decrease in the size of the fish prey populations. Compared to the previous breeding season, post-breeders in 1998 consumed larger fish. This could be explained by the fact that post-breeders preyed less intensively on the small sized *H. antarcticus* than during the breeding period (Table II, Casaux *et al.* 2002), but also by the fact that they preyed on larger *Trematomus newnesi*, *H. antarcticus* and *N. coriiceps* specimens, which also suggests that these birds might exploit alternative feeding grounds.

As commented above, the foraging strategy used during the post-breeding period might depend on the prey availability around colonies. This study was carried out at a locality far from the main historical commercial fishing grounds (Kock 1992) where the littoral fish availability is higher and more diverse than observed in exploited areas such as around the South Shetland Islands (Barrera-Oro *et al.* 2000, Casaux *et al.* 2003). Thus, in order to understand better the foraging behaviour of post-breeding Antarctic shags, future studies should include areas with contrasting fish availability.

Acknowledgements

We would like to thank M. Favero, P. Silva, N. Coria and G. Shandikov for field assistance. We thank the members of Primavera Station for their logistic support. This is contribution to the Laboratorio de Investigaciones en Ecología y Sistemática Animal (LIESA) No 41.

References

Barrera-Oro, E. & Casaux, R. 1996a. Fish as diet of the blue-eyed shag *Phalacrocorax atriceps bransfieldensis* at Half-moon Island, South Shetland Islands. *Cybium*, **20**, 37–45.

Barrera-Oro, E. & Casaux, R. 1996b. Validation of age determination in *Notothenia coriiceps*, by means of a tag-recapture experiment at Potter

Cove, South Shetland Islands. *Archive of Fishery and Marine Research*, **43**, 205–216.

Barrera-Oro, E., Marschoff, E. & Casaux, R. 2000. Trends in relative abundance of fjord *Notothenia rossii*, *Gobionotothen gibberifrons* and *Notothenia coriiceps* at South Shetland Islands, after commercial fishing in the area. *CCAMLR Science*, **7**, 43–52.

Bernstein, N. & Maxson, S. 1985. Reproductive energetics of blue-eyed shags in Antarctica. *Wilson Bulletin*, **97**, 450–462.

Birt, V., Birt, T., Goulet, D., Lairus, D. & Montevecchi, W. 1987. Ashmole's halo: direct evidence for prey depletion by a seabird. *Marine Ecology Progress Series*, **40**, 205–208.

Blankley, W. 1981. Marine food of kelp gulls, lesser sheathbills and imperial cormorants at Marion Island (subantarctic). *Cormorant*, **9**, 77–84.

Brothers, N. 1985. Breeding biology, diet and morphometrics of the king shag, *Phalacrocorax albiventer purpurascens*, at Macquarie Island. *Australian Wildlife Research*, **12**, 81–94.

Casaux, R. 2003. On the accuracy of the pellet analysis method to estimate the food intake in the Antarctic shag, *Phalacrocorax bransfieldensis*. *Folia Zoologica*, **52**, 67–76.

Casaux, R., Baroni, A. & Barrera-Oro, E. 2002. Fish in the diet of the Antarctic shag *Phalacrocorax bransfieldensis* breeding at four colonies in the Danco Coast, Antarctic Peninsula. *Antarctic Science*, **14**, 32–36.

Casaux, R. & Barrera-Oro, E. 1993. The diet of the blue-eyed shag, *Phalacrocorax atriceps bransfieldensis* at the west Antarctic Peninsula. *Antarctic Science*, **5**, 335–338.

Casaux, R. & Barrera-Oro, E. 2002. Effect of a shore-based sampling programme on *Notothenia coriiceps* populations. *Antarctic Science*, **14**, 221–224.

Casaux, R. & Barrera-Oro, E. 2006. Shags in Antarctica: their feeding behaviour and ecological role in the marine food web. *Antarctic Science*, **18**, 3–14.

Casaux, R., Barrera-Oro, E., Baroni, A. & Ramón, A. 2003. Ecology of inshore notothenioid fish from the Danco Coast, Antarctic Peninsula. *Polar Biology*, **26**, 157–165.

Casaux, R., Barrera-Oro, E., Favero, M. & Silva, P. 1998. New correction factors for the quantification of fish represented in pellets of the imperial cormorant *Phalacrocorax atriceps*. *Marine Ornithology*, **26**, 35–39.

Casaux, R., Coria, N. & Barrera-Oro, E. 1997a. Fish in the diet of the Antarctic shag *Phalacrocorax bransfieldensis* at Laurie Island, South Orkney Islands. *Polar Biology*, **18**, 219–222.

Casaux, R., Favero, M., Coria, N. & Silva, P. 1997b. Diet of the imperial cormorant *Phalacrocorax atriceps*: comparison of pellets and stomach contents. *Marine Ornithology*, **25**, 1–4.

Casaux, R., Favero, M., Silva, P. & Baroni, A. 2001. Sex differences in diving depths and diet of Antarctic shags at the South Shetland Islands. *Journal of Field Ornithology*, **72**, 22–29.

Casaux, R. & Ramón, A. 2002. The diet of the South Georgia shag *Phalacrocorax georgianus* at the South Orkney Islands in five consecutive years. *Polar Biology*, **25**, 557–561.

Coria, N., Casaux, R., Favero, M. & Silva, P. 1995. Analysis of the stomach content of the blue-eyed shag *Phalacrocorax atriceps bransfieldensis* at Nelson Island, South Shetland Islands. *Polar Biology*, **15**, 349–352.

Derenne, P., Mary, G. & Mougin, J. 1976. Le cormoran a ventre blanc *Phalacrocorax albiventer melanogenis* (Blyth) de l'archipel Crozet. *CNFRA*, **40**, 191–219.

Espitalier-Noel, G., Adams, N. & Klages, N. 1988. Diet of the imperial cormorant *Phalacrocorax atriceps* at sub-Antarctic Marion Island. *Emu*, **88**, 43–46.

Everson, I. 1970. The population dynamics and energy budget of *Notothenia neglecta* Nybelin at Signy Island, South Orkney Islands. *British Antarctic Survey Bulletin*, No. 23, 25–50.

Favero, M., Casaux, R., Silva, P., Barrera-Oro, E. & Coria, N. 1998. The diet of the Antarctic shag during summer at Nelson Island, Antarctica. *Condor*, **100**, 112–118.

Glass, B. 1978. Winter observations of birds at Palmer Station in 1977. *Antarctic Journal of the United States*, **13**(4), 145.

Green, K. & Williams, R. 1997. Biology of the Heard Island shag *Phalacrocorax nivalis*. 3. Foraging, diet and diving behaviour. *Emu*, **97**, 76–83.

Green, K., Williams, R. & Slip, D. 1990a. Diet of Macquarie Island cormorant *Phalacrocorax atriceps purpurascens*. *Corella*, **14**, 53–55.

Green, K., Williams, R., Woehler, E., Burton, H., Gales, N. & Jones, R. 1990b. Diet of the Heard Island cormorant *Phalacrocorax atriceps nivalis*. *Antarctic Science*, **2**, 139–141.

Holdgate, M. 1963. Observations of birds and seals at Anvers Island, Palmer Archipelago, in 1955–57. *British Antarctic Survey Bulletin*, No. 2, 45–51.

Kato, A., Nishiumi, I. & Naito, Y. 1996. Sexual differences in the diet of king cormorants at Macquarie Island. *Polar Biology*, **16**, 75–77.

Kock, K. 1992. *Antarctic fish and fisheries*. Cambridge: Cambridge University Press, 359 pp.

Leopold, M., van Damme, C. & van der Veer, H. 1998. Diet of cormorants and the impact of cormorant predation on juvenile flatfish in the Dutch Wadden Sea. *Journal of Sea Research*, **40**, 93–107.

North, A. 1996. Locomotory activity and behaviour of the Antarctic teleost *Notothenia coriiceps*. *Marine Biology*, **126**, 125–132.

Orta, J. 1992. Family Phalacrocoracidae (cormorants). *In* del Hoyo, J., Elliot, A. & Sargatal, J., *eds*. *Handbook of the birds of the world*. Vol. 1. Barcelona: Lynx Editions, 326–353.

Ridoux, V. 1994. The diets and dietary segregation of seabirds at the subantarctic Crozet Islands. *Marine Ornithology*, **22**, 1–192.

Schlatter, R. & Moreno, C. 1976. Hábitos alimentarios del cormorán antártico, *Phalacrocorax atriceps bransfieldensis* (Murphy) en Isla Green, Antarctica. *Serie Científica del Instituto Antártico Chileno*, **4**, 69–88.

Shaw, P. 1986. Factors affecting the breeding performance of Antarctic blue-eyed shags *Phalacrocorax atriceps*. *Ornis Scandinavia*, **17**, 141–150.

Tomo, A. 1970. Cadenas tróficas observadas en la bahía de Puerto Paraíso (Península Antártica) en relación con las variaciones de la fertilidad de sus aguas. *Contribución Científica del Instituto Antártico Argentino*, **131**, 14 pp.

Tremblay, Y., Cook, T. & Cherel, Y. 2005. Time budget and diving behaviour of chick rearing Crozet shags. *Canadian Journal of Zoology*, **83**, 971–982.

Wanless, S. & Harris, M. 1993. Use of mutually exclusive foraging areas by adjacent colonies of blue-eyed shags (*Phalacrocorax atriceps*) at South Georgia. *Colonial Waterbirds*, **16**, 176–182.

Wanless, S., Harris, M. & Morris, J. 1992. Diving behaviour and diet of the blue-eyed shag at South Georgia. *Polar Biology*, **12**, 713–719.