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On the accuracy of the pellet analysis method to estimate the food intake in the Antarctic shag, *Phalacrocorax bransfieldensis*

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Abstract. The possibility to study quantitatively the diet of the Antarctic shag *Phalacrocorax bransfieldensis* by the analysis of pellets, applying correction factors to compensate for the digestion and loss through the gastrointestinal tract of fish otoliths represented in pellets, was evaluated at two localities of the South Shetland Islands. For such purpose, the results from the analysis of 566 pellets (= regurgitated casts) collected at Harmony Point, and 296 at Duthoit Point, throughout the 1995/96 and 1996/97 breeding seasons, were corrected with the mentioned factors and the shag daily consumption rate was estimated. The estimations indicated that, except for Duthoit Point in 1996/97, the daily food intake increased from November to January (pre-laying to late-rearing) and slightly decreased in February when chicks start to fledge, thus reflecting the energy requirements at the nest. These estimations, in general, are in line with those previously obtained for other colonies and/or shag species by different methods, which suggests that after correction the use of pellets is an acceptable method to quantify the diet of the Antarctic Shag.

Key words: Antarctica, Antarctic shag, daily food intake, diet

Introduction

Most of the studies on the diet of the Antarctic shag *Phalacrocorax bransfieldensis* (previously known as blue-eyed shag or imperial cormorant *P. atriceps bransfieldensis*) have been based on the analysis of pellets (= regurgitated casts). This method has been extensively used in shags (Green et al. 1990a, 1990b, Barrett 1991, Harris & Wanless 1991, Wanless et al. 1992, among others) since it provides diet information with little effort in a short time, without disturbance to the colony. Otoliths within the pellets show a high level of species specificity and from their measurements the size and mass of the ingested fish can be calculated (see Jobling & Breiby 1986, Casaux & Barrera-Oro 1993). However, the technique may give biased results due to the erosion of the otoliths during digestion, or their loss into the gastrointestinal tract (Jobling & Breiby 1986). These biases were demonstrated experimentally in feeding trials on other species such as the cape cormorant *Phalacrocorax capensis* (Duffy & Laurenson 1983), the European shag *Phalacrocorax aristotelis* (Johnstone et al. 1990), the cormorant *Phalacrocorax carbo sinensis* (Zijlstra & Van Eerden 1995) and also on *P. bransfieldensis* (Casaux et al. 1995). In these studies it was concluded that the analysis of pellets underestimates the number and mass of fish ingested. Thus, it was suggested that the pellet analysis should not be used to estimate the daily food intake of shags (Carss et al. 1997).

It was thought that the estimation of correction factors could serve to diminish the errors caused by digestive processes (see Casaux et al. 1995, 1998, Dirksen et al. 1995).

A feeding experiment with a captive Antarctic shag allowed the estimation of correction factors for four fish prey species (Casaux et al. 1995). These factors were applied to data from pellet analysis and the results were compared to those obtained from the analysis of stomach contents collected simultaneously (Casaux et al. 1997a). The correction factors appeared to be somewhat high, probably due to some experimental deficiencies: the feeding trial was carried out on one bird only, some of the fish species were scarcely offered as food to the shag and wild conditions were not appropriately reproduced (Casaux et al. 1998). On the other hand, the length and mass of fish ingested may be better approached by the analysis of stomach contents, but this method demands more time in the field and produces disturbance to the colony (Coria et al. 1995). It was also suggested that by the comparison of a high number of pellets and stomach contents collected simultaneously, better fitted correction factors could be obtained (Coria et al. 1995). The analysis of pellets reflects temporal variations in the diet (Casaux & Barrera-Oro 1995), which were also reflected by the analysis of stomach contents (Casaux et al. 1997b) in conjunction with observations on foraging behaviour (Favero et al. 1998). Thus, by the examination of pellets and stomach contents collected simultaneously from incubation to late rearing, Casaux et al. (1998) calculated correction factors for specific periods of the breeding season.

As also occur with discriminant functions, when the correction factors are tested with the sample used to generate them, their precision is overestimated. Thus, the aim of this study is to analyse in different periods of two breeding seasons and at two localities in the South Shetland Islands the accuracy of the correction factors estimated by Casaux et al. (1998) as well as to evaluate the applicability of pellet analysis in estimating the food intake of the Antarctic shag.

Material and Methods

Totals of 566 (266 in 1995/96 and 300 in 1996/97), and 296 (173 and 123) regurgitated pellets of the Antarctic shag *P. bransfieldensis* were collected at Harmony Point (62°17'S, 59°14'W) and at Duthoit Point (62°19'S, 58°51'W), both at Nelson Island, South Shetland Islands, during the 1995/96 (hereafter 1995) and 1996/97 (1996) breeding seasons respectively.

The samples were obtained only from active nests every two days at Harmony Point and monthly at Duthoit Point; however, for this study the pellets from Harmony Point were grouped by month. The samples were processed following the method used by Casaux & Barrera-Oro (1993) and the length and mass of the fish ingested by the shags were estimated from the otolith length using the equations described by Hecht (1987), Williams & McEldowney (1990) and Casaux et al. (1997b).

The daily food intake (DFI) was estimated as follows:

$$DFI = \sum(MFP*PCi*NP*CFi)$$

where MFP is the mean mass of fish represented per pellet, PCi is the proportional contribution in mass to the diet of the prey "i", NP is the mean number of pellets produced daily per individual and CFi is the correction factor to compensate the loss and digestion of the otoliths of the species "i" (taken from Casaux et al. 1998) (Table 1). Due to the frequent consumption of pellets by the sheathbill *Chionis alba* at the colony of Harmony

Table 1. Correction factors estimated to compensate for the digestion and loss through the gastrointestinal tract of the otoliths of fish represented in pellets of the Antarctic shag *Phalacrocorax bransfieldensis*. Taken from Casaux et al. (1998).

	November	**December**	**January**	**February**
Notothenia coriiceps	2.87	4.23	9.52	9.52
Harpagifer antarcticus	0.76	0.58	6.50	6.50
Lepidonotothen nudifrons	1.95	2.17	12.77	12.77
Trematomus newnesi	4.17	3.78	5.59	5.59
Gobionotothen gibberifrons	6.80	2.30	2.30	2.30
Notothenia rossii	2.36	2.36	2.36	2.36
Pagothenia bernacchii	2.00	2.00	2.00	2.00

Point it was not possible to estimate the mean number of pellets produced daily per shag at this locality. Thus, the values previously estimated for Duthoit Point by Casaux et al. (1998) were adopted.

As the analysis of 141 and 74 stomach contents collected at Harmony Point through the 1995 and 1996 breeding seasons, respectively, indicated that fish largely predominated in mass in the diet of this shag (99.6 and 99.3% in both seasons) (Casaux 1998), non-fish organisms were not considered in the estimations. Therefore, the daily fish intake is considered as the daily food intake.

The daily metabolisable energy intake (DME) was estimated assuming that fish provide an energy content of 4.76 Kj*g^{-1} (Dunn 1975) and are assimilated with an efficiency of 75% (Wiens 1984).

Results

The diet of the Antarctic shag was similar in composition in both seasons at both localities. Fish were by far the main prey, followed by molluscs and polychaetes (Tables 2 and 3).

Among fish, *Notothenia coriiceps* was the most frequent prey and predominated in mass in both seasons at both localities. *Harpagifer antarcticus* was the most important prey by number, except at Duthoit Point in 1996 where *Lepidonotothen nudifrons* was the most numerous fish (Tables 4 and 5).

Except for Duthoit Point in 1996, where a steady increase from November to February was observed, the estimated daily take of fish by mass and metabolisable energy intake increased from November to January (pre-laying to late-rearing) and slightly decreased in February when chicks start to fledge (Tables 6 and 7).

Discussion

As observed in previous studies carried out at different localities of the South Shetland Islands (Barrera-Oro & Casaux 1996a, Casaux & Barrera-Oro 1993, 1995, 1996, Casaux et al. 1997a, 1998, Coria et al. 1995, Favero et al. 1998), fish were the main component in the diet of the Antarctic shag and among them *N. coriiceps* was the most important prey throughout the breeding season, followed by *H. antarcticus* or *L. nudifrons*. Considering that shags are opportunistic feeders (Craven & Lev 1987, Keller 1995), these findings indicate broad similarities in the prey availability between both seasons and localities.

When Casaux et al. (1998) estimated, by the comparison of pellets and stomach contents, the correction factors tested in this study, they observed slight qualitative (the trophic spectrum represented in pellets was wider than that observed in stomach contents) but important quantitative differences between both methods. These differences are explained by the problem of erosion and loss of otoliths associated with pellet analysis and also by a higher number of food loads represented in pellets (4 to 7, Casaux et al. 1997a) compared to the stomach contents (1). However, as was suggested by Wanless et al. (1993) for *P. aristotelis* and by Favero et al. (1998) for *P. bransfieldensis*, the stomach contents might reflect mainly the chicks' diet, the adult food being completely or partially digested before returning to the nest. Thus, pellets may reflect more appropriately both adult and chick diet (see also Harris & Wanless 1993), which also would explain the differences observed. If confirmed for the Antarctic shag, this finding may suggests that biases could be also associated with the estimation of correction factors by this method. It is obvious that during pre-laying, laying and incubation the food represented in stomach contents reflects the adult diet. On the other hand, for the Antarctic shag at Harmony Point, it was recently observed that the food carried to the nest by parents during early- and mid-rearing seemed to exceed the energy requirements of the chicks (Casaux 1998). Also, according to Bowmaker (1963), the durations of the foraging trips were shorter than the time required by shags to digest their own food. From this information it could be inferred that the stomach contents collected from birds arriving from foraging trips during these periods of the breeding season represent not only the chicks' diet but also, at least partially,

Table 2. The composition of the diet of the Antarctic shag *Phalacrocorax bransfieldensis* at Harmony Point (A) and at Duthoit Point (B) during the 1995/96 breeding season. Number of pellets analysed in parenthesis, F%= Frequency of occurrence percent, N%= Importance by number percent.

A)

	November (26)		**December (77)**		**January (124)**		**February (39)**	
	F%	**N%**	**F%**	**N%**	**F%**	**N%**	**F%**	**N%**
Fish	100.0	91.3	100.0	71.9	100.0	91.3	100.0	87.9
Snails	---	---	27.3	16.9	27.4	2.1	28.2	4.4
Octopods	---	---	15.6	2.1	20.2	1.8	25.6	1.9
Polychaetes	19.2	4.4	33.8	6.0	57.3	4.0	33.3	3.7
Bivalves	11.5	2.5	11.7	2.7	4.8	0.2	10.3	1.8
Limpets	11.5	1.9	3.9	0.2	4.0	0.2	2.6	0.1
Amphipods	---	---	---	---	---	---	2.6	0.1
Krill	---	---	1.3	0.1	9.7	0.4	---	---
Algae	92.3	---	92.2	---	87.1	---	79.5	---

B)

	November (33)		**December (29)**		**January (58)**		**February (53)**	
	F%	**N%**	**F%**	**N%**	**F%**	**N%**	**F%**	**N%**
Fish	100.0	74.0	100.0	82.6	100.0	86.0	100.0	85.9
Snails	---	---	---	---	19.0	1.3	15.1	1.6
Octopods	24.2	17.5	27.6	7.3	48.3	5.5	24.5	8.2
Polychaetes	30.3	6.1	44.8	9.3	58.6	5.8	26.4	3.9
Bivalves	---	---	3.4	0.5	6.9	1.0	---	---
Limpets	9.1	0.3	3.4	0.3	3.5	0.2	1.9	0.1
Amphipods	12.1	2.0	---	---	5.2	0.2	5.7	0.3
Algae	97.0	---	93.1	---	100.0	---	98.1	---

Table 3. The composition of the diet of the Antarctic shag *Phalacrocorax bransfieldensis* at Harmony Point (A) and at Duthoit Point (B) during the 1996/97 breeding season. Sampling size in parenthesis, F%= Frequency of occurrence percent, N%= Importance by number percent.

A)

	November (110)		**December (56)**		**January (76)**		**February (58)**	
	F%	**N%**	**F%**	**N%**	**F%**	**N%**	**F%**	**N%**
Fish	100.0	73.6	100.0	91.1	100.0	94.8	100.0	91.7
Snails	7.3	1.1	17.9	1.9	14.5	1.2	22.4	5.4
Octopods	7.3	1.7	7.1	1.5	19.7	1.4	19.0	0.7
Polychaetes	56.4	20.8	16.1	2.5	29.0	1.9	34.5	1.5
Bivalves	10.0	2.6	17.9	2.6	9.2	0.6	15.5	0.7
Limpets	1.8	0.2	1.8	0.4	1.3	0.1	1.7	0.1
Krill	---	---	---	---	1.3	0.1	---	---
Algae	78.2	---	96.4	---	80.3	---	75.9	---

B)

	November (31)		**December (30)**		**January (32)**		**February (30)**	
	F%	**N%**	**F%**	**N%**	**F%**	**N%**	**F%**	**N%**
Fish	100.0	64.1	100.0	81.8	100.0	87.6	100.0	83.4
Snails	12.9	0.5	23.3	1.6	18.8	1.2	16.7	0.8
Octopods	16.1	2.5	20.0	1.6	40.6	8.7	36.7	6.6
Polychaetes	77.4	32.6	50.0	14.4	21.9	2.2	50.0	9.0
Bivalves	6.5	0.3	6.7	0.4	3.1	0.2	---	---
Limpets	3.2	0.1	3.3	0.2	3.1	0.2	3.3	0.2
Algae	100.0	---	100.0	---	100.0	---	100.0	---

the adults' diet, thus validating the methodology followed to estimate the correction factors.

The daily metabolisable energy intake (DME) estimated for November (the individuals were in the pre-laying, laying and incubating periods) was similar to that estimated by Favero et al. (1998) for incubating shags at Duthoit Point (1254 $Kj*d^{-1}$ for males and 954 $Kj*d^{-1}$ for females) by the analysis of stomach contents but lower than the daily energy expenditure (DEE) reported by Bernstein & Maxson (1985) also for incubating Antarctic shags (2754-2384 $Kj*d^{-1}$). Van Heezik & Seddon (1989) observed that the stomach pH in *Megadyptes antipodes* increased with the mass of food in the stomach. If a similar phenomenon occurred in the Antarctic shag, it would be expected that in periods of lower food intake (such as November) the otoliths found in pellets would be more eroded, which could explain the low values obtained for that month. The fact that the correction factors for this period were underestimated should be also considered. By contrast, the values estimated for December (most of the individuals were in incubating and early-rearing period) are in line with the DEE estimated by Bernstein & Maxson (1985) for early-rearing shags (2688 and 2330 $Kj*d^{-1}$ for males and females respectively).

The DME estimated for January and February (mainly middle-rearing to fledging) were higher than those obtained by Favero et al. (1998) for this period (3834 and 2257 $Kj*d^{-1}$ for males and females respectively). However, in that study it was assumed that the values were lower than expected probably due to biases in the methodology (see Favero et al. 1998). The estimations presented here were also higher than the DEE estimated for late-rearing Antarctic shags by Bernstein & Maxson (1985) (2844 and 2443 $Kj*d^{-1}$). However, during part of their study the colony experienced a reproductive success 75%

Table 4. Fish represented in the diet of the Antarctic shag *Phalacrocorax bransfieldensis* as reflected by the analysis of pellets collected at Harmony Point (A) and at Duthoit Point (B) during the 1995/96 breeding season. Sampling size in parenthesis, F%= Frequency of occurrence percent, N%= Importance by number percent, M%= Importance by mass percent.

A)

	November (26)			**December (77)**			**January (124)**			**February (39)**		
	F%	**N%**	**M%**	**F%**	**N%**	**M%**	**F%**	**N%**	**M%**	**F%**	**N%**	**M%**
Notothenia coriiceps	80.8	34.2	87.3	83.1	22.1	74.9	71.0	9.8	59.3	79.5	10.9	65.9
Harpagifer antarcticus	3.9	33.6	5.8	28.6	54.8	13.1	53.2	72.6	28.0	53.9	76.4	27.4
Lepidonotothen nudifrons	7.7	7.5	2.3	15.6	8.6	5.6	35.5	7.9	7.4	25.6	5.2	5.0
Trematomus newnesi	---	---	---	6.5	0.6	0.3	8.9	0.7	0.7	10.3	0.8	0.7
Gobionotothen gibberifrons	15.4	2.7	0.2	9.1	2.0	4.0	20.2	1.1	0.3	12.8	0.8	0.1
Notothenia rossii	3.9	2.1	2.6	2.6	0.2	2.0	1.6	0.1	1.1	---	---	---
Parachaenichthys charcoti	---	---	---	---	---	---	4.8	0.2	2.3	---	---	---
Pagothenia bernacchii	3.9	0.7	0.5	---	---	---	4.0	0.3	0.2	2.6	0.3	0.8
Pseudochaenichthys georgianus	---	---	---	---	---	---	0.8	0.0	0.4	---	---	---
Notolepis coatsi	---	---	---	---	---	---	0.8	0.1	0.3	---	---	---
Nototheniops nybelini	---	---	---	2.6	0.2	0.2	---	---	---	---	---	---
Electrona antarctica	---	---	---	2.6	0.2	0.0	---	---	---	---	---	---
Gymnoscopelus nicholsi	---	---	---	---	---	---	1.6	0.1	0.1	---	---	---
Gymnodraco acuticeps	3.9	1.4	1.3	---	---	---	---	---	---	---	---	---
Unidentified	38.5	17.8	---	39.0	11.2	---	46.8	7.1	---	48.7	5.6	---

B)

	November (33)			**December (29)**			**January (58)**			**February (53)**		
	F%	**N%**	**M%**	**F%**	**N%**	**M%**	**F%**	**N%**	**M%**	**F%**	**N%**	**M%**
Notothenia coriiceps	63.6	8.3	59.6	79.3	14.7	75.2	75.9	9.2	55.3	71.7	11.7	67.0
Harpagifer antarcticus	45.5	68.6	28.1	31.0	42.6	13.4	70.7	52.4	22.1	43.4	49.6	15.3
Lepidonotothen nudifrons	24.2	3.3	1.3	34.5	19.4	5.5	60.3	21.2	13.4	39.6	15.8	8.2
Trematomus newnesi	21.2	5.0	5.0	17.2	3.1	2.2	31.0	2.5	2.6	20.8	4.4	3.8
Gobionotothen gibberifrons	18.2	1.3	3.2	3.5	0.6	0.0	15.5	1.3	1.3	20.8	1.9	3.1
Notothenia rossii	3.0	0.2	2.8	6.9	0.6	3.4	3.5	0.2	2.8	---	---	---
Parachaenichthys charcoti	---	---	---	---	---	---	5.2	0.2	1.2	3.8	0.4	2.6
Pagothenia bernacchii	---	---	---	6.9	0.6	0.3	6.9	0.4	0.4	1.9	0.1	0.2
Nototheniops nybelini	---	---	---	---	---	---	5.2	0.4	0.2	---	---	---
Unidentified	45.5	13.4	---	58.6	18.2	---	60.3	12.2	---	49.1	16.2	---

lower than in previous years (Maxson & Bernstein 1980), which suggests a reproductive effort much lower than that observed at the South Shetland Islands during this study. Additionally, it is important to consider that the estimations in this study represent not only the adults' requirements but also those from their chicks.

On the other hand, the estimations for January and February presented here represent more than twofold the DME estimated for December in this study. However, considering that as chicks grew older both males and females markedly increased the time spent foraging as well as the number of foraging trips (Casaux 1998) and that the food represented in the pellets reflects the diet of an adult and half of its broods (the breeding success in 1995 and 1996 was 1.32 and 1.15 chicks per nest at Harmony Point and 1.65 and 1.14 at Duthoit Point), the DME estimated for January and February seems to be reasonable. Drent & Daan (1980) and Masman et al. (1989) observed that the optimal working level in bird parents is fourfold the basal metabolic rate (BMR). Considering that the BMR for the Antarctic shag is approximately 1340 Kj*d-1 (assuming a mean body mass of 2900 g,

Table 5. Fish represented in the diet of the Antarctic shag *Phalacrocorax bransfieldensis* as reflected by the analysis of pellets collected at Harmony Point (A) and at Duthoit Point (B) during the 1996/97 breeding season. Sampling size in parenthesis, F%= Frequency of occurrence percent, N%= Importance by number percent, M%= Importance by mass percent.

A)

	November (110)			**December (56)**			**January (76)**			**February (58)**		
	F%	**N%**	**M%**	**F%**	**N%**	**M%**	**F%**	**N%**	**M%**	**F%**	**N%**	**M%**
Notothenia coriiceps	91.8	42.2	84.0	94.6	32.2	79.7	86.8	12.2	65.4	93.1	11.4	55.0
Harpagifer antarcticus	14.5	35.4	5.4	16.1	37.2	5.8	55.3	62.7	25.4	79.3	68.8	32.2
Lepidonotothen nudifrons	10.0	6.5	1.4	12.5	11.6	3.0	46.1	11.6	6.7	62.1	10.6	8.1
*Trematomus newnes*i	2.7	0.4	0.1	1.8	0.6	0.2	7.9	0.4	0.4	1.7	0.1	0.1
Gobionotothen gibberifrons	0.9	0.1	0.0	1.8	0.2	0.0	6.6	0.3	0.1	15.5	0.8	2.0
Notothenia rossii	3.6	0.8	3.7	1.8	0.4	2.2	---	---	---	---	---	---
Parachaenichthys charcoti	5.5	1.3	5.1	5.4	1.7	7.1	2.6	0.2	1.8	8.6	0.4	2.3
Pagothenia bernacchii	3.6	0.7	0.3	1.8	1.4	2.0	1.3	0.1	0.1	3.5	0.1	0.3
Lepidonotothen larseni	---	---	---	---	---	---	2.6	0.1	0.1	1.7	0.1	0.1
Nototheniops nybelini	---	---	---	1.8	0.2	0.1	1.3	0.1	0.0	1.7	0.1	0.0
Electrona antarctica	0.9	0.1	0.0	---	---	---	1.3	0.1	0.0	---	---	---
Muraenolepis microps	---	---	---	---	---	---	1.3	0.1	0.1	---	---	---
Unidentified	29.1	12.4	---	30.4	14.5	---	57.9	12.2	---	55.2	7.8	---

B)

	November (31)			**December (30)**			**January (32)**			**February (30)**		
	F%	**N%**	**M%**	**F%**	**N%**	**M%**	**F%**	**N%**	**M%**	**F%**	**N%**	**M%**
Notothenia coriiceps	77.4	11.9	69.2	90.0	19.5	79.2	62.5	10.3	63.9	90.0	16.3	76.4
Harpagifer antarcticus	29.0	36.2	9.7	23.3	29.7	6.4	18.8	11.2	3.2	33.3	33.7	9.6
Lepidonotothen nudifrons	22.6	24.1	8.4	43.3	23.0	7.3	62.5	53.9	22.0	50.0	28.5	10.6
Trematomus newnesi	3.2	0.2	0.2	26.7	4.3	1.9	12.5	1.6	1.2	13.3	1.2	1.1
Gobionotothen gibberifrons	19.4	2.1	4.2	10.0	0.8	3.3	9.4	0.9	2.5	10.0	0.8	0.1
Notothenia rossii	3.2	0.2	3.4	---	---	---	3.1	0.2	3.6	---	---	---
Parachaenichthys charcoti	9.7	1.2	3.0	3.3	0.3	0.8	6.3	0.9	2.6	6.7	0.6	1.9
Pagothenia bernacchii	3.2	0.2	0.2	10.0	1.1	3.3	9.4	0.7	0.9	3.3	0.2	0.3
Trematomus eulepidotus	3.2	0.4	0.9	---	---	---	---	---	---	---	---	---
Pagetopsis macropterus	3.2	0.2	0.9	---	---	---	---	---	---	---	---	---
Nototheniops nybelini	---	---	---	3.3	0.3	0.3	---	---	---	---	---	---
Unidentified	54.8	23.4	---	56.7	21.4	---	71.9	22.2	---	46.7	19.1	---

and using the equation described by Kendeigh et al. 1977), the estimations presented here are in line with the predictions of those authors. Moreover, Wanless et al. (1992) estimated for adult *Phalacrocorax georgianus* and half of their broods at South Georgia a daily energy requirement of 2970-7120 Kj*d^{-1}, which is in agreement with the estimations for Harmony Point and Duthoit Point. However, it is interesting to note that the values for Harmony Point could be slightly overestimated. Given that females mainly regurgitated early in the morning, part of their pellets were probably ingested by *C. alba* before our arrival to the colony and therefore most of the pellets collected at this locality may have been produced by males, which provided more food to the nests (Casaux 1998, Favero et al. 1998).

The analysis of pellets, applying correction factors to compensate the digestion and loss of the otoliths throughout the gastrointestinal tract, seems to be an acceptable method to quantify the diet of the Antarctic shag that demands little time in the field without disturbing the birds (see also Dirksen et al. 1995). However, one of the main goals of this method is that the daily consumption of different prey species or different components of their populations can be estimated. In this sense *N. coriiceps* provided, depending on the period, from 60 to 93% of the energy ingested by the Antarctic shag at the colonies under study. Considering that the estimated consumption of fish by the shags at Harmony Point (45 and 67 active nests) during the 1995 and 1996 breeding seasons (November to February) was 13 and 21.5 metric tonnes and that the estimation for Duthoit Point (104 and 79 active nests) was 28.5 and 25.9 metric tonnes for 1995 and 1996 respectively, *P. bransfieldensis* may play

Table 6. Mean mass of fish represented per pellet (g) (MFP), corrected mean mass of fish represented per pellet (g) (CMFP), mean number of pellets produced daily per shag (NP), daily fish intake (g) (DFI) and daily metabolisable energy intake (Kj) (DME) estimated from pellets collected at Harmony Point (A) and at Duthoit Point (B) during the 1995/96 breeding season.

A

	November	December	January	February
MFP	228.2	315.8	376.2	322.0
CMFP	760.2	1116.4	3202.4	2817.5
NP	0.51	0.74	0.59	0.59
DFI	367.7	826.1	1889.4	1662.3
DME	1384.1	2949.2	6745.2	5934.1

B

	November	December	January	February
MFP	258.0	245.8	396.8	303.3
CMFP	630.3	871.2	3438.3	2640.3
NP	0.51	0.74	0.59	0.59
DFI	321.0	644.3	2028.6	1557.8
DME	1146.0	2301.6	7242.1	5561.3

Table 7. Mean mass of fish represented per pellet (g) (MFP), corrected mean mass of fish represented per pellet (g) (CMFP), mean number of pellets produced daily per shag (NP), daily fish intake (g) (DFI) and daily metabolisable energy intake (Kj) (DME) estimated from pellets collected at Harmony Point (A) and at Duthoit Point (B) during the 1996/97 breeding season.

A

	November	December	January	February
MFP	309.2	353.6	392.2	398.5
CMFP	812.5	1287.7	3443.4	3365.4
NP	0.51	0.74	0.59	0.59
DFI	414.4	952.9	2031.6	1985.6
DME	1479.4	3401.9	7252.8	7088.6

B

	November	December	January	February
MFP	381.9	375.2	319.2	397.5
CMFP	1012.1	1414.7	2986.0	3712.5
NP	0.51	0.74	0.59	0.59
DFI	516.2	1046.9	1761.7	2190.4
DME	1842.8	3737.4	6289.3	7819.7

an important roll in the regulation of populations of *N. coriiceps*, a fish species with a marked site fidelity (Everson 1970, Burchett 1983, Barrera-Oro & Casaux 1996b, North 1996). On the other hand, considering that shags forage close to the colonies, their energetic requirements and how they are met should be considered when fisheries, based on shags' prey species and/or developed in localities surrounding their colonies, are planned.

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LITERATURE

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 (1): 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. *Arch. Fish. Mar. Res. 43 (3): 205–216*.

BARRETT R. 1991: Shags (*Phalacrocorax aristotelis* L.) as potential sampler of juvenile Saithe (*Pollachius virens* (L.)) stocks in Northern Norway. *Sarsia 76: 153–156*.

BERNSTEIN N. & MAXSON S. 1985: Reproductive energetics of Blue-eyed Shags in Antarctica. *Wilson Bull. 97(4): 450–462*.

BOWMAKER A. 1963: Cormorant predation on two central African lakes. *Ostrich 34: 1–26*.

BURCHETT M. 1983: Abundance of the nearshore fish population at South Georgia (Antarctica) sampled by trammel net. *British Antarct. Surv. Bull. 61: 39–43*.

CARSS D. & THE DIET ASSESSMENT AND FOOD INTAKE WORKING GROUP 1997: Techniques for assessing Cormorant diet and food intake: towards a consensus view. *Suppl. Ric. Biol. Selvaggina 26: 197–230*.

CASAUX R. 1998: Biología reproductiva y ecología alimentaria del Cormorán Antártico *Phalacrocorax bransfieldensis* (Aves, Phalacrocoracidae) en las Islas Shetland del Sur, Antártida. *Ph. D. Thesis, University of La Plata, 262 pp*.

CASAUX R. & BARRERA-ORO E. 1993: The diet of the Blue-eyed Shag *Phalacrocorax atriceps bransfieldensis* feeding in the Bransfield Strait. *Antarct. Sci. 5 (4): 335–338*.

CASAUX R. & BARRERA-ORO E. 1995: Variation in the diet of the Blue-eyed Shag *Phalacrocorax atriceps* throughout the breeding season at Half-moon Island, South Shetland Islands. *Commission for the Conservation of Antarctic Marine Living Resources, Ecosystem Monitoring and Management Working Group, Document WG-EMM-95/78, 12 pp*.

CASAUX R. & BARRERA-ORO E. 1996: Fish in the diet of the Blue-eyed Shag *Phalacrocorax atriceps* at the South Shetland Islands: six years of monitoring studies. *Commission for the Conservation of Antarctic Marine Living Resources, Ecosystem Monitoring and Management Working Group, Document WG-EMM-96/31, 8 pp*.

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. Mar. Ornithol. 26: 35–39*.

CASAUX R., CORIA N. & BARRERA-ORO E. 1997b: Fish in the diet of the Antarctic Shag *Phalacrocorax bransfieldensis* at Laurie Island, South Orkney Islands. *Polar Biol. 18(3): 219–222*.

CASAUX R., FAVERO M., BARRERA-ORO E. & SILVA P. 1995: Feeding trial on an imperial cormorant *Phalacrocorax atriceps*: preliminary results on fish intake and otolith digestion. *Mar. Ornithol. 23: 101–106*.

CASAUX R., FAVERO M., CORIA N. & SILVA P. 1997a: Diet of the Imperial Cormorant *Phalacrocorax atriceps*: comparison of pellets and stomach contents. *Mar. Ornithol. 25: 1–4*.

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 Biol. 15: 349–352*.

CRAVEN S. & LEV E. 1987: Double-crested Cormorants in the Apostle Islands, Wisconsin, U.S.A.: population trends, food habits and fishery depredations. *Colonial Waterbirds 10: 64–71*.

DIRKSEN S., BOUDEWIJN T., NOORDHUIS R. & MARTEIJN E. 1995: Cormorants *Phalacrocorax carbo sinensis* in shallow eutrophic freshwater lakes: prey choice and fish consumption in the non-breeding period and effects of large-scale fish removal. *Ardea 83(1): 167–184*.

DRENT R. & DAAN S. 1980: The prudent parent: energetic adjustments in avian breeding. *Ardea 68: 225–252*.

DUFFY D. & LAURENSON L. 1983: Pellets of Cape Cormorants as indicators of diet. *Condor 85: 305–307*.

DUNN E. 1975: Caloric intake of nestling Double-crested Cormorants. *Auk 92: 553–565*.

EVERSON I. 1970: The population dynamics and energy budget of *Notothenia neglecta* Nybelin at Signy Island, South Orkney Islands. *British Antarct. Surv. Bull. 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*.

GREEN K., WILLIAMS R. & SLIP D. 1990a: Diet of Macquarie Island Cormorant *Phalacrocorax atriceps purpurascens*. *Corella 14(2): 53–55*.

GREEN K., WILLIAMS R., WOEHLER E., BURTON H., GALES N. & JONES R. 1990b: Diet of the Heard Island cormorant *Phalacrocorax atriceps nivalis*. *Antarct. Sci. 2 (2): 139–141*.

HARRIS M. & WANLESS S. 1991: The importance of lesser sandeel *Ammodytes marinus* in the diet of the Shag *Phalacrocorax aristotelis. Ornis Scandinavica 22: 375–382*.

HARRIS M. & WANLESS S. 1993: The diet of Shags *Phalacrocorax aristotelis* during chick-rearing period assessed by three methods. *Bird Study 40: 135–139*.

HECHT T. 1987: A guide to the otoliths of Southern Ocean fishes. *South Afr. J. Antarct. Res. 17 (1): 87 pp*.

JOBLING M. & BREIBY A. 1986: The use and abuse of fish otoliths in studies of feeding habits of marine piscivores. *Sarsia 71: 265–274*.

JOHNSTONE I., HARRIS M., WANLESS S. & GRAVES J. 1990: The usefulness of pellets for assessing the diet of adult Shags *Phalacrocorax aristotelis. Bird Study 37: 5–11*.

KELLER T. 1995: Food of cormorants *Phalacrocorax carbo sinensis* wintering in Bavaria, Southern Germany. *Ardea 83 (1): 185–192*.

KENDEIGH S., DOLNIK V. & GAVRILOV V. 1977: Avian energetics. In: Pinowski J. & Kendeigh S.C. (eds), Granivorous birds in Ecosystems. *Cambridge Univ. Press, London: 127–204*.

MASMAN D., DIJKSTRA C., DAAN S. & BULT A. 1989: Energetic limitation of avian parental effort: Field experiments in the kestrel (*Falco tinnunculus*). *J. Evol. Biol. 2: 435–455*.

MAXSON S. & BERNSTEIN N. 1980: Ecological studies of Southern Black-backed Gulls, Blue-eyed Shags, and Adelie Penguins at Palmer Station. *Antarct. J. U. S. 15: 157*.

NORTH A. 1996: Locomotory activity and behaviour of the Antarctic teleost *Notothenia coriiceps. Mar. Biol. 126: 125–132*.

VAN HEEZIK Y. & SEDDON P. 1989: Stomach sampling in the Yellow-eyed Penguin: erosion of otoliths and squid beaks. *J. Field Ornithol. 60: 451–458*.

WANLESS S., HARRIS M. & MORRIS J. 1992: Diving behaviour and diet of the blue-eyed shag at South Georgia. *Polar Biol. 12: 713–719*.

WANLESS S., HARRIS M. & RUSSELL F. 1993: Factors influencing food-load sizes brought in by Shags *Phalacrocorax aristotelis* during chick rearing. *Ibis 135: 19–24*.

WIENS J. 1984: Modelling the energy requirements of seabirds populations. In: Whittow G. & Rahn H. (eds), Seabirds energetics. *Plenum Press, New York & London: 255–284*.

WILLIAMS R. & MCELDOWNEY A. 1990: A guide to the fish otoliths from waters off the Australian Antarctic Territory, Heard and Macquarie Islands. ANARE *Res. Notes 75: 1–173*.

ZIJLSTRA M. & VAN EERDEN H. 1995: Pellet production and the use of otoliths in determining the diet of Cormorants *Phalacrocorax carbo sinensis*: trials with captive birds. *Ardea 83(1): 123–132*.