NEW CORRECTION FACTORS FOR THE QUANTIFICATION OF FISH REPRESENTED IN PELLETS OF THE IMPERIAL CORMORANT *PHALACROCORAX ATRICEPS*

RICARDO J. CASAUX[1], ESTEBAN R. BARRERA-ORO[1], MARCO FAVERO[2] & PATRICIA SILVA[2]

[1]*Instituto Antártico Argentino, Cerrito 1248, 1010 Buenos Aires, Argentina (pipocasaux@overnet.com.ar)*
[2]*Universidad Nacional de Mar del Plata, Departamento de Biología, Funes 3350, 7600 Mar del Plata, Argentina*

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SUMMARY

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A comparative analysis was carried out on stomach contents and pellets (regurgitated casts) of the Imperial Cormorant *Phalacrocorax atriceps* collected throughout the breeding season at Nelson Island, South Shetland Islands, Antarctica. This allowed an estimation of correction factors to compensate for the loss and digestion of otoliths in pellets and more accurately estimate the real mass of ingested fish. These factors were calculated for *Notothenia coriiceps, Harpagifer antarcticus, Nototheniops nudifrons, Trematomus newnesi, Gobionotothen gibberifrons, Notothenia rossii, Pagothenia bernacchii* and *Parachaenichthys charcoti,* but not for *Pleuragramma antarcticum, Notolepis coatsi* and *Electrona antarctica* since they were only represented in pellets. Fish were the main prey and *N. coriiceps* and *H. antarcticus* were the dominant species both in mass and number. Observations of activity patterns showed that daily foraging trips per bird increased in number but diminished in duration through the breeding season. These trends reflected the increase in the chicks' energetic demands.

INTRODUCTION

The diet of the Imperial Cormorant or Blue-eyed Shag *Phalacrocorax atriceps* has been usually studied by the analysis of pellets or regurgitated casts (Schlatter & Moreno 1976, Blankley 1981, Green *et al.* 1990a,b, Barrett 1991, Wanless *et al.* 1992, Casaux & Barrera-Oro 1993, Barrera-Oro & Casaux 1996). This method provides valuable information with little effort in the field. However, due to erosion and digestion of the otoliths in the gastrointestinal tract (Hartley 1948, Duffy & Laurenson 1983, Jobling & Breiby 1986, Johnstone *et al.* 1990), the estimation of the number, length and mass of the ingested fish is, at least for some species, biased. Collection of stomach contents is a disturbing technique for both adults and chicks, and one that demands more time in the field but, although also with some biases associated, better reflects qualitatively and quantitatively the diet.

In a feeding experiment on a captive Imperial Cormorant, Casaux *et al.* (1995) provided preliminary correction factors aimed at evaluating quantitatively the mass of fish ingested. However, those factors were tested and shown to be somewhat high, probably because natural conditions were not appropriately reproduced in the feeding trial (Casaux *et al.* 1997). Thus, the aim of this study is to provide new correction factors estimated for different periods and for the whole breeding season by the comparative analysis of pellets and stomach contents of Imperial Cormorants collected simultaneously at Nelson Island, South Shetland Islands, Antarctica.

METHODS

The study was carried out in a colony of Imperial Cormorants (120 nests) at Duthoit Point (62º18'S, 58°47'W), Nelson Island, South Shetland Islands, Antarctica, from 1 December 1994 to 3 February 1995. The sampling design consisted of three periods of four days each (Table 1); the pellets and stomach contents were obtained during the first three days of each period, whereas the remaining day was used for observations on foraging activity.

One hundred and twelve pellets (40, 40 and 32 in the three periods, respectively) were collected in an undisturbed sector of the colony by visiting marked nests (13, nine and nine nests in each sampling period) every 12 hours. Prior to each sampling period all old pellets were removed from the studied nests. All pellets observed in those nests were collected every 12 hours. The individuals sampled for pellet analysis were not included in the stomach sampling. To estimate the mean number of pellets produced daily per bird it was assumed that both males and females have similar regurgitation rates. There was no evidence of the existence of pellets regurgitated by chicks, therefore, we assumed that all pellets came from adults. The pellets were dried to constant mass at 60°C. Their contents were sorted into prey classes under a binocular microscope. The otoliths (all sagittal) were cleaned and identified where possible to species, using descriptions and illustrations in North *et al.* (1984), Hecht (1987), Williams & McEldowney (1990) and our own reference collection. They were separated into right and left, the most abundant being considered as the approximate number of fish present by species in each pellet. Length in cm and mass in g of these fish were calculated by means of equations estimated from measurements of otolith length (OL). The equations were:

Notothenia coriiceps[1]
TL = –11.4918+11.31757*OL cm (n = 161)
Mass = $0.0032*TL^{3.4407}$+25.439 g (n = 501)
Harpagifer antarcticus[1]
TL = 3.268603+1.812654*OL cm (n = 124)
Mass = $0.954388+e^{(0.292596*TL-0.367153)}$ g (n = 124)
Nototheniops nudifrons[1,2]
TL = 0.37+3.19*OL cm (n = 46)
SL = $33.78*OL^{0.96}$ mm (n = 11)
Mass = $4.01*10^{-7}*SL^{3.81}$ g (n = 11)
Trematomus newnesi[1]
TL = 1.568699+4.166653*OL cm (n = 84)
Mass = $0.146477*TL^{2.127549}$ g (n = 77)
Gobionotothen gibberifrons [2]
TL = $17.64*OL^{1,468}$ mm (n = 85)
Mass = $2.98*10^{-6}*TL^{3.2}$ g (n = 78)
Pagothenia bernacchii [2]
TL = $53.52*OL^{0.979}$ mm (n = 32)
Mass = $9.76*10^{-7}*TL^{3.44}$ g (n = 20)
Electrona antarctica [2]
SL = $31.42*OL^{1.109}$ mm (n = 19)
Mass = $1.08*10^{-5}*SL^{3.05}$ g (n = 19)
Pleuragramma antarcticum [2]
TL = $99.6*OL^{1.05}$ mm(n = 32)
Mass = $1.08*10^{-5}*TL^{2.9}$ g (n = 41)
Notolepis coatsi [2]
TL = $55.85*OL^{1.79}$ mm (n = 8)
Mass = $0.153*OL^{6.29}$ g (n = 6)

TABLE 1

Development stages of Imperial Cormorant chicks throughout the sampling periods at Duthoit Point, Nelson Island

	Date	Stage	Chick mass (g)	Chick age (d)*
Period 1	1–4 Dec 1994	Incubation	–	–
Period 2	22–25 Dec 1994	Early rearing	288, n=52, SE=55	9
Period 3	31 Jan–3 Feb 1995	Late rearing	2683, n=40, SE=73	42

* Estimated from M. Favero (unpubl. data).

TABLE 2

Fish species represented in the diet of the Imperial Cormorant at Duthoit Point as reflected by the analysis of A: pellets; B: stomach contents

Fish species	Period 1			Period 2			Period 3			Total		
	F%	N%	M%	F%	N%	M%	F%	N%	M%	F%	N%	M%
A: Pellets												
N. coriiceps	60.0	4.2	43.0	25.0	1.4	18.2	46.9	3.8	40.7	44.0	3.0	33.2
H. antarcticus	65.0	71.4	36.0	75.0	71.3	44.9	71.9	73.3	20.1	70.6	71.8	35.7
N. nudifrons	50.0	16.5	10.6	55.0	20.9	19.1	50.0	12.6	12.3	51.7	17.3	14.2
T. newnesi	45.0	5.6	7.2	40.0	4.0	6.4	50.0	8.1	11.0	45.0	5.6	7.8
G. gibberifrons	18.0	1.7	2.8	22.5	0.9	2.1	31.3	2.1	15.9	23.9	1.5	5.4
P. bernacchii	3.0	0.2	0.5	15.0	1.3	4.3	3.1	0.1	0.1	7.0	0.6	1.8
P. charcoti	–	–	–	2.5	0.1	0.1	–	–	–	0.1	0.0	0.0
N. rossii	–	–	–	2.5	0.2	5.0	–	–	–	0.1	0.1	1.9
P. antarcticum	2.5	0.2	0.1	–	–	–	–	–	–	0.1	0.1	0.0
N. coatsi	2.5	0.2	0.0	–	–	–	–	–	–	0.1	0.1	0.0
*E. antarctica**	2.5	0.1	0.0	–	–	–	–	–	–	0.1	0.0	0.0
B: Stomach contents												
N. coriiceps	56.3	14.6	53.8	58.7	11.9	40.9	53.3	9.4	50.4	56.1	11.9	48.5
H. antarcticus	33.3	58.5	11.9	41.3	51.2	13.8	42.2	62.6	17.0	38.8	57.6	14.3
N. nudifrons	20.8	12.5	9.0	34.8	26.5	22.0	44.4	20.9	20.4	33.1	20.0	17.1
T. newnesi	25.0	11.6	13.1	17.4	7.9	12.8	8.9	6.0	8.0	17.3	8.5	11.2
G. gibberifrons	2.0	0.6	7.7	–	–	–	4.4	0.6	2.8	2.2	0.4	3.5
P. bernacchii	–	–	–	2.2	0.3	1.7	2.2	0.3	1.3	1.4	0.2	1.0
P. charcoti	4.0	1.8	0.2	8.7	1.5	2.6	2.2	0.3	0.1	5.0	1.2	0.9
N. rossii	2.0	0.3	4.1	4.3	0.6	6.2	–	–	–	2.2	0.3	3.3

*Length estimated in standard length.
F%: Frequency of occurrence percent.
N%: Importance in number percent.
M%: Importance in mass percent.

Notothenia rossii

TL = $66.14*OL^{1.2}$ mm (n = 34)

Mass = $1.77*10^{-6}*TL^{3.38}$ g (n = 22)

TL: Total length
SL: Standard length
Mass: Fish body mass
[1] Calculated using unpublished fish data from Potter Cove, South Shetland Islands.
[2] Taken from Hecht (1987).

Simultaneously with the pellet collection, 139 stomach contents (46, 46 and 47 in periods 1, 2 and 3, respectively) were obtained from birds returning to their nests from foraging trips applying the 'shaking' technique used by Cooper (1985) and Coria *et al.* (1995); individual birds were sampled only once a day. When tested on Imperial Cormorants, this technique proved to be as effective as stomach flushing (see Coria *et al.* 1995). To avoid biases due to sexual and/or daily prey and predator differential activity, each sampling day was separated in three time periods (08h00–12h00, 13h00–17h00 and 18h00–22h00 local time), obtaining a minimum of five stomach contents per period. In the field, the samples were wet-weighed and sorted into alimentary items. Fish total length (to 0.1 cm) and mass (in g) were recorded. When the specimens obtained were partially digested, the otoliths were recovered and measured to calculate their size and mass by applying the equations described above.

Each pellet and stomach content sampling period was complemented with one day of continuous direct observations at five to seven undisturbed nests, totalling 864 bird hours (336, 288 and 240 in the three periods, respectively) recording a total of 94 foraging trips. During incubation and early chick rearing, the duration of the trips was used to distinguish foraging (mean = 170 and 126 min, respectively) from other trips (e.g. gathering nest material or bathing, mean = 7 and 10 min for both periods). In the late rearing period, a foraging trip was identified when the birds returned to the nests and fed the chicks immediately.

To compare results and calculate correction factors to compensate for the loss and digestion of otoliths found in pellets and to estimate more accurately the original fish mass ingested, the mean mass of each fish species ingested daily per bird as reflected by both methods (Msc, for stomach content; Mp, for pellets) were estimated for each sampling period and for the whole season. For such purposes, the relative importance by mass of each fish species as reflected by the stomach contents (RIsc = M%/100, see Table 2b), the mean fish mass in the stomach contents (FMsc) and the daily number of foraging trips (FT) were considered to calculate that value for stomach contents (Msc = FMsc*RIsc*FT). Similarly, the relative importance in mass of each fish species in pellets (RIp = M%/100, see Table 2a), the mean fish mass per pellets (FMp) and the mean number of pellets produced per day (NP) were used for regurgitated casts (Mp = FMp*RIp*NP) (Tables 3 & 4). The proportional difference between this pair of values is the factor (CF) to be applied to the fish mass of each species estimated from pellets (CF = Msc/Mp) (Table 4). Correction factors to compensate the underestimation in number can be calculated in an analogous manner.

TABLE 3

Data used in the estimation of correction factors: mean fish mass per stomach contents (FMsc), number of daily foraging trips (FT), mean fish mass per pellet (FMp), and number of pellets produced per day (NP)

	FMsc (g)	FT	FMp (g)	NP
Period 1	213.4	1.7	310.1	0.51
Period 2	205.5	2.0	294.3	0.74
Period 3	221.8	4.6	225.3	0.59
Total period	213.6	2.8	280.2	0.60

RESULTS AND DISCUSSION

As has been widely reported for cormorants from other localities (Schlatter & Moreno 1976, Blankley 1981, Espitalier-Noel *et al.* 1988, Green *et al.* 1990a,b, Barrett 1991, Wanless *et al.* 1992, Casaux & Barrera-Oro 1995a, Barrera-Oro & Casaux 1996) and also previously for Duthoit Point (Casaux & Barrera-Oro 1993, Casaux *et al.* 1997), pellet analysis showed that fish were the main prey of the Imperial Cormorant. Molluscs and polychaetes followed in order of importance (Table 5). A total of 3510 fish was represented; 3125 were identified to 11 species: *N. coriiceps*, *H. antarcticus*, *N. nudifrons*, *T. newnesi*, *G. gibberifrons*, *N. rossii*, *P. bernacchii*, *Parachaenichthys charcoti*, *P. antarcticum*, *N. coatsi* and *E. antarctica*. *Harpagifer antarcticus* was the most important fish, both in frequency and mass,

TABLE 4

Correction factors (CF) estimated by comparison of the mean mass (g) of fish ingested daily per bird estimated from stomach contents (Msc) and pellets (Mp)

Fish species	Period 1			Period 2			Period 3			Total		
	Msc	Mp	CF	Msc	Mp	CF	Msc	Mp	CF	Msc	Mp	CF
N. coriiceps	195.2	68.0	2.87	168.1	39.7	4.23	514.1	54.0	9.52	290.1	55.8	5.20
H. antarcticus	43.2	57.0	0.76	56.7	97.7	0.58	173.5	26.7	6.50	85.5	60.0	1.43
N. nudifrons	32.7	16.8	1.95	90.4	41.6	2.17	208.1	16.3	12.77	102.3	23.9	4.28
T. newnesi	47.5	11.4	4.17	52.6	13.9	3.78	81.6	14.6	5.59	67.0	13.0	5.15
G. gibberifrons	27.9	4.1	6.80	–	4.5	–	28.6	21.1	1.36	20.9	9.1	2.30
P. bernacchii	–	0.8	–	7.0	9.3	0.75	13.3	0.1	133.0	6.0	3.0	2.00
P. charcoti	0.7	–	–	10.7	0.2	53.50	1.0	–	–	–	–	–
N. rossii	14.9	–	–	25.5	10.8	2.36	–	–	–	–	–	–

TABLE 5

The diet of the Imperial Cormorant at Duthoit Point as reflected by the analysis of pellets and stomach contents

Prey taxa	Pellets *		Stomach contents		
	F%	N%	F%	N%	M%
Fish	100.0	93.0	100.0	91.3	97.9
Octopods	48.2	5.0	11.5	2.3	1.8
Gastropods	10.7	0.7	–	–	–
Nacella concinna	1.8	0.1	–	–	–
Bivalves	5.4	0.2	–	–	–
Gammariids	–	–	14.4	5.5	0.2
Euphausia superba	–	–	3.6	0.5	0.0
Polychaetes	18.8	1.0	0.7	0.1	0.0
Algae	70.5	–	–	–	–
Stones	80.4	–	0.7	–	–

*Percentage in mass not estimated since most of the remains from secondary items were shells, valves, mandibles and exoskeletons.
F%: Frequency of occurrence percent.
N%: Numerical abundance.
M%: Importance in mass percent.

followed by *N. coriiceps* (Table 2a). The cormorants produced a mean of 0.6 pellets per day, with an estimated mean mass of fish per pellet of 280.2±185.1 g (Table 3).

The results obtained from stomach contents have been extensively discussed by Favero *et al.* (1995). In agreement with previous studies at Duthoit Point (Coria *et al.* 1995), stomach content examination showed that fish constituted the bulk of the diet, followed by molluscs and gammarids (Table 5). A total of 1028 fish was recovered; 1019 were identified to eight species: *N. coriiceps, H. antarcticus, N. nudifrons, T. newnesi, G. gibberifrons, N. rossii, P. bernacchii* and *P. charcoti. Notothenia coriiceps* was the most frequent and important in mass, whereas H. antarcticus prevailed in number (Table 2b). The mean mass of the stomach contents was 219.6±120.3 g, with no significant differences between periods ($F_{(df2,n131)}$ = 0.453, $P > 0.5$) (Table 3).

The analysis of the diet of the Imperial Cormorant by both methods qualitatively showed similar results (see also Casaux *et al.* 1997). The trophic spectrum observed in pellets was wider than that reflected in the stomach contents, probably because each pellet contains the remains of four to seven meals (Casaux *et al.* 1997). As observed by Wanless *et al.* (1993) in the European Shag *Phalacrocorax aristotelis* and as suggested by Casaux & Barrera-Oro (1995b) for the Imperial Cormorant, food loads carried to the nests by breeders are primarily for their chicks and may not represent the whole prey spectrum of breeding adults. Pellets seem to reflect more appropriately both adult and chick diet (see also Harris & Wanless 1993), which also would explain the differences observed. Not unexpectedly, some quantitative differences were observed, mainly in the relative importance of fish species eaten. These differences can be partially explained by the second hypothesis previously mentioned, but are also related to erosion by digestion of otoliths found in pellets or their loss throughout the gastrointestinal tract (see Jobling & Breiby 1986).

The number of daily foraging trips per bird averaged 1.7, 2.0 and 4.6 in the three periods, respectively (Kruskall-Wallis Test, $P < 0.001$) (see Favero *et al.* 1995) (Table 3). The duration of the trips diminished significantly throughout the season averaging 173, 126 and 91 min in the three periods ($F(2.71) = 5.979$, $P < 0.01$). These trends reflect the increase of the chicks' energetic demands throughout the breeding season, and have been discussed in detail by Casaux & Barrera-Oro (1995a) and Favero *et al.* (1995).

For most fish species, the correction factors estimated for the third period were the highest (Table 4). Probably this could be explained by the foraging behaviour of Greater Sheathbills *Chionis alba*, which were associated with a nearby Gentoo Penguin *Pygoscelis papua* colony but during this period also preyed on fish remains available around the cormorant nests and secondarily on pellets. As a consequence, some pellets may have been ingested by the sheathbills from the studied nests resulting in an underestimation of the mass ingested daily per bird. The fact that the loads carried to the nests by breeding Imperial Cormorants could primarily represent the chicks' diet (Wanless *et al.* 1993, Casaux & Barrera-Oro 1995b) whereas pellets seem to reflect more appropriately both adult and chick diet (see also Harris & Wanless 1993), adds more doubt in relation to the accuracy of the factors estimated for the third period since they could compensate for the differences between chick and adult diet rather than for the loss and erosion of otoliths represented in pellets. During period 1 (incubation) the cormorants were not feeding chicks thus, the loads carried to the nest represents the adult diet and in consequence pellets and stomach contents are fully comparable. Something similar occurred during period 2 when chicks (average nine days old, Table 1) ingested small amounts of partially digested flesh and few otoliths were fed to them. Thus, it is expected that the factors estimated for these periods better compensate for the loss and erosion of otoliths in pellets, especially when it is considered that the activity of Greater Sheathbills in the cormorant colony during this time was negligible.

In general, the correction factors calculated in this study were lower than those obtained previously in a feeding trial on the Imperial Cormorant (Casaux *et al.* 1995). The accuracy of these factors was found to be somewhat high (Casaux *et al.* 1997), with the suggestion that they were biased because the feeding experiment was conducted on a single captive bird only, some of the fish species were scarcely used to feed the cormorant and natural conditions were not appropriately reproduced (Casaux *et al.* 1995). In contrast, the correction factors presented here were estimated using a combined methodology applied to a larger number of samples. As a consequence it is expected that these factors can be used for quantitative estimations of the mass of some of the benthic-demersal fish species represented in the pellets of the Imperial Cormorant.

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REFERENCES

BARRERA-ORO, E.R. & CASAUX, R.J. 1996. Fish as diet of the Blue-eyed Shag *Phalacrocorax atriceps bransfieldensis* at Half-moon Island, South Shetland Islands. *Cybium* 20: 37–45.

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

BLANKLEY, W.O. 1981. Marine food of Kelp Gulls, Lesser Sheathbills and Imperial Cormorants at Marion Island (Subantarctic). *Cormorant* 9: 77–84.

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

CASAUX, R.J. & BARRERA-ORO, E.R. 1995a. Variations in the diet of the Blue-eyed Shag *Phalacrocorax atriceps* throughout the breeding season at Half-moon Island, South Shetland Islands. CCAMLR Ecosystem Monitoring and Management Working Group. WG-EMM-95/78.

CASAUX, R.J. & BARRERA-ORO, E.R. 1995b. A methodological proposal to monitor changes in coastal fish populations by the analysis of pellets of the Blue-eyed Shag *Phalacrocorax atriceps*. CCAMLR Ecosystem Monitoring and Management Working Group.WG-EMM-95/84.

CASAUX, R.J., 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. Orn.* 23: 101–106.

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

COOPER, J. 1985. A note on the diet of Cape Cormorant *Phalacrocorax capensis* at Mercury Island, South West Africa, in November 1978. *S. Afr. J. Mar. Sci.* 3: 129–130.

CORIA, N.R., CASAUX, R.J., FAVERO, M. & SILVA, P. 1995. Analysis of the stomach contents of the Blue-eyed Shag *Phalacrocorax atriceps bransfieldensis* at Nelson Island, South Shetland Islands. *Polar Biol.* 15: 349–352.

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

ESPITALIER-NOEL, G., ADAMS, N.J. & KLAGES, N.T. 1988. Diet of the Imperial Cormorant *Phalacrocorax atriceps* at sub-Antarctic Marion Island. *Emu* 88: 43–46.

FAVERO, M., CASAUX, R.J., SILVA, P., BARRERA-ORO, E.R. & CORIA, N.R. 1995. The diet of the Blue-eyed Shag *Phalacrocorax atriceps* during summer at Nelson Island, Antarctica: temporal variations and consumption rates. CCAMLR Ecosystem Monitoring and Management Working Group. WG-EMM-95/82.

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

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

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

HARTLEY, P. 1948. The assessment of the food of birds. *Ibis* 90: 361–381.

HECHT, T. 1987. A guide to the otoliths of Southern Ocean fishes. *S. Afr. J. Antarct. Res.* 17: 1–87.

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

NORTH, A., BURCHETT, M., GILBERT, C. & WHITE, M. 1984. Identification of fish from the Southern Ocean by means of otoliths. *Br. Antarct. Surv. Bull.* 62: 83–94.

SCHLATTER, R.P. & MORENO, C.A. 1976. Hábitos alimentarios del cormorán antártico, *Phalacrocorax atriceps bransfieldensis* (Murphy) en Isla Green, Antártida. *Serie Científica del Instituto Antártico Chileno* 4: 69–88.

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

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

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.