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Does prey availability affect the foraging effort and breeding success in the Antarctic Shag (*Phalacrocorax bransfieldensis*)?

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Abstract Information on diet composition, foraging effort and breeding success of the Antarctic Shag (*Phalacrocorax bransfieldensis*) was obtained at three colonies on the Antarctic Peninsula, during the 1997/98 breeding season. Fish was the most important prey at each of the colonies sampled, followed by octopods and gastropods. Among colonies, there were marked differences in the size of the fish consumed, which was smaller at Py Point. This was mainly due to the larger number of specimens of the smallest fish prey species consumed there. Shags from Py Point performed longer foraging trips and spent more time per day foraging. Although at the beginning of the study the number of chicks per nest observed at the three colonies was similar, the number surviving to fledge at Py Point was markedly lower. The relative higher foraging effort and lower breeding success observed at Py Point might be related to the differences in the fish consumed between colonies. My results suggest that the decline in the inshore fish populations observed around the South Shetland Islands could be one of the reasons explaining the steady decrease in the number of breeding Antarctic Shags observed at colonies monitored in this archipelago.

Keywords Antarctic Shag, breeding success, foraging effort, prey size

Introduction

Prey availability affects the foraging strategy, breeding success and population parameters of their predators (see Montevecchi, 1993, for review). In this sense, Casaux and Barrera-Oro (1996) suggested that the decrease in the inshore populations of *Gobionotothen gibberifrons* and *Notothenia rossii,* observed in shallow waters of the South Shetland Islands (Barrera-Oro et al., 2000), may be one of the possible factors causing a steady decrease in the number of breeding Antarctic Shags (*Phalacrocorax bransfieldensis*) in colonies studied at this archipelago. However, monitoring studies on the Antarctic Shag at the South Shetland Islands started after the decrease of these two fish species, hence conclusive information was lacking.

Casaux et al. (2002) provided information on the diets of the Antarctic Shag at four locations of the Danco Coast, west Antarctic Peninsula. They reported that the prey consumed at one of those locations, Py Point, differed markedly from that consumed at the other three. Interestingly, the diet of shags from Py Point was broadly similar to that of Antarctic Shags breeding in the South Shetland Islands (reviewed in Casaux et al., 1998).

Simultaneous with the diet study at the Danco Coast, we also obtained information on foraging effort and breeding success of Antarctic Shags from three of the

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colonies under scrutiny. Due to adverse weather and sea conditions and logistic limitations, it is difficult to obtain detailed and concurrent information on diet, foraging effort and breeding performance from different shag colonies in Antarctica. Thus, and despite the limited information, the aim of this study is a preliminary exploration of the interactions between diet composition, foraging effort and breeding performance. The results are discussed in relation to the steady decrease in the number of breeding shags observed at the South Shetland Islands.

Methods

The information presented was collected during the 1997/98 breeding season at three colonies located at the Danco Coast, west Antarctic Peninsula: Primavera Island (64°09′S, 60°59′W, 9 breeding pairs), Midas Island (within the Antarctic Specially Protected Area N° 134, 64°10′S, 61°05′W, 23 breeding pairs) and Py Point (64°13′S, 61°00′W, 22 breeding pairs) (Fig. 1). The distance between the two farthest colonies (Primavera Island and Py Point) is 9.2 km.

The diet of breeding Antarctic Shags was studied with the analysis of 465 pellets (regurgitated casts) (Primavera Island, 151 pellets; Midas Island, 165 pellets; and Py Point, 149 pellets) collected from 20 December 1997 (early-mid rearing) to 20 February 1998 (fledging –post-fledging). For the analysis of the samples we used the methods described in Casaux et al. (2002).

The information on foraging effort was collected by continuous direct observation from dawn to dusk of 9 nests at Primavera Island, 8 nests at Midas Island, and 11 nests at Py Point during 12, 22 and 24 January 1998 respectively. The weather conditions during the three days of observations were similar. The observations were performed "ad libitum" (see Altmann, 1974) with the naked eye or using binoculars (8 × 23) from a vantage point up to 30 m from the farthest nests; no reaction of the shags to the presence of the observer

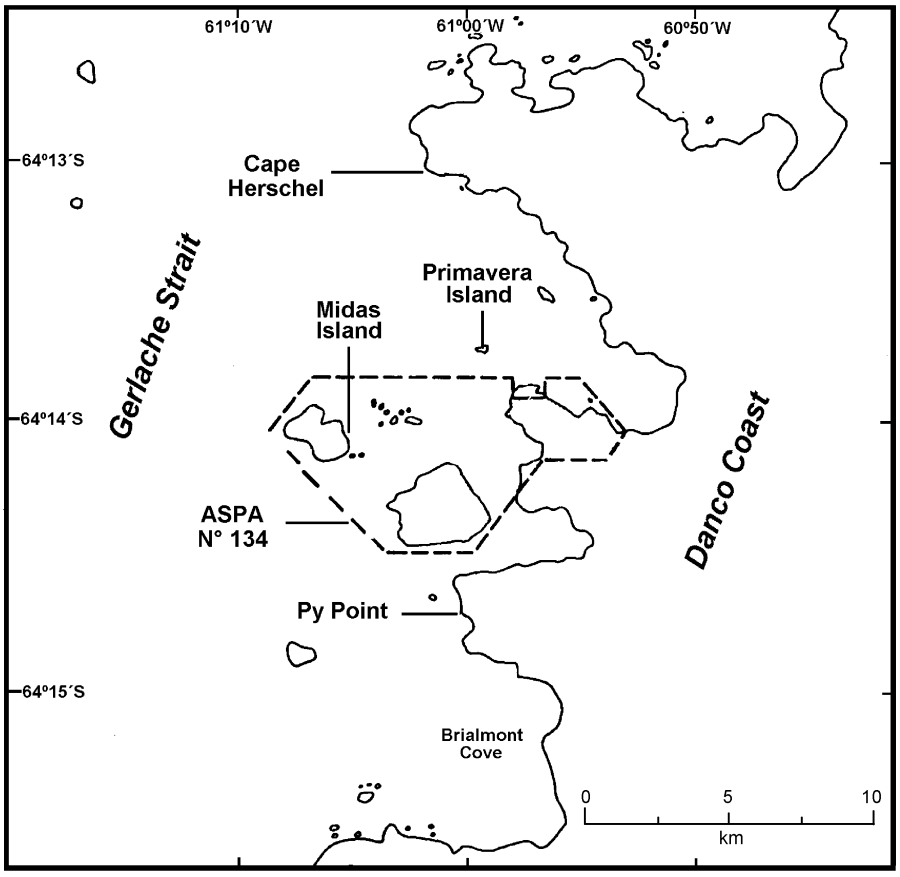

Fig. 1 Map showing the location of the colonies of the Antarctic Shag studied at the Danco Coast, Antarctic Peninsula and the SCAR Antarctic Specially Protected Area (ASPA) N° 134.

was evident. The colonies were mapped and the nests numbered, which enabled observations to be attributed to each individual. To prevent misidentification of the members of a pair, males were banded on the right and females on the left leg. Times were recorded to the nearest minute using a portable tape recorder. The time was expressed as local time (GMT-3). The trips performed by the individuals for bathing (at short distances in front of the colony) or gathering nest material were registered and excluded from analyses; thus, the information related to the time spent by the individuals out of the colony only represents foraging times (including essential and non-essential feeding activities). Due to the distance among the station and the colonies and among colonies, the weather and sea conditions and the absence of places appropriated to set up camp at Midas Island and Py Point, I was unable to increase the number of observations on the foraging patterns.

Casaux and Baroni (2004) reported for rearing chick Antarctic Shags at the South Shetland Islands that the number of daily foraging trips and the daily time spent foraging increased as chicks grew older and at increasing energy requirements at the nest. To determine if the differences among colonies in the foraging patterns were related to differences in the age of the chicks or in the energy requirements at the nest, from 14 to 20 January 1998 (almost concurrently with the observations on foraging activity) we weighed (a gross indicator of the age of the chicks, see Casaux 2004) 13 chicks selected randomly at each study colony.

The information on the brood size and breeding success was derived from direct counts of the number of chicks at all the nests at the colonies studied. Due to weather/sea conditions and the distance among colonies, the chick counts were not carried out simultaneously. The firsts counts (early to mid rearing chick period) were made on 20 December 1997 at Primavera Island, 21 December 1997 at Midas Island and 1 January 1998 at Py Point, whereas the lasts counts (late rearing to fledging) date from 27 January 1998, 7 February 1998 and 24 January 1998.

Results

Fish, followed in importance by octopods and gastropods, were the most frequent (frequency of occurrence) and important prey by number at all the colonies considered (Table 1). The shags from Py Point preyed more frequently and intensively on octopods and gastropods than those from the other two colonies.

Among fish, benthic-demersal species of the family Nototheniidae predominated in the diet. *Notothenia coriiceps* and *G. gibberifrons* were the most important prey species and contributed similar masses to the diets of shags from Primavera Island and Midas Island; they were followed in importance by *Trematomus newnesi* (Table 2). Although *N. coriiceps* also predominated in the diet of shags from Py Point, this species was followed in importance by *H. antarcticus,* whereas *G. gibberifrons* was poorly represented. As a consequence of diet composition, there were marked differences among colonies in the size of the fish ingested (Primavera Island: 10.5 ± 4.9 cm; Midas Island: 12.1 ± 5.6 cm; Py Point: 9.0 ± 4.4 cm; ANOVA, $F = 188.5$, df = 2, $p < 0.001$), the smallest fish being consumed by shags from Py Point (Newman-Keuls (N-K), $p < 0.001$) (see Casaux et al., 2002, for detail).

Overall, the foraging activity took place during daylight hours between 6:30 h and 21:30 h. Except in one case, females undertook the first trip of the day for each pair and males undertook the last. There were significant differences among colonies in the number of daily foraging trips by males (ANOVA, $F = 3.91$, df = 2, $p < 0.05$) and pairs ($F = 5.74$, df = 2, $p < 0.01$), in the duration of the trips by males ($F = 11.34$, df = 2, $p < 0.001$) and pairs ($F = 6.96$, df = 2, $p < 0.01$), and in the daily time spent foraging by males ($F = 3.84$, df = 2, $p < 0.05$), females ($F = 13.34$, df = 2, $p < 0.001$) and pairs ($F = 16.96$, df = 2, $p < 0.001$) (Table 3). Whereas males (N-K, $p < 0.05$) and females (N-K, ns) from Midas Island undertook more daily foraging trips, individuals of both sexes at Py Point undertook longer foraging trips (differences were statistically significant in males; N-K, $p < 0.05$). This resulted in more daily time spent foraging by males (N-K, $p < 0.05$), females (N-K,

Table 1 Composition of the diet of the Antarctic Shag at three localities of the Danco Coast, Antarctic Peninsula. Percentage frequencies of occurrence (*F*%) and number (*N*%). Information taken from Casaux et al. (2002).

	Primavera I.		Midas I.		Py Point	
	F%	*N*%	*F*%	*N*%	*F*%	*N*%
Fish	100.0	94.2	100.0	89.3	100.0	82.8
Octopods	17.2	2.6	24.9	3.4	28.2	8.1
Gastropods	10.1	1.7	22.1	3.7	22.8	7.2
Bivalves	6.6	0.7	9.7	2.0	5.4	0.3
Amphipods	17.2	–	21.2	–	28.2	–
Polychaetes	11.3	0.8	17.0	1.6	28.2	1.6

Table 2 Fish represented in the diet of the Antarctic Shag at three localities of the Danco Coast, Antarctic Peninsula. Percentage frequencies of occurrence (*F*%), number (*N*%) and mass (*M*%). Information taken from Casaux et al. (2002).

	Primavera I.			Midas I.			Py Point		
	F%	*N*%	*M*%	*F*%	*N*%	*M*%	*F*%	*N*%	*M*%
Nototheniidae									
Gobionotothen gibberifrons	50.3	17.1	30.9	58.8	20.8	38.3	24.8	3.8	8.0
Lepidonotothen larseni	5.3	0.9	1.2	1.2	0.2	0.1	2.0	0.1	0.1
Lepidonotothen nudifrons	60.3	19.3	8.8	60.6	18.3	6.2	48.3	9.8	5.9
Notothenia coriiceps	49.7	8.8	33.0	58.2	15.9	39.5	48.3	11.3	54.3
Notothenia rossii	0.7	0.1	1.7	–	–	–	0.7	0.1	1.7
Trematomus bernacchii	27.2	4.5	5.7	21.2	4.4	3.9	24.9	3.1	5.7
Trematomus newnesi	53.0	14.9	11.4	58.8	20.6	10.2	38.3	7.0	6.5
Trematomus scotti	3.3	0.2	0.3	0.6	0.1	0.1	0.7	0.0	0.0
Pagothenia borchgrevinki	2.0	0.3	0.2	4.2	0.4	0.3	5.4	0.5	0.2
Harpagiferidae									
Harpagifer antarcticus	28.5	22.0	5.6	20.0	7.8	1.8	48.3	50.0	16.9
Bathydraconidae									
Parachaenichthys charcoti	2.7	0.3	1.1	1.8	0.2	0.1	3.4	0.2	0.9
Channichthyidae									
Chaenodraco wilsoni	0.7	0.1	0.1	–	–	–	–	–	–
Myctophidae									
Electrona antarctica	0.7	0.1	0.0	–	–	–	–	–	–
Paralepididae									
Notolepis coatsi	–	–	–	0.6	0.1	0.0	0.7	0.0	0.0
Unidentified	60.9	11.4	–	52.1	11.3	–	72.5	14.0	–

Table 3 Number of daily foraging trips, duration of trips (min) and daily time spent foraging (min) observed in the Antarctic Shag at three colonies located at the Danco Coast, Antarctic Peninsula, during the 1997/98 breeding season. Values are expressed as mean ± standard deviation.

	Daily number of trips			Duration of trips (min)			Daily time spent foraging (min)		
	Py Point	Primavera I.	Midas I.	Py Point	Primavera I.	Midas I.	Py Point	Primavera I.	Midas I.
Males	3.55 ± 1.6	3.63 ± 1.6	5.63 ± 2.0	129.95 ± 105.4	92.14 ± 71.2	50.02 ± 44.9	472.36 ± 143.9	321.38 ± 175.0	282.50 ± 164.3
Females	5.10 ± 1.5	3.43 ± 1.4	6.00 ± 3.1	110.82 ± 90.8	93.46 ± 59.6	91.94 ± 107.9	553.60 ± 62.79	320.43 ± 150.1	552.50 ± 88.0
Pairs	8.60 ± 2.6	5.86 ± 1.9	11.63 ± 4.8	119.23 ± 97.4	92.74 ± 65.6	71.66 ± 85.8	1009.10 ± 159.4	519.83 ± 140.2	835.00 ± 181.0

$p < 0.001$) and pairs (N-K, $p < 0.05$) from Py Point than in the other two colonies.

The mass of the chicks from the colonies at Primavera Island (2711.5 ± 410.4 g, range 2100–3250 g), Midas Island (2972.7 ± 253.3 g, range 2600–3400 g) and Py Point (2920.8 ± 218.9 g, range 2600–3300 g) did not differ statistically (Kruskal-Wallis ANOVA, df = 2, n.s.), which reflects the similarity in the age of the chicks among colonies. Moreover, the narrow range in the mass of the chicks also reflects the similarity in the age of the chicks within colonies. According to the mass of the chicks and the brood size observed during the initial and lasts counts (see below), the energy requirements at Py Point were similar or lower than at the other two colonies under study.

The mean numbers of chicks per nest observed during the initial counts were 2.6 at Primavera Island, 2.5 at Midas Island and 2.6 at Py Point. During the lasts counts the number of chicks per nest at Primavera Island (2.2) and Midas Island (2.2) remained high but decreased markedly at Py Point (1.6). This resulted in significant differences in the breeding success between Py Point and the remaining colonies ($\chi^2_3 > 28.3$; $p < 0.001$).

Discussion

The study suffers from several methodological shortcomings. As suggested earlier, due to the distance among the station and the colonies (only accessible by sea) and among colonies, the weather and sea conditions and the absence of places appropriated to set up camp at Midas Island and Py Point, I was unable to increase the number of observations on the foraging patterns or to obtain more detailed information on breeding and population parameters. However, detailed and concurrent information on diet, foraging effort and breeding performance from different shag colonies is difficult to obtain in Antarctica. Moreover, the identification of neighboring colonies with marked concurrent differences in the composition of the diet is a rare phenomenon in Antarctica. Such conditions are essential to develop these kinds of studies and allow the elimination of weather and sea conditions as explanatory hypotheses for the observed differences in foraging efforts and breeding success. Despite these shortcomings, the consistency of the results suggests that the database is appropriate for the purposes of this study, especially when taking into account that this is the first study aimed at exploring the interactions among diet composition, foraging effort and breeding performance in the Antarctic Shag, a species whose breeding populations are steadily declining at the colonies under study at the South Shetland Islands (Casaux and Barrera-Oro, 1996, 2006).

Similar to previous reports for other shag species in sub-Antarctic and Antarctic areas (Shaw, 1984; Green et al., 1990; Wanless and Harris, 1993; Ridoux, 1994; Kato et al., 1996; Casaux et al., 1997; Casaux and Ramón, 2002), demersal-benthic fish were the main prey of Antarctic Shags at the three colonies considered in this study (Table 1).

Among 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. *Notothenia coriiceps* was the main prey at all the sampling sites, followed in similar importance by *G. gibberifrons* at Primavera Island and Midas Island and to a lesser extent by *H. antarcticus* at Py Point. Thus, the composition of the diet and the size of the fish ingested by shags from Py Point differed markedly from the other colonies. Given that shags are opportunistic feeders (Craven and Lev, 1987; Keller, 1995), the differences in the composition of the diet may reflect differences in prey availability around the colonies. This hypothesis is supported by the fact that shags from Primavera Island and Midas Island foraged mainly in open waters, close to the Gerlache Strait, whereas those from Py Point foraged mainly in inner waters at Brialmont Cove (Fig. 1). Interestingly, the composition of the diet of shags from Py Point was similar to that observed in Antarctic Shags foraging at different localities at the South Shetland Islands (see Casaux et al., 1998, for review).

Shags from Py Point spent more time in foraging per day than those from the other colonies. The highest difference between colonies in the daily time spent foraging was observed in males which is crucial for the breeding success, given that male Antarctic Shags provide more food to the nest than their partners (even in relation to the mass of the individuals) (Casaux, 1998; Favero et al., 1998). Given that throughout the study period the brood size and the energy requirements at the nests at Py Point were similar or smaller than those at Primavera and Midas Islands, the fact that there were no differences detected in the age of the chicks and the occasional observations on birds at sea, suggests that there were no marked differences in the extents of the foraging areas used by individuals from the different colonies. The differences among colonies in the foraging effort might be related to greater difficulties to cover the energy demands of the foraging trips suffered by shags from Py Point. Perhaps, the limited availability of *G. gibberifrons* around Py Point forced the shags from this colony to forage more intensively on another benthic fish species, such as the smaller and more cryptic *H. antarcticus*, which may have resulted in an increase in the time required to cover the energy demands of the foraging trips. According to the proportional contribution to the diet by mass of the different fish species (see Table 2) to cover their own energy requirements (according to Bernstein and Maxson, 1985, and Casaux et al. 1995, conservatively assumed as 2800 $kJ \cdot day^{-1}$ per individual) and those of the chicks at the nest (considering the brood size observed at the beginning of the study period and a daily energy requirement for a chick weighing 2750 g of 3480 $kJ \cdot day^{-1}$, estimated from Weathers (1992)), each pair is estimated to consume on a daily basis approximately 212 fish at Py Point, 160 fish at Midas Island and 175 fish at Primavera Island. This assumes that fish provide an energy content of 4.76 $kJ \cdot g^{-1}$ (Dunn, 1975) and are assimilated with an efficiency of 75% (Wiens, 1984), given the number of preys caught daily, the different composition of the

diet of shags from Py Point seems to explain the higher foraging effort observed at this location. Moreover, it should be mentioned that the small sized and cryptic *H. antarcticus* lives sheltered under rocks (Daniels and Lipps, 1982) (which implies that specimens from this species are difficult to locate) and, as well, that larger fish provide proportionately more energy than smaller ones (Hislop et al., 1991).

Given that in the Antarctic Shag the duration of the foraging trips and the daily time spent foraging depends on many factors such as brood size, the age of the chicks, weather and sea conditions around the colonies, prey distribution and abundance, as well as the daily time available to forage (Casaux, 1998; Casaux and Baroni, 2004), a comparison of those parameters among areas might result in biased conclusions. Nevertheless, the present results from the Danco Coast and analogous information from the South Shetland Islands (Casaux and Baroni, 2004) agree on that at both locations, the duration of the foraging trips and the daily time spent foraging tended to increase with decreasing breeding success. Although Antarctic Shags seem to use the duration of their foraging trips as a buffer to compensate for variable food levels (Casaux and Baroni, 2004), under severe weather or low food conditions they might be unable to compensate fully for food shortages, thus resulting in increasing chick mortality (Casaux and Baroni, 2004).

From a similar initial number of chicks per nest, the breeding success at Py Point was markedly lower than that observed at the other two colonies. During the study period I did not observe predation on chicks while the sea and weather conditions were similar around the three colonies, the inference being that these factors are unlikely to explain the higher chick loss at Py Point. In the absence of sibling aggression, the most likely cause of brood reduction at Py Point could have been, as reported for other bird species, the direct competition between siblings for food (Dyrcz, 1974; Bryant, 1978; Ryden and Bengtsson, 1980) or the selective starvation of the "victim" chick by its parents (Horsfall, 1984); both types of behavior are related to limited food provisioning by parents. The lack of previous information did not allow to know if, compared to the remaining colonies, the colony at Py Point was composed by younger/less experienced breeding individuals from which it is due to expect longer foraging times and lower breeding performance than from older/more experienced individuals.

Although several factors may determine the foraging patterns and breeding success in Antarctic Shags (see earlier discussion), the comparison of data from the colonies under study at the Danco Coast suggests that the relative high foraging effort and low breeding success observed at Py Point seems to be, at least partially, explained by the replacement of *G. gibberifrons* by *H. antarcticus* in the diets of these shags. Interestingly, at Cape Herschel, a colony located within the study area, *N. coriiceps* and *G. gibberifrons* were the main prey species and *H. antarcticus* scarcely represented (see Casaux et al., 2002), the breeding success was similar to that observed at Primavera and Midas Islands (2.2 chicks per nest). Barrera-Oro and Marschoff (1991) and Barrera-Oro et al. (2000) observed a decrease in the inshore population of *G. gibberifrons* and *N. rossii* at the South Shetland Islands from the early eighties, suggesting that the effect of the commercial fishery around this archipelago at the end of the 1970s is the most likely reason for this trend. As a consequence of their limited availability around the colonies, these fish species are scarcely represented in the diet of Antarctic Shags from the South Shetland Islands, i.e., *N. coriiceps* and *H. antarcticus*, as at Py Point, where these two species are the main prey (see Casaux and Barrera-Oro, 1996; Casaux et al., 1998).

In Antarctic Shags low breeding success and high foraging efforts might imply a low recruitment and high adult mortality respectively, with both factors adversely affecting the population trends of this bird. In line with these premises and with the present results from the Danco Coast, the reported decrease in the abundance in inshore waters of the South Shetland Islands of *G. gibberifrons* and *N. rossii* (Barrera-Oro and Marschoff, 1991; Barrera-Oro et al., 2000), two probably former important fish preys of the Antarctic Shag may have, to some extent, affected the decreasing trend in the number of breeding pairs of this bird observed during the last 17 years in the colonies studied in this archipelago.

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猎物利用率对南极鸬鹚（*Phalacrocorax bransfieldensis*）觅食努力及繁殖成功率的影响

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摘要：通过调查获得了南极半岛 3 个南极鸬鹚（*Phalacrocorax bransfieldensis*）群落在 1997/98 年繁殖期的食物组成、觅食努力及繁殖成功率的相关资料。鱼类是这 3 个鸬鹚群落最主要的食物来源，其次是八足类及腹足类动物。3 个群落的鸬鹚所捕食的鱼类大小有显著差异，在 Py Point 处的最小，这主要是因为在该处获得的小体型的鱼类样本数目最多。Py Point 处的鸬鹚觅食路径最长，日均觅食时间最多。Py Point 处的雏鸟存活率最低，虽然在调查初期这 3 个群落的平均窝雏数几近相同。该处鸬鹚的觅食努力最多但繁殖成功率却最低，可能与群落之间捕食的鱼类差异有关。南设得兰岛附近靠近海岸的鱼类种群数量不断下降，或许能解释为何在该列岛繁殖的鸬鹚群数目越来越少。

关键词：南极鸬鹚，繁殖成功率，觅食努力，猎物大小