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PELLETS AND PREY REMAINS AS INDICATORS OF THE DIET OF TWO SYMPATRIC SKUAS (AVES: STERCORARIIDAE) ON KING GEORGE ISLAND, ANTARCTICA

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Abstract: South Polar skua (*Stercorarius maccormicki*) and Brown skua (*Stercorarius antarcticus lonnbergi*) have opportunistic feeding habits and are the dominant predators in terrestrial Polar regions. These skuas exploit a wide range of food items, including marine organisms, other birds, and even garbage. In the present study, we compare the diets of these two skua species during the breeding season, using pellets and prey remains collected within their territories. The samples were collected at six sites in Admiralty Bay, on King George Island, Antarctica. We identified eight different items, which we classified as “penguin”, “flying bird”, “skua”, “fish”, “gastropod”, “krill”, “egg” and “marine debris”. In the first breeding season (2008/2009), penguins and flying birds were the food resources more abundant for both skua species, and their diet composition was similar. In the second breeding season (2010/2011) South Polar skua exploited more fish and flying birds than Brown skua; the latter exploited more eggs and penguins. Our findings corroborate those of previous studies, demonstrating that in sympatry South Polar skua exploit more fish than Brown skua. The diet of South Polar skua also varied between breeding seasons, reflecting the opportunistic foraging behavior of these skuas. As in other studies, we recorded that skua is a food resource for both skua species, but it was more common in the diet of South Polar skua. Marine debris was recorded only in the samples of Brown skua. Birds are important food items for both skuas, although significant differences were found in the diets of these sympatric species, with shifts in the composition of the diet probably reflecting fluctuations in the abundance of prey populations, which are known to be common at Admiralty Bay, although more data will be needed to confirm this link.

Keywords: Brown skua; fish; food resources; penguins; South Polar skua.

INTRODUCTION

Congeneric species may compete for food when they occur in sympatry, which may lead to resource partitioning (MacArthur & Levins 1967, Pfenninger & Nowak 2008). In oceanic environments, resource partitioning has been documented in a number of different seabird species (Young *et al.* 2010, Mancini & Bugoni 2014), including polar taxa (Ainley 1992, Robertson *et al.* 2014, Dehnhard *et al.* 2019). South Polar skua (*Stercorarius maccormicki*) (Charadriiformes, Stercorariidae) and Brown skua (*Stercorarius antarcticus lonnbergi*) (Charadriiformes, Stercorariidae) are the most common species of the genus *Stercorarius* found on the Antarctic Peninsula and nearby islands, such as the South Shetland Archipelago (Pietz 1987, Ritz *et al.* 2005, Costa & Alves 2007, 2012), the only regions in the southern hemisphere where the two species occur in sympatry (Parmelee 1988). These seabirds have opportunistic feeding habits, acting as predators, scavengers, and kleptoparasites (Maxson & Bernstein 1982, Norman & Ward 1990, Baker & Barbraud 2001). Their diets include a wide range of food items, including marine organisms (Votier *et al.* 2003), other birds (Moller-Schwarze & Moller-Schwarze 1973, Trillmich 1978, Pietz 1987, Zipan & Norman 1993, Brooke *et al.* 1999), and even garbage discarded by humans (Pietz 1987, Phillips *et al.* 2004).

Where they occur in sympatry, Brown skua feeds primarily on terrestrial resources, such as penguins, while the South Polar skua focuses more on marine resources (Trivelpiece & Volkman 1982, Pietz 1987). Seabird diets can be assessed by a range of different methods, including invasive techniques, such as the analysis of the stomach contents of euthanized specimens, and non-invasive techniques, such as the observation of feeding behavior, the analysis of feces, pellets, prey remains (Duffy & Jackson 1986, Carss *et al.* 1997), and also stable isotopes (Hobson 1987, 1995, Quillfeldt *et al.* 2005). Skuas, like many seabirds, regurgitate pellets containing the indigestible components of the ingested prey, such as feathers and bones, which provide important evidence on the composition of their diets (Sick 1997). These pellets are found frequently in breeding areas, and can be collected with minimal disturbance to the animals (González-Solís *et al.* 1997, Moncorps *et al.* 1998). One other non-invasive technique is the analysis of prey remains left in skua territories. Prey remains include animal carcasses or the remains of animals, such as wings, legs, and feet, which accumulate in the area around the nest, and can provide valuable data on the composition of the diet and, in particular, the taxonomic identification of prey items (Votier *et al.* 2003).

Pellets and prey remains have been used in qualitative studies of skua diets at a number of different Antarctic sites (Zipan & Norman 1993, Moncorps *et al.* 1998, Baker & Barbraud 2001, Votier *et al.* 2001, 2003) and may provide the best evidence for the comparison of diets among periods and sites (Votier *et al.* 2003). Studies of the diets of sympatric skuas have been carried out in different areas of Antarctica. Previous studies at Admiralty Bay, an important reproductive area for both birds and mammals on King George Island, off the South Shetland Islands, have focused on the foraging behavior of Brown skua (Carneiro *et al.* 2015), and the comparison of Brown skua and South Polar skua (Trivelpiece & Volkman 1982, Carneiro *et al.* 2010). To date, however, no studies have compared the diets of the two species through systematic monitoring over different breeding seasons, using evidence from both pellets and prey remains. Other seabird populations in this area fluctuate considerably between years (Petry *et al.* 2015), and many of these species represent a substantial component of the diet of the local skuas (Reinhardt *et al.* 2000). These fluctuations in the populations of prey species would be expected to be reflected in the intraspecific and interspecific variation in the skua diets, given the sympatry of the two species in this area.

In the present study, we investigated the diet of South Polar skua and Brown skua at Admiralty Bay, King George Island, through the analysis of pellets and prey remains, collected from the territories of these two birds. We compared the data between the two skua species in each breeding season (2008/2009 and 2010/2011) and also compared seasons in the case of South Polar skua, in order to test the hypothesis that the diets of the two skua species diverge significantly where they occur in sympatry.

MATERIAL AND METHODS

The present study took place at Admiralty Bay (62°05'00"S; 58°23'28"W) on King George Island, part of the South Shetland Archipelago, off the coast of the Antarctic Peninsula. Admiralty Bay is an Antarctic Specially Managed Area (ASMA) which encompasses the breeding grounds of a number of mammals and seabirds (13 bird species breed in this area), diverse marine ecosystems, and terrestrial vegetation habitats (Rakusa-Suszczewski 1980).

The study period encompassed the 2008/2009 and 2010/2011 breeding seasons, which lasted from December to March. During the first breeding season, the study areas were Keller Peninsula and Hennequin Point. In the second breeding season, the Créping Point, Thomas Point, Demay Point, and Vaureal Peak areas were also included in the surveys (Figure 1). The location of each skua territory surveyed during the present was recorded using a handheld GPS receiver (Garmin, GPSMAP® 60CSX). The breeding territories of all the skuas in each study area were surveyed, and, during these surveys, all the pellets encountered were retrieved, placed in plastics bags, and kept frozen until their arrival in Brazil. Each nest (or territory) was investigated once during each study period, and all the pellets and prey remains encountered in each case were registered, collected, and photographed.

Prey remains and pellets were identified based on the dimensions, configuration and/or color of the components, which included wings, legs, beaks, shells, and bones. The pellets were separated out manually and analyzed using a stereoscopic microscope (Olympus SZX9). The material was classified according to its appearance and assigned to one of eight categories: "penguin", "flying bird" and "skua" (vertebrae, bones, bills, feathers, wings, legs and feet), "fish" (vertebrae, bones, scales, otoliths, and jawbones), "gastropod"

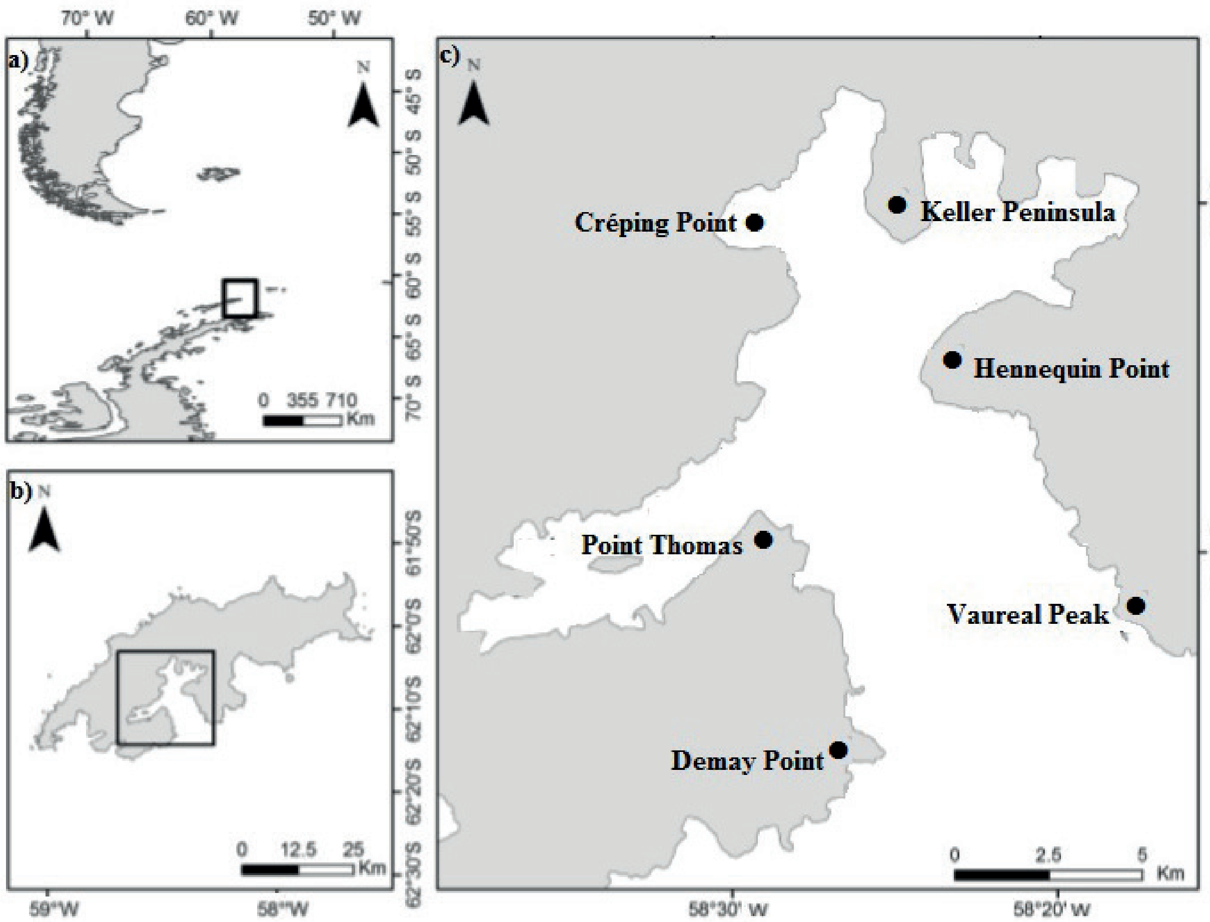

Figure 1. a) Location of King George Island (highlighted) in the South Shetlands Archipelago off the Antarctic Peninsula, and b) Admiralty Bay, within the square on King George Island. c) Survey areas at Admiralty Bay, Demay Point, Point Thomas, Créping Point, Keller Peninsula, Hennequin Point, and Vaureal Peak. Adapted from Petry *et al.* (2015).

(shells), "egg" (fragments of eggshell, and damaged eggs), "krill", and "marine debris". Each item was assigned to one of these categories and identified to the lowest possible taxon, by the authors Ana Olivia Reis and Erli Schneider Costa, based on their previous experience with the local fauna and the guide of Shirihai & Kirwan (2008). We assumed that the damaged eggs found during the fieldwork and those with intact shells, including skua eggs, were laid by the bird whose nest was closest to where the samples were collected. The identification of the egg species was not possible when analyzing pellet samples because eggs invariably appear as minute fragments of shell, which are impossible to identify reliably. We recorded cannibalism only when the species of skua that had been preyed on could be identified, which was only possible when the birds' behavior was observed, but not through the analysis of pellets or prey remains. We were unable to identify the fish items taxonomically because we did not analyze the otoliths. The "marine debris" category comprises any solid or synthetic material of anthropic origin. Although three penguin species of the genus *Pygoscelis* breed in the study area, it was only possible to identify a few of the items to species, so they were classified only as "penguin".

We determined the frequency of occurrence of each category as the number of times that the item appears (n_x) in all samples (N) collected for one of the skua species in a given breeding season (Table 1). We used Jaccard's coefficient (J) to verify the similarity of the composition of the diets between skua species in each breeding season and between the breeding seasons for the South Polar skua. We also performed two-sample binomial z tests to compare the differences in consumption for each food item between skua species and between the breeding seasons for the South Polar skua. These analyses included only the items that were recorded for both species in the same season. We applied the statistical analyses to the most generic categories, that is, "penguin", "flying bird", "egg", "fish", "gastropod", "skua" and "krill". We did not include in these analyses the items identified from behavioral observations, as in the case of cannibalism. Food items that were used by only one species were also not analyzed. "Marine debris" was also not analyzed because this is not considered to be a source of food.

RESULTS

A total of 237 samples, including 184 prey remains (90 from South Polar skua and 94 from Brown skua) and 53 pellets (31 and 22, respectively) were collected in the two breeding seasons and analyzed in the present study. In 2008/2009 (first breeding season), we investigated all the breeding territories of both skua species at Hennequin Point and Keller Peninsula, where 62 samples were collected from the 53 nests found in these two areas (Erli S. Costa, pers. comm.). In 2010/2011 (second breeding season), we collected 175 samples from 154 nests in six reproductive territories (Figure 1).

All the gastropod shells were identified as *Nacella concinna* (Archaeogastropoda, Nacellidae) and the krill were all assigned to the genus *Euphausia* (Euphausiacea, Euphausiidae). We identified three species of flying bird in the samples: Wilson's storm petrel, *Oceanites oceanicus* (Procellariiformes, Hydrobatidae), Antarctic tern, *Sterna vittata* (Charadriiformes, Laridae), and Cape petrel, *Daption capense* (Procellariiformes, Procellariidae), and two species of penguin (Sphenisciformes, Spheniscidae), Adélie penguin (*Pygoscelis adeliae*) and Gentoo penguin (*P. papua*). We recorded unidentified skua species (*Stercorarius* spp.) only in the samples of prey remains, and the predation of two individuals of South Polar skua by behavioral observation. The eggs were assigned to Adélie penguin, Chinstrap penguin (*P. antarctica*), unidentified skua species, Antarctic tern, and Southern giant petrel, *Macronectes giganteus* (Procellariiformes, Procellariidae). A piece of wood and a piece of plastic found in two pellets were classified as "marine debris". In the material collected for Brown skua (Table 1), the item "flying bird" was recorded in 63.6 % of the samples collected in the first breeding season (N = 11) and in 21.9 % of those collected in the second breeding season (N = 105). The item "penguin" was recorded in 54.5 % of the samples collected in the first breeding season, and in 37.1% of those from the second season. The items "gastropod" and "marine debris" were only recorded in the first breeding season, in two samples each (18.1 %), whereas "skua" was only recorded in the second season (3.8 %). The items "fish" and "egg" were both recorded only once in the first breeding

Table 1. Frequency of occurrence (%) of the different food items identified in the diets of Brown skua and South Polar skua in pellets and prey remains collected in two breeding seasons (2008/2009 and 2009/2010) on King George Island, Antarctica.

Food item	Brown skua				South Polar skua			
	2008/2009 (N = 11)		2010/2011 (N = 105)		2008/2009 (N = 52)		2010/2011 (N = 69)	
	N	%	N	%	N	%	N	%
Penguin	**6**	**54.5**	**29**	**37.1**	**25**	**48.0**	**5**	**7.2**
Unidentified	6	54.5	21	20.0	25	48.0	3	4.3
Pygoscelis adeliae, chick	0	0	8	7.6	0	0	0	0
Pygoscelis papua, adult	0	0	0	0	0	0	2	2.8
Flying Bird	**7**	**63.6**	**23**	**21.9**	**21**	**40.3**	**17**	**24.6**
Unidentified	3	27.2	11	10.4	7	13.4	0	0
Oceanites oceanicus	2	18.1	4	3.8	8	15.3	9	13.0
Sterna vittata	2	18.1	0	0	5	9.6	6	8.6
Daption capense	0	0	8	7.6	1	1.9	2	2.8
Skua	**0**	**0**	**4**	**3.8**	**8**	**15.3**	**14**	**20.2**
Stercorarius sp., chick	0	0	4	3.8	8	15.3	12	17.3
Stercorarius maccormicki, adult	0	0	0	0	0	0	2	2.8
Egg	**1**	**9.0**	**56**	**53.3**	**0**	**0**	**6**	**8.6**
Unidentified	1	9.0	1	0.95	0	0	2	2.8
Pygoscelis adeliae	0	0	43	40.9	0	0	0	0
Pygoscelis antarctica	0	0	8	7.6	0	0	0	0
Sterna vittata	0	0	0	0	0	0	3	4.3
Macronectes giganteus	0	0	3	2.8	0	0	0	0
Stercorarius sp.	0	0	1	0.9	0	0	1	1.4
Fish	**1**	**9.0**	**6**	**5.7**	**16**	**30.7**	**20**	**28.9**
Krill	**0**	**0**	**0**	**0**	**1**	**1.9**	**3**	**4.3**
Gastropod	**2**	**18.1**	**0**	**0**	**7**	**13.4**	**4**	**5.7**
Marine debris	**2**	**18.1**	**0**	**0**	**0**	**0**	**0**	**0**

season (9.0 %), with "egg" increasing to 53.3 % in the second season, while "fish" was recorded in 5.7 % of the samples.

In the case of South Polar skua, the item "penguin" was recorded in 48.0 % of the samples collected during the first breeding season (N = 52), but in only 7.2 % of those collected in the second breeding season (N = 69). The item "flying bird" was recorded in 40.3 % of samples in the first breeding season, and in 24.6 % in the second season, while "fish" was recorded in 30.7 % of the samples in the first breeding season and 28.9 % in the second season, and skua in 15.3 % and 20.2 %, respectively. Minor items were "gastropod" (13.4 % in the first season and 5.7 % in the second), "krill" (1.9 % and 4.3 %, respectively), and "egg", all recorded only in the second breeding season, in 8.6 % of the samples collected. In the first breeding season, the contribution of the different items to the diet did not vary between the two skua species (Chi-square with Yates' correction; $\chi^2 = 5.87$, df = 3, $p > 0.05$) although the composition of their diets was significantly different in the second breeding season ($\chi^2 = 53.97$, df = 4, $p < 0.001$). The composition of the diet of South Polar skua also varied between the two breeding seasons sampled ($\chi^2 = 17.3$, df = 3, $p < 0.001$). With the exception of "fish", which varied marginally in the first breeding season ($z = 1.942$, $p = 0.052$), none of the other food items varied significantly ("penguin": $z = 0.375$, $p = 0.707$, "flying birds": $z = 1.392$, $p = 0.164$, "gastropod": $z = 0.360$, p

= 0.719). In the second breeding season, "penguin" (z = 3.778, p < 0.001), "skua" (z = -2.735, p = 0.006), "egg" (z = 7.482, p < 0.001) and "fish" (z = -3.909, p < 0.001) varied between the two skua species and "flying birds" (z = 1.392, p = 0.164) was the only food item with a similar frequency. For the South Polar skua, "penguin" (z = 5.319, p < 0.001) and "flying birds" (z = 2.056, p = 0.040) differed between the two breeding seasons, whereas "skua" (z = -0.294, p = 0.769), "fish" (z = 0.210, p = 0.834), "gastropod" (z = 1.379, p =0.168) and "krill" (z = -0.774, p = 0.439) did not vary statistically. Jaccard's similarity index demonstrated that the composition of the diets of the two skua species was 0.50 in the first breeding season, 0.39 in the second breeding season, and 0.64 for South Polar skua between seasons.

DISCUSSION

In the present study, we found that the diets of Brown and South Polar skuas at Admiralty Bay varied between species and also between years in the latter species. A number of studies have shown that the diets of sympatric skuas differ mainly in the exploitation of marine resources by South Polar skuas, in contrast with the consumption of terrestrial organisms by Brown skuas (Peter *et al.* 1990, Reinhardt *et al.* 2000, Carneiro *et al.* 2010). On Anvers Island, southwest of King George Island off the Antarctic Peninsula, the diets of the two skua species recorded in two different periods were marked by consumption of fish (more than 70 % of the diet) in South Polar skua, in contrast with the Brown skua, which consumed primarily penguin (Pietz 1987). On Potter Peninsula, King George Island, Hahn *et al.* (2008) also found a preference for fish in South Polar skua, which, according to these authors, is one of the seabirds that most consume pelagic fish in the maritime Antarctic. We recorded a similar result in the present study. Our results show that, at Admiralty Bay, South Polar skua consumed more fish than Brown skua in both breeding seasons. This result has not been recorded in all studies of these sympatric skuas, however. At Cierva Point, on the Antarctic Peninsula, for example, Malzof & Quintana (2008) found that fish was the principal item consumed by both skua species, although South Polar skua consumed more of this item than Brown skua. At Deception Island, during one breeding season, Grilli & Montalti (2012) found that penguins were the main food of both skuas, although the second most important items were flying birds for South Polar skua and fish for Brown skua.

By contrast, penguin was one of the principal food items consumed by both skua species in the first breeding season, although in the second breeding season, we found that Brown skua consumed penguins and eggs more frequently than South Polar skua. In Admiralty Bay, Carneiro *et al.* (2010) found that South Polar skua were opportunistic predators of penguins, or scavengers, given that Brown skua monopolizes penguin territories. On Deception Island, Grilli & Montalti (2012) associated high rates of predation of penguin by South Polar skua with differences in the size of the populations of the skua species, because the reduced population of Brown skua in this area would allow South Polar skua to exploit penguin breeding territories more effectively. In the same area as our study, the population of South Polar skua is increasing, while that of Brown skua is decreasing (Costa & Alves, 2008; Carneiro *et al.* 2010), which may explain the greater consumption of penguins by South Polar skua in the first breeding season. Petry *et al.* (2015) also recorded a marked reduction in the penguin populations at Admiralty Bay in the second season of our study, which might account for the differences in the consumption of penguin by the skuas between the two breeding seasons.

Birds, including penguin, were important foods for both skua species in our study. In the case of the flying birds, Wilson's storm petrel, Antarctic tern and Cape petrel were consumed by both skua species, but only Brown Skua consumed Southern giant petrel (egg). Some authors have suggested that skuas tend to prey mainly on the most abundant species (Norman & Ward 1990, Mougeot *et al.* 1998). At Admiralty bay, during the second breeding period of the present study, the abundance of potential bird prey was high (see Petry *et al.* 2015). Considerable fluctuations in these prey populations are known to occur in this region (Petry *et al.* 2015), and they may have influenced the variation in the consumption of bird and penguin by South Polar skua between the two breeding seasons. Although we found a major similarity in the composition of the diet of South Polar skua between the seasons, the proportions of food items (in particular birds) did vary significantly. These findings may also be accounted for by the opportunistic foraging behavior of this species, given that the use of a food resource may be related directly to its availability, as found in a previous study of Brown skuas on the South Orkney Islands (Grilli & Montalti, 2014).

The adults, chicks, and eggs of skuas were also important food items for both skua species in the present study, as observed by Malzof & Quintana (2008), although South Polar skua consumed skua more frequently than Brown skua. Cannibalism has been observed frequently in skuas (see Pietz 1987, Mougeot *et al.* 1998) and is probably common in these birds. It is likely that cannibalism is one of the principal causes of breeding failure in these birds (Young 1963), although we observed cannibalism only in South Polar Skua. Pietz (1987) recorded sibling aggression and cannibalism in South Polar skuas in response to a scarcity of resources. Our observation of cannibalism was recorded during the second breeding season, when there was a significant reduction in the consumption of penguins and flying birds by South Polar skua, which may have made this behavior more likely. Cannibalism has also been linked to food shortages in other seabird species, such as Socotra Cormorant (*Phalacrocorax nigrogularis*) (Gubiani *et al.* 2012) and Long-tailed jaeger (*Stercorarius longicaudus*) (Vooren & Chiaradia1989). Carneiro *et al.* (2010) suggested that, at Admiralty Bay, if breeding pairs of South Polar skua attempt to settle a territory defended by Brown skuas, in the vicinity of a penguin colony, their eggs and chicks may be subject to predation by Brown skua, although further studies are required to confirm this relationship.

In general, considering the two breeding seasons, both skua species consumed similar food items albeit at varying frequencies. Studies of other sympatric seabird species in Antarctica have also found similarities in the composition of their diets (Wilson 2010, Bertolin & Casaux 2019, Dehnhard *et al.* 2019). Dehnhard *et al.* (2019) concluded that the niches of generalist species, even in sympatry, may overlap considerably in areas with an abundant food supply, which is typical of the breeding season of Antarctic animals. Our results showed differences in the proportions of the items in the diets of the two skua species, with the variation observed between seasons possibly being related to the flexibility of these birds in their foraging strategies and exploitation of different resources (Reinhardt *et al.* 2000; Malzof & Quintana 2008; Grilli & Montalti 2014; Borghello *et al.* 2019). These results also confirm the opportunistic foraging behavior of the two study species, as already reported previously (Maxson & Bernstein 1982, Norman & Ward 1990, Baker & Barbraud 2001).

Debris was found only in the pellets of Brown skua and krill were ingested only by South Polar skua. Pietz (1987) recorded krill in the diets of both skuas and, although it is not their principal food, its contribution may be underestimated in pellets, given that these crustaceans are easily digested by birds (Malzof & Quintana 2008). This is only the third record of the ingestion of plastic debris by Brown skua in Antarctica. Grilli & Montalti (2012) found plastic in one Brown skua pellet on Deception Island, while Ibañez *et al.* (2020) recently recorded plastic in 9 % of Brown skua pellets collected on the Antarctic Peninsula, although they were only found in the pellets of breeding birds. Plastic debris is known to be a worldwide phenomenon (Avio *et al.* 2017), but few studies have focused on Antarctica (Gall & Thompson 2015), where the ingestion of plastic by seabirds has been reported in only two other studies, one on South Polar skua on Ross Island (Mund & Miller 1995), and the other on Wilson's storm petrel and Cape petrel on Ardery Island (Van Franeker & Bell 1988). In a study of Great skua (*S. skua*; Charadriiformes, Stercorariidae) on the Faroe Islands in the northern hemisphere, Ryan & Fraser (1988) showed that minute plastic debris in the pellets may be lost to the environment before sample collection, or that they may be eliminated in the feces.

Although pellets may underestimate the amount of plastic ingested by seabirds (Hammer *et al.* 2016), dietary analyses can be a useful tool for the evaluation of marine pollution (Van Franeker *et al.* 2011). Seabirds, such as skuas, are able to regurgitate material that is difficult to digest (Sick 1997), including inorganic debris, which means that these birds can be used as an indicator of environmental quality. Seabirds that are generalists (Caldwell *et al.* 2020), scavengers (Santos *et al.* 2016), and top predators (Ibañez *et al.* 2020) also tend to ingest relatively large amounts of plastic, given that they feed on a wide variety of food items. The ingestion of plastic can have a negative effect on reproduction and the survival of seabirds by provoking physiological problems, and may also expose them indirectly to persistent pollutants (Lavers & Bond 2016), which may pose an even greater risk to these animals. Marine plastic pollution is a global environmental problem (UNEP 2014, Worm *et al.* 2017), and cannot be overlooked in any part of the world, in particular the most remote regions, such as the continent of Antarctica.

Future studies using stable isotopes may be a potential alternative for the conventional dietary studies, by helping to identify more specific differences in the diets of both study species, such as temporal and spatial information in the exploitation of food resources (Dalerum & Angerbjörn 2005). Our results indicate that, although both the sympatric skuas studied here consume similar food items, their diets vary in the proportions of these items, and also confirm their opportunistic feeding behavior. The difference in the diet of South Polar skua between the two breeding seasons indicates the importance of long-term data, particularly where the availability of prey fluctuates considerably between years, as observed in the Antarctic region.

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REFERENCES

Ainley, D. G., Ribic, C. A., & Fraser, W. R. 1992. Does prey preference affect habitat choice in Antarctic seabirds? Marine Ecology Progress Series, 90, 207–221. DOI: 10.3354/meps090207

Avio, C. G., Gorbi, S., & Regoli, F. 2017. Plastics and microplastics in the oceans: from emerging pollutants to emerged threat. Marine Environmental Research, 128, 2–11. DOI: 10.1016/j.marenvres.2016.05.012

Baker, S. C., & Barbraud, C. 2001. Foods of the South Polar skua *Catharacta maccormicki* at Ardery Island, Windmill Islands, Antarctica. Polar Biology, 24, 59–61. DOI: 10.1007/s003000000163

Bertolin, M. L., & Casaux, R. 2019. Diet overlap among top predators at the South Orkney Islands, Antarctica. Polar Biology, 42, 371–383. DOI: 10.1007/s00300-018-2428-9

Borghello, P., Torres, D. S., Montalti, D., & Ibañez, A. E. 2019. Diet of the Brown Skua (*Stercorarius antarcticus lonnbergi*) at Hope Bay, Antarctic Peninsula: differences between breeders and non-breeders. Polar Biology, 42(2), 385–394. DOI: 10.1007/s00300-018-2429-8

Brooke, M. DeL., Keith, D., & Rov, N. 1999. Exploitation of inland breeding Antarctic petrels by South Polar skuas. Oecologia, 121, 25–31. DOI: 10.1007/s004420050903

Caldwell, A., Seavey, J., & Craig, E. 2020. Foraging strategy impacts plastic ingestion risk in seabirds. Limnology and Oceanography Letters, 5(1), 163–168. DOI: 10.1002/lol2.10126

Carneiro, A. P., Manica, A., Trivelpiece, W. Z., & Phillips, R. A. 2015. Flexibility in foraging strategies of brown skuas in response to local and seasonal dietary constraints. Journal of Ornithology, 156, 625–633. DOI: 10.1007/s10336-015-1156-y

Carneiro, A. P. B., Polito, M. J., Sander, M., & Trivelpiece, W. Z. 2010. Abundance and spatial distribution of sympatrically breeding *Catharacta* spp.(skuas) in Admiralty Bay, King George Island, Antarctica. Polar biology, 33(5), 673–682. DOI: 10.1007/s00300-009-0743-x

Carss, D. N., Bevan, R. M., Bonetti, A., Cherubini, G., Davies, J., Doherty, D., El Hili, A., Feltham, M. J., Grade, N., Granadeiro, J. P., Gromadzka, J., Harari, Y. N. R. A., Holden, T., Keller, T., Lariccia, G., Mantovani, R., McCarthy, T. K., Mellin, M., Menke, T., Mirowska-Ibron, I., Muller, W., Musil, P., Nazirides, T., Suter, W., Trauttmansdorff, J. F. G., Volponi, S., & Wilson, B. 1997. Techniques for assessing cormorant diet and food intake:

towards a consensus review. Supplemento alle Ricerche di Biologia della Selvaggina, 26, 197–230. DOI: 10.13140/RG.2.1.5185.2880

Costa, E. S., & Alves, M. A. S. 2007. Biologia reprodutiva e ecologia comportamental de skuas antárticas *Catharacta maccormicki* e *C. lonnbergi*. Oecologia Brasiliensis, 11, 78–94.

Costa, E. S., & Alves, M. A. S. 2008. The breeding birds of Hennequin Point: an ice-free area of Admiralty Bay (Antarctic Specially Managed Area), King George Island, Antarctica. Revista Brasileira de Ornitologia, 16, 137–141.

Costa, E. S., & Alves, M. A. S. 2012. Climatic changes, glacial retraction and the skuas (*Catharacta* sp. Stercorariidae) in Hennequin Point (King George Island, Antarctic Peninsula). Pesquisa Antartica Brasileira, 5, 163–170.

Dalerum, F., & Angerbjörn, A. 2005. Resolving temporal variation in vertebrate diets using naturally occurring stable isotopes. Oecologia, 144(4), 647–658. DOI: 10.1007/s00442-005-0118-0

Dehnhard, N., Achurch, H., Clarke, J., Michel, L. N., Southwell, C., Sumner, M. D., Eens, M., & Emmerson, L. 2019. High inter-and intraspecific niche overlap among three sympatrically breeding, closely related seabird species: Generalist foraging as an adaptation to a highly variable environment? Journal of Animal Ecology, 89(1), 104–119. DOI: 10.1111/1365-2656.13078

Duffy, D. C., & Jackson, S. 1986. Diet studies of seabirds: a review of methods. Colonial Waterbirds, 9, 1–17. DOI: 10.2307/1521138

Gall, S. C., & Thompson, R. C. 2015. The impact of debris on marine life. Marine Pollution Bulletin, 92, 170–179. DOI: 10.1016/j.marpolbul.2014.12.041

González-Solís, J., Oro, D., Pedrocchi, V., Lluis, J., & Ruiz, X. 1997. Bias associated with diet samples in Audouin's gulls. Condor, 99, 773–779. DOI: 10.2307/1370488

Grilli, M. G., & Montalti, D. 2012. Trophic interactions between brown and south polar skuas at Deception Island, Antarctica. Polar Biology, 35, 299–304. DOI: 10.1007/s00300-011-1054-6

Grilli, M. G., & Montalti, D. 2014. Variation in diet composition during the breeding cycle of an Antarctic seabird in relation to its breeding chronology and that of its main food resource. Polar Biology, 38(5), 643–649. DOI: 10.1007/s00300-014-1627-2

Gubiani, R., Benjamin, S., & Muzaffar, S. B. 2012. First record of cannibalism in Socotra Cormorants (*Phalacrocorax nigrogularis*): large, immature birds opportunistically feed on younger conspecifics. Waterbirds, 35, 338–341. DOI: 10.1675/063.035.0215

Hahn, S., Ritz, M.S., & Reinhardt, K. 2008. Marine foraging and annual fish consumption of a south polar skua population in the maritime Antarctic. Polar Biology, 31, 959–969. DOI: 10.1007/s00300-008-0436-x

Hammer, S., Nager, R. G., Johnson, P. C. D., Furness, R. W., & Provencher, J. F. 2016. Plastic debris in great skua (*Stercorarius skua*) pellets corresponds to seabird prey species. Marine Pollution Bulletin, 103, 206–210. DOI: 10.1016/j.marpolbul.2015.12.018

Hobson, K. A. 1987. Use of stable-carbon isotope analysis to estimate marine and terrestrial protein content in gull diets. Canadian Journal of Zoology, 65(5), 1210–1213. DOI: 10.1139/z87-187

Hobson, K. A. 1995. Reconstructing avian diets using stable carbon and nitrogen isotope analysis of egg components: Patterns of isotopic fractionation and turnover. Condor, 97, 752–762. DOI: 10.2307/1369183

Ibañez, A. E., Morales, L. M., Torres, D. S., Borghello, P., Haidr, N. S., & Montalti, D. 2020. Plastic ingestion risk is related to the anthropogenic activity and breeding stage in an Antarctic top predator seabird species. Marine Pollution Bulletin, 157, 111351. DOI: 10.1016/j.marpolbul.2020.111351

Lavers, J. L., & Bond, A. L. (2016). Ingested plastic as a route for trace metals in Laysan Albatross (*Phoebastria immutabilis*) and Bonin Petrel (*Pterodroma hypoleuca*) from Midway Atoll. Marine Pollution Bulletin, 110(1), 493–500. DOI: 10.1016/j.marpolbul.2016.06.001

MacArthur, R., & Levins, R. (1967). The limiting similarity, convergence, and divergence of coexisting species. The American Naturalist, 101(921), 377–385. DOI: 10.1086/282505

Malzof, S. L., & Quintana, R. D. 2008. Diet of the south polar skua and the

Brown Skua at Cierva Point, Antarctic Peninsula. Polar Biology, 31, 827–835. DOI: 10.1007/s00300-008-0421-4

Mancini, P. L., & Bugoni, L. 2014. Resources partitioning by seabirds and their relationship with other consumers at and around a small tropical archipelago. ICES Journal of Marine Science, 71(9), 2599–2607. DOI: 10.1093/icesjms/fsu105

Maxson, S. J., & Bernstein, N. P. 1982. Kleptorparasitism by south polar skuas on blue-eyed shags in Antarctica. Wilson Bulletin, 94, 269–281.

Moller-Schwarze, D., & Moller-Schwarze, C. 1973. Differential predation by South Polar Skuas in an Adelie Penguin rookery. Condor, 75, 127–131.

Moncorps, S., Chapuis, J. L., Haubreux, D., & Bretagnolle, V. 1998. Diet of the brown skua (*Catharacta lonnbergi*) on the Kerguelen archipelago: comparisons between techniques and between islands. Polar Biology, 19, 9–16. DOI: 10.1007/s003000050210

Mougeot, F., Genevois, F., & Bretagnolle, V. 1998. Predation on burrowing petrels by the brown skua (*Catharacta skua lönnbergi*) at Mayes Island, Kerguelen. Journal of Zoology, 244(3), 429–438. DOI: 10.1111/j.1469-7998.1998.tb00047.x

Mund, M. J., & Miller, G. D. 1995. Diet of the south polar skua *Catharacta maccormicki* at Cape Bird, Ross Island, Antarctica. Polar Biology, 15, 453–455. DOI: 10.1007/BF00239723

Norman, F. I., & Ward, S. J. 1990. Foods of the South Polar skua at Hop Island, Rauer Group, East Antarctica. Polar Biology, 10, 489–493. DOI: 10.1007/s003000000163

Parmelee, D. F. 1988. The hybrid skua – a southern ocean enigma. Wilson Bulletin, 100, 345–356.

Peter, H-U., Kaiser, M., & Gebauer, A. 1990. Ecological and morphological investigations on South Polar Skuas (*Catharacta maccormicki*) and Brown Skuas (*Catharacta skua lonnbergi*) on Fildes Peninsula, King George Island, South Shetland Islands. Zoologische Jahrbuecher Abteilung fuer Systematik Oekologie und Geographie der Tiere, 117, 201–218.

Petry, M. V., Valls, F. C. L., de Souza Petersen, E., Krüger, L., da Cruz Piuco, R., & dos Santos, C. R. 2015. Breeding sites and population of seabirds on Admiralty Bay, King George Island, Antarctica. Polar Biology, 39, 1343–1349. DOI: 10.1007/s00300-015-1846-1

Pfenninger, M., & Nowak, C. 2008. Reproductive isolation and ecological niche partition among larvae of the morphologically cryptic sister species *Chironomus riparius* and *C. piger*. PLoS One, 3(5), e2157. DOI: 10.1371/journal.pone.0002157

Phillips, R. A., Phalan, B., & Forster, I. P. 2004. Diet and long-term changes in population size and productivity of brown skuas (*Catharacta antarctica lonnbergi*) at Bird Island, South Georgia. Polar Biology, 27, 555–561. DOI: 10.1007/s00300-004-0633-1

Pietz, P. J. 1987. Feeding and nesting ecology of sympatric South Polar and Brown Skuas. Auk, 104, 617–627. DOI: 10.1093/auk/104.4.617

Quillfeldt, P., McGill, R. A., & Furness, R. W. 2005. Diet and foraging areas of Southern Ocean seabirds and their prey inferred from stable isotopes: review and case study of Wilson's storm-petrel. Marine Ecology Progress Series, 295, 295–304. DOI: 10.3354/meps295295

Rakusa-Suszczewski, S. 1980. Environmental conditions and the functioning of Admiralty Bay (South Shetland Islands) as a part of the near shore Antarctic ecosystem. Polish Polar Ressearch, 1, 11–27.

Reinhardt, K., Hahn, S., Peter, H-U., & Wemhoff, H. 2000. A review of the diets of Southern Hemisphere skuas. Marine Ornithology, 28, 7–19.

Ritz, M. S., Hahn, S., Janicke, T., & Peter, H-U. 2005. Hybridization between South polar skua (*Catharacta maccormicki*) and Brown skua (*C. antarctica lonnbergi*) in the Antarctic Peninsula region. Polar Biology, 29, 153–159. DOI: 10.1007/s00300-005-0034-0

Robertson, G. S., Bolton, M., Grecian, W. J., Wilson, L. J., Davies, W. & Monaghan, P. 2014. Resource partitioning in three congeneric sympatrically breeding seabirds: Foraging areas and prey utilization. The Auk: Ornithological Advances, 131(3), 434–446. DOI: 10.1642/AUK-13-243.1

Ryan, P. G., & Fraser, M. W. 1988. The use of great skua pellets as indicators of plastic pollution in seabirds. Emu, 88, 16–19.

Santos, R. G., Andrades, R., Fardim, L. M., & Martins, A. S. 2016. Marine debris ingestion and Thayer's law–The importance of plastic color. Environmental Pollution, 214, 585–588. DOI: 10.1016/j.envpol.2016.04.024

Shirihai, H., & Kirwan, G. M. 2008. Complete guide to Antarctic wildlife. Princeton: Princeton University Press.

Sick, H. 1997. Ornitologia Brasileira. Rio de Janeiro: Editora Nova Fronteira: p.58.

Trillmich, E. 1978. Feeding territories and breeding success of South Polar Skuas. Auk, 95, 23–33. DOI: 10.2307/4085492

Trivelpiece, W., & Volkman, N. J. 1982. Feeding strategies of sympatric South Polar *Catharacta maccormicki* and Brown Skuas *C. lönnbergi*. Ibis, 124 (1), 50–54. DOI: 10.1111/j.1474-919X.1982.tb03740.x

UNEP. 2014. Plastic debris in the ocean. In: UNEP Year Book 2014 Emerging Issues Update. pp. 49–53. Nairobi:United Nations Environment Programme.

Van Franeker, J. A., & Bell, P. J. 1988. Plastic ingestion by petrels breeding in Antarctica. Marine Pollution Bulletin, 19(12), 672–674. DOI: 10.1016/0025-326X(88)90388-8

Van Franeker, J. A., Blaize, C., Danielsen, J., Fairclough, K., Gollan, J., Guse, N., Hansen, P. L., Heubeck, M., Jensen, J. K., Le Guillou, G., Olsen, B., Olsen, K. O., Pedersen, J., Stienen, E. W. M., & Turner, D. M. 2011. Monitoring plastic ingestion by the northern fulmar *Fulmarus glacialis* in the North Sea. Environmental Pollution, 159, 2609–2615. DOI: 10.1016/j.envpol.2011.06.008

Vooren, C. M., & Chiaradia, A. 1989. *Stercorarius longicaudus* and *S. parasiticus* in Southern Brazil. Ardea, 77, 233–235.

Votier, S. C., Bearhop, S., Ratcliffe, N., & Furness, R. W. 2001. Pellets as indicators of diet in great skuas *Catharacta skua*. Bird Study, 48, 373–376. DOI: 10.1080/00063650109461237

Votier, S. C., Bearhop, S., Maccormick, A., Ratcliffe, N., Furness, R. W. 2003. Assessing the diet of great skuas, *Catharacta skua*, using five different techniques. Polar Biology, 26, 20–26. DOI: 10.1007/s00300-002-0446-z

Wilson, R. P. 2010. Resource partitioning and niche hyper-volume overlap in free-living Pygoscelid penguins. Functional Ecology, 24, 646– 657. DOI: 10.1111/j.1365-2435.2009.01654.x

Worm, B., Lotze, H. K., Jubinville, I., Wilcox, C., & Jambeck, J. 2017. Plastic as a persistent marine pollutant. Annual Review of Environment and Resources, 42, 1–26. DOI: 10.1146/annurev-environ-102016-060700

Young, E. C. 1963. The breeding behaviour of the South Polar skua *Catharacta maccormicki*. Ibis, 105, 203–233. DOI: 10.1111/j.1474-919X.1963.tb02496.x

Young, H. S., McCauley, D. J., Dirzo, R., Dunbar, R. B., & Shaffer, S. A. 2010. Niche partitioning among and within sympatric tropical seabirds revealed by stable isotope analysis. Marine Ecology Progress Series, 416, 285–294. DOI: 10.3354/meps08756

Zipan, W., & Norman, F. I. 1993. Foods of the south polar skua *Catharacta maccormicki* in the eastern Larsemann Hills, Princess Elizabeth Land, East Antarctica. Polar Biology, 13, 255–262. DOI: 10.1007/BF00238761

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