Fish prey of sub-Antarctic fur seals *Arctocephalus tropicalis* at the Tristan da Cunha Islands, South Atlantic Ocean

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Abstract

Some top predator populations in the South Atlantic and South Indian oceans are in decline, presumably contingent upon reduced food availability, precipitated by climate change. This phenomenon impacts on the positions of major ocean frontal zones which are hypothesised to act as natural dispersal borders for fish in the Southern Ocean. We investigate this hypothesis by establishing the vertebrate diet of sub-Antarctic fur seals, *Arctocephalus tropicalis,* at Tristan da Cunha Island (37°15′S 12°25′W) and Gough Island (40°19'S, 9°57'W), South Atlantic Ocean. The diet of these island populations, located on either side of the Subtropical Convergence, are compared with published dietary information from populations further south on islands located within the Polar Frontal Zone. To this end fur seal scats were collected and analysed for remains of hard parts from prey in 2012-2013. The myctophid fish *Gymnoscopelus piabilis, Protomyctophum tenisoni* and *Symbolophorus barnardi* predominated in the diet. *Lampichthys gemellarii, Myctophum aurolaternatum, S. barnardi* and the *Diaphus* genus are recorded for the first time in the diet of *A. tropicalis*. Sub-Antarctic fur seal populations clustered around the Subtropical Convergence (~41º40’S), compared with those in the Polar Frontal Zone (~47º25’ to

~50º47’), showed a considerable difference in the myctophid fish prey taken. The latitudinal differences in the fish diet of sub-Antarctic fur seals support suggestions that major frontal zones act as natural dispersal borders for fish in the Southern Ocean.

Key words: *A. tropicalis,* climate change, diet, myctophid fish, frontal zones, foraging range

Introduction

The Southern Ocean is undergoing substantial changes associated with anthropogenically driven climate change (Turner et al. 2014). Southern Ocean ecosystems are under pressure from resource exploitation and climate change, and information on the foraging behaviour of marine predators is needed to identify regions that should be considered for protection (Hindell et al. 2020; Requena et al. 2020). Sub-Antarctic fur seal populations (Hofmeyr et al. 2016) primarily occur at the Tristan da Cunha Islands (South Atlantic Ocean) and at Amsterdam and Saint Paul Islands (South Indian Ocean) which are clustered around the Subtropical Convergence (Deacon 1982; Beauplet et al. 2004; Requena et al. 2020), and the Prince Edward Islands and Îles Crozet (South Indian Ocean), together with Macquarie Island (South Pacific Ocean), which are located within the Polar Frontal Zone, bound by the Subantarctic Front to the north and the Antarctic Polar Front to the south (Koubbi 1993; Moore et al. 1999; Ansorge and Lutjeharms 2007).

The Tristan da Cunha (TdC) islands (Fig. 1A) are home to more than 63% of the global population of sub-Antarctic fur seals (Hofmeyr et al. 2016). The overwhelming majority breeds on Gough Island (Bester et al. 2006), the southernmost and most isolated island in the archipelago at 40°19'S, 9°57'W (Fig. 1B). Much smaller numbers of seals breed at the three northern islands, centered on 37°04'S, 12°18'W (Fig. 1B): Tristan da Cunha (TdC), Inaccessible and Nightingale islands (Bester et al. 2019). The northern islands of the Tristan da Cunha group and the southernmost Gough Island (GI) belong to different oceanographic systems (Requena et al. 2020), separated by the Subtropical Convergence Front. The northern islands lie in the warm temperate realm of the South Central Atlantic Gyre, whereas GI is in the Subtropical Convergence Zone, with colder water all year round (Requena et al. 2020).

Nothing is known about the fish diet of sub-Antarctic fur seals at the TdC islands, with the exception of an earlier study based on stomach samples, which were skewed towards hard to digest prey items retained in stomachs. Cephalopods therefore appeared to dominate the diet, but the fur seals also took bony fish (Bester and Laycock 1985). Opportunistic and pelagic foragers, sub-Antarctic fur seals are known to feed on a variety of myctophid and notothenid fish, cephalopods, and small numbers of crustaceans throughout their range (Hofmeyr et al. 2016). They also kill and feed on northern rockhopper penguins *Eudyptes moseleyi* at Amsterdam Island (Paulian 1964; Tollu 1974) and the TdC northern islands (Bester et al. 2020), and perhaps at GI (Ryan and Kerr 2012).

This study aims to (a) provide preliminary information on the fish diet of sub-Antarctic fur seals from scats collected at the TdC islands, including GI, and (b) using published accounts, comment on the latitudinal variation in the diet of the species. Relatively small sample sizes, spread over two years and various seasons (see methods and results below), prevented us from exploring any detailed spatio-temporal variation in prey taken, and by inference, preferred foraging areas. Here we simply list the species of fish prey taken by the sub-Antarctic fur seals from TdC and GI for comparison, as well as with other conspecific populations, in a latitudinal context.

Methods

Hard parts from prey found in scat samples of marine predators are the best possible approach to study diet in a non-invasive and relatively easy way, despite the biases (Dellinger and Trillmich 1988; Arim and Naya 2003; Casper et al. 2004).

Scats were collected opportunistically (2012-2013) from two southeast coast beaches (Tumbledown and Seal beaches) on GI, as well as from the only colony of sub-Antarctic fur seals on TdC at Seal Bay on the south coast. Scat collections were broadly assigned to seasons that were delineated based on the seasonal cycle of the fur seals; 1) breeding and pupping season in late spring-early summer (October to January), 2) post-breeding moult and lactation in late summer-mid autumn (February to May), and 3) late lactation in winter (June to September) following Bester (1981), Kerley (1983), Bester and Bartlett (1990) and Luque et al. (2007).

Of all scats collected, only those scats containing fish prey hard parts (sagittal otoliths) were included for comparison. Otoliths too eroded to be identified were excluded from analyses. Scats were individually processed (see Makhado et al. 2013) and the percentage frequency of occurrence (%FO) of fish hard parts was expressed as the number of times each species appeared within all scats containing otoliths, while percentage numerical abundance (%NA) was the number of otoliths of each fish species present in all scats.

A seasonal comparison of prey species taken (this study) and the calculation of the percentage mass of prey species (see Makhado et al. 2013) was not possible due to the small sample sizes, and the strong bias against large prey (Arim and Naya 2003) which may be taken seasonally. Such a change in diet from small to large prey is associated with a large increment in the incidence of empty scats in pinnipeds (Naya et al. 2002), which therefore introduces a bias against larger prey species occurring in scats. Also, less than the minimum number (n = 94) of scats were collected which would allow existing differences (over time and between areas) to be statistically detected, nor the minimum number (n = 59) of scats necessary to identify principal prey remains occurring in >5% of scats (Trites and Joy 2005). Although the latter do not represent a general rule for all pinniped dietary studies, it was decided to do a basic comparison of prey taken by sub-Antarctic fur seals at TdC island and GI. The most important prey was nominally identified as those with %NA > 10.0% following Reisinger et al. (2018).

Results

A total of 49 scats were collected at TdC in late spring-early summer and winter, while 34 scats were collected at GI in late spring-early summer, late summer-mid autumn and in winter. Of the 49 scats collected from TdC, 10 contained no otoliths, and of the 34 scats collected from GI, 19 contained no otoliths. A total of 749 and 493 identifiable otoliths were removed from scats collected at TdC and GI respectively during the whole study period (Table 1). These were identified to species (n = 13) and to genera only (n = 4), with a further six unknown genera appearing in the scat samples.

Three species predominated namely *G. piabilis, P. tenisoni* and *S. barnardi*. *Symbolophorus* sp. mostly occurring in scats from GI (Table 1). *Symbolophorus barnardi* were found in 46.7% and 43.6% of the scats containing otoliths at GI and TdC respectively (Table 1). *Gymnoscopelus piabilis* (31.2%) and *P. tenisoni* (39.1%) showed the highest %NA in fur seal scats from TdC, *G. piabilis* being also abundant at GI (41.0%) (Table 1).

Of the minor prey species in this study, *Diaphus* sp., *Gymnoscopelus bolini*, *Lampichthys procerus*, *Metelectrona ventralis*, *Myctophum aurolaternatum*, *Scopelosaurus ahlstromi* and *Symbolophorus boops* only occurred in scats from GI, whereas *G. fraseri*, *L. gemellarii* and *Protomyctophum* sp. only were only present in scats from TdC. *Electrona carlsbergi* and *G. nicholsi* featured at both GI and TdC.

Discussion

The lanternfish *Symbolophorus barnardi*, *Lampichthys gemellarii*, *Myctophum aurolaternatum* and the *Diaphus* genus (Myctophidae) consumed by sub-Antarctic fur seals from TdC and GI (Table 1) has not previously been recorded in their diet anywhere The closely related *L. procerus* are taken in small numbers at GI, Amsterdam Island (Beauplet et al. 2004) and at Marion Island (de Bruyn et al. 2009; Reisinger et al. 2018) while *M. phengodes* was one of four major prey species of sub-Antarctic fur seals at Amsterdam Island (Beauplet et al. 2004). The *Symbolophorus* genus has previously been recorded in diets of sub-Antarctic fur seals at Amsterdam Island, although not identified to species level (Beauplet et al. 2004). Very few *S. boops* were recorded at GI, and elsewhere only in small numbers from Marion Island (Reisinger et al. 2018). Many *Symbolophorus* sp. otoliths were, however, severely digested or broken, making their identification challenging. Hence the species *S. boops* and *S. barnardi* might have had a much larger contribution to the diet of the fur seals at GI.

Eight of the myctophid species, *G. bolini*, *G. fraseri*, *L. gemellarii*, *L. procerus*, *M. ventralis, M. aurolaternatum*, *S. ahlstromi* and *S. boops*, were present exclusively at either TdC or GI. This is likely an artefact of the small sample sizes and seasonal effects. These islands are situated only 380 km apart, a distance regularly covered by SAFS at Amsterdam and Marion islands (Beauplet et al. 2004; de Bruyn et al. 2009) and at the TdC islands (MNB unpubl. data). Furthermore, the foraging ranges of the TdC and GI fur seal populations overlap (Requena et al. 2020; MNB, unpubl. data).

Considering only the prey species that could be identified to species level, although many could not, the most important prey of sub-Antarctic fur seals at both GI and TdC combined, nominally identified as those with %NA > 10.0%, was *G. piabilis* (35.9%), followed by *P. tenisoni* (27.86%) and finally *S. barnardi* (10.79%). This is in contrast to Amsterdam Island where *Symbolophorus* sp. (22.6% compared to 25.35% for all *Symbolophorus* spp. combined at GI), outstripped three other major species (Beauplet et al. 2004). None of the aforementioned three major species occurred in scats on the TdC islands, nor at any other sub-Antarctic island in the Southern Ocean (e.g., Robinson et al. 2002; Luque et al. 2007; Makhado et al. 2013; Reisinger et al. 2018).

Similar to the present study, *G. piabilis* was, on average, the most important prey (24.49% to 26.2%) at Marion Island in some years (Makhado et al. 2006; Reisinger et al. 2018), and second only to *G. fraseri* (both species > 25%) at Îles Crozet (Luque et al. 2007). The second most important species *P. tenisoni* (this study), occasionally featured strongly at Marion Island (17.0%, Reisinger et al. 2018). Other minor species (≤ 10% NA) taken at TdC islands (Table 1) such as *G. fraseri* invariably were present in seal scats from Marion Island at between 11.21-16.9% (Klages and Bester 1998; Makhado et al. 2013; Reisinger et al. 2018), and as high as 33.13% in some winters (de Bruyn et al. 2009). *Gymnoscopelus nicholsi* and *Electrona carlsbergi* may be important (between 10.0% and 22.0%) at Marion Island in some years (de Bruyn et al. 2009; Reisinger et al. 2018), while *G. bolini* may outstrip (~28%) all of the abovementioned species in other years (de Bruyn et al. 2009). The staple diet of sub-Antarctic fur seals at Macquarie Island, *E. subaspera* at 94.0% NA (Robinson et al. 2002), is also found at Marion Island usually in small numbers (Klages and Bester 1998; de Bruyn et al. 2009; Makhado et al. 2013; Reisinger et al.

2018) but has not been recorded at the TdC islands (this study) and Amsterdam Island (Beauplet et al. 2004).

Clearly, geographical position of island breeding colony sites has an impact on the diet of sub-Antarctic fur seals in the Southern Ocean. *Metelectrona ventralis,* for example, is distributed from 36˚S to 51˚S latitude (Smale et al. 1995) and taken by SAFS at both temperate (this study) and sub-Antarctic islands (e.g. Klages & Bester 1998; Luque et al. 2007). On the other hand, the most species rich myctophid genus, *Diaphus*, include pseudoceanic warm-water species as well as cool temperate, oceanic species, which are generally found north of 38ºS off South Africa (Prosch et al. 1989; Hulley and Lutjeharms 1995). *Myctophum aurolaternatum* frequents the warm Agulhas current and *Lampichthys gemellarii* are found in tropical and subtropical waters off the southern African coast (Smale et al. 1995). *Lampichthys procerus* is found in the region of, or slightly to the north of the Subtropical Convergence (Hulley 1981). *Scopelosaurus ahlstromi* too is found in tropical and subtropical waters circum-globally while *Symbolophorus barnardi* is a subtropical species (Hulley 1981). *Symbolophorus* sp., found in the diet of SAFS at Amsterdam Island (Beauplet et al. 2004) and the TdC islands, do not appear at more southerly islands due to its distribution not extending beyond ~30˚S (Smale et al. 1995).

The Subtropical Convergence acts as a northern border for many myctophid distributions (Smale et al. 1995). TdC, GI and Amsterdam Island are all closely associated with the Subtropical Convergence (Beauplet et al. 2004; Requena et al. 2020) and it is therefore expected that diets of sub-Antarctic fur seals would be more similar at these localities. With the exception of *S. boops*, a semi-subantarctic species that is known to occur in colder waters south of the Subtropical Convergence and north of the Subantarctic Front (Hulley 1981), the abovementioned warm-water and cool-temperate species are not found at sub-Antarctic islands. Therefore, major frontal zones such as the Subantarctic Front possibly act as natural dispersal borders for fish in the Southern Ocean (Andrew et al. 1995; Smale et al. 1995; this study).

Studies of the diet of top predators that act as sentinel species which can indicate an ecosystem response to changing environmental conditions (Hazen et al. 2019), need to factor in their foraging range. *Scopelosaurus* sp., predominantly warm temperate ocean species, were unexpectedly also identified as prey of sub-Antarctic fur seals at Marion Island (Reisinger et al. 2018) and Île de la Possession, Îles Crozet (Luque et al. 2007), in particular, which lie well south of the Subtropical Convergence. *Scopelosaurus ahlstromi* specifically are only found north of the Subtropical Convergence (Smale et al. 1995) but appeared in scats at Marion Island (Reisinger et al. 2018). This would result from the foraging range of sub-Antarctic fur seals from GI (Requena et al. 2020) and Marion Island (de Bruyn et al. 2009; Wege et al. 2019) that includes areas to the north of the Subtropical Convergence. Small-scale foraging areas of sub-Antarctic fur seals from Marion Island during winter were even located to the north of 38^{o}S latitude (Wege et al. 2019).

Conclusions

In general, the sub-Antarctic fur seal populations of the TdC islands, clustered around the Subtropical Convergence, show diets broadly similar to the more southern populations at Îles Crozet, Macquarie Island and Marion Island which all lie within the Polar Frontal Zone. The myctophids *Gymnoscopelus*, *Electrona* and *Protomyctophum* are found in scats collected at all islands with breeding populations of sub-Antarctic fur seals, affirming the importance of myctophids in the diet of sub-Antarctic fur seals. The differences that exist relates to the taxonomical composition of myctophid fish at the species level. The different fish prey species distribution, as well as their presence in the diet of sub-Antarctic fur seals would indicate a higher dependency on the latitudinal rather than on the longitudinal position of the islands (Andrew et al. 1995; Robinson et al. 2002; this study).

Climate change and the continual southward movement of the Antarctic Polar Frontal Zone (Deacon 1982; Ansorge et al. 1999), could have consequences for foraging strategies of top predators in the Southern Ocean. Climate change here includes a robust warming at the sub-Antarctic and mid-latitude islands, most pronounced in austral summer (Richard et al. 2012). Populations at different islands are expected to have different response times to change depending on their proximity to the changing fronts. Colonies of sub-Antarctic fur seals at islands associated with the Subtropical Convergence could possibly reveal the effects of warming waters and southward movements of prey earlier than those island populations further south. This is consistent with observed or forecasted declines in abundance of other top predators in the Southern Ocean at the northern extent of their distributional ranges (e.g., Cristofari et al. 2018; Weimerskirch et al. 2018; Jones et al. 2020) likely attributed to distributional range shifts as a response to rapid climate change by these species. Studying various predator populations throughout the Southern Ocean will give a more accurate representation of diet composition and dependence of predators on particular prey species, as it focuses on a broader ecological scale.

Author Contributions

MNB and PJNdB conceived and designed research, MNB wrote the manuscript, modelled on a chapter in the M.Sc. dissertation of LJS. MNB and PJNdB conducted field work, and supervised LJS who analysed data. TG provided logistic support and permitted the research. All authors read and approved the manuscript.

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Compliance with ethical standards

Conflict of interest: The authors declare that they have no conflict of interests.

Ethical approval: Field procedures were approved by the TdC Conservation Department and the Animal Ethics Committee of the University of Pretoria.

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Table 1: Number of fish prey species otoliths (Num), the percentage frequency of occurrence (%FO) and percentage numerical abundance (%NA) of each prey species collected in scats from Gough Island (n = 15) and Tristan da Cunha (n = 39) in 2012-2013. Numbers in brackets are the number of scats in which otoliths of each species were found. The most prevalent prey species in the diet, nominally identified as those with %NA > 10.0% following Reisinger et al. (2018), at one island (*), and at both islands (**), are indicated.

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Prey Species	Gough Island			Tristan da Cunha		
	Num	%FO	%NA	Num	%FO	%NA
Diaphus sp.	5 (1)	6.67	1.01	0 (0)	0.0	0.0
Electrona carlsbergi	49 (6)	40.00	9.94	3 (3)	7.69	0.40
Gymnoscopelus bolini	3 (1)	6.67	0.61	0 (0)	0.0	0.0
Gymnoscopelus fraseri	0 (0)	0.0	0.0	2 (2)	5.13	0.27
Gymnoscopelus nicholsi	9 (3)	20.0	1.83	55 (7)	17.95	7.34
*Gymnoscopelus piabilis***	202 (12)	80.0	40.97	234 (8)	20.51	31.24
Gymnoscopelus sp.	1 (1)	6.67	0.20	31 (6)	15.38	4.14
Lampichthys gemellarii	0 (0)	0.0	0.0	3 (1)	2.56	0.40
Lampichthys procerus	1 (1)	6.67	0.20	0 (0)	0.0	0.0
Metelectrona ventralis	36 (9)	60.0	7.30	0 (0)	0.0	0.0
Myctophum aurolaternatum	3 (1)	6.67	0.61	0 (0)	0.0	0.0
Protomyctophum sp.	0 (0)	0.0	0.0	3 (3)	7.69	0.40
*Protomyctophum tenisoni***	53 (10)	66.67	10.75	293 (8)	20.51	39.12
Scopelosaurus ahlstromi	3 (3)	20.0	0.61	0 (0)	0.0	0.0
*Symbolophorus barnardi***	65 (7)	46.67	13.18	69 (17)	43.59	9.21
Symbolophorus boops	6 (2)	13.33	1.22	0 (0)	0.0	0.0
Symbolophorus sp.*	54 (4)	26.67	10.95	4 (1)	2.56	0.53
Unidentified spp.	3 (1)	6.67	0.61	52 (25)	64.10	6.94
Total	493			749		

Fig. 1 A Position of the TdC islands in the South Atlantic Ocean. **B** The positions of the four constituent islands of the TdC. The approximate position of the Subtropical Front is indicated on both maps.

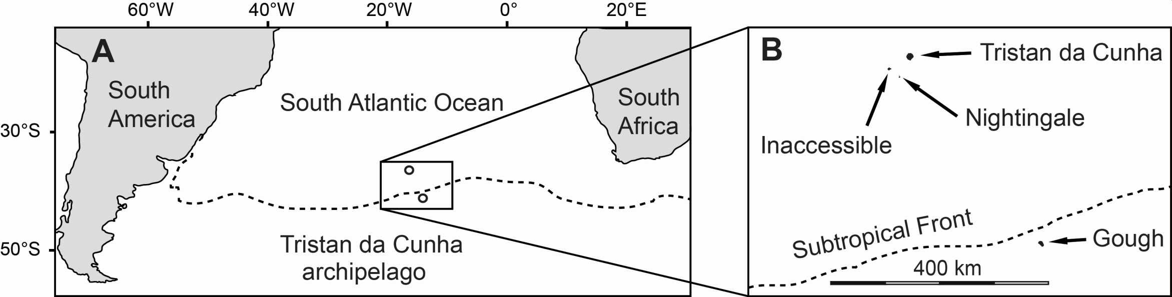
60°W
40°W
20°W
0°
20°E
30°S
50°S
A
South America
South Atlantic Ocean
South Africa
Tristan da Cunha archipelago
B
Tristan da Cunha
Inaccessible
Nightingale
Subtropical Front
Gough
400 km

Table 1: Number of fish prey species otoliths (Num), the percentage frequency of occurrence (%FO) and percentage numerical abundance (%NA) of each prey species collected in scats from Gough Island (n = 15) and Tristan da Cunha (n = 39) in 2012-2013. Numbers in brackets are the number of scats in which otoliths of each species were found. The most prevalent prey species in the diet, nominally identified as those with %NA > 10.0% following Reisinger et al. (2018), at one island (*), and at both islands (**), are indicated.

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Prey Species	Gough Island			Tristan da Cunha		
	Num	%FO	%NA	Num	%FO	%NA
Diaphus sp.	5 (1)	6.67	1.01	0 (0)	0.0	0.0
Electrona carlsbergi	49 (6)	40.00	9.94	3 (3)	7.69	0.40
Gymnoscopelus bolini	3 (1)	6.67	0.61	0 (0)	0.0	0.0
Gymnoscopelus fraseri	0 (0)	0.0	0.0	2 (2)	5.13	0.27
Gymnoscopelus nicholsi	9 (3)	20.0	1.83	55 (7)	17.95	7.34
*Gymnoscopelus piabilis***	202 (12)	80.0	40.97	234 (8)	20.51	31.24
Gymnoscopelus sp.	1 (1)	6.67	0.20	31 (6)	15.38	4.14
Lampichthys gemellarii	0 (0)	0.0	0.0	3 (1)	2.56	0.40
Lampichthys procerus	1 (1)	6.67	0.20	0 (0)	0.0	0.0
Metelectrona ventralis	36 (9)	60.0	7.30	0 (0)	0.0	0.0
Myctophum aurolaternatum	3 (1)	6.67	0.61	0 (0)	0.0	0.0
Protomyctophum sp.	0 (0)	0.0	0.0	3 (3)	7.69	0.40
*Protomyctophum tenisoni***	53 (10)	66.67	10.75	293 (8)	20.51	39.12
Scopelosaurus ahlstromi	3 (3)	20.0	0.61	0 (0)	0.0	0.0
*Symbolophorus barnardi***	65 (7)	46.67	13.18	69 (17)	43.59	9.21
Symbolophorus boops	6 (2)	13.33	1.22	0 (0)	0.0	0.0
Symbolophorus sp.*	54 (4)	26.67	10.95	4 (1)	2.56	0.53
Unidentified spp.	3 (1)	6.67	0.61	52 (25)	64.10	6.94
Total	493			749		