DIET OF BLACK-BROWED *THALASSARCHE MELANOPHRYS* AND ATLANTIC YELLOW-NOSED *T. CHLORORHYNCHOS* ALBATROSSES AND WHITE-CHINNED *PROCELLARIA AEQUINOCTIALIS* AND SPECTACLED *P. CONSPICILLATA* PETRELS OFF SOUTHERN BRAZIL

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SUMMARY

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The diet of the Black-browed Albatross *Thalassarche melanophrys,* Atlantic Yellow-nosed Albatross *T. chlororhynchos,* White-chinned Petrel *Procellaria aequinoctialis* and Spectacled Petrel *P. conspicillata* were studied by analyzing the contents of digestive tracts of birds found washed ashore or incidentally caught by pelagic longline fisheries off southern Brazil between 1994 and 2004. Cephalopod beaks, fish otoliths and eye lenses were dominant in the digestive tracts of birds. About 90% of the food items of petrels were in the gizzard and were mainly cephalopod beaks, which are resistant to digestion. Among anthropogenic items ingested, plastics were the most frequent and most numerous. Cephalopods predominated in the diet of White-chinned and Spectacled Petrels, mainly squid from the family Histioteuthidae. Fish had greater importance in the diet of both albatross species. Demersal fish occurred in the diet of albatrosses and the White-chinned Petrel. Coastal fish distributed over the continental shelf were found in a higher number and diversity in beached birds than in birds killed in longline fisheries. Cephalopods predominated in both number and diversity in the diet of longline-caught birds, mainly sub-Antarctic and subtropical species. Approximately 40% of this diet was composed of fish and cephalopods that were probably discarded from fisheries, evidence of a strong interaction between these birds and fisheries in southern Brazil.

Key words: Diet, Procellariiformes, albatrosses, petrels, cephalopods, fish, Brazil

INTRODUCTION

In the Southern Hemisphere, albatrosses and petrels (Procellariiformes) are among the most diverse and abundant seabirds (Harrison 1985; Warham 1990, 1996). They play an important role as top predators in pelagic marine ecosystems (Prince & Morgan 1987). Only two species of procellariiforms breed in Brazil: the Trindade Petrel *Pterodroma arminjoniana* [Trindade Island (Olmos *et al.* 2001)] and Audubon's Shearwater *Puffinus lherminieri* [islands off the state of Espírito Santo and the Fernando de Noronha Archipelago (Sick 1997, Soto & Filippini 2003)]. Imber (2004) also suggested breeding by the Kermadec Petrel *Pt. neglecta* on Trindade Island. However, the waters off southern and southeastern Brazil are important feeding grounds for many species of procellariiforms (Neves 2000).

Approximately 30 species of procellariiforms breed on sub-Antarctic islands and along the Antarctic coast of the Atlantic Ocean, 18 of which occur regularly in Brazilian waters (Vooren & Brusque 1999). The Black-browed Albatross *Thalassarche melanophrys* and White-chinned Petrel *Procellaria aequinoctialis* use southern Brazilian waters as a wintering area, whereas the Atlantic Yellow-nosed Albatross *T. chlororhynchos* and Spectacled Petrel *Pt. conspicillata* occur throughout the year (Neves 2000).

Black-browed Albatrosses and White-chinned Petrels have a circumpolar distribution in the Southern Ocean, breeding at many sub-Antarctic islands, such as South Georgia and the Falklands/Malvinas in the Atlantic Ocean (Harrison 1985, Croxall & Gales 1998). The Atlantic Yellow-nosed Albatross breeds only in the Tristan da Cunha group (including Gough Island) in the southern Atlantic (Harrison 1985). The sole breeding site of the Spectacled Petrel is Inaccessible Island in the Tristan da Cunha group (Ryan & Moloney 2000). These four species are among the seabirds most often caught incidentally in longline fisheries off southern Brazil (Neves & Olmos 1997, Olmos *et al.* 2001).

Human activities have influenced the feeding behaviour and survival of albatrosses and petrels. Many oceanic birds feed off fishery discards or steal bait from hooks in longline fisheries (Prince & Morgan 1987). These interactions also occur in Brazilian waters (e.g. Vooren & Fernandes 1989, Vaske 1991). Whereas such interactions represent an easy source of food for seabirds, they also make the birds vulnerable to incidental bycatch. The decline of a number of seabird populations in the Southern Hemisphere, especially albatrosses and petrels, has been attributed to a high level of bycatch in longline fisheries (e.g. Brothers 1991, Neves & Olmos 1997).

Most studies on the diet of Procellariiformes have been conducted in breeding colonies where these birds are more accessible (e.g. Prince & Morgan 1987, Cherel & Klages 1997). Information on the diet of albatrosses and petrels during the non-breeding period on important feeding grounds such as southern Brazil may help to determine and reinforce the use of measures for mitigating bycatch in longline fisheries. The present study describes and quantifies the diet of Black-browed and Atlantic Yellow-nosed Albatrosses and White-chinned and Spectacled Petrels caught incidentally in longline fisheries or found washed ashore in southern Brazil.

METHODS

We performed a diet analysis on 126 specimens (56 Black-browed Albatrosses, 27 Atlantic Yellow-nosed Albatrosses, 36 White-chinned Petrels and seven Spectacled Petrels) collected between 1994 and 2004. Of the 126 specimens, 57 were incidentally caught in nine commercial pelagic longline fishing cruises off southern Brazil (28–33°S, 36–54°W), 18 were obtained from four scientific cruises operating with pelagic longlines on the Rio Grande do Sul slope (27–34°S, 47–51°W) and the remaining 51 specimens were found washed ashore on the Rio Grande do Sul coast (29–33°S) (Fig. 1).

We extracted digestive tracts from the connection between the proventriculus and the esophagus to the cloaca. The largest proventriculus and ventriculus lengths were recorded for well-preserved specimens. All items found in the proventriculus, ventriculus and intestine were collected from each specimen. Perishable contents were fixed in 10% formalin and preserved in 70% ethanol. Cephalopod beaks were preserved in a 1:1 solution of 70% ethanol and glycerin (Santos 1999). Fish otoliths and anthropogenic debris were cleaned and preserved dry. The following definitions were adopted:

- Food item—any food remains identified to the lowest taxon
- Prey—individual organisms ingested by the bird
- Food remains—a prey, or part thereof, found in the digestive tract
- Food contents—the set of food remains found in the digestive tract
- Debris—any anthropogenic object

Food items (whole fish, otoliths, scales, teeth and hypural bones) were identified following Figueiredo & Menezes (1978, 1980), Pinedo (1982), Corrêa & Vianna (1992) and Naves (1999). Cephalopod beaks were identified following Clarke (1986), Santos & Haimovici (1998) and Santos (1999). Systematic collections of the Fundação Universidade Federal do Rio Grande were consulted to assist in species identification. The number of fish prey in each specimen was determined by the maximum number of entire prey, hypural bones or the number of pairs of otoliths or eye lenses. The number of cephalopod prey was determined from the maximum number of either upper or lower beaks of each species or the number of pairs of eye lenses.

Otoliths and cephalopod beaks were measured microscopically with an ocular micrometer. Only sagitta otoliths were considered. For each otolith, the length and an index of digestion (ID) were recorded. Measurements of otoliths [ID of 0 meaning no sign of wear or digestion; ID of 1 meaning slightly worn otolith edges, but sulcus acusticus still well defined (Bugoni & Vooren 2004)] were used in the regression to calculate the total length (TL) and body mass (M) of the fish. The upper (URL) and lower (LRL) rostral lengths of squids and upper (UHL) and lower (LHL) hood lengths of cephalopod beaks were used in regression equations to estimate the mantle length (ML) and body mass (M) of squids and octopuses respectively. Only non-fragmented cephalopods beaks were considered. Appendix 1 gives the equations used to estimate the body or mantle length and mass of each fish and cephalopod prey. The body mass of fish with no measurable otoliths and cephalopods with no measurable beaks were determined as the mean body mass of the lowest corresponding taxon, estimated after pooling all samples from the same predator species. The same procedure was adopted when the regression equation was not available for a given prey.

These parameters were calculated for each food item found in the food contents of each bird species:

- Frequency of occurrence (FO) in the contents (i.e. number of contents with occurrence of the food type)
- Relative frequency of occurrence (FO%) (i.e. FO as a percentage of the total number of contents examined
- Number of prey (N) counted in the polled sample of contents
- Numerical proportion (N%) in the diet (i.e. N as a percentage of the total number of prey of all food types in the polled sample)
- Total mass (M) of all prey in the polled sample
- Mass proportion of each prey (M%) relative to all food items in the polled sample
- The Index of Relative Importance (IRI) described by Pinkas *et al.* (1971), with volumetric modification, where IRI = (Nr% + M%) FO% (Castley *et al.* 1991)

The Mann–Whitney nonparametric test for independent samples (StatSoft 1996) at a significance level of 0.05 was applied to test differences among the mean number of fish, cephalopods and anthropogenic objects in the contents of beached birds and birds caught by longline fisheries.

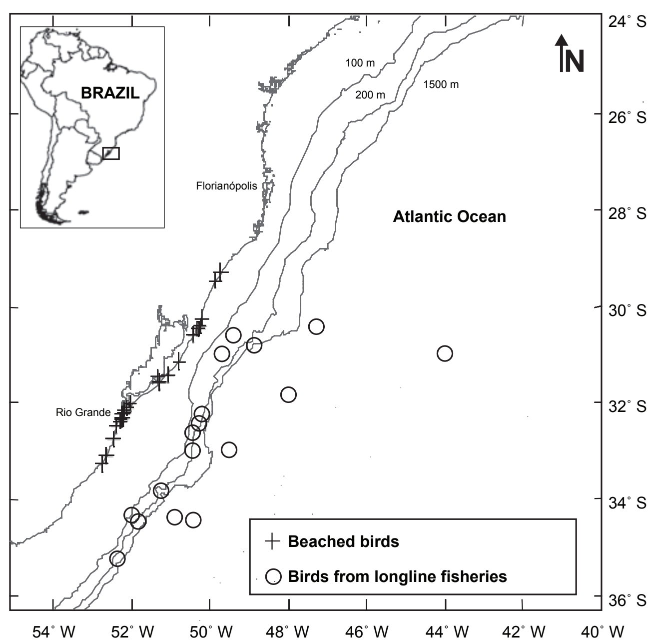

Fig 1. Sampling locations of beached birds on the Rio Grande do Sul coast and of birds incidentally caught by pelagic longline fisheries in Brazilian waters.

RESULTS

Most of the Black-browed Albatrosses in the sample were juveniles; most of the Atlantic Yellow-nosed Albatrosses were adults. All Black-browed Albatrosses caught by longline fisheries and 55% of the beached birds were juveniles. Adult Atlantic Yellow-nosed Albatrosses represented 94% of specimens caught by longline fisheries and 75% of beached birds.

The proportion of birds with food contents in their digestive tracts varied between species and by the origin of the sample. Food remains were found in the digestive tract of 83% of Atlantic Yellow-nosed Albatrosses and 75% of White-chinned Petrels washed ashore. All individuals of both species that were incidentally caught in longline fisheries contained food remains. In contrast, in Black-browed Albatrosses, food remains were found in 83% of beached and in 77% of incidentally caught birds.

TABLE 1
Contents of the proventriculus (P) and ventriculus (V) of 45 Black-browed Albatrosses *Thalassarche melanophrys*, 26 Atlantic Yellow-nosed Albatrosses *T. chlororhynchos*, 32 White-chinned Petrels *Procellaria aequinoctialis* and seven Spectacled Petrels *P. conspicillata* from southern Brazil

Object types	*T. melanophrys*		*T. chlororhynchos*		*P. aequinoctialis*		*P. conspicillata*	
	P	V	P	V	P	V	P	V
Fish								
Sagitta otoliths	24	31	7	13	4	30	—	6
Asteriscus otoliths	1	—	—	—	—	—	—	—
Eye lenses	39	67	4	9	1	64	—	—
Teeth	6	—	1	—	2	—	—	—
Hypural bones	3	—	—	—	—	—	1	—
Other teleost bones	23	6	22	—	12	2	2	—
Flesh	6	1	5	—	—	—	—	—
Entire teleosts	1	—	—	—	3	—	—	—
Shark skin	1	1	—	—	—	—	—	—
Cephalopods								
Cephalopod beak	22	57	6	42	25	877	22	178
Eye lenses	10	10	3	19	—	85	—	7
Flesh	4	—	1	—	2	—	2	—
Entire cephalopods	1	—	1	—	1	—	—	—
Birds								
Ramphotheca	1	—	—	—	—	—	—	—
Feet	1	—	—	—	—	—	—	—
Feathers	3	—	1	—	—	—	—	—
Crustaceans								
Exoskeletons	—	1	—	—	—	—	—	—
Total food objects	146	174	51	83	50	1058	27	191
Anthropogenic items								
Plastic fragments	—	—	—	—	—	17	—	1
Plastic pellets	—	—	—	—	—	16	—	1
Monofilament lines	—	—	—	1	—	16	1	—
Plastic packing	100	28	1	—	1	47	—	—
Styrofoam	—	12	—	—	—	—	—	—
Hooks	1	—	—	—	—	—	—	—
Cord	—	—	—	—	—	3	—	—
Total anthropogenic items	101	40	1	1	1	99	1	2
Stones	—	—	—	—	—	25	—	2
TOTALS	247	214	52	84	51	1182	28	195

The main food contents for the four species were fish otoliths, cephalopod beaks and eye lenses. The ventriculus contained most of the food items found in the digestive tract of White-chinned (95%) and Spectacled (88%) Petrels. For Black-browed and Atlantic yellow-nosed Albatrosses the proportions were 54% and 62% respectively (Table 1). The mean number of food items found in the ventriculus was 32.0 for petrels and 3.6 for albatrosses, probably because of the large numbers of cephalopod beaks in petrels,

TABLE 2
Stomach contents of Black-browed Albatrosses *Thalassarche melanophrys* found dead on the shore (n = 25) and caught by longlines (n = 20) in southern Brazil

Food type	Frequency of occurrence (%)	Number (n) %	Mass (g) %	IRI
All teleosts	67	60	65	8339
Sciaenidae				
Micropogonias furnieri	2	1	2	8
Paralonchurus brasiliensis	11	4	1	51
Macrodon ancylodon	2	1	< 1	2
Cynoscion guatucupa	2	2	3	11
Pogonias cromis	2	1	< 1	2
Unidentified Sciaenidae	4	3	2	23
All Sciaenidae	22	12	8	443
Batrachoididae				
Porichthys porosissimus	4	1	2	13
Triglidae				
Prionotus punctatus	4	2	1	12
Engraulidae				
Lycengraulis grossidens	2	1	<1	2
Pomatomidae				
Pomatomus saltatrix	7	3	7	66
Mugilidae				
Mugil spp.	4	1	< 1	7
Phycidae				
Urophycis brasiliensis	2	1	2	7
Trichiuridae				
Trichiurus lepturus	2	1	2	6
Ariidae				
Unidentified Ariidae	2	1	1	3
Unidentified teleost	47	39	42	3782
All cephalopods	56	38	35	4020
Teuthida				
Unidentified Teuthida	9	6	5	99
Ommastrephidae				
Illex argentinus [a]	2	1	<1	2
Unidentified *Ommastrephidae*	7	2	2	27
All Ommastrephidae	9	3	1	39
Gonatidae				
Gonatus spp.	7	3	3	37
Histioteuthidae				
Histioteuthis sp. A	16	9	6	236
Histioteuthis sp. B	4	2	4	29
Histioteuthis spp.	9	3	6	79
All Histioteuthidae	22	14	15	657
Loliginidae				
Loligo sanpaulensis	7	3	<1	20
Ancistrocheiridae				
Ancistrocheirus lesueurii	2	1	1	4
All Teuthida	42	30	25	2331
Octopoda				
Octopodidae				
Octopus vulgaris	2	1	1	4
Alloposidae				
Haliphron atlanticus	2	1	1	4
Ocythoidae				
Ocythoe tuberculata	2	1	1	4
All Octopoda	7	2	4	37
Unidentified cephalopods	7	5	5	69
Elasmobranchii				
Unidentified Elasmobranchii	4	1	—	6
Crustaceans				
Unidentified Decapoda	2	1	—	1
Birds				
Sternidae				
Sterna spp.	2	1	—	1
TOTALS		162 prey	25786.9g	

[a] Used as bait in longline fisheries (Neves & Olmos 1997), and in this study occurred only in the diet of birds incidentally caught by longline fisheries.
IRI = index of relative importance.

representing 93% of food items in the White-chinned and 83% in the Spectacled. Stones were found only in petrels.

Most food items found in the ventriculus of the two petrel species were in an advanced stage of digestion. Of otoliths, 44% were too digested (ID 2 and 3) and, of cephalopod beaks, most were fragmented to small pieces so that they could not be used for species identification. In albatrosses, especially Black-browed Albatrosses from longline fisheries, the main fish remains were flesh, eye lenses, vertebrae and other bones. Otoliths were found in the intestines of albatrosses (eight Black-browed Albatrosses, FO = 2%; 15 Atlantic Yellow-nosed Albatrosses, FO = 7%). Only one cephalopod beak was found in the intestine of an Atlantic Yellow-nosed Albatross.

TABLE 3
Stomach contents of Atlantic Yellow-nosed Albatrosses *T. chlororhynchos* (n = 5) found dead on the shore and 21 specimens caught by longlines in southern Brazil

Food type	Frequency of occurrence (%)	Number (n) %	Mass (g) %	IRI
All teleosts	58	53	37	5218
Sciaenidae				
Micropogonias furnieri	4	4	5	41
Umbrina canosai	2	1	1	5
Unidentified Sciaenidae	4	20	8	112
All Sciaenidae	7	25	14	273
Batrachoididae				
Porichthys porosissimus	7	4	8	79
Macrouridae				
Malacocephalus occidentalis	2	2	1	8
Unidentified teleost	22	22	14	792
All cephalopods	38	46	63	4085
Teuthida				
Unidentified Teuthida	4	4	5	39
Ommastrephidae				
Illex argentinus	11	6	7	149
Ornithoteuthis sp.	4	1	2	11
Unidentified *Ommastrephidae*	11	9	11	214
All Ommastrephidae	20	16	20	711
Gonatidae				
Gonatus spp.	2	1	1	5
Histioteuthidae				
Histioteuthis sp. A	4	7	7	63
Histioteuthis sp. B	4	2	4	30
Histioteuthis spp.	13	9	20	377
All Histioteuthidae	20	19	30	980
Loliginidae				
Unidentified Loliginidae	2	1	2	6
All Teuthida	36	42	58	3538
Unidentified cephalopods	7	4	5	59
Elasmobranchii				
Unidentified Elasmobranchii	2	1	—	3
TOTALS		80 prey	5149.8g	

The ventriculus was relatively larger in petrels than in albatrosses. In albatrosses, the mean length was 24.7 mm (range: 20.1–26.7 mm) and represented about 17% of the proventriculus length. In petrels, the mean length of the ventriculus was 28.6 mm (26.9–30.2 mm) and represented *c.* 30% of the proventriculus length.

The specific composition of ingested food

Black-browed Albatross
Twenty-seven food items were found in the diet of the Black-browed Albatross. Fish represented 65% of the total prey mass (Table 2), with a greater importance in beached birds (73%) than in longline-caught birds (59%). Demersal fish, such as the Whitemouth Croaker *Micropogonias furnieri*, Banded Croaker *Paralonchurus brasiliensis,* King Weakfish *Macrodon ancylodon,* Bluewing Searobin *Prionotus punctatus,* Brazilian Codling *Urophycis brasiliensis* and Atlantic Midshipman *Porichthys porosissimus,* constituted 29% of the total number of fish in beached birds and 5% in longline-caught birds. This difference was statistically significant ($\chi^2 = 10.9$, $p = 0.0009$).

Histioteuthidae occurred in diet of both samples and represented the highest FO% and N% among the cephalopods (Table 2). The Sao Paulo Squid *Loligo sanpaulensis,* Sharpear Enope Squid *Ancistrocheirus lesueurii* and Octopoda *Octopus vulgaris, Haliphron atlanticus* and *Ocythoe tuberculata* occurred only in the diets of beached birds. Differences in the mean number of fish and cephalopods between beached and longline-caught birds were nonsignificant (fish: $U = 216.5$, $p = 0.3$; cephalopods: $U = 207.5$, $p = 0.2$).

The mean estimated total length (TL) and body mass of fish ingested by Black-browed Albatrosses were 246 mm and 164.7 g. One 959.6 mm Largehead Hairtail *Trichiurus lepturus* was possibly an exception. The mean estimated mantle length and body mass of ingested cephalopods were 94.9 mm and 149.1 g (Table 6).

Remains of a juvenile tern *Sterna* sp. were found in a beached Black-browed Albatross (Colabuono *et al.* 2007).

Atlantic Yellow-nosed Albatross
Eleven food items (six fish and five cephalopods) were identified in the diet of the Atlantic Yellow-nosed Albatross. Fish represented 53% of the total number of prey and occurred in 58% of stomachs (Table 3).

The only prey found in beached birds were fish, but cephalopods predominated in the diet of birds caught by longlines, representing 73% of the total mass, the highest FO (81%) and the highest number (51%). Demersal fish, mainly Sciaenidae, were present in both samples. We observed no significant difference in the mean number of fish found in the digestive tract of beached and longline-caught birds ($U = 43.5$, $p = 0.2$). Among the cephalopods, Histioteuthidae represented 19% of the prey and occurred only in birds caught by longline fisheries. The mean estimated total length and body mass of ingested fish were 200.6 mm and 90.8 g. The mantle length of cephalopods varied from 35.3 mm to 157.3 mm (mean: 81.6 mm). The estimated body mass of cephalopods averaged 89.9 g (Table 6).

White-chinned Petrel

Fourteen food items were identified in the diet of White-chinned Petrel specimens. Cephalopods had the highest frequency of occurrence (91%), number (92%), mass (90%) and IRI. Cephalopods predominated in the diet of both beached and incidentally caught birds, and represented squid from the families Ommastrephidae, Histioteuthidae, Chiroteuthidae, and Ocythoidae (Table 4). Demersal fish accounted for 23% of the total number of fish found in the diet of longline-caught birds. In contrast, only one demersal fish species, Atlantic Midshipman, was identified from the food contents of beached birds, representing 8.3% of all fish. The mean number of cephalopods was significantly higher in longline-caught birds than in beached birds ($U = 27$, $p = 0.00002$). No significant differences were found in the mean number of fish between the two samples ($U = 130$, $p = 0.3$).

The estimated mean total length and body mass of fish ingested by White-chinned Petrels were 162.5 mm and 62.5 g. The estimated mean mantle length and body mass of ingested cephalopods were 69 mm and 107.4 g (Table 7).

Spectacled Petrel

A total of 121 food items (five fish and 116 cephalopods) were found in the diet of seven longline-caught Spectacled Petrels. The cephalopods included Histioteuthidae (*Histioteuthis* sp. B and *Histioteuthis* spp.), Ommastrephidae, and Octopoteuthidae (*Octopoteuthis* sp.). The Histioteuthidae occurred in higher numbers (Table 5). The estimated mean mantle length and body mass of cephalopods were 83.8 mm and 121 g (Table 7).

Anthropogenic objects

Hooks, pieces of cord and plastics were found in the digestive tracts of the birds. Plastics were separated into five categories:

- Plastic fragments (small, hard pieces of larger manufactured objects)
- Plastic pellets (raw products of the plastics industry)
- Monofilament line
- Foam plastics (e.g. Styrofoam)
- Pieces of plastic bags

In the entire sample, plastics represented 84% of total debris and occurred in 90% of birds that ingested anthropogenic objects. Plastic pellets were found only in the ventriculus of petrels. Anthropogenic objects occurred in 14% of Black-browed Albatrosses and in 55% of White-chinned Petrels. In both species, an average of three anthropogenic objects per food content was found. A lower occurrence of anthropogenic objects was observed in Atlantic Yellow-nosed Albatrosses (11%) and Spectacled Petrels (28%), with a mean number of 0.04 and 0.08 anthropogenic objects per content respectively. In petrels, 99% of these objects occurred in the ventriculus; in albatrosses, objects were found mostly in the proventriculus (Table 1).

Anthropogenic objects occurred in 27% of beached birds and 24% of longline-caught birds. The difference between the mean number of anthropogenic objects found in the digestive tracts of beached and incidentally caught birds was nonsignificant ($U = 105.0$; $p = 0.8$). A piece of a plastic bag was the only anthropogenic object found in the intestine (in a Black-browed Albatross).

TABLE 4

Composition of food contents of White-chinned Petrels *Procellaria aequinoctialis* found dead on the shore (n = 12) and caught by longlines (n = 20) in southern Brazil

Food type	Frequency of occurrence (%)	Number (n) %	Mass (g) %	IRI
All teleosts	41	8	10	760
Sciaenidae				
Micropogonias furnieri	6	1	<1	12
Cynoscion guatucupa	3	<1	<1	1
All Sciaenidae	6	1	1	10
Batrachoididae				
Porichthys porosissimus	3	<1	1	3
Engraulidae				
Unidentified *Engraulidae*	3	<1	<1	1
Atherinopsidae				
Atherinella brasiliensis	3	<1	<1	1
Gempylidae				
Thyrsitops lepidopoides	3	<1	<1	2
Scombridae				
Scomber japonicus [a]	3	<1	<1	1
Trichiuridae				
Trichiurus lepturus	6	<1	<1	4
Unidentified teleost	34	6	8	465
All cephalopods	91	92	90	16 429
Teuthida				
Unidentified Teuthida	81	35	30	5 265
Ommastrephidae				
Illex argentinus	3	<1	<1	1
Unidentified *Ommastrephidae*	16	3	3	91
Histioteuthidae				
Histioteuthis sp. A	6	<1	1	6
Histioteuthis sp. B	6	<1	1	10
Histioteuthis spp.	6	<1	4	29
All Histioteuthidae	38	6	6	456
Chiroteuthidae				
Chiroteuthis sp.	3	<1	<1	1
All Teuthida	91	44	41	7 735
Octopoda				
Ocythoidae				
Ocythoe tuberculata	3	<1	<1	1
All Octopoda	3	<1	<1	1
Unidentified cephalopods	84	48	48	8 064
TOTALS		604 prey	42 902.3g	

[a] Used as bait in longline fisheries (Vaske & Castello 1998), and in this study occurred only in the diet of birds incidentally caught by longline fisheries.

DISCUSSION

An absence of food items was observed in 13% of the birds analyzed, suggesting that these birds had not fed for some time. Otoliths are digested in approximately 24–48 h in the digestive tracts of procellariiforms; cephalopod beaks can remain in the ventriculus for weeks (Furness *et al.* 1984). No difference in the percentages of digestive tracts without food was found between beached and longline-caught birds. It is thus not possible to correlate the cause of death with absence of food in the digestive tract. During the guard stage of the breeding season, procellariiforms can go for days without feeding (Warham 1990), but in the non-breeding period, absence of food in the digestive tract could be related to the low availability of prey in the environment. This low prey availability can consequently make seabirds more vulnerable to being caught by longline fisheries.

Juvenile and adult albatrosses of both species were found dead on the beach, which confirms that individuals at varying maturity stages occur in proximity to the southern Brazilian coast. Juvenile Black-browed Albatrosses and adult Atlantic Yellow-nosed Albatrosses predominated among longline-caught birds. This pattern may be related to a relatively higher abundance of the respective maturity stages of these species in longline fishing grounds. During the non-breeding period, adult Black-browed Albatrosses feed in other areas, whereas juveniles feed off the Brazilian coast. For this reason, immature individuals are more vulnerable to incidental catches in longline fisheries in this area (Neves 2000). In one year of surveying tuna-fishing vessels operating off southeastern and southern Brazil, 97% of Black-browed Albatrosses caught were immature birds (Neves & Olmos 1997). In contrast (also to our findings), Neves (2000) found that 89% of Atlantic Yellow-nosed Albatrosses incidentally caught off southern and southeastern Brazil were immature.

TABLE 5
Stomach contents of Spectacled Petrels *Procellaria conspicillata* (n = 7) caught by longlines off southern Brazil

Food type	Frequency of occurrence (%)	Number (n) %	Mass (g) %	IRI
All teleosts	29	4	6	297
Unidentified teleosts	29	4	6	297
All cephalopods	86	96	94	16 240
Teuthida				
Unidentified Teuthida	86	26	24	4 242
Ommastrephidae				
Unidentified *Ommastrephidae*	14	8	9	243
Histioteuthidae				
Histioteuthis sp. B	14	< 1	1	31
Histioteuthis spp.	57	3	3	360
All Histioteuthidae	71	4	4	300
Octopoteuthidae				
Octopoteuthis spp.	14	< 1	4	99
All Teuthida	71	38	35	5 183
Unidentified cephalopods	86	57	58	9 864
TOTALS		121 prey	7 059.8g	

Characteristics of food contents

Food contents found in all four bird species consisted mainly of hard structures resistant to digestion, such as cephalopod beaks, otoliths and eye lenses. Cephalopod beaks accumulated in higher numbers than otoliths did because of the beaks' greater resistance to digestion (Furness *et al.* 1984, Jackson & Ryan 1986).

In the two albatross species (as compared with the two petrel species), the ventriculus is small in relation to the proventriculus. The morphology of the digestive tract of albatrosses is an intermediate stage between Charadriiformes, Pelecaniformes and Sphenisciformes (in which the proventriculus and ventriculus are united into a single compartment) and most petrels, which show evident constriction between the two compartments (Ryan 1988). Cephalopod beaks and otoliths were very fragmented in the ventriculus of petrels, but these structures were found intact in the ventriculus of albatrosses. The function of the ventriculus is to retain undigested items and break them down to fragments small enough to be eliminated through the cloaca. Albatrosses eliminate these objects through regurgitation, but the presence of whole cephalopod beaks and otoliths in the intestine indicates that, in large birds, these structures probably can also be eliminated through the cloaca. In petrels, these structures are retained in the ventriculus longer, where they are fragmented before passing through the intestine. Stones and some anthropogenic debris (small plastic fragments and pellets) found in the ventriculus of petrels can help in fragmenting less digestible items.

Diet composition

The diets of the four procellariiform species studied consisted mainly of cephalopods and fish. Cephalopods predominated in petrel diet; fish showed greater importance in the albatrosses' diet. In South Georgia, fish are the main prey of the Black-browed Albatross (Prince 1980, Reid 1996, Cherel & Klages 1997). Black-browed Albatrosses breeding in Chile feed mostly on fish [69%–89% of mass for all prey consumed, with discards from fisheries predominating (Arata & Xavier 2003)]. In the Kerguelen Islands, the proportion of cephalopods and fish in the diet of the Black-browed Albatrosses was similar, but fish predominated, with 84% of mass, in the diet of the Indian Yellow-nosed Albatross *Thalassarche carteri* (Cherel *et al.* 2002). In contrast to the findings of the present study, fish predominated in the diet of White-chinned Petrels in the Benguela region, South Africa (Jackson 1988). Gonatidae, Histioteuthidae and Chiroteuthidae squid were the main prey found in the diet of White-chinned Petrels off New Zealand (Imber 1976). This finding suggests that within a species, the main diet can vary from cephalopods to fish depending on local prey availability.

Fish

The main fish species found in the diets of the two albatross species and the White-chinned Petrel are abundant on the southern Brazil continental shelf (Haimovici *et al.* 1996). Bluewing Searobin, Striped Weakfish *Cynoscion guatucupa,* Argentine Croaker *Umbrina canosai,* King Weakfish, Brazilian Codling, Banded Croaker, Whitemouth Croaker, Largehead Hairtail and Atlantic Midshipman are species often discarded by trawl fisheries in southern Brazil either because they are of low commercial value or because of their small size (Ruffino & Castello 1993, Haimovici *et al.* 1996, Haimovici & Mendonça 1996). These demersal (and some pelagic) fish would be available to the birds after being discarded and left floating at the sea surface.

Most fish found in the food contents of the birds were juveniles or too small for sale and constituted most of trawl fishery discards (Haimovici *et al.* 1996). For example, specimens of Bluewing Searobin and Brazilian Codling smaller than 200 mm long are discarded by commercial fisheries (Haimovici & Mendonça 1996). The mean total length of Whitemouth Croaker, a commercially important demersal fish found in the diet of the White-chinned Petrel, was 116 mm. The size this fish attains at sexual maturity is 180–200 mm (Ruffino & Castello 1993). A similar pattern was observed for Banded Croaker in the diet of the Black-browed Albatross and Argentine Croaker in the diet of the Atlantic Yellow-nosed Albatross.

The occurrence of the Chub Mackerel *Scomber japonicus* and White Snake Mackerel *Thyrsitops lepidopoides* in the diet of the White-chinned Petrel is evidence of interactions between these birds and pelagic fisheries. Chub Mackerel is used as bait in commercial pelagic longline fisheries off southern Brazil (Vaske & Castello 1998), and White Snake Mackerel is a subtropical species caught by oceanic commercial fishing operations (Nakamura & Parin 1993). The Western Softhead Grenadier *Malacocephalus occidentalis* (Macrouridae) appeared only once in the diet of the Atlantic Yellow-nosed Albatross; nevertheless, it is normally found

TABLE 6
Total length (TL), mantle length (ML) and mass of fish and cephalopods from Black-browed *Thalassarche melanophrys* and Atlantic Yellow-nosed *T. cholororhynchos* Albatrosses off southern Brazil

Prey	*Thalassarche melanophrys*							*Thalassarche chlororhynchos*						
	TL/ML (mm)			Mass (g)			Items	ML/TL (mm)			Mass (g)			Items
	Mean	Min.	Max.	Mean	Min.	Max.	(n)	Mean	Min.	Max.	Mean	Min.	Max.	(n)
All fish	246.0	75.0	959.6	164.7	8.4	758.2	26	200.6	77.2	316.7	90.8	4.3	338.8	9
Micropogonias furnieri	279.8	252.0	307.6	278.4	189.2	367.6	2	181.0	118.5	267.0	94.7	15.3	229.3	3
Umbrina canosai	—	—	—	—	—	—	—	154.5	—	—	50.2	—	—	1
Paralonchurus brasiliensis	159.0	107.0	194.0	43.6	8.4	73.0	5	—	—	—	—	—	—	—
Macrodon ancylodon	201.4	—	—	66.0	—	—	1	—	—	—	—	—	—	—
Cynoscion guatucupa	246.1	196.5	279.3	168.6	76.8	240.3	4	—	—	—	—	—	—	—
Pogonias cromis	75.0	—	—	9.0	—	—	1	—	—	—	—	—	—	—
Porichthys porosissimus	275.7	—	—	220.5	—	—	1	195.3	77.2	316.7	138.3	4.3	338.8	3
Prionotus punctatus	183.9	163.0	204.7	68.7	43.8	92.2	2	—	—	—	—	—	—	—
Lycengraulis grossidens	139.8	—	—	17.0	—	—	1	—	—	—	—	—	—	—
Pomatomus saltatrix	245.0	126.5	431.9	245.3	20.9	758.2	4	—	—	—	—	—	—	—
Mugil spp.	287.2	166.3	393.4	261.1	48.2	493.7	3	—	—	—	—	—	—	—
Urophycis brasiliensis	198.1	—	—	57.1	—	—	1	—	—	—	—	—	—	—
Trichiurus lepturus	959.6	—	—	564.2	—	—	1	—	—	—	—	—	—	—
Malacocephalus occidentalis	—	—	—	—	—	—	—	261.2	247.5	274.8	34.1	27.7	40.6	2
All cephalopods	94.9	17.3	252.4	149.1	2.0	306.0	35	81.6	35.3	157.3	89.9	29.7	295.7	18
Illex argentinus	192.6	171.4	213.8	141.2	97.0	185.4	2	157.3	—	—	75.5	—	—	1
Histioteuthis sp. A	77.7	58.1	188.8	158.2	62.3	306.0	12	50.5	35.3	55.2	57.3	29.7	86.4	6
Histioteuthis sp. B	91.5	58.1	140.5	203.4	72.3	428.3	4	52.4	43.7	60.9	61.2	43.2	79.2	2
Histioteuthis spp.	69.4	69.4	89.3	107.9	53.8	167.9	4	75.9	35.3	117.7	143.5	29.7	295.7	6
Gonatus spp.	155.4	88.3	252.4	129.6	21.8	322.8	5	121.2	—	—	45.8	—	—	1
Loligo sanpaulensis	34.3	17.3	53.6	25.9	2.0	42.3	4	—	—	—	—	—	—	—
Ornithoteuthis volatilis	—	—	—	—	—	—	—	110.0	—	—	90.0	—	—	1
Ancistrocheirus lesueurii	170.6	—	—	291.5	—	—	1	—	—	—	—	—	—	—
Haliphron atlanticus	—	—	—	268.4	—	—	1	—	—	—	—	—	—	—
Ocythoe tuberculata	—	—	—	305.9	—	—	1	—	—	—	—	—	—	—
Octopus vulgaris	100.7	—	—	343.4	—	—	1	—	—	—	—	—	—	—

in food contents of several albatross species. These birds probably fed on floating discarded fish, because this species is a deepwater inhabitant (Cherel & Klages 1997).

Elasmobranch remains were probably ingested after being discarded around fishing vessels. According to Haimovici & Mendonça (1996), discards consist mainly of elasmobranches and small fish, respectively representing *c.* 50% and 20% of the total catch in double-rig trawl fisheries targeting fish and shrimp in southern Brazil.

Cephalopods
Most cephalopods found in the four seabird diets float when dead or are bioluminescent (e.g. *Histioteuthis* spp., *Chiroteuthis* spp., *Octopoteuthis* spp., *Gonatus* spp. and Sharpear Enope Squid) and are thus available to scavengers at the sea surface. Surface availability is not the case for octopus and most Ommastrephidae and Loliginidae squid (Lipinski & Jackson 1989). These species (e.g. Sao Paulo Squid) were therefore probably preyed upon during their vertical migrations to the surface (Mello *et al.* 1992).

Histioteuthis sp. A is distributed mainly in subtropical waters; *Histioteuthis* sp. B and *Chiroteuthis* spp. occur in sub-Antarctic waters. *Gonatus* spp. occur mostly in Antarctic waters (Xavier *et al.* 2003). The presence of cephalopod beaks from Antarctic and sub-Antarctic regions indicates the long period during which prey can remain in the digestive tract. Oceanic species, such as the squid *Illex argentinus,* occurred in the diet of the Black-browed Albatross. Although this squid is dominant on the outer continental shelf and upper slope off southern Brazil (Haimovici & Perez 1991, Santos 1992), it is also used as bait in longline fisheries (Neves & Olmos 1997). Sharpear Enope Squid (Roper *et al.* 1984) and the Tuberculate Pelagic Octopus *Ocythoe tuberculata* have been reported in the diets of several species of albatrosses and petrels (Imber 1992). However, coastal-water cephalopods, such as the Sao Paulo Squid and the Common Octopus *Octopus vulgaris,* were also found. The former is the most abundant coastal squid in southern Brazil (Andriguetto & Haimovici 1991, Santos & Haimovici 1998). The four seabird species studied here all forage in coastal and oceanic waters alike, although most cephalopods found in the diet were pelagic species, suggesting that these birds feed mainly on cephalopods from the oceanic environment.

The mass importance and the IRI of food items can be influenced by the way in which these birds catch their prey. Albatrosses and petrels can tear and rip prey up before ingesting it, and in some cases, they do not ingest the entire item (Thompson & Riddy 1995). When this occurs, the consumed mass does not correspond to the reconstituted mass of the prey.

Anthropogenic items
Plastic was the most frequent and numerous anthropogenic item ingested by the four seabird species. Plastic is a low-density material that can float at or near the sea surface (Morris 1980). All four species feed on prey caught at the surface and animals that float after death. Therefore, the ingestion of plastic could have occurred primarily as a result of debris mistaken for potential food items. These seabirds follow fishing vessels, and they could ingest plastic together with discarded material.

Other types of objects found in the digestive tract of these birds—including hooks, foam plastics and cord—could also have been ingested in error. Hooks could be ingested when birds scavenge discards (for example, fish heads containing hooks) around fishing vessels (Huin & Croxall 1996). Some of these objects could have

TABLE 7
Total length (TL), mantle length (ML) and mass of fish and cephalopods from White-chinned *Procellaria aequinoctialis* and Spectacled *P. conspicillata* Petrels off southern Brazil

Prey	*Procellaria aequinoctialis*							*Procellaria conspicillata*						
	TL/ML (mm)			Mass (g)			Items	TL/ML (mm)			Mass (g)			Items
	Mean	Min.	Max.	Mean	Min.	Max.	(n)	Mean	Min.	Max.	Mean	Min.	Max.	(n)
All fish	162.5	50.0	322.0	62.5	1.2	189.7	13	—	—	—	—	—	—	—
Micropogonias furnieri	116.5	50.0	198.0	31.1	1.2	84.8	6	—	—	—	—	—	—	—
Cynoscion guatucupa	99.2	—	—	18.0	—	—	1	—	—	—	—	—	—	—
Porichthys porosissimus	229.5	197.0	262.0	133.1	77.9	188.3	2	—	—	—	—	—	—	—
Atherinella brasiliensis	156.3	152.6	160.0	31.4	28.8	34.1	2	—	—	—	—	—	—	—
Thyrsitops lepidopoides	322.0	—	—	189.7	—	—	1	—	—	—	—	—	—	—
Scomber japonicus	221.0	—	—	89.5	—	—	1	—	—	—	—	—	—	—
All cephalopods	69	15.4	103.5	107.4	8.7	266.8	31	83.8	15.4	208.0	121.0	8.7	360.0	7
Illex argentinus	157.3	—	—	75.5	—	—	1	—	—	—	—	—	—	—
Histioteuthis sp. A	73.7	66.6	80.8	115.6	93.9	137.3	2	—	—	—	—	—	—	—
Histioteuthis sp. B	112.1	—	—	266.8	—	—	2	69.4	—	—	101.9	—	—	1
Histioteuthis spp.	66.5	15.4	103.3	107.9	8.7	226.7	21	35.3	15.4	46.7	33.4	43.2	48.3	2
Chiroteuthis spp.	78.0	—	—	127.9	—	—	1	—	—	—	—	—	—	—
Ocythoe tuberculata	—	—	—	127.8	—	—	1	—	—	—	—	—	—	—
Octopoteuthis spp.	—	—	—	—	—	—	—	198.1	188.1	208.0	323.0	286.0	360.0	2

resulted from secondary ingestion, such as small granules of foam plastics and plastic pellets that are often found in the digestive tract of several fish species (Carpenter *et al.* 1972, Kartar *et al.* 1976).

The harmful effects of ingesting anthropogenic debris include reduction in the storage capacity of the proventriculus, reduction in digestive efficiency and reduction in feeding stimulus (Connors & Smith 1982, Ryan 1988). Debris can also cause obstruction of the digestive tract (Bourne 1976), especially in the ventriculus, where most items accumulate. The number of birds with debris in the digestive tract was higher among beached than among longline-caught birds, but the difference was not significant. Accumulation of solid items in the digestive tract probably affects the digestive process. Nevertheless, attributing the death of beached birds to the ingestion of such objects is difficult.

The food contents of beached birds revealed a higher number and diversity of continental shelf fish, probably from trawl-fishery discards. Cephalopods had increased importance in birds caught in longline fisheries. Fish and cephalopods from pelagic waters and the continental shelf were present in both samples. Thus, these birds used both the coastal and oceanic environments as feeding areas. The cephalopods that comprised the diet of these birds came mainly from sub-Antarctic and subtropical waters. Moreover, the birds fed on cephalopods that are available naturally in the environment. About 40% of the total fish found in the food contents may originate from fishery discards, which is evidence of a strong interaction between these birds and fisheries in southern Brazil.

Fishery discards are greatly attractive to these birds, because their dietary preferences overlap with prey species targeted by commercial fisheries. Therefore, restriction of fish discards into the sea, a measure generally proposed, may be considered to be of great importance for minimizing the number of albatrosses and petrels caught incidentally by longline fisheries.

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APPENDIX 1

Equations used to calculate the mass and total length (TL) of fish and mantle length (ML) of cephalopods ingested by Black-browed *Thalassarche melanophrys* and Atlantic Yellow-nosed *T. chololorhynchos* Albatrosses and White-chinned *Procellaria aequinoctialis* and Spectacled *P. conspicillata* Petrels off southern Brazil

Species	Length (mm)	Mass (g)
Fish	(total length)	
Atherinella brasiliensis [a,b]	$31.932036\ \mathrm{Otl}^{1.1347503}$	$3.8638877(10^{-7})\mathrm{TL}^{3.605203}$
Cynoscion guatucupa [a,b]	$12.719507\ \mathrm{Otl}^{1.22121}$	$0.0000028\ \mathrm{TL}^{3.2433257}$
Lycengraulis grossidens [a,b]	$38.106486\ \mathrm{Otl}^{1.080817}$	$4.2407473(10^{-7})\mathrm{TL}^{3.5467624}$
Macrodon ancylodon [b,c]	$-6.412 + 18.451\ \mathrm{Otl}$	$1.633(10^{-6})\mathrm{TL}^{3.3014}$
Malacocephalus occidentalis [c]	$38.984\ \mathrm{Otl} - 39.01$	$0.0061\ \mathrm{Otl}^{4.2211}$
Micropogonias furnieri [a,b]	$16.434024\ \mathrm{Otl}^{1.158209}$	$0.0000019\ \mathrm{TL}^{3.3303687}$
Mugil spp. [a,b]	$23.33166e^{0.3448573\ \mathrm{Otl}}$	$0.000048\ \mathrm{TL}^{2.702358}$
Paralonchurus brasiliensis [c]	$25.99\ \mathrm{Otl} - 21.624$	$0.0103\ \mathrm{Otl}^{4.1699}$
Pogonias cromis [c]	$65.159\ \mathrm{Otl} - 300.38$	$0.0113\ \mathrm{Otl}^{4.6549}$
Pomatomus saltatrix [a]	$17.959854\ \mathrm{Otl}^{1.255077}$	$0.000015\ \mathrm{TL}^{2.9232217}$
Porichthys porosissimus [b,c]	$-8.335 + 26.734\ \mathrm{Otl}$	$6.1769(10^{-6})\mathrm{Otl}^{3.0948}$
Prionotus punctatus [a,b]	$24.812663\ \mathrm{Otl}^{1.1901627}$	$0.0000025\ \mathrm{TL}^{3.2740894}$
Trichiurus lepturus [b,c]	$-171.424 + 176.718\ \mathrm{Otl}$	$2.141(10^{-8})\mathrm{TL}^{3.477}$
Umbrina canosai [b,c]	$-68.42 + 33.49\ \mathrm{Otl}$	$1.09(10^{-5})\mathrm{TL}^{3.044}$
Urophycis brasiliensis [b,c]	$-22.65 + 24.254\ \mathrm{Otl}$	$2(10^{-7})\mathrm{TL}^{3.7386}$
Cephalopods	(mantle length)	
Haliphron atlanticus [g]	—	$1.70\ \mathrm{LHL}^{3.20}$
Ancistrocheirus lesueurii [e]	$-41.3 + 40.75\ \mathrm{LRL}$	$e[-0.194 + 3.56\ \ln(\mathrm{LRL})]$
Chiroteuthis sp. [c]	$-13 + 22.21\ \mathrm{LHL}$	$e[1.594 + 2.31\ \ln(\mathrm{LHL})]$
Gonatus sp. [e]	$-43.4 + 42.87\ \mathrm{LRL}$	$e\{-0.655 + [3.33\ \ln(\mathrm{LRL})]\}$
Histioteuthis spp. [e]	$-13 + 22.21\ \mathrm{LRL}$	$e[1.594 + 2.31\ \ln(\mathrm{LRL})]$
Illex argentinus [e]	$-12.228 + 55.187\ \mathrm{LRL}$	$2.2750\ \mathrm{LRL}^{3.1210}$
Loligo sanpaulensis [b,f]	$13.546e^{1.211\mathrm{URL}}$	$0.3408e^{2.765\mathrm{URL}}$
Octopoteuthis sp. [d]	$-0.4 + 17.33\ \mathrm{LRL}$	$\ln 0.166 + 2.31\ \ln(\mathrm{CRI})$
Octopus vulgaris [e]	$21.695\ \mathrm{UHL}^{1.0234}$	$2.776\ \mathrm{LHL}^{3.2127}$
Ornithoteuthis volatilis [d]	$-16.96 + 38.81\ \mathrm{LRL}$	$\ln 0.165 + 2.66\ \ln(\mathrm{LRL})$

[a] Naves (1999).
[b] Bugoni & Vooren (2004).
[c] M. Haimovici (Laboratório de Recursos Pesqueiros Demersais e Cefalópodes, Fundação Universidade Federal do Rio Grande. unpubl. data).
[d] Clarke (1986).
[e] Santos (1999).
[f] Santos & Haimovici (1998).
[g] Santos *et al.* (2002).
Otl = otolith length; LRL = lower rostral length; URL = upper rostral length; LHL = lower hood length; UHL = upper hood length.