FISH PREY OF WILSON'S STORM PETREL *OCEANITES OCEANICUS* AT SOUTH GEORGIA

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ABSTRACT. The first quantitative data on fish eaten by Wilson's storm petrels were obtained from identification and measurement of a small collection of otoliths in samples regurgitated by adults feeding chicks at South Georgia. All identifiable fish were myctophids with *Protomyctophum normani* predominating and *P. bolini* the only other species identified. Specimens were estimated to be 63–84 mm in total length (i.e. adults) and 1.8–3.9 g in weight. How Wilson's storm petrels catch such relatively large fish is discussed and its fish diet is compared with that of other storm petrels.

INTRODUCTION

Of the nine species of storm petrels for which dietary data are available, fish are important prey for eight species (Croxall and others, in press). Despite this, most of the few identifications of fish prey are only to the family level (Harrison and others, 1983; Hatch, 1983; Obst, 1986). Only for two species (Leach's storm petrel *Oceanodroma leucorhoa* (Linton, 1978) and white-faced storm petrel *Pelagodroma marina* (Imber, 1981)), however, have the species of fish taken been identified.

The main reason for the paucity of data on the fish prey of storm petrels is that they eat small fish and make long foraging trips during the chick-rearing period (when food samples are most readily obtained). This results in regurgitated material being highly digested (many samples consisting only of oily liquid) and corresponding difficulties in prey identification. However, increasing ability to identify fish from their otoliths and to use the measurements of these to estimate the size and weight of the whole specimen, offers fresh opportunities to acquire detailed information on the fish diet of seabirds. Here we present data, based on a small collection of otoliths, from Wilson's storm petrel *Oceanites oceanicus* on South Georgia, which provide the first information on the identity and size of the fish eaten by this species.

METHODS

Regurgitations were obtained, between 6 March and 1 April, from Wilson's storm petrels caught in mist nets when arriving to feed their chicks at night on Bird Island at South Georgia (54° 00′ S, 38° 02′ W). The regurgitations, which are an anti-predator response, were produced when the birds hit the net or were handled. Vomit was collected in polythene bags attached to funnels. It contained on average 13% oily liquid which was weighed and discarded. The solid remains were examined and otoliths removed, stored dry and shipped to the United Kingdom. Here, otoliths were drawn, using a binocular microscope with drawing tube, and maximum length and breadth measured from the drawing and converted into true length (to the nearest 0.01 mm and accurate to within 3%). Drawing the otolith provides a permanent record of its shape and reduces the possibility of damaging fragile otoliths compared to measuring with calipers. Thickness was measured, to 0.01 mm, with vernier calipers. Weight was recorded to 0.0001 g. Otoliths were identified using reference specimens and illustrations (North and others, 1984; Hecht, 1987; British Antarctic

Survey (BAS), unpublished data). Estimates of fish standard and total length and weight were made using published regression equations based on otolith length (Adams and Klages, 1987; Hecht, 1987), supplemented by unpublished BAS data from additional specimens.

Results

Fish were present in 21 (41 %) of the 51 regurgitated samples which contained solid material and made up 28.3 % of Wilson's storm petrels' diet by weight. About 26 individual fish could be recognized in the samples but only 16 otoliths were recovered. Of these, 6 were too fragmentary to permit identification. The remainder (Table I) included 3 otoliths that could only be identified as Myctophidae, 6 (probably representing five individuals) of *Protomyctophum normani* and 2 (probably representing one individual) of *P. bolini*.

All the intact otoliths were in good condition and appeared to be essentially undigested (at least in so far as maximum length was concerned). It was inconceivable that any otoliths had lost more than 10 % of total length; estimates of fish lengths and weights corrected on this basis are included in Table I for comparison. The variation in estimated size and weight of the *P. normani* was not great, with ranges of 72–89 mm and 2.6–3.9 g; the single *P. bolini* was slightly smaller (63 mm and 1.8 g).

Some additional evidence on the size of fish prey is available from skeletal and flesh material in the samples. All flesh intact enough to be identified was of myctophids (presence of characteristic photophores on the skin). Nearly intact fish (lacking heads) weighed 1.7 g (SD 0.51, range 1.5–2.5 g; $n = 5$). Post-cranial skeletons (mainly nearly intact) measured 27.6 mm (SD 8.3, range 16–45 mm; $n = 14$). Including correction factors based on the length and weight of *P. normani* heads, these measurements represent fish of standard length 30–65 mm, weighing 1.5–3.5 g. This is consistent with, though including some smaller specimens than, the otolith samples.

Discussion

Previous remarks on fish in the diet of Wilson's storm petrel are confined to statements that they eat midwater myctophids (Obst, 1986), the presence of a single larval fish in a regurgitation from King George Island, South Shetland Islands (Wasilewski, 1986) and the probable identification of one *Pleuragramma antarcticum* (Nototheniidae) from stomach samples taken in the Ross Sea, Antarctica (Ainley and others, 1984).

Because the present sample of fish eaten by Wilson's storm petrel is so small, we confine our comments to considering how such prey may be caught and to comparisons with the nature and size of fish prey taken by other storm petrels.

Implications for feeding ecology of Wilson's storm petrel

Although fish only comprised 1 % of individuals in the samples regurgitated by Wilson's storm petrel, they were a very significant element in the diet, forming 28 % by weight (Croxall and others, in press). There were no indications that fish other than myctophids were taken and *Protomyctophum normani* predominated in the identifiable material, contributing 83 % by numbers and 87 % by estimated mass.

Hulley's (1981) material suggested that *P. normani* only occurs north of 50° S; however, it is present but fairly uncommon around South Georgia (BAS, unpublished data). *P. bolini*, which Hulley (1981) recorded south to 60° S, is much more frequently caught in the South Georgia area being common offshore at 150–600 m depth (BAS,

Table I. Otolith dimensions (mm) and weight ($g \times 10^{-3}$) and estimates of fish standard length (SL) and total length (TL) (mm) and weight (g) from prey samples from Wilson's storm petrel at South Georgia

		Otolith measurements				*Fish size (uncorrected)*			*Fish size (corrected)**		
Sample	*Fish*	*Length*	*Breadth*	*Thickness*	*Weight*	*SL*	*TL*	*Weight*	*SL*	*TL*	*Weight*
21	Myctophidae	1.11	1.55	0.29	0.9	—	—	—	—	—	—
21	Myctophidae	1.34	1.73	0.30	0.9	—	—	—	—	—	—
30	*Protomyctophum normani*	1.94	1.80	0.36	1.7	59	74	2.8	69	86	3.6
30	*P. normani*	1.90	1.82	0.37	1.8	57	71	2.6	67	83	3.3
33	*P. bolini*	1.79	1.94	0.43	2.2	—	63	1.8	—	67	2.2
33	*P. bolini*	1.82	2.02	0.49	2.3	—	63	1.8	—	68	2.3
35	*P. normani*	2.10	1.86	0.41	1.9	67	84	3.9	78	97	5.0
39	*P. normani*	2.02	1.79	0.51	2.0	63	79	3.3	73	91	4.2
47	*P. normani*	1.98	2.00	0.36	1.7	61	76	3.0	71	88	3.9
47	*P. normani*	2.10	2.04	0.47	2.3	67	84	3.9	78	97	5.0
Overall	*P. bolini*										
	Mean	1.81	1.98	0.46	2.25	—	63	1.8	—	67.5	2.25
	SD	0.02	0.06	0.04	0.07	—	—	—	—	0.7	0.7
	Range	1.79–1.82	1.94–2.02	0.43–0.49	2.2–2.3	—	—	—	—	67–68	2.2–2.3
	P. normani										
	Mean	2.01	1.89	0.41	1.90	62.3	78.0	3.3	72.7	90.3	4.2
	SD	0.08	0.11	0.06	0.23	4.1	5.3	0.6	4.6	5.8	0.7
	Range	1.90–2.10	1.79–2.04	0.36–0.51	1.7–2.3	57–67	71–84	2.6–3.9	67–78	83–97	3.3–5.0

* Corrected for 10% digestion of otolith length.

unpublished data). Both species undertake daily vertical migrations but Hulley (1981) suggests that *P. normani* is typically a more shallow-living species, which may explain its greater abundance in surface waters.

P. normani is believed to become sexually mature at about 48 mm standard length (Hulley, 1981). It is likely, therefore, that most if not all specimens taken by Wilson's storm petrel were adult fish. Considering that the largest crustaceans taken were amphipods *Themisto gaudichaudii* of 22 mm length (weighing 0.2 g) and Antarctic krill *Euphausia superba* of 25–50 mm length (weighing *c.* 0.2–0.7 g) (Croxall and others, in press), this raises the question of why myctophids of similar size to the crustaceans (e.g. juvenile fish), are not taken.

Wilson's storm petrels characteristically feed by dipping to pick items from the surface whilst skimming over it or, more often, hovering with feet touching the sea. There are occasional records of sub-surface seizing and plunging (Prince and Morgan, 1987). Essentially, therefore, Wilson's storm petrels are confined to taking prey from the sea surface or from depths shallower than 10–15 cm. Small planktonic crustaceans 5–50 mm long, weighing 0.005–0.7 g have limited powers of independent movement and are likely to be a reasonably straightforward prey target. Adult f[illegible] 30–85 mm long weighing 1.5–4.0 g would seem to be a different proposition.

Myctophids are likely only to be available at the surface at night (and many of the crustacean prey probably have similar daily movements), when their bioluminescence might aid in recognition by Wilson's storm petrels. However, most myctophid light organs are laterally or ventrally placed, except for mature males which have dorsal supra-caudal photophores. The absence of juveniles may reflect a difference between juvenile and adult fish in the extent of vertical migration, or that juveniles, which lack dorsal photophores, are not easily seen. It is also possible that the specimens taken might be post-spawning adults, which might even be moribund, or that juveniles are only present around South Georgia at certain seasons. Finally, very small otoliths (e.g. from juvenile fish) might have been overlooked when the samples were processed in the field. Further material, especially from other times of year, is needed to resolve this.

In whatever way Wilson's storm petrel, which is only 18 cm long, catches and ingests 3–8 cm long fish, such prey must constitute a very economic source of food, especially if the energy required to catch any single item is similar. Two of the larger fish have a mass equivalent to the typical meal delivered to the chick (Croxall and others, in press), whereas this would require at least 10 of the largest crustaceans. However, fish are only present in 41% of samples, which suggests that such potential prey (or possibly individuals of the right size and status) may be of limited availability during each feeding trip.

The only reports of *Protomyctophum normani* in food samples from other sub-Antarctic seabirds come from king *Aptenodytes patagonicus*, macaroni *Eudyptes chrysolophus* and the rockhopper *Eudyptes chrysocome* penguins at Marion Island, south Indian Ocean (Adams and Klages, 1987; Brown and Klages, 1987). *P. normani* was the third commonest myctophid (after *Krefftichthys anderssoni* and *P. tenisoni*) in the samples. The estimated size and weight range of individuals in the king penguin samples was 43–125 mm and 0.7–11.0 g and in the macaroni and rockhopper penguin samples it was 56–85 mm. These results are surprisingly similar, considering the much larger size of penguins, to those for Wilson's storm petrel. Penguins, however, are able to forage to considerable depth, reaching 230 m in king penguins and nearly 100 m in macaroni penguins (Croxall and others, 1988), so the absence of juvenile *P. normani* in the samples is less likely to be attributable to differential vertical migration. That smaller myctophids are both available and consumption is shown by

king penguins taking *Krefftichthys* as small as 11 mm standard length. One can only speculate that juvenile and adult *P. normani* may have different distributions in sub-antarctic regions, perhaps with only adults occurring in the vicinity, or south of, the Antarctic Polar Front.

Other species of midwater myctophids which are common around South Georgia include *Krefftichthys anderssoni*, *Protomyctophum tenisoni*, *Gymnoscopelus braueri*, *Electrona antarctica* and *E. carlsbergi*. Also common in the nearshore surface waters of the island are the early stages of Notothenioidei including *Nototheniops larseni*, *Notothenia gibberifrons*, *Pagothenia hansoni*, and *Champsocephalus gunnari* (BAS, unpublished observations). These do not have photophores but are 20–40 mm long, which is within the size range of the observed prey of Wilson's storm petrel. It is surprising that more species of myctophiids or early stages of the Notothenioidei were not recorded in the diet but this may be due to the small number of samples available for study.

Comparison with fish prey of other storm petrels

All other storm petrels studied are recorded to eat fish, but identifications are restricted to the prey of four species. Sternoptychidae were taken by sooty storm petrels *Oceanodroma tristrami* at the Hawaiian Islands (Harrison and others, 1983) and Cottidae, Gadidae, Myctophidae and Scorpaeniformes by fork-tailed storm petrels in Alaska (Hatch, 1983). One *Lampichthys procerus* (Myctophidae) 70 mm long and three *Maurolicus muelleri* (Sternoptychidae) 46–48 mm long were present in white-faced storm petrel *Pelagodroma marina* samples from the Chatham Islands (Imber, 1981). The myctophid probably has similar habits to those discussed here. *Maurolicus* is typically found in depths of 150–400 m during the day but moves inshore and towards the surface at night (Clarke, 1982). In south-east Australia fish of 45–50 mm length belong to the small proportion of the population which lives for 2 years (Clarke, 1982).

Linton (1978) made a detailed study of the diet of Leach's storm petrel at two sites (Nova Scotia and Newfoundland). The fish element (8–13 % by numbers, 67–69 % by volume) was dominated by myctophids (50–55 % by volume) with *Electrona*, *Myctophum* and *Ceratoscopelus* being identified. Estimated lengths ranged from 10–90 mm but 70 % of individuals were 35–60 mm long. Cod *Gadus morhua* formed 30–40 % by weight of the fish diet, specimens being first-year individuals ranging from 35–105 mm long (60 % between 50–75 mm). The hatchet fish *Argyropelacus aculeatus* comprised 3–11 % by volume, individuals ranging from 13–35 mm long (71 % between 25–35 mm). Other fish identified were the gadid *Enchelyopus cimbrius* (25–85 mm), jacks *Caranx* sp. (15 mm), hake *Merluccius bilineatus* (75 mm) and *Sphoeroides maculatus* (35 mm). All these fish, which are of similar size to those taken by Wilson's storm petrel, are known to migrate to the surface waters at night and are presumably caught in similar fashion. There is also a tendency for Leach's storm petrel to take apparently disproportionate numbers of the larger size classes of available prey.

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References

ADAMS, N. J. *and* KLAGES, N. T. 1987. Seasonal variation in the diet of the king penguin (*Aptenodytes patagonicus*) at sub-Antarctic Marion Island. *Journal of Zoology, London*, **212**, 303–24.

AINLEY, D. G., O'CONNOR, E. F. *and* BOEKELHEIDE, R. J. 1984. The marine ecology of birds in the Ross Sea, Antarctica. *American Ornithologists Union Ornithological Monographs*, No. 32, 97 pp.

BROWN, C. R. *and* KLAGES, N. T. 1987. Seasonal and annual variation in diets of macaroni *Eudyptes chrysolophus chrysolophus* and southern rockhopper penguins *E. chrysocome chrysocome* at sub-Antarctic Marion Island. *Journal of Zoology, London*, **212**, 7–28.

CLARKE, T. A. 1982. Distribution, growth and reproduction of the lightfish *Maurolicus muelleri* (Sternoptychidae) off south-east Australia. *CSIRO Marine Laboratory Report*, No. 145, 12 pp.

CROXALL, J. P., DAVIS, R. W. *and* O'CONNELL, M. J. 1988. Diving patterns in relation to diet in gentoo and macaroni penguins, *Pygoscelis papua* and *Eudyptes chrysolophus*, at South Georgia. *Condor*.

CROXALL, J. P., HILL, H. J., LIDSTONE-SCOTT, R., O'CONNELL, M. J. *and* PRINCE, P. A. In press. Food and feeding ecology of Wilson's storm petrel *Oceanites oceanicus* at South Georgia. *Journal of Zoology, London*.

HARRISON, C. S., HIDA, T. S. *and* SEKI, M. P. 1983. Hawaiian seabird feeding ecology. *Wildlife Monographs*, No. 85, 1–71.

HATCH, S. A. 1983. Fork-tailed and Leach's storm petrels. (*In* BAIRD, P. A. *and* GOULD, P. J. *eds. The breeding biology and feeding ecology of marine birds in the Gulf of Alaska*. Anchorage, Alaska: U.S. Fish and Wildlife Service, 32–66.)

HECHT, T. 1987. A guide to the otoliths of Southern Ocean fishes. *South African Journal of Antarctic Research*, **17**, 1–87.

HULLEY, P. A. 1981. Results of the research cruises of FRV 'Walter Herwig' to South America. LVIII. Family Myctophidae (Osteichthyes, Myctophiformes). *Archiv für Fischereiwissenschaft*, **31**, 1–300.

IMBER, M. J. 1981. Diets of storm petrels *Pelagodroma and Garrodia* and of prions *Pachytila* (Procellariiformes): ecological separation and bill morphology. (*In* COOPER, J. *ed. Proceedings of the symposium on birds of the sea and shore*, 1979. Cape Town, African Seabird Group, 63–88.)

LINTON, A. 1978. The food and feeding habits of Leach's storm petrel (*Oceanodroma leucorhoa*) at Pearl Island, Nova Scotia and Middle Lawn Island, Newfoundland. M.Sc. thesis, Dalhousie University.

NORTH, A. W., BURCHETT, M. S., GILBERT, C. J. *and* WHITE, M. G. 1984. Identification of fish from the Southern Ocean by means of otoliths. *British Antarctic Survey Bulletin*, No. 62, 83–94.

OBST, B. S. 1986. Wax digestion in Wilson's storm petrel. *Wilson Bulletin*, **92**, 189–95.

PRINCE, P. A. *and* MORGAN, R. A. 1987. Diet and feeding ecology of Procellariiformes. (*In* CROXALL, J. P. *ed. Seabirds: feeding ecology and role in marine ecosystems*. Cambridge, Cambridge University Press, 135–71).

WASILEWSKI, A. 1986. Ecological aspects of the breeding cycle in the Wilson's storm petrel *Oceanites oceanicus* (Kuhl), at King George Island (South Shetland Islands, Antarctica). *Polish Polar Research*, **7**, 173–216.