DIETARY VARIATION IN CHICK-FEEDING AND SELF-PROVISIONING CAPE PETREL *DAPTION CAPENSE* AND SNOW PETREL *PAGODROMA NIVEA* AT SIGNY ISLAND, SOUTH ORKNEY ISLANDS, ANTARCTICA

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Received 25 November 2011, accepted 10 May 2012

SUMMARY

FIJN, R.C., VAN FRANEKER, J.A. & TRATHAN, P.N. 2012. Dietary variation in chick-feeding and self-provisioning Cape Petrel *Daption capense* and Snow Petrel *Pagodroma nivea* at Signy Island, South Orkney Islands, Antarctica. *Marine Ornithology* 40: 81–87.

Food web knowledge is a prerequisite for adequate resource management in the Antarctic ecosystem. Accurate dietary specifications for the major consumers within the Antarctic ecosystem are needed. Procellariid species are the most numerous avian species in Antarctica and account for 20% to 40% of the overall consumption by seabirds in the area. Diet composition of two important procellariids, Cape and Snow Petrels, was studied at Signy Island during the breeding season 2005–2006. Food samples were obtained by stomach flushing of both chick-feeding birds and self-provisioning birds. Original prey mass was reconstructed from identifiable remains in the stomach samples. Significantly different diet compositions were found between chick-feeding and self-provisioning Cape Petrels based on reconstructed weight (chick-feeders 39:61:0:0, fish:crustacean:squid:other; self-provisioning birds 28:65:7:1, F:C:S:O). By contrast, no significant differences were found between chick-feeding Snow Petrels (66:34:0:0, F:C:S:O) and self-provisioning birds (68:32:0:0, F:C:S:O). Dominant prey items were Antarctic Krill *Euphausia superba* and the myctophid fish *Electrona antarctica*. Compared with findings undertaken at other locations, Cape Petrels at Signy Island had higher dietary fractions of crustaceans. Similarly, this study shows higher fractions of krill and lower fractions of fish in Snow Petrels at Signy Island than at other locations. A reasonable explanation for the high crustacean fraction in both seabird species might be the local high abundance of Antarctic Krill. This emphasises that local differences in diets need to be taken into account in modelling studies. Also, fish is an abundant prey item in both species, showing that, even in a strongly krill-dominated region, fish may remain an important part of the diet of Antarctic petrel species. The differences in diet between chick-feeding and self-provisioning Cape Petrels also show the importance of studying both groups in overall dietary research.

Key words: diet, water-off-load, Snow Petrel, Cape Petrel, chick-feeding, self-provisioning, Antarctica

INTRODUCTION

Procellariids are the most numerous Antarctic seabirds and are thought to account for between 20% and 40% of the overall prey consumed by seabirds in the region (Van Franeker *et al.* 1997). Antarctic Krill *Euphausia superba* has long been considered the main link between the lower trophic levels and all Antarctic consumers, including warm-blooded vertebrates (Everson 1977) such as petrels. However, the distribution of krill in the Southern Ocean is not homogeneous (Atkinson *et al.* 2004, 2008), and many procellariids occur in areas where Antarctic Krill is less abundant (Ridoux & Offredo 1989). Past studies show that fish and squid are also important food sources for petrels (e.g. Ainley 1992, Creet *et al.* 1994, Coria *et al.* 1995, Hodum & Hobson 2000, Van Franeker *et al.* 2001). The idea that petrels eat more fish than previously believed does not undermine the position of krill as the "cornerstone" or "keystone" species of the Antarctic ecosystem, as many fish consume krill.

A quantitative approach is critical if we are to understand nutrient cycling and food web interactions. Many previous studies of Antarctic procellariid diets were qualitative rather than quantitative (Bierman & Voous 1950) or used such different sampling methods (e.g. Ainley *et al.* 1992, Liddle 1994, Soave *et al.* 1996, Hodum & Hobson 2000, Soave *et al.* 2000, Van Franeker *et al.* 2001, Cherel *et al.* 2002) that comparisons between studies are difficult.

The diets of Cape Petrel (e.g. Arnould & Whitehead 1991, Coria *et al.* 1997, Casaux *et al.* 1998, Van Franeker *et al.* 2001) and Snow Petrel (e.g. Ferretti *et al.* 2001, Van Franeker *et al.* 2001) have been studied extensively but only once, and in little detail, at Signy Island, South Orkney islands (Beck 1969). Krill is abundant around the Antarctic Peninsula and many studies have been carried out there, perhaps biasing perceptions of the importance of krill in petrel diets and skewing representations of Antarctic food webs. In general, diets of Cape Petrels are thought to be dominated by krill, whereas Snow Petrels are thought to prefer fish.

Studies of the interactions between predators and their prey in Antarctic marine ecosystems have provided important information about the diet and food consumption of seabirds and about their potential interactions with commercial fisheries, particularly that for Antarctic Krill. Indeed, increasing exploitation of marine resources in the Southern Ocean has focused scientific research on the management of marine ecosystems (Croxall, 1994). One important input for management is knowledge about what is required by natural predators in the system. However, to date, most dietary research has been carried out on chick-feeding seabirds, although chick-feeding accounts for only 5% of the total annual food intake of fulmarine petrels (Van Franeker *et al.* 2001). Separating the diets of chick-feeding and self-provisioning birds is important because the diet of chick-feeding and self-provisioning Antarctic petrel species are thought to be different (e.g. Van Franeker *et al.* 2001, Quilfeldt 2002). Whether we assume that self-provisioning and chick-feeding diets are similar has major consequences for modelling Antarctic food webs and hence for management of natural resources. Our aim was therefore to determine whether the abundance of krill in the Peninsula area, including the South Orkney islands, would be reflected in petrel diets and whether there are dietary differences between self-provisioning (non-breeding) and chick-feeding seabirds, by revisiting the diet of Cape and Snow Petrels at Signy Island.

STUDY AREA AND METHODS

The feeding ecology of adult Cape and Snow Petrels was studied at Signy Island, South Orkney Islands (60°42'S, 45°35'W) from 14 December 2005 to 21 February 2006. Two colonies were used to study both self-provisioning and chick-feeding birds at Factory Cove and Pinder Gully on the east coast of Signy Island. Other colonies visited only for self-provisioning bird sampling were at Gourlay Peninsula, Observation Corner and North Point.

Non-breeding birds were used to study self-provisioning diets of both species. To study chick-feeding diets, birds raising chicks were sampled when they returned to the colony to feed the chick. Birds were captured with a noose pole on days when there was no precipitation or strong winds. As a precaution to minimize disturbance and food-deprivation to the chick, sampling was carried out on only one parent per nest site per season and only after the chick-guarding period ended. Morphometric measurements were taken to determine the sex of all captured birds following methods described in Van Franeker & Ter Braak (1993). We obtained complete diet samples by the stomach flushing or Water-Off-Loading (WOL) technique (Wilson 1984). To confirm that all stomach contents were collected, a second flush was applied, which yielded clear water in all cases. In the field, samples were drained over a 0.5 mm sieve and stored in a polyethylene container. Some birds regurgitated before the WOL sampling was done. These regurgitates were collected, stored and analysed separately. After handling, birds were released close to the nest site on a spot that permitted the bird to decide whether to return immediately to the nest site.

In the laboratory, within two days after collection, diet samples were rinsed under running tap water and drained over a 0.5 mm sieve. Drained contents were weighed to record total drained weight (DRW). All recognizable items were sorted into the main prey groups (fish, crustacean, squid or “other”) using a binocular microscope. The fish part was divided into fish meat, fish bones (vertebral columns and other hard material were measured), fish eyes (fresh and old, diameter was recorded) and fish otoliths (identified to the lowest taxonomic level and otolith length recorded). The crustacean part was divided into different species of crustaceans and, if possible, eyeball diameter and carapace lengths were recorded. Squid were rarely encountered in the samples but if encountered, beaks and arm lengths were measured. In the “other” category, most items were non-food.

The total weight of the stomach contents was reconstructed (reconstructed weight, REW) based on several parts of the prey items found. Fish otoliths, fish eyes, euphausid carapaces and euphausid eyes were used to estimate the original size and weight of prey items. REW was determined only in diet samples with a total DRW over 1 g to avoid uncertainties about meal size and composition. Samples with a DRW of 1 g or less were often old and had probably undergone substantial digestion, increasing the chance of missing specific remains of prey items. All fish taxonomic otolith identification was carried out following Hecht (1987), Williams and McEldowney (1990) and Reid (1996). Otolith length and/or height were measured using a Zeiss Discovery Stereomicroscope and Axiovision (version 4.8.2.0). The total length and mass of each individual identified was estimated from otolith length (OL) using the equations in Williams and McEldowney (1990) and Reid (1996). No correction was made for erosion of otoliths, as no correction factor could be determined due to the absence of fresh, uneroded otoliths in the samples. We recognise that disregarding otolith erosion leads to a conservative measure of the proportion of fish in the reconstructed diets. If no otoliths were found in the samples, the number of eye lenses was used to estimate the number of fish in the sample. In this case, the average otolith length of all samples (1.81 mm for the most common fish prey *Electrona antarctica*) was used to provide an estimate of consumed fish. Crustacean identification was carried out following Morris *et al.* (1988), Hill (1990), Reid & Measures (1998) and Shreeve (2005). Reconstructed mass of krill in a diet sample was calculated from the number of eye pairs classified as either adult (eye diameter > 1.5 mm) or juvenile (eye diameter < 1.5 mm). A sub-sample of intact Antarctic Krill *Euphausia superba* was taken from each of the two groups to estimate average carapace lengths for both demographic categories and thus to calculate the average mass of one individual of the group. The total length and mass of the individuals identified were estimated from carapace length (CL) using the equations in Reid & Measures (1998). Most other crustaceans encountered were intact, so mass could be determined with some certainty. Squid remains were occasionally encountered, but complete individuals or identifiable remains, including complete squid beaks, were not retrieved. To reconstruct original prey mass, the size of body parts, such as arms, was recorded and total length was estimated, following which the equation for original mass following Clarke (1986) of the most common squid species known to occur around the South Orkney Islands (*Histioteuthis spec.*) was used to generically estimate original mass.

Diet composition was compared within species between self-provisioning and chick-feeding birds. Differences in diet composition between the different prey groups were tested using a non-parametric Mann–Whitney U test (Quinn and Keough 2002) using SPSS version 15.0.

RESULTS

A total of 90 Cape Petrel samples were collected from 31 chick-feeding and 59 self-provisioning birds. In the latter category, only seven samples had more than 1 g of food (DRW), so these were used in the REW analysis. For Snow Petrels, a total of 20 chick-feeding and four self-provisioning birds were sampled (of which three had > 1 g DRW).

Prey items found included fish, crustaceans and squid (Tables 1 and 2). In chick-feeding Cape Petrels, five species of fish were found: *Electrona antarctica*, *E. carlsbergi, Lepidonotothen larseni, Gymnoscopelus nicholsi* and *G. braueri*, in contrast to only two species in self-provisioning birds (*E. antarctica* and *E. carlsbergi*). In chick-feeding Snow Petrels, *E. antarctica*, *L. larseni* and *G. braueri* were found as prey items, whereas in self-provisioning Snow Petrels only remains of *E. antarctica* were found (Table 1).

At least six species of crustaceans were found in the diets of the two petrel species, with *Euphausia superba* being the most abundant (Table 2) as well as *Themisto gaudichaudii* (common, but sometimes suspected to originate from fish prey; i.e. secondary consumption), several species of Gammarid amphipods (common, especially in self-provisioning Cape Petrels), *Pasiphaea scotiae* (infrequent, only in Snow Petrel) and *Calanoides acutus* (infrequent). Squid remains were found; however, identification to species level was not possible.

Four Cape Petrels had manmade non-biological material in the stomach, including fragments of plastic. Other non-food items found in bird stomachs were grapefruit particles, stones, moss, terrestrial arthropods and parasitic worms. No other prey items of nutritional value were found in this study.

Drained and reconstructed food mass and proportional composition of the reconstructed samples are shown in Table 3. Frequency of occurrence of different prey types is shown for all samples, including those of less than 1 g DRW. For chick-feeding Cape Petrels, the mean mass of drained stomach samples was 33.6 g (SD = 14.7 g, range: 2.7–55.4 g, n = 31) compared with 10.1 g (SD = 12.7 g, range: 1.1–37.0 g, n = 7) for self-provisioning individuals. In chick-feeding Snow Petrels, the mean mass of drained stomach samples was 23.9 g (SD = 11.5 g, range: 11.7–48.3 g, n = 20) and in self-provisioning birds 29.1 g (SD = 8.2 g, range: 1.4–17.9 g, n = 3). In further analyses, only the reconstructed weight based on identifiable prey remains was used to determine diet composition for both species (Table 3).

TABLE 1
Main fish prey items found in Cape and Snow Petrels at Signy Island in 2005–2006

Petrel species, prey sample	Mean otolith length (mm) ± SD (range)	Mean reconstructed weight (g) ± SD (range)
Chick-feeding Cape Petrel (n = 31)		
Electrona antarctica (n = 88)	1.81 ± 0.36 (0.93–2.88)	7.15 ± 4.16 (0.84–26.59)
Electrona carlsbergi (n = 2)	3.07 (2.76–3.38)	6.60 (4.75–8.44)
Lepidonotothen larseni (n = 6)	1.66 ± 0.23 (1.50–2.00)	0.29 ± 0.10 (0.22–0.43)
Gymnoscopelus nicholsi (n = 4)	1.52 ± 1.46 (2.51–5.64)	19.81 ± 15.39 (1.36–33.24)
Gymnoscopelus braueri (n = 2)	3.03 (2.77–3.28)	30.97 (22.81–39.13)
Self-provisioning Cape Petrel (n = 7)		
Electrona antarctica (n = 8)	1.66 ± 0.35 (1.19–2.08)	5.51 ± 3.20 (1.79–9.80)
Electrona carlsbergi (n = 1)	2.79	4.89
Chick-feeding Snow Petrel (n = 20)		
Electrona antarctica (n = 129)	1.73 ± 0.33 (0.60–2.37)	6.27 ± 3.22 (0.22–14.73)
Lepidonotothen larseni (n = 11)	1.72 ± 0.44 (1.07–2.55)	0.31 ± 0.19 (0.03–0.67)
Gymnoscopelus braueri (n = 1)	2.56	17.67
Self-provisioning Snow Petrel (n = 3)		
Electrona antarctica (n = 16)	1.66 ± 0.22 (1.24–1.98)	5.16 ± 1.96 (2.03–8.46)

TABLE 2
***Euphausia superba* found in Cape and Snow Petrels at Signy Island in 2005–2006**

Petrel species, *E. superba* sample	Mean carapace length (mm) ± SD (range)	Mean total length (mm) ± SD (range)	Mean reconstructed weight (g) ± SD (range)
Cape Petrel			
Euphausia superba juvenile (n = 32)	10.9 ± 1.46 (8–14)	36.2 ± 3.1 (29.9–42.7)	0.36 (0.19–0.62)
Euphausia superba adult (n = 248)	16.7 ± 1.89 (12–20)	47.0 ± 4.0 (38.4–55.4)	0.85 (0.44–1.45)
Snow Petrel			
Euphausia superba juvenile (n = 13)	11.2 ± 1.24 (9–13)	26.4 ± 12.2 (13.0–40.5)	0.38 (0.24–0.52)
Euphausia superba adult (n = 24)	15.8 ± 1.44 (13–19)	46.4 ± 3.1 (40.5–53.3)	0.82 (0.52–1.26)

Significantly higher proportions of fish were found in chick-feeding Cape Petrels than in self-provisioning birds (U = 38.00, $P < 0.01$, $r = -0.43$) as well as lower proportions of crustaceans (U = 27.00, $P < 0.01$, $r = -0.50$). Both squid (U = 84.50, n.s., $r = -0.28$) and other (U = 93.00, n.s., $r = -0.34$) fractions were not significantly different; however, these latter components were both minor dietary elements. Chick-feeding Cape Petrels had a diet composition, based on REW, of 39:61:00:00 (fish:crustacean:squid:other) with a mean REW of 71.7 g (SD = 31.7 g; range: 4.1–135.7 g; n = 31). Self-provisioning Cape Petrels had a diet composition, based on REW, of 28:65:07:01 (F:C:S:O) with a mean REW of 20.8 g (SD = 26.3 g; range: 1.7–78.2 g; n = 7).

No significant differences were found between chick-feeding and self-provisioning Snow Petrels in fish (U = 19.00, n.s., $r = -0.21$), crustacean (U = 18.00, n.s., $r = -0.23$), squid or other (both: U = 28.50, n.s., $r = -0.39$) fractions. Chick-feeding Snow Petrels had a diet composition, based on REW, of 68:32:0:0 (F:C:S:O) with a mean REW of 61.9 g (SD = 32.6 g; range: 9.6–136.2 g; n = 20). Self-provisioning Snow Petrels had a diet composition, based on REW, of 66:34:0:0 (F:C:S:O) with a mean REW of 83.1 g (SD = 8.0 g; range: 19.8–35.8 g; n = 3).

Fish and crustaceans represented the most common prey items in terms in frequency of occurrence (Table 3). The major difference between Cape and Snow Petrels in frequency of occurrence of the different fractions was the low representation of fish in self-provisioning Cape Petrels (8%), compared with 87% in chick-feeding birds. Among Snow Petrels, 100% contained fish. No squid was found in chick-feeding Snow Petrels, unlike self-provisioning birds (Table 3).

DISCUSSION

The diet composition of Cape Petrels at Signy Island was dominated by crustaceans and fish, based on percentage REW. Several previous studies have been undertaken on Cape Petrel diets from other study sites in the South Orkney islands; these reported diet compositions based on DRW proportions of 15:64:0:21 (F:C:S:O) at Signy Island (Beck 1969, recalculated in Croxall & Prince 1980), 65:35:0:0 (Coria *et al.* 1997) and 2:97:0:1 (Soave *et al.* 1996). Although based only on drained food mass, these studies confirm that, within the South Orkney islands, both fish and krill are predominantly taken, but diet composition is highly variable between sites and years. One study using the reconstructed weight of WOL samples collected from Cape Petrels from colonies in Wilkes Land, Antarctica, found diet compositions of 46:18:36:0 (self-provisioning) and 62:34:4:0 (chick-feeding) (Van Franeker *et al.* 2001). An analysis of self-provisioning birds collected at sea found a diet composition of 69:3:19:9, based on REW (Ainley *et al.* 1992). The main difference between these two studies and our study is the lower percentage of fish prey found at Signy Island for both self-provisioning and chick-feeding birds. In addition, the proportion of squid found in the diet of self-provisioning Cape Petrel was much lower in our study.

The diet of Snow Petrels at Signy Island was also dominated by fish and crustaceans, based on REW. Within the South Orkney islands, Ferretti *et al.* (2001) found a diet composition of 90:9:0:0 for Snow Petrels (Ferretti *et al.* 2001). A high fish fraction and minor crustacean fraction has generally been reported for Snow Petrels (e.g. Ridoux & Offredo 1989, Ferretti *et al.* 2001) except for one at-sea study that reported a composition of 52:32:15:2 (Griffith 1983). As with Cape Petrels, all of these studies were based on DRW instead of REW. Studies using the REW method for Snow Petrel diets showed a composition of 59:2:38:0 (self-provisioning) and 92:3:4:0 (chick-feeding) (WOL samples collected at colonies, Van Franeker *et al.* 2001) and 92:6:2:0 (Ainley *et al.* 1992, birds collected at sea). Crustaceans were less important in previous studies of Snow Petrels diets, but our study clearly showed that crustaceans can form a substantial dietary component at some locations or in some years.

At several locations throughout the Antarctic, fish have been found to be the major component of the diet of fulmarine petrels (Arnould & Whitehead 1991; Ainley *et al.* 1992; Creet *et al.* 1994; Coria *et al.* 1997; Van Franeker *et al.* 2001), although the species taken varies. The notothenid *Pleuragramma antarcticum* was found mostly in diets in the Antarctic Peninsula region (Creet *et al.* 1994) and Wilkes Land (Van Franeker *et al.* 2001), while the myctophid *Electrona antarctica* was found mostly in the Weddell Sea (Ainley *et al.* 1992) and around the South Orkney islands (Coria *et al.* 1997; Casaux *et al.* 1998). In our study, *E. antarctica* was also found to be the most commonly

TABLE 3
Diet composition of complete stomach samples from Cape and Snow Petrels at Signy Island in 2005–2006

Species, sample	n for samples > 1 g	n for all samples	Average DRW, samples > 1 g (g)	Average REW, samples > 1 g (g)	REW composition fish: crustaceans: squid: other, samples > 1 g (%)	Frequency of occurrence fish: crustaceans: squid: other, all samples (%)
Cape Petrel						
All	38	90	29.3	62.3	38:61:0:0	36:83:6:1
Self-provisioning	7	59	10.1	20.8	28:65:7:1	8:75:5:2
Chick-feeding	31	31	33.6	71.7	39:61:0:0	87:100:6:0
Snow Petrel						
All	23	24	22.0	57.5	68:32:0:0	100:96:4:4
Self-provisioning	3	4	29.1	83.1	68:32:0:0	100:100:25:0
Chick-feeding	20	20	23.9	61.9	66:34:0:0	100:95:0:0

caught fish for both Cape and Snow Petrels. The nutritional value of myctophids is high compared with other prey items (Van der Putte *et al.* 2006), and thus it must form an attractive prey for seabirds. Although myctophids occur mainly over deeper water and are not commonly found over shelves, around the South Orkneys islands this species constitutes a major energy source for surface feeding predators. *E. antarctica* is also one of the most commonly taken fish items around the South Orkney islands by Antarctic Fur Seals *Arctocephalus gazella* (Daneri & Coria 1994). Around the South Shetland islands, Blue-eyed Cormorants *Phalacrocorax atriceps brandsfieldensis* (Coria *et al.* 1995) commonly take myctophids as their main prey item, although some previous studies found negligible proportions of myctophids in the closely related South Georgia Shag *Phalacrocorax georgianus* (Casaux & Ramon 2002). *E. antarctica* is supposed to make a diel migration of 300–650 m during the day and occurs close to the surface at night (Torres & Somero 1988). However, its prevalence in surface-feeding seabird diets indicates that it must sometimes remain close to the surface during daylight (including dusk and dawn).

Crustaceans, in particular Antarctic Krill, are known to be important components of Antarctic seabird diets. Beck (1969) and Arnould & Whitehead (1991) suggest that all fulmarine petrels probably feed on krill and that this forms their staple diet. Other studies suggested that krill is more important in the subantarctic regions (Croxall & Prince 1980; Ridoux 1984), while some propose that diets are diverse and that krill is just one of the crustaceans taken (Ainley *et al.* 1992). Our study shows that for both Cape and Snow Petrels feeding around Signy Island, Antarctic Krill is indeed a major dietary item for both self-provisioning and chick-feeding birds, although for Snow Petrels fish is the most important component. The high proportion of larger adult krill (and thus higher energy content) found in this study compared with the lower proportion of juvenile krill might explain the higher fraction of crustaceans in the diets of petrels at Signy Island in contrast to other studies (Ainley *et al.* 1992; Van Franeker *et al.* 2001). Targeting crustaceans in areas where immature krill dominates the population is less attractive due to the lower energy content per prey item, compared to areas where adult (larger and higher energy content per prey item) krill is present. Similarly to this study, Soave *et al.* (1996) and Coria *et al.* (1997) reported larger mean krill lengths than in other study areas (Van Franeker *et al.* 2001) suggesting a higher proportion of adult krill around the South Orkney islands. Other crustaceans found in this study were *Themisto gaudichaudii*, Gammarid amphipods, *Calanoides acutus* and the decapod *Pasiphaea scotiae*. These are all species also found in previous studies of fulmarine petrel diets.

The squid fraction in this study was very small in both Snow Petrels and Cape Petrels. Squid are supposedly an important food source for fulmarine petrels (Lipinski and Jackson 1989). Van Franeker *et al.* (2001) showed higher squid fractions in the self-provisioning diets of both Snow and Cape Petrels and concluded that squid is an important dietary item throughout the year. Both Soave *et al.* (1996), Coria *et al.* (1997) and our study show a low overall occurrence of squid in petrel diets around the South Orkney islands, but this might be related to levels of local abundance and distribution, or to seasonal shifts in prey. The occurrence of squid in the diet of fulmarine petrels may be more common in offshore wintering areas (Ainley *et al.* 1992).

Four diet samples from Cape Petrels were found to include manmade non-biological material in the stomach, including plastics. This is a common phenomenon in seabirds, but the incidence of plastics in true Antarctic seabirds such as the Snow Petrel is generally lower than for more northerly migrating species such as Cape Petrels (Van Franeker & Bell 1988). Finding plastic items in our study right at the beginning of the breeding season might indicate "plastic-import" from the wintering areas rather than from a local source. In our study no other prey items of nutritional value were found. Elsewhere, other prey items found in petrel diets have included carrion (Ridoux & Offredo 1989), gelatinous prey items such as jellyfish and salps (Ainley *et al.* 1992) and pteropods (Van Franeker *et al.* 2001). The scavenging nature of fulmarine petrel foraging behaviour is a factor that may influence the quantitative approach of diet studies. In our study, one Snow Petrel was found to have eaten a fish eyeball of 13 mm diameter, representing a prey item very much larger that could normally be taken; generally fish eyeballs with diameters of approximately 3 mm are found. This may indicate the scavenging of a large fish.

Several studies have shown differences between chick-feeding and self-provisioning diets in fulmarine petrels (e.g. Creet *et al.* 1994; Lorentsen *et al.*1998; Van Franeker *et al.* 2001). Causes of such compositional shifts might be local abundance of prey items, higher energy content of certain prey items or specific nutritional requirements for chicks (Van Franeker *et al.* 2001). For example, in albatross chicks, faster growth rates have been shown to be associated with fish and krill diets rather than with squid diets (Prince and Ricketts 1981); this might cause chick-rearing adults to prefer certain prey items in favour of others. Climate variability and change can have major impacts on Southern Ocean ecosystems (Trathan *et al.* 2007), affecting prey abundance and availability to predators (Murphy *et al.* 2007). This means that accurate dietary information can be derived only from studies covering a wide range of temporal and spatial variability. Our study, although based on a modest sample size, when compared with earlier publications, shows the relevance of such widespread sampling.

ACKNOWLEDGEMENTS

The Netherlands Polar Program (NPP) of the Council for Earth and Life Sciences of the Netherlands Organisation for Scientific Research (ALW-NWO) and the foreign office of the VU University Amsterdam (Van Dittmer Fonds) co-funded the fieldwork of this study. Antarctic research by IMARES is commissioned by the Netherlands Ministry of Economic Affairs, Agriculture and Innovation under its Statutory Research Task Nature & Environment WOT-04-009-036 and was also supported by ALW-NWO under project nr. 851.20.011. This paper is a contribution to the BAS Ecosystem programme. We thank Mike Dunn for his great help in the field and in the laboratory. We thank Rachael Shreeve and Geraint Tarling for their help identifying crustacean prey items. We thank Elisa Bravo Rebolledo and Mardik Leopold for their help with otolith measurements and Richard Phillips for advice during the preparation of this project. We also thank two anonymous reviewers who helped us to greatly improve this paper.

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