Thus far, most assessments of the potential link between seabird reproductive performance and food supply have focused on chick growth rate, maximum chick body mass, or mass at fledging (e.g., Ricklefs et al. 1984; Croxall 1984). Growth rate is thought to be particularly sensitive to variations in the rate of food delivery, which in turn is assumed to correlate with food availability (Barrett et al. 1987; Monaghan et al. 1989). Critical evaluations of the link between food supply and reproductive performance will benefit from direct examinations of the magnitudes and patterns of energy flow, from marine environment through parents to offspring.

Most studies of seabird energetics have focused on adults (reviewed by Green and Brothers 1989) and our understanding of the adult-offspring energy dyad is incomplete. Knowledge of nestling energy requirements and how they relate to organismal traits and environmental conditions is essential to evaluating the putative link between food supply and reproductive performance.

There is considerable international interest in the role of seabirds in antarctic marine ecosystems and how human activities may affect seabird populations. Instantaneous and cumulative food consumption and energy flux are crucial indices of the impact of petrels on the marine ecosystem and, in turn, of the possible consequences of ecosystem changes (e.g., large-scale krill harvesting) on petrel populations. By studying diet, energy metabolism, and chick growth over three consecutive breeding seasons, valuable insights will be gained into the interannual variation in population energetics at Prydz Bay and how such variation affects seabird reproductive performance.

The field site for this study is Hop Island in the Rauer Island group, approximately 40 kilometers south-southwest of Australia's Davis Station. The field season began on 5 November 1993 and continued until 18 February 1994. Due to shipping schedules we were unable to remain in the field through the end of the fledging period. This first season provided baseline data on attendance patterns throughout the breeding season, laying dates, incubation period, hatching dates, and nestling survival through the late-nestling period. Chick growth curves were generated from daily nestling morphometric measurements.

Measurements of field metabolic rates of chicks and of breeding adults of both species were made using the doubly labeled water (DLW) technique. Diet samples were collected from breeding adults of both species. Preliminary analysis of samples indicates that snow petrels fed primarily on fish whereas the diet of cape petrels was composed primarily of krill. Fecal samples from chicks were collected to establish diet from stable isotope analysis (ratio of nitrogen-15 to nitrogen-14) of the feces. Feeding rates and meal sizes were determined from observations of nest sites and from overnight chick weighing measurements.

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Antarctic procellariiform seabirds can smell krill

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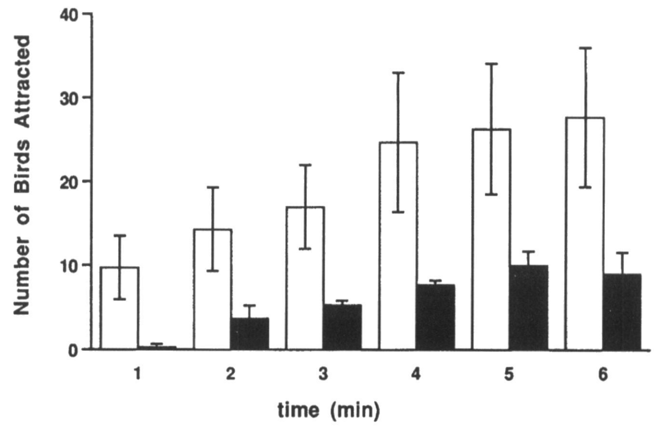
Procellariiform seabirds (i.e., the petrels, albatrosses, and shearwaters) have an exquisitely developed olfactory system (Bang 1965, 1966). The olfactory prowess of these birds has been documented for a number of different species (Hutchinson and Wenzel 1980; Jouventin and Robin 1984; LeQuette, Verheyden, and Jouventin 1989; Clark and Shah 1991). Still, why these birds have evolved such a keen sense of smell or precisely how they use olfactory information in the wild remains a mystery.

Procellariiform seabirds are readily attracted to fishy smelling oils deployed at sea (e.g., cod liver or tuna oil, fish homogenate), suggesting that olfactory cues might be used to locate food (Grubb 1972; Hutchinson and Wenzel 1980; Jouventin and Robin 1984; LeQuette et al. 1989). Antarctic krill (*Euphausia superba*) is a preferred prey of many petrels (Prince and Morgan 1987), and scientists speculate that procellariiforms may be able to detect krill swarms using olfactory cues (Clark and Shah 1991). Clark and Shah have used simulation models to describe the dispersion of specific aromatics derived from krill (e.g., trimethylamine and pyrazine). Their results suggest that even a relatively small (0.5-meter diameter) krill swarm may be detectable to foraging petrels from distances of kilometers, given the right atmospheric parameters. Although untested, this idea is intriguing since many tubenosed species live highly pelagic lifestyles, often foraging at night over large stretches of open ocean where krill swarms can be small and patchily distributed.

As part of an ongoing study on seabird foraging, I conducted shipboard experiments designed to test the hypothesis that procellariiforms are able to detect krill at sea using olfactory cues. Preliminary experiments were performed aboard the National Oceanic and Atmospheric Administration ship *Surveyor* near Elephant Island during February and March 1993 and continued aboard the R/V *Nathaniel Palmer* near South Georgia during May and June 1993. For these experiments, I presented birds with perfumed vegetable oil slicks paired with unscented control slicks. My aim was to produce a plume of odor emanating from a slick. The plume approximated aromatic concentrations typical of what birds might naturally encounter (nanomolar range). The scents used were cod liver oil, crude krill extract, two aromatic components of krill (trimethylamine and pyrazine), and one foreign odorant, phenylethyl alcohol (rose scent). Once slicks were deployed, two teams of "blind" observers (one team per slick) simultaneously recorded numbers, behaviors, and species identities of birds that arrived. A bird was considered to show interest if it

- flew upwind directly over the slick within approximately 1 meter of the surface,
- alighted on, or
- patterned over the slick.

Combined data from 18 experiments produced a number of compelling results. First, procellariiforms were more attracted to slicks scented with crude krill extract than to nonscented control slicks (figure). Northern and southern giant petrels, cape petrels, blue petrels, antarctic petrels, kerguelen petrels, and black-browed albatrosses were also strongly attracted to pure krill aromatics (G-test, $p<0.05$). The relative attractiveness of odors differed between species. Cape petrels, for example, were highly attracted to trimethylamine and less attracted to pyrazine, phenylethyl alcohol, and cod liver oil in descending order. This response is of particular interest since we have also shown that cape petrels alter their turning behavior over nonvisible krill swarms in a manner consistent with an olfactory foraging strategy (Veit et al., *Antarctic Journal*, in this issue). Blue petrels, on the other hand, responded more strongly to cod liver oil than to any other odorant. Apparently, the attractiveness of odorants had no relationship



Numbers of procellariiform seabirds attracted to krill scented oil slicks (white bars) and nonscented slicks (black bars). This graph shows the cumulative arrival of birds 1–6 minutes after slicks were deployed. Data are from three paired trials and are presented as means and standard errors.

to prevailing weather conditions, suggesting that these differences were not strictly due to discrepancies in odor volatilities or transport. Together, these results provide intriguing evidence that antarctic procellariiform seabirds use olfactory cues to locate food resources.

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