

NOTE

Seabirds as indicators of marine resources: black-browed albatrosses feeding on ommastrephid squids in Kerguelen waters

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ABSTRACT: The species, distributions and abundances of squids in the Southern Ocean are difficult to assess by conventional oceanographic means. The study of the food and feeding ecology of squid-eating predators such as procellariiform seabirds appears to be a supplemental way to collect useful information on cephalopod biology. Regurgitations were collected from 52 chicks of the black-browed albatross *Diomedea melanophrys* at Kerguelen Island in February 1994. Cephalopod remains were removed and identified by means of beaks, gladius and mantle. Squid beaks of the family Ommastrephidae amounted to 55% (n = 348) of the accumulated squid beaks. They were also those most often regurgitated in association with partially digested crowns and mantles (90% of the squid fresh remains, n = 28). Two species of ommastrephids equally dominated the squid diet, *Martialia hyadesi* (only found once in Kerguelen waters) and a *Todarodes* species, probably *T. angolensis*, previously unknown in the area. The concomitant satellite tracking of 16 adult birds over a total of 35 foraging trips identified their main feeding areas as the inner shelf break to the NE and over a bank to the SE of Kerguelen Island. Taken together, albatross dietary and foraging data indicate that juveniles of *M. hyadesi* and *Todarodes* sp. concentrate over the upper shelf slope to the east of Kerguelen Island, some of them occurring in the top 5 m of the water column where they are caught by the albatrosses.

KEY WORDS: Bioindicator · Diet · Antarctic · Marine food web · Satellite tracking

Pelagic squid and fish are highly mobile, patchily distributed and consequently very difficult to survey by conventional oceanographic methods. In the Southern Ocean, squids constitute a key group in the pelagic food webs, but little information is available on species composition, distribution and biology because of the inadequacies of sampling techniques (Clarke 1983, Kock 1987). Dietary data from top predators have been used to overcome this problem and have provided valuable data on squid ecology (Clarke 1980, Imber & Berruti 1981). For example, the onychoteuthid squid *Kondakovia longimana*, a major prey item for many

sea mammals and birds, was first described in 1972 but has rarely been found in nets (Lu & Williams 1994), and comparison of squids eaten by a variety of top-predators with those obtained with several kinds of nets shows striking differences in the species, abundance and size of specimens caught (Clarke 1977, Clarke 1983, Rodhouse 1990).

Seabirds are particularly useful samplers of pelagic prey that avoid ships and fishing gear and that often occur in the upper 5 to 10 m of the water column, i.e. in the layer of the seawater rarely included in acoustic surveys. They can also be useful as sampling agents for otherwise unstudied marine fauna at sites that are not easily or not usually surveyed by conventional means (Montevecchi 1993). Moreover, compared with vessel surveys, data on seabird food and feeding ecology have the advantage of being easily collected and inexpensive and allow a broader spatial and temporal coverage. Until now, attempts to locate bird feeding areas, and thus prey aggregations, with some precision relied mainly upon visual observations and were therefore subordinated to oceanographic cruises. On the other hand, information on diet without knowing the location of feeding areas is of limited use in terms of assessing predator-prey interactions.

The recent development of satellite tracking of large seabirds (Jouventin & Weimerskirch 1990) along with keys for the identification of hard parts of digested prey (e.g. squid beaks, otoliths) (Clarke 1986, Hecht & Hecht 1987, Williams & McEldowney 1990) now allows the use of predators as samplers and indicators of species composition and location of marine cephalopod and fish fauna. Satellite fixes permit the journeys of foraging seabirds to be accurately mapped (Weimerskirch et al. 1993); and, even if foraging tracks do not necessarily equate to precise feeding locations, they allow the areas of potential feeding to be located. Moreover, some albatrosses fly directly to and from a specific marine

sector where they spend most of their foraging time, thus clearly delimiting zones that are likely to be feeding areas (Weimerskirch & Robertson 1994).

Here, we report the occurrence and location of aggregations of ommastrephid squids in Kerguelen waters using dietary data and satellite tracking of the black-browed albatross *Diomedea melanophrys* during the chick-rearing period.

Materials and methods. Food samples were collected from 38 black-browed albatross chicks after a returning parent had completed feeding them at Canyon des Sourcils Noirs (49° 41' S, 70° 14' E, southern Kerguelen Island) between 10 and 27 February 1994. An additional 14 incomplete stomach contents were also taken opportunistically during this period. All samples were kept frozen until analysis in the laboratory. Cephalopod flesh and beaks were subsequently removed from the samples and stored in 70% ethyl alcohol. Squid beaks were identified by comparison with material held in our own reference collection and by the use of Clarke (1986). Since 2 distinct species of *Todarodes* with similar beaks occur in Kerguelen waters, *Todarodes* sp. in the text refers to both *T. angolensis* and *T. filippovae* (see 'Discussion'). The term Ommastrephidae sp. was applied when eroded ommastrephid beaks did not allow differentiation among the 3 species (*T. angolensis*, *T. filippovae*, *Martialia hyadesi*) or when only ommastrephid mantle and/or gladius were found in stomach contents. Lower rostral length (LRL) was measured to the nearest 0.1 mm using Vernier calipers. Allometric equations given by Clarke (1986) and Rodhouse & Yeatman (1990) were used to estimate dorsal mantle length (ML) and whole wet body mass.

Nine satellite transmitters [seven T2038 Toyocom (Toyo Communication Equipment Ltd, Minato-ku, Tokyo, Japan) and two 100 Microwave (Microwave Telemetry Inc., Columbia, MD, USA) platform transmitter terminals] were used successively on a total of 16 individual breeding black-browed albatrosses, thus allowing the recording of 1290 locational fixes during 35 foraging trips in February 1994. Birds visiting their chicks for feeding were captured and fitted with the transmitters, which were attached directly to the back feathers using adhesive tape. The transmitters were then left on the birds during 1 to 4 successive foraging trips before being recovered at the next feeding visit. Satellite fixes were obtained through the Argos system and the data were analysed following Weimerskirch et al. (1993).

Results. In February 1994, the mean (\pm SD) duration of foraging trips of black-browed albatrosses fitted with transmitters was 4.2 ± 3.8 d (range: 0.7 to 21.0 d, $n = 35$). Satellite locations indicate that during these trips albatrosses foraged mainly over the inner shelf

break of Kerguelen Island, only 18% of the locational fixes being situated over deeper water (>1000 m), i.e. the outer shelf break and oceanic area (Fig. 1A). The map clearly indicates that birds foraged in northern, eastern and southern waters but never on the western Kerguelen shelf, i.e. rarely W of 68° 30' E. Four areas showed large numbers of locational fixes. One area along the coast indicated the proximity of the breeding colony. Two other areas were situated on the inner shelf break, the largest and more important zone being N-NE at a distance of 150 to 200 km from the colony. The smallest was in the South, at a distance of 125 km. The fourth zone was a bank, cited as New Bank in Ensor & Shaughnessy (1990) or as Shell Bank on the bathymetric chart (Heard Island, Australian Antarctic Division, 1995), situated 480 km away from the colony at about 51° 40' S, 76° 30' E (Fig. 1A).

From a total of 6, 3 food samples regurgitated by chicks recently fed by an adult fitted with a satellite transmitter contained fresh remains of ommastrephid squids. The feeding trips of these 3 adult albatrosses are depicted in Fig. 1B–D. Two of them foraged in the N-NE area, where they caught 1 individual of *Todarodes* sp. and 1 unidentified ommastrephid, respectively (Fig. 1C, D). The third albatross preyed upon 3 *Martialia hyadesi* over the distant New Bank (Fig. 1B). On their way back from the foraging grounds, albatrosses flew quickly to the colony. For example, the first 2 birds spent 6 and 8.5 h, respectively, on their return trips from the N-NE area (Fig. 1C, D), and the third bird flew for 22 h to return from New Bank to its breeding colony (Fig. 1B). Interestingly, the squids caught by the latter bird were more fully digested than those taken by the 2 other albatrosses coming from a less distant fishing area.

Analysis of both accumulated beaks and fresh remains in the 38 complete regurgitations of black-browed albatross chicks gave a total of 229 individuals of ommastrephid squids, these squids occurring in 87% of the samples (Table 1). When considering all

Table 1 Ommastrephid squids in 38 complete stomach contents of black-browed albatross *Diomedea melanophrys* chicks from Canyon des Sourcils Noirs, Kerguelen Island

	No. of items	No. of stomachs	% Frequency of occurrence
Ommastrephidae	229	33	86.8
<i>Martialia hyadesi</i>	45	17	44.7
<i>Todarodes</i> sp.	40	16	42.1
Medium	37	14	36.8
Large	3	3	7.9
Ommastrephidae sp.	144	23	60.5

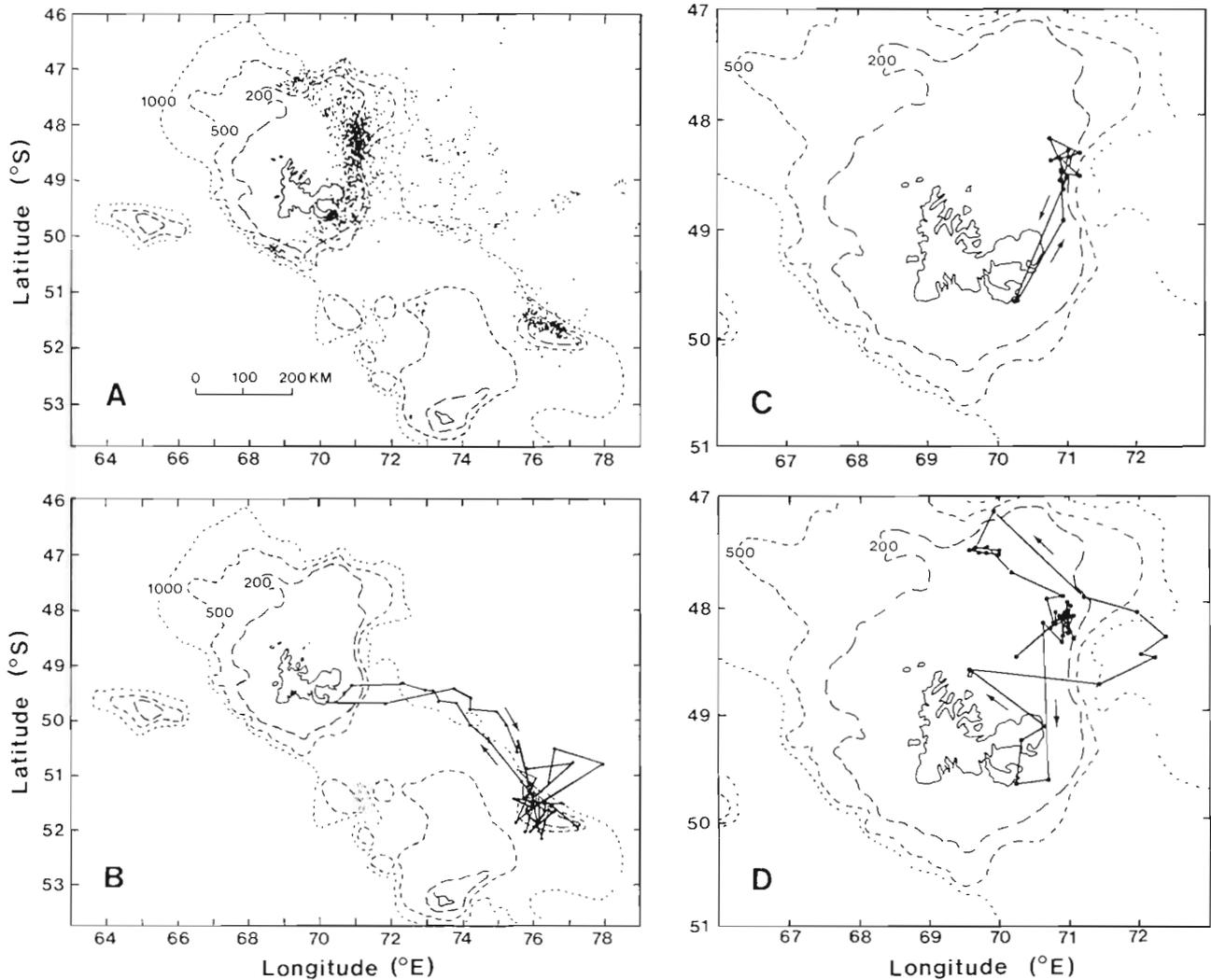


Fig. 1 (A) Distribution of 1290 satellite locational fixes of black-browed albatrosses *Diomedea melanophrys* from Kerguelen Island during the chick-rearing period, and (B, C, D) detailed tracks of individual foraging trips performed by 3 different birds. Bird B caught 3 individuals of *Martialia hyadesi*, Bird C 1 Ommastrephidae sp., and Bird D 1 *Todarodes* sp. Each data point corresponds to 1 satellite fix, and straight lines were drawn between consecutive fixes to delineate tracks of foraging trips. Arrows indicate flight direction

52 samples, upper and lower beaks of ommastrephids amounted to 55% ($n = 348$) of the accumulated squid beaks. Beaks of ommastrephids were also those most often regurgitated in association with partially digested buccal crowns and mantles (90% of the squid fresh remains, $n = 28$).

The squid diet was equally dominated in terms of numbers and percent frequency by *Martialia hyadesi* and *Todarodes* sp. (Table 1). The size-frequency distribution of the LRL for *M. hyadesi* shows a single peak (Fig. 2), the mean value (\pm SD) being 4.5 ± 0.3 mm (range: 3.9 to 5.2 mm). The ML of *M. hyadesi* estimated from LRL was 235 ± 8 mm (218 to 254 mm) and the mean body mass 231 ± 28 g (175 to 301 g). Two size

classes of *Todarodes* sp. beaks were found (Fig. 2). The main peak occurred for a LRL of 5.1 ± 0.4 mm (4.4 to 5.7 mm), which corresponds to an estimated ML and body mass of 198 ± 15 mm (171 to 225 mm) and 219 ± 44 g (146 to 303 g), respectively. Two large lower beaks (9.9 and 10.6 mm LRL) of *Todarodes* sp. were also found as accumulated items; they belonged to squids with an estimated ML of 397 and 428 mm and an estimated mass of 1421 and 1759 g, respectively.

Discussion. To our knowledge, this study is the first to report the species and locality of previously unknown marine resources using both dietary analysis and satellite tracking of top predators. Ommastrephid squids from Kerguelen waters were previ-

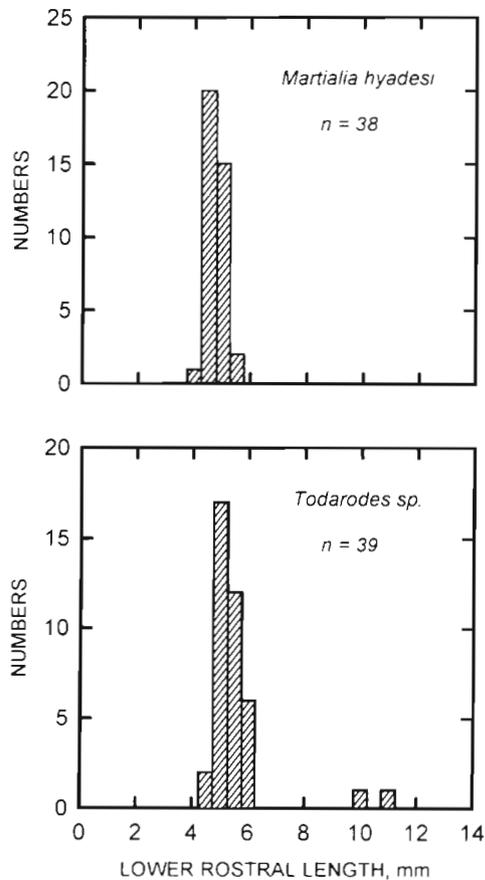


Fig. 2. Frequency distribution of lower rostral length of *Martialia hyadesi* and *Todarodes sp.* in the diet of black-browed albatrosses *Diomedea melanophrys* from Kerguelen Island

ously known from only a few specimens (Duhamel & Piatkowski 1993), including only 1 individual of *M. hyadesi* (Piatkowski et al. 1991). The food and foraging trips of breeding black-browed albatrosses indicate the common occurrence of juvenile *Martialia hyadesi* and *Todarodes sp.* over the upper slope east of Kerguelen Island in February 1994. Ommastrephid squids were also a main part of the black-browed albatross' diet in other years (authors' unpubl. data), thus confirming their importance for the nutrition of this top-predator species and strongly suggesting that they are a predictable marine resource in Kerguelen waters.

In agreement with a previous study using dyed birds (Weimerskirch et al. 1988), satellite tracking shows that breeding black-browed albatrosses from the colony of Canyon des Sourcils Noirs travel and forage on the shelf, shelf break and adjacent banks east of 68° 30' E during the rearing period. The concentration of birds in the 3 main feeding zones is not related to the presence of fishing vessels, as none was operating in

these areas in February 1994. In the present study, the analysis of individual trips furthermore indicates that birds spent much of their time foraging over the inner shelf break area and New Bank, where the water depth was in the range of 200 to 1000 m. They then returned in an almost straight line from these areas to the colony in a few hours to deliver the partially digested food to their chicks. The fact that a large number of crowns and mantles of ommastrephid squids were found in the chicks' stomach contents suggests that the squids were caught recently by the adults and were concentrated on the Kerguelen shelf break and New Bank. This hypothesis is supported by satellite fixes from 3 trips of individual birds that fed their chicks with ommastrephid squids (Fig. 2). Such a localisation of *Martialia hyadesi* and *Todarodes sp.* on the shelf break agrees with the known habitat characteristics of these species. Off the Namibian and South African coast, *T. angolensis* is mainly found on the upper continental slope (Laptikhovskiy 1989, Roelleveld 1989, Villanueva & Sanchez 1989). In the South Atlantic, *M. hyadesi* was caught both on the upper slope of the Patagonian shelf and near the Antarctic Polar Front (Rodhouse 1991), this front lying close to the Kerguelen archipelago (Park et al. 1993).

The foraging behaviour of black-browed albatrosses in Kerguelen waters emphasizes the importance of slope areas for the nutrition of albatrosses. Satellite tracking of wandering albatrosses from Crozet Island indicates that, when performing trips of short duration, this species feeds on the shelf break (Weimerskirch et al. 1993, Weimerskirch et al. 1994). Observations at sea confirm that trend. For example, numerous albatrosses of different species forage over the continental slope off southeastern Australia outside the breeding season (Wood 1992).

The outer shelf and inner shelf break north and east of Kerguelen Island are known as productive zones subject to the influence of a NE meander of the Antarctic Polar Front (Plancke 1977, Park et al. 1993). This peculiar hydrological feature induces high phytoplankton production and, consequently, large aggregations of zooplankton and fish, including myctophid fish (see review in Duhamel 1993), which form the bulk of the food of *Martialia hyadesi* in the South Atlantic (Rodhouse et al. 1992). Along with the visual observation of fur seals at sea (Ensor & Shaughnessy 1990), the foraging behaviour of black-browed albatrosses over New Bank suggests that aggregations of marine organisms also occur there. The study of the food and feeding ecology of top predators appears therefore a successful and relatively cheap way to collect useful information on marine ecosystems and food webs from remote areas, thus allowing the identification of productive zones.

Our data confirm the circumpolar distribution of *Martialia hyadesi* in the vicinity of the Antarctic Polar Frontal Zone (Piatkowski et al. 1991, Rodhouse 1991). All specimens of *M. hyadesi* eaten by black-browed albatrosses from Kerguelen belonged to the same size class and were juveniles, as indicated by the wings of the lower beak that were undarkened or just beginning to darken. In South Georgia, both black-browed and grey-headed albatrosses prey massively upon young, immature *M. hyadesi* (Rodhouse et al. 1990, Rodhouse & Prince 1993), and annual consumption of *M. hyadesi* by known predators in the Scotia Sea has been estimated to be 330 000 t (Rodhouse et al. 1993). The present study is the first to find substantial numbers of that ommastrephid squid in the diet of a cephalopod feeder away from the South Georgia region, suggesting that *M. hyadesi* may also be an important prey species for top predators in other poorly known areas located in the Subantarctic-Antarctic zone.

Similar to the case for *Martialia hyadesi*, all but 3 individuals of *Todarodes* sp. eaten by black-browed albatrosses were juveniles, the wings of lower beaks being undarkened. The 3 remaining individuals were adult squids of large size with wings of the lower beak fully keratinized. Eight well preserved ommastrephid squids were collected in Kerguelen waters in February 1994 either as bycatches in bottom trawls or in stomach contents of Patagonian toothfish. There was 1 specimen of *M. hyadesi* and 7 individuals of *Todarodes angolensis*, a species previously unknown from that area (authors' unpubl. data). Interestingly, the specimen of *M. hyadesi* (LRL: 4.1 mm) belonged to the same size class as that eaten by the black-browed albatross, and the 7 *T. angolensis* were either juvenile (LRL: 5.1 ± 0.4 mm, $n = 5$) or adult squids (LRL: 11.0 and 11.6 mm), like those found in the albatross diet. These results obtained from both predators and hauls at the same time of the year suggest that only 1 size class of *M. hyadesi* and 2 of *Todarodes* sp. occurred in Kerguelen waters in February 1994. They also suggest that *T. angolensis*, and not the closely related species *T. filippovae* that was also found in the area (Duhamel & Piatkowski 1993), was the species of *Todarodes* eaten by albatrosses.

Most ommastrephid mantles showed marks of several wounds made by the bird's beak, suggesting that the juvenile squids were probably caught alive or moribund, but not dead. Because black-browed albatrosses sample only the top 5 m of seawater (Prince et al. 1994), juveniles of *Martialia hyadesi* and *Todarodes* sp. must commonly occur in the epipelagic waters surrounding Kerguelen Island. Research cruises aboard fishing vessels in other areas confirm the presence of young *M. hyadesi* (Rodhouse 1991) and *T. angolensis*

(Laptikhovskiy 1989, Villanueva & Sanchez 1989) near the surface at night performing daily vertical migration. Using stomach temperature sensors, it has recently been shown that wandering albatrosses mainly feed during daylight hours (Weimerskirch & Wilson 1992), and preliminary data indicate that black-browed albatrosses from South Georgia are able to feed both at night and during the day (Croxall & Prince 1994). The use of such devices on Kerguelen birds appears to be a promising way to ascertain if black-browed albatrosses catch squids through vertical migration, i.e. at night and at dawn/dusk, or whether some cephalopods are available in surface waters even during the day.

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