Distribution of seabirds in the African sector of FIBEX

R.W. Abrams
Percy FitzPatrick Institute of African Ornithology,
University of Cape Town, Rondebosch 7700

The paper presents a quantitative account of the abundance of seabirds (excluding penguins) in relation to environmental features in a small area of the Southern Indian Ocean. Plankton-eating birds were abundant. Piscivorous birds were less numerous, but their biomass was slightly higher than that of the planktivores. Cephalopod-eaters and species in a mixed-diet class were widespread, but not as abundant as either planktivores or piscivores. Planktivores were most abundant in a narrow latitudinal band at 61° – 63°S. High planktivore abundance was correlated positively (about 33 %) with relatively warm air and surface-water temperatures and low barometric pressure, and high piscivore abundance (about 32 %) with weak winds and cloudy to wet weather. The abundance of cephalopod-eaters correlated very poorly (about 4 %) with these variables.

Die artikel bied 'n kwantitatiewe opname van die voorkoms van seevoëls (pikkewyne uitgesluit) in samehang met omgewingskenmerke in 'n klein gedeelte van die Suidelike Indiese Oseaan. Planktonvretende voëls was volop. Visvreters was minder talryk, maar hul biomassa was effens groter as dié van die planktonvreters. Die kefalopode-vreters en spesies met 'n gemengde dieet het wyd versprei voorgekom, maar was minder volop as òf die plankton- òf die visvreters. Die planktonvreters was die volopste in 'n smal breedtegraadband van 61° tot 63°S. 'n Hoë voorkomssyfer van planktonvreters was positief (sowat 33 %) met betreklike warm lug- en oppervlakwatertemperatuur en lae barometerdruk gekorreleer; 'n hoë voorkomssyfer (sowat 32 %) vir visvreters het met ligte wind en bewolkte tot reënerige weer saamgehang. Die voorkomssyfer van kefalopode-eters het swak (4 %) met hierdie veranderlikes gekorreleer.

Introduction

During the austral summer of 1980/1981, an international survey was carried out, as part of BIOMASS (Biological Investigations of Marine Antarctic Systems and Stocks), in order to gain information on the distribution and abundance of krill *Euphausia superba* and its predators in the Southern Ocean (Anon. 1977). The survey, known as FIBEX (First International BIOMASS Experiment), was made in areas believed to contain dense concentrations of krill (Mauchline 1980).

This paper gives a preliminary account of the distribution of pelagic seabirds (excluding penguins because they are difficult to detect and count at sea) in the FIBEX sector of the Southern Indian Ocean surveyed by South Africa. More particularly, the report deals with the abundance of seabirds in relation to selected environmental features, in a preliminary assessment of the usefulness of seabirds as indicators of peculiar oceanic biotopes and prey populations.

Materials and methods

The M.V. *S.A. Agulhas* operated from 16 February to 10 March, 1981, in an area bounded by 59° and 69°S and 15° and 30°E (Fig. 1). All birds flying past, and passed by, the moving ship (mean speed = 23,4 km/h) in a 1-km-wide transect were recorded as described by Griffiths (1981), during 585 10-minute seabird observations (referred to as stations). Barometric pressure, air and surface-water temperatures, wind strength (Beaufort scale) and weather (cloud cover and precipitation, scaled from 1 (clear) to 6 (storm)) were recorded at each station.

The avifauna was analysed according to species richness (BSR = total number of species), Shannon-Wiener diversity index (BSD = H = εp log p, where pi is the proportion of the ith species in the community), abundance (number of individuals) and biomass (total live-weight of all birds) at each station in relation to four principal diet and four feeding-method categories (Appendix 1). Patterns of seabird dispersion were examined from computer-drawn maps, using the SOPS plotting programme (Abrams *et al.* 1982). Linear and stepwise multiple regression and factor analysis (PCA) were used to characterise relationships within the avifauna and between the birds and their environment. Linear correlation matrices, including all biotic and abiotic parameters, facilitate

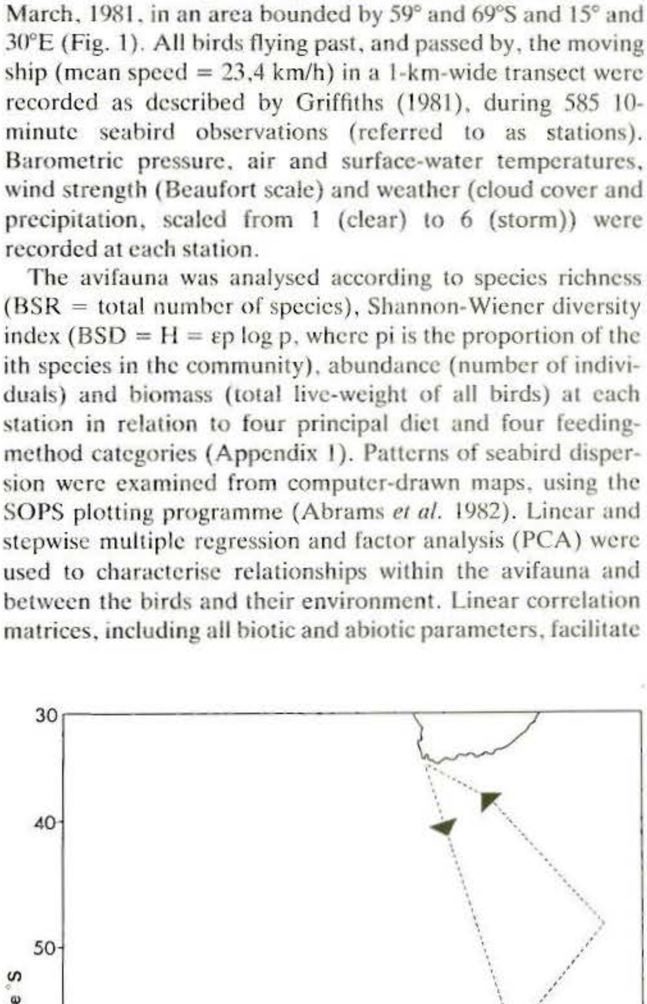

Fig. 1. Cruise track of the M.V. *S.A. Agulhas* in the South African sector of FIBEX in the Southern Indian Ocean, 16 February-10 March, 1981.

Appendix 1

Principal food-type and feeding-method groups, body-weights and percentage abundance (numbers of individuals) of species observed in the FIBEX sector of the Southern Ocean. Food and feeding classification based on data in Ashmole (1971) and unpublished records taken from the FitzPatrick Institute which also maintains records of bird weights.

Food-type	Feeding-method	Species	Body-weight (kg)	Abundance (%)
Plankton	Surface-filter	*Pachyptila* spp., prions	0,15	44,50
	Surface-seize	*Halobaena caerulea*, blue petrel	0,20	16,55
	Dip/patter	*Oceanites oceanicus*, Wilson's stormpetrel	0,04	0,38
		Oceanodroma leucohora, Leach's stormpetrel	0,05	0,34
Cephalopods	Surface-seize/scavenge	*Diomedea exulans*, wandering albatross	8,60	0,06
	Surface-seize/scavenge	*Diomedea melanophris*, blackbrowed albatross	3,50	0,02
	Surface-seize/scavenge	*Diomedea cauta*, shy albatross	4,10	<0,01
	Surface-seize/scavenge	*Diomedea chrysostoma*, greyheaded albatross	3,60	0,02
	Surface-seize/scavenge	*Phoebetria fusca*, sooty albatross	2,50	0,05
	Surface-seize/scavenge	*Phoebetria palpebrata*, lightmantled sooty albatross	2,70	0,43
	Surface-seize/scavenge	*Daption capense*, pintado petrel	0,45	0,13
	Surface-seize/scavenge	*Procellaria aequinoctialis*, whitechinned petrel	1,21	1,36
	Surface-seize/scavenge	*Pterodroma lessonii*, whiteheaded petrel	0,75	0,24
	Surface-seize/scavenge	*Fulmarus glacialoides*, Antarctic fulmar	1,00	0,24
Fish	Pursuit-plunge	*Puffinus griseus*, sooty shearwater	0,79	20,50
	Dip/patter	*Sterna paradisaea*, Arctic tern	0,13	9,86
Mixed	Surface-seize/scavenge	*Macronectes giganteus*, southern giant petrel	4,10	0,13
	Surface-seize/scavenge	*Thalassoica antarctica*, Antarctic petrel	0,70	0,80
	Surface-seize/scavenge	*Pagodroma nivea*, snow petrel	0,30	1,23
	Surface-seize/scavenge	*Pterodroma brevirostris*, Kerguelen petrel	0,33	3,37

focusing on noteworthy patterns. Use of this technique does not imply tests of hypotheses, since inferential statistics require certain assumptions to be met which are not valid for these data. Multi-colinearity and non-normal distributions were adjusted when multiple regressions were calculated between diet groups and physical variables. These analyses are not, however, meant to be taken as inferential tests of hypotheses, but rather as characterisations of associations between seabirds and major environmental features.

Results

Seabirds tended to be clumped (Fig. 2) in the area between 61° – 63°S, especially plankton-eaters (Fig. 3). During this study two species and 25 birds were recorded at an average observation station (Table 1). Planktivores (including krill eaters) contributed the greatest numbers of species and individuals per station (Tables 2 and 3). Although there were relatively few piscivorous species (Appendix 1), they were abundant and accounted for a biomass slightly higher than that of the planktivores. Cephalopod-eaters, and those species placed in a mixed-diet class (species not classifiable as either predominantly plankton-, cephalopod- or fish-eaters), were widespread, but not as abundant as either planktivores or piscivores (Tables 2 and 3). Correlations between the principal diet groups and the feeding methods used by the birds (Table 4), and between each of the four diet and feeding method groups separately (Tables 5 and 6), showed that there was no trend in co-occurrence between to different diet groups. Planktivores and piscivores co-occurred together but were not entirely coincident, in a narrow latitudinal band at 61° – 63°S (Figs. 3 and 4).

The abundance of planktivores and piscivores was correlated with 33 per cent and 32 per cent, respectively, of the variation of the physical parameters considered here; not more than 4 per cent of the variation of abundance of cephalopod-eaters was explained by these variables (Table 7). High planktivore abundance was associated with relatively warm air and surface-water temperatures and low barometric pressure. High planktivore abundance was also associated with cloudy to wet weather and relatively calm winds (Fig. 5). High piscivore abundance was associated with high barometric pressure, weak winds and cloudy weather (Table 7, Fig. 5). In addition to these primary biotic-abiotic associations, the various seabird diet groups were associated with other combinations of abiotic variables (Table 7).

Discussion

In the Southern Ocean, avian abundance and biomass tend to be high near the Subtropical Convergence (39° – 43°S), sub-Antarctic and Polar Fronts (47° – 48°, 51° – 53°S, respectively; Valentine & Lutjeharms 1983) and the Antarctic Continental Water Boundary (variable), but species richness and abundance do not usually reach levels observed in neritic regions (Griffiths *et al.* 1982). The overall abundance and non-random

Table 1

Mean species richness (BSR), diversity (BSD), abundance (number of individuals) and biomass (kg live-weight) of seabirds (excluding penguins) at 585 stations in the South African sector of FIBEX in the southern Indian Ocean.

	BSR	BSD	Abundance	Biomass
Mean	2,01	0,44	25,24	7,82
S.D.	1,29	0,43	39,14	25,77
Range	0-7	0-1,83	0-1574	0-322,50
Total			15608	4657

Table 2

Mean abundance (number of individuals) of seabirds (excluding penguins) according to four principal food-type classes at 585 stations in the South African sector of FIBEX in the southern Indian Ocean.

	Food type			
	Plankton	Cephalopods	Fish	Mixed
Mean	16,44	0,69	6,62	1,49
S.D.	81,49	2,22	34,79	3,11
Range	0-1573	0-44	0-460	0-32

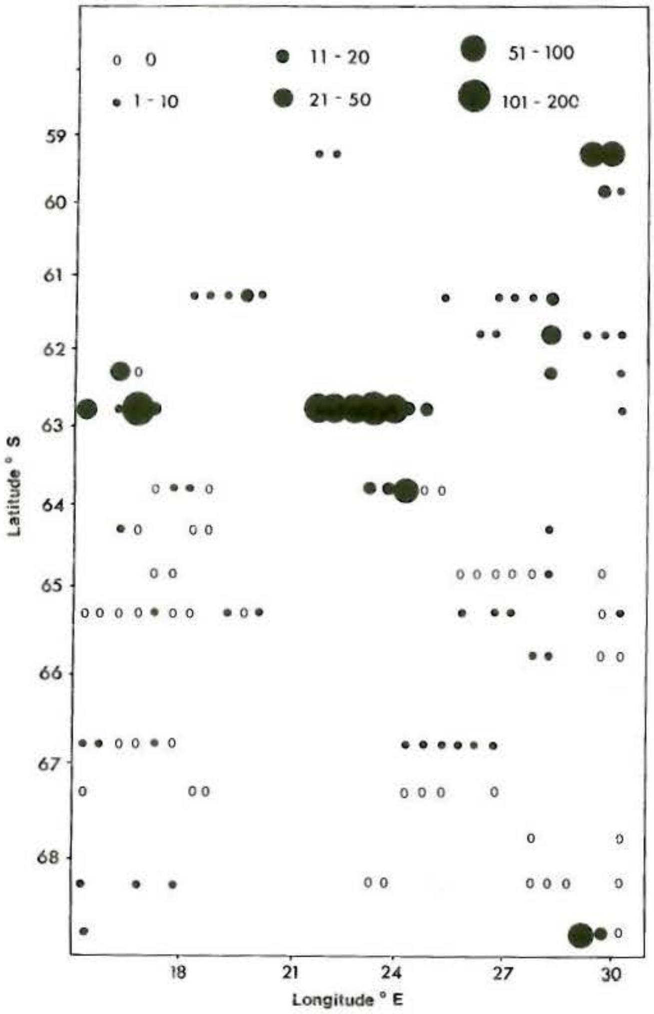

Fig. 2. The distribution and mean abundance (no. individuals) of seabirds (excluding penguins) according to half-degree quadrats in the South African sector of FIBEX in the southern Indian Ocean, 16 February-10 March, 1981.

Table 3

Coefficients of correlation (r) between species richness (BSR), diversity (BSD), abundance (number of individuals) and biomass, and food-type groups of seabirds (excluding penguins) at 585 stations in the South African sector of FIBEX in the southern Indian Ocean.

Food type	BSR	BSD	Abundance	Biomass
Plankton	0,526	0,230	0,826	0,521
Cephalopods	0,469	0,419	0,251	0,285
Fish	0,238	0,054	0,540	0,730
Mixed	0,454	0,408	0,306	0,084

Table 4

Coefficients of correlation (r) between food-type and feeding-method groups of seabirds (excluding penguins) at 585 stations in the South African sector of FIBEX in the southern Indian Ocean.

Feeding method	Food type			
	Plankton	Cephalopods	Fish	Mixed
Surface-seizing	0,398	0,422	-0,053	0,613
Surface-filtering	0,945	0,156	0,202	0,048
Pursuit-plunging	0,246	0,002	0,906	-0,136
Dipping/pattering	-0,100	-0,081	0,304	0,248

Table 5

Coefficients of correlation (r) between food-type groups of seabirds (excluding penguins) at 585 stations in the South African sector of FIBEX in the southern Indian Ocean.

Food-type	Plankton	Cephalopods	Fish
Cephalopods	0,132	1,000	
Fish	0,184	-0,037	1,000
Mixed	0,045	0,078	-0,021

Table 6

Coefficients of correlation (r) between feeding-method groups of seabirds (excluding penguins) at 585 stations in the South African sector of FIBEX in the southern Indian Ocean.

Feeding-method	Surface-filtering	Pursuit plunging	Dipping/Pattering
Surface-seizing	0,240	-0,108	0,093
Surface-filtering	1,000		
Pursuit-plunging	0,287	1,000	
Dipping/Pattering	-0,171	-0,081	1,000

Table 7

Coefficients of determination (R^2) between abundance (no. individual birds) of four food-type groups of seabirds (excluding penguins) and subsets of five physical variables (BAR = barometric pressure. AIR = air temperature, WAT = surface-water temperature, WIN = wind strength, WEA = weather) in the South African sector of FIBEX in the southern Indian Ocean. The directional influence of each variable in the regression equation is indicated (+, −).

Physical variables	Food type			
	Plankton	Cephalopods	Fish	Mixed
BAR	−	−		
AIR	+ 0,33	+ 0,04		
WAT	+	+		
BAR	−		+	
WAT	+ 0,31		+ 0,32	
WIN	−		−	
AIR	+	+	−	−
WAT	+ 0,22	+ 0,04	+ 0,31	− 0,14
WIN	−	+	−	+
BAR	−		+	−
WIN	− 0,16		− 0,32	+ 0,14
WEA	+		+	−
AIR	+	+		
WAT	+ 0,22	+ 0,04		
WEA	+	+		
AIR	+	+	−	−
WIN	− 0,14	+ 0,04	− 0,31	+ 0,14
WEA	+	+	+	−
BAR		−		
AIR		+ 0,04		
WEA		+		
WAT	+		+	−
WIN	− 0,16		− 0,31	+ 0,13
WEA	+		+	−
BAR	−	−		
WAT	+ 0,29	+ 0,01		
WEA	+	+		
BAR		−	+	−
AIR		+ 0,04	− 0,32	− 0,15
WIN		+	−	+

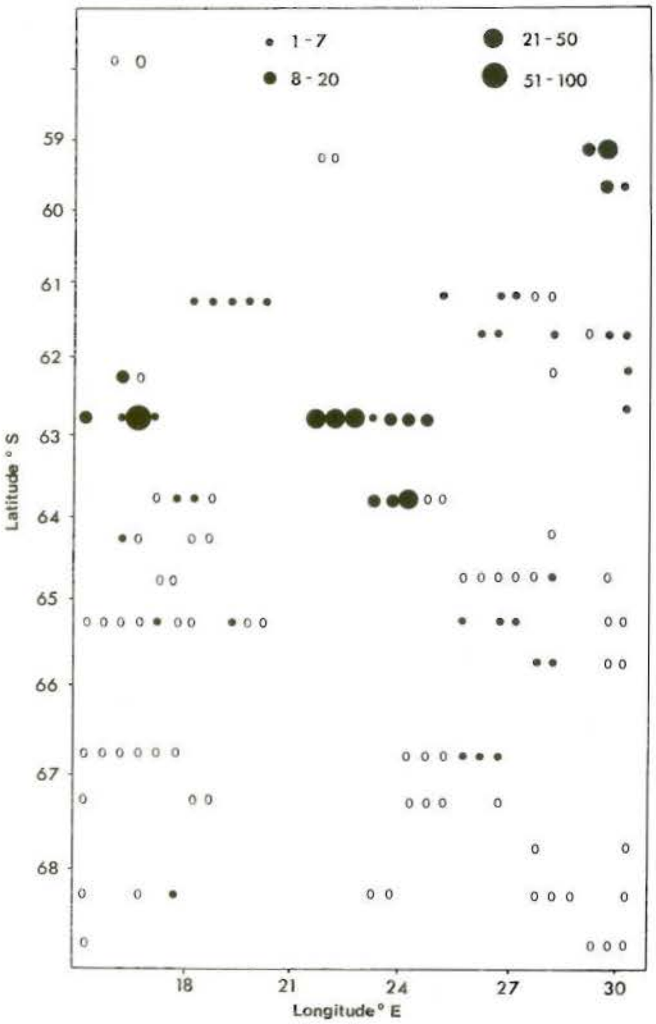

Fig. 3. The distribution and mean abundance (no. individuals) of plankton-eating seabirds (excluding penguins) according to half-degree quadrats in the South African sector of FIBEX in the southern Indian Ocean, 16 February-10 March, 1981.

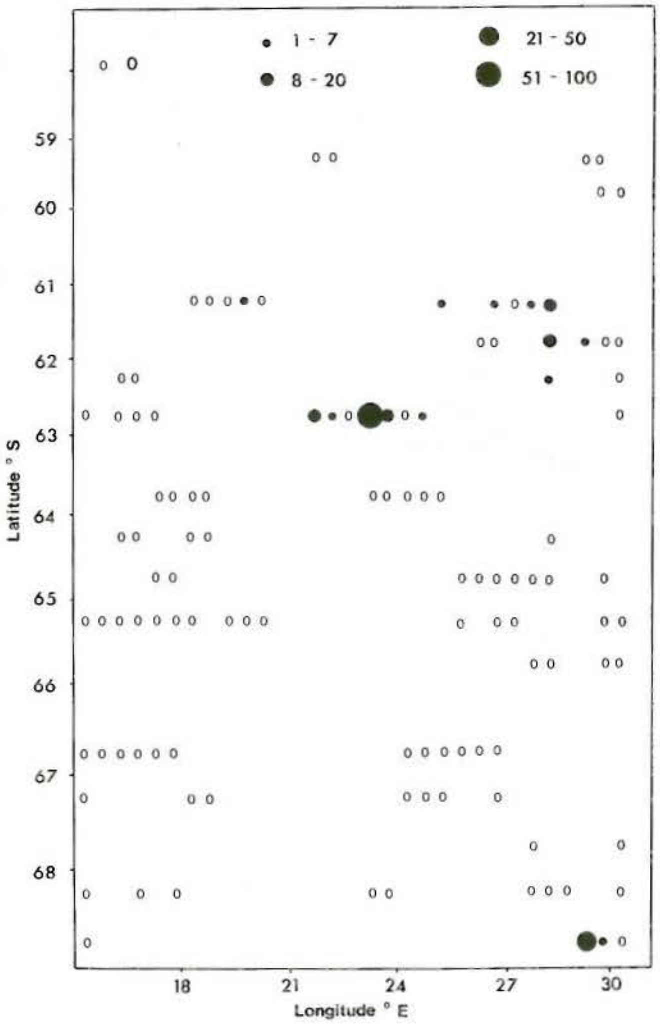

Fig. 4. The distribution and mean abundance (no. individuals) of fish-eating seabirds (excluding penguins), according to half-degree quadrats in the South African sector of FIBEX in the southern Indian Ocean, 16 February-10 March, 1981.

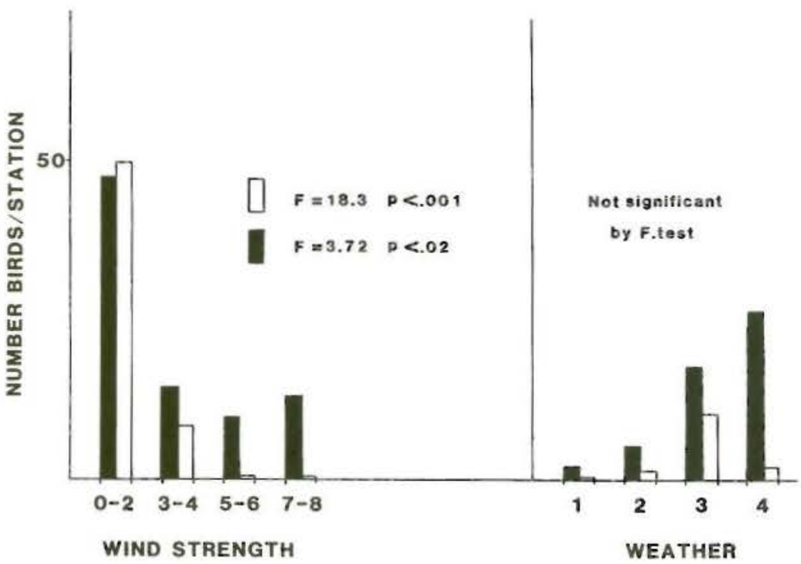

Fig. 5. Mean abundance per 585 stations of planktivorous (solid bar) and piscivorous (open bar) seabirds in association with wind strength (Beaufort scale) (a) and weather (1 = clear to 6 = storm) (b) in the South African sector of FIBEX in the Southern Ocean. Statistical significance by ANOVA (BMDPIV).

distribution of birds in the South African sector of FIBEX was similar to that observed generally in the African sector of the Southern Ocean (cf. Griffiths *et al.* 1982).

In the area considered here, the abundance of planktivores, mostly prions *Pachyptila* spp. and the blue petrel *Halobaena caerulea*, is believed to reflect the birds' response to an abundance of plankton and krill which tend to be concentrated near upwelling zones in the latitudes associated with the Antarctic Continental Water Boundary (Ainley & Jacobs 1981, Deacon 1982, Marr 1962).

The co-occurrence of the main concentrations of piscivorous and planktivorous seabirds in areas of relatively warm water (which could be upwelled subsurface Antarctic water) suggests a dynamic process in the vicinity of 61° – 63°S which enhanced seabird foraging. I propose that a dynamic process, such as a current-meander induced eddy (Petersen *et al.* 1982), passed eastwards through the study area and was detected by planktivorous birds as a patch of enriched water containing elevated nutrient or plankton (including euphausiids) concentrations. Piscivorous and other seabirds were subsequently attracted to the process, perhaps as larger prey were attracted to the plankton (including euphausiids) concentrations. Such a series of events explains the spatio-temporal lag between piscivores and planktivores and the longitudinal patchiness of bird distributions, and merits testing by biological and physical oceanographers. From the bird distribution it appears that prey distribution is not continuous along a front. I feel that the extreme clumping of birds in certain areas can only represent their attraction to concentrated food resources. The low percentage variance explained by correlations of seabirds and abiotic features necessitates careful interpretation of the nature of seabird navigation and foraging behaviour. Multidisciplinary input is needed to determine if the redundancy of seabird-abiotic associations (Table 7) reflects the complicated environment, the use by seabirds of multiple cues in locating prey (see Baker 1972), or, as is most likely, both conditions apply.

The presence of piscivores, chiefly Arctic terns *Sterna paradisaea* relatively close to Antarctica, presumably is associated with an enhanced availability of fish at the Antarctic shelf (Targett 1981), and the presence of ice on which terns can roost. Species in the mixed-diet class, especially the Antarctic petrel *Thalassoica antarctica* and snow petrel *Pagodroma nivea* which breed in Antarctica, were also abundant close to the continent, probably because of the increased availability of food at the ice edges and polynas (Zink 1981, Griffiths 1983), and at oceanic fronts or other dynamic processes created by the East Wind and Circumpolar Currents (Ainley & Jacobs 1981). The Kerguelen petrel *Pterodroma brevirostris* predominated amongst the mixed-diet class observed farther north in the vicinity of 61° – 63°S.

I suspect that planktivores, being relatively small-bodied and requiring frequent meals of small prey items, are more dependent on regular location of patchy sources of abundant food than are larger species. The distribution of large-bodied seabirds, such as albatrosses, is more random since they apparently require to encounter food items less frequently (Griffiths *et al.* 1982). All these speculations are in need of further study. For instance, the possibility of barometric pressure and weather fronts influencing the foraging and dispersion of certain seabirds (Mendelsohn 1981) requires nonlinear analysis which, while beyond the scope of this paper, is underway at present. Temporal lags probably occur between environmental changes and the birds' responses. A better understanding of these lags should begin to emerge when more fine-scale environmental information becomes available. This should allow more rigorous statistical assessment of particular associations between individual species, and trophic groups of seabirds, and their environments. Ultimately, it is these associations which might facilitate the use of seabirds as predictors of prey populations. We are currently analysing much larger data sets, including many more abiotic and biotic variables, than are reported here, in examining the potential usefulness of pelagic seabirds as predictors of peculiar oceanic biotopes and prey populations.

Acknowledgements

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