Seabird distribution and the transport of nutrients from marine to terrestrial ecosystems

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The distribution and abundance of seabirds was studied in the southwest Indian Ocean during March-April 1976. A total of 17 200 birds of 46 species was counted during the survey. Generally, birds were sparsely distributed over the subtropical waters but were more abundant and widespread in the sub-Antarctic zone. Peaks in abundance occurred near the islands and in the vicinity of the subtropical convergence (40°S). The estimated biomass density of the seabirds between 20° and 30°S was 0,2 kg/km²; between 30° and 40°S, 1,6 kg/km² and between 40° and 50°S, 7,7-10,3 kg/km². Different species were encountered at different distances from land, supporting the hypothesis that closely related species tend to occur over different water zones. The distance from land that a seabird must fly to feed during the breeding season is a major determinant of foraging pattern, feeding behaviour, breeding strategy and social organisation. The hypothesis is advanced that these features in turn have an important bearing on the contribution made by each species to the import of nutrients from the marine to the terrestrial ecosystem principally through determining the frequency at which food is brought to the island, the growth rate and energy requirements of chicks and the duration of the breeding season.

Die verspreiding en rykdom van seevoëls in die suidwestelike Indiese Oseaan was vanaf Maart tot April 1976 bestudeer. 'n Totaal van 17 200 voëls van 46 spesies is tydens die opname getel. Oor die algemeen was die voëls in die subtropiese waters yl versprei, maar in die sub-Antarktiese sone was hulle volop en wyd versprei. Die grootste hoeveelheid voëls was naby die eilande en in die omgewing van die sub-tropiesekonvergensie (40°S). Die beraamde biomassa-densiteit van seevoëls tussen 20° en 30°S was 0,2 kg/km²; tussen 30° en 40°S, 1,6 kg/km² en tussen 40° en 50°S, 7,7-10,3 kg/km². Verskillende spesies is op verskillende afstande van die land af teëgekom, wat die hipotese, dat verwante spesies neig om in verskillende water sones voor te kom, ondersteun. Die afstand wat 'n seevoël tydens broeiseisoen van die land moet vlieg om kos te kry is 'n belangrike faktor wat sy kossoek-patroon, voedingsgedrag, aanteling en sosiale organisasie bepaal. Die hipotese word verder geneem daarin dat hierdie kenmerke verder 'n belangrike invloed het op die bydrae wat elke spesie maak tot die invoer van voedingstowwe van die see na landekosisteme hoofsaaklik deur die frekwensie wat voedsel na die eiland gebring word, die groeitempo en energiebenodighede van kuikens en die duur van die broeiseisoen vas te stel.

Introduction

Animals can be important components of nutrient cycles by affecting the amounts of nutrients imported to and exported from ecosystems, by redistributing nutrients within and between ecosystems and by influencing the rates of nutrient circulation. A complete understanding of the functioning of nutrient cycles requires not only an empirical assessment of the nutrient fluxes but also an understanding of the ecological factors which determine animal behaviour and thereby influence the process of nutrient cycling.

Seabirds are particularly suitable for studying the role of mobile animals in the dynamics of nutrient cycling. Most species feed exclusively at sea and when breeding, import nutrients to their terrestrial breeding grounds. The distribution and density of prey and the distance offshore that adults must fly to feed are major determinants of each species' foraging pattern, feeding behaviour, breeding strategy and social organisation (Harris 1977, Nelson 1977).

The object of this paper is to describe the distribution of seabirds in the southwest Indian Ocean during autumn 1976, from which the hypothesis will be advanced that the distance offshore that a species feeds may play a key role in determining the relative contributions made by different species to the nutrient cycles of the island ecosystems in which they breed.

Methods

Observations of birds at sea were made during cruise MD-08 of the MS *Marion Dufresne* from 8 March to 26 April 1976. The ship travelled approximately 18 500 km across the southwestern Indian Ocean, from Réunion (21°00'S, 55°24'E) to the sub-Antarctic islands of Marion and Prince Edward (46°54'S, 37°45'E), the Crozet archipelago (46°24'S, 51°48'E) and Kerguelen (49°30'S, 69°36'E). Cruise tracks and local noon positions are given in Frost, Grindley & Wooldridge (1976).

A total of 152 hours was spent recording the distribution of birds at sea. Observations were made in all weathers from one or other side of the ship's bridge (21 m asl). A 180° horizontal field of view, usually parallel to the ship's course and over which visibility was best, was scanned regularly to an estimated distance of one kilometre. All birds seen during 10-minute sample periods within this area were recorded if they passed across an imaginary line running at right angles from the ship. Birds following the ship were recorded separately at the end of each 10-minute period. Watches of successive 10-minute periods were maintained for at least one hour at a time. Counts were made throughout the day.

Environmental data (sea surface temperature, sea surface conditions, wind speed and direction, cloud cover and visibility), and the ship's position, course and speed were recorded daily at 08h00, 12h00 and 18h00 local time. The great circle distance from nearest land was calculated at the start of each hour of observation. For distances closer than 20 km radar was used for measurement.

In the analyses the standard unit of bird abundance was taken as the number of birds seen per hour. This value included both the sum of all individuals flying past the ship in six successive 10-minute periods and the highest number of

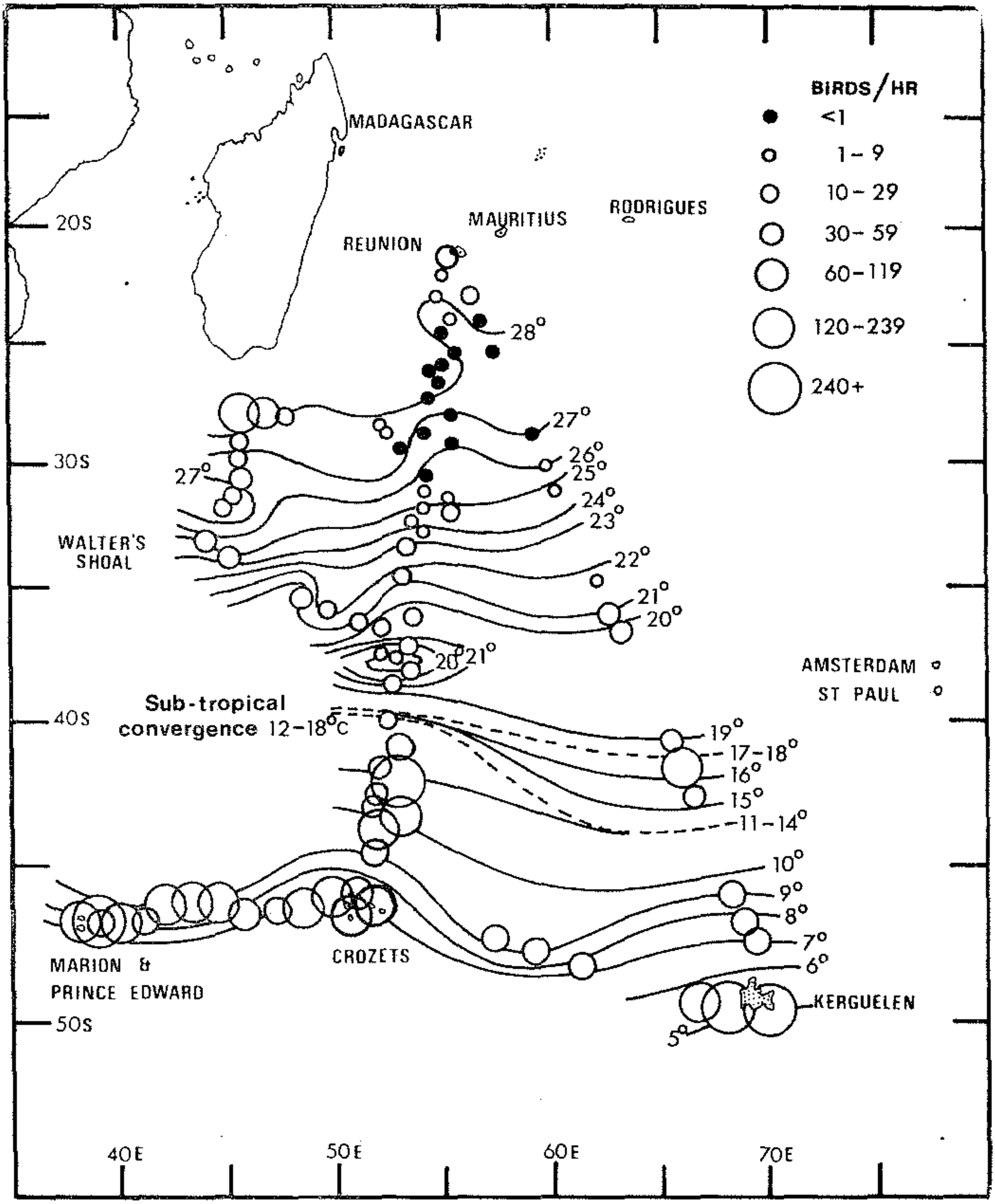

Fig. 1 The distribution and abundance (birds/h) of seabirds in the southwest Indian Ocean, March-April, 1976. Three entries are given for each day, representing the morning, midday and afternoon values.

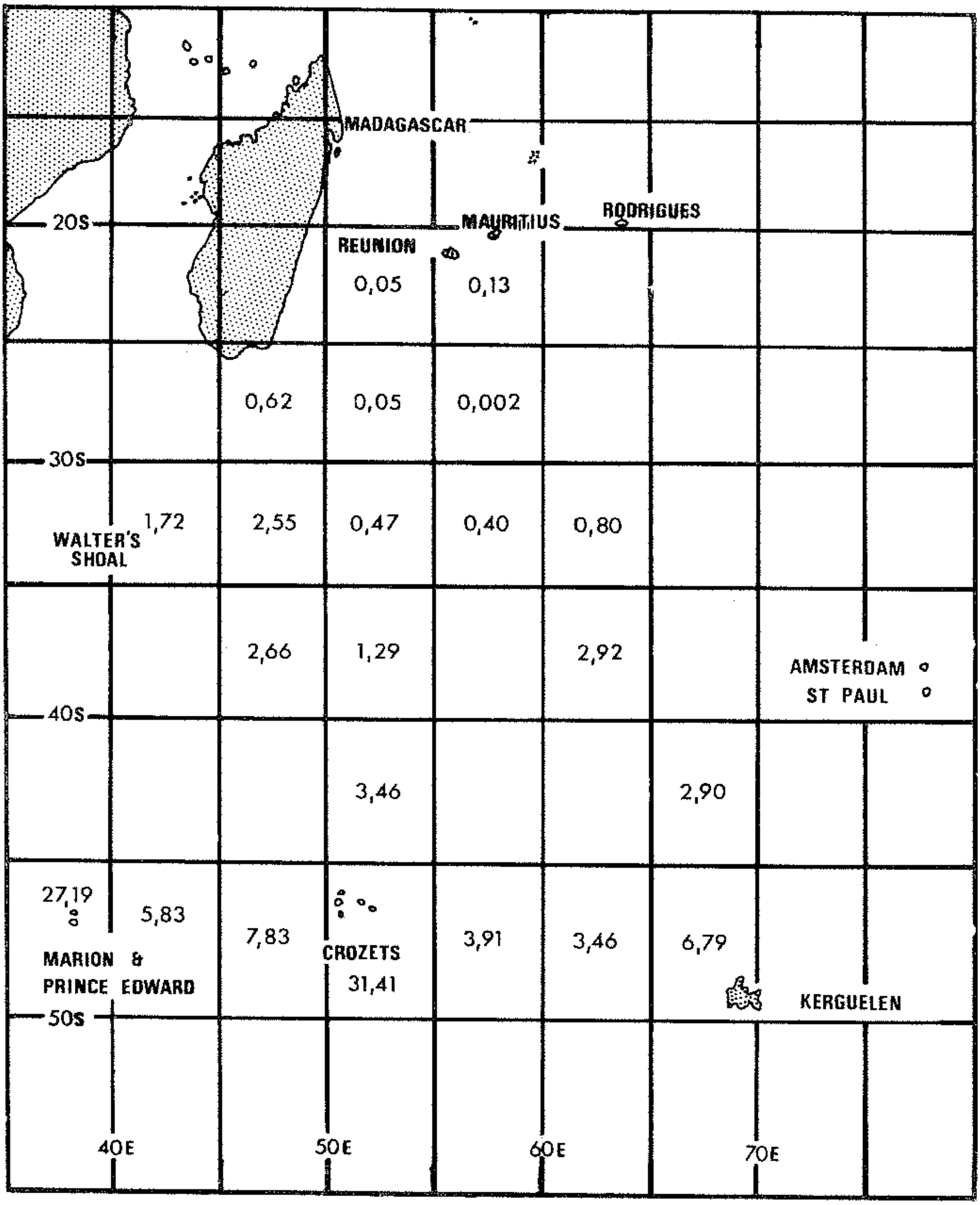

Fig. 2. Biomass density (kg/km²) of seabirds per 5° square in the south-west Indian Ocean.

individuals of each species recorded following the ship during the same sample period.

The estimated density of each species in a given region was calculated from:

$$D_{ij} = x_{ij} / 1{,}85 v_j \text{ (birds/km}^2\text{)}$$

where D_{ij} is the estimated density of species i in region j; x_{ij} is the mean number of individuals of species i recorded per hr in region j and v_j is the mean speed of the ship (in knots) while in region j. The constant 1,85 converts nautical miles to km and the width of the search area is taken to be one kilometre.

Estimates of the biomass density of seabirds in a particular region was calculated from:

$$M_j = \sum_{i=1}^{n} w_i . D_{ij} \text{ (kg/km}^2\text{)}$$

where M_j is estimated biomass density in region j and w_i is the mean mass (kg) of individuals of species i (a list of body mass values used here is housed at the FitzPatrick Institute).

Results

Seabird abundance

A total of 17 200 birds of 46 species was recorded during the survey. The mean number of birds recorded per hr for the periods 06h00-10h59, 11h00-14h59 and 15h00-18h59 are shown in Fig. 1.

Generally, birds were very sparsely distributed over the region 20°-30°S, particularly south of Réunion. The majority of species recorded were tropical, the sooty tern *Sterna fuscata* being the commonest. Large flocks of this species were recorded south of Madagascar, in the vicinity of sea mounts on the Madagascar Ridge. This was also the area of greatest sperm whale *Physeter catodon* abundance (Frost & Best 1976), with which the terns appeared to associate.

The number of seabirds increased between 30°-40°S, mainly because of the increasing presence of numbers of sub-Antarctic seabirds. Seabird abundance was greatest in the vicinity of Walter's Shoal (33°10'S, 43°58'E), in the region of 36°S 63°E and immediately north of the subtropical convergence at approximately 40°S.

Seabirds were abundant and widespread in the sub-Antarctic (40°-50°S) and large concentrations were noted particularly in the vicinity of the islands and in the region of the subtropical convergence. Up to 400 birds/h were recorded in these areas at times. The most frequently recorded species in this zone were the prions *Pachyptila* spp., white chinned petrel *Procellaria aequinoctialis* and soft-plumaged petrel *Pterodroma mollis*. Few penguins were recorded, other than around the islands. Both the macaroni penguin *Eudyptes chrysolophus* and rockhopper penguin *E. chrysocome* were moulting ashore at this time.

Biomass

The biomass of birds (kg/km²) has been calculated for 5° squares between 20° and 50°S (Fig. 2). In the region 20°-30°S biomass was very low (mean = 0,2 kg/km², range 0,002-0,62 kg/km²). Between 30°S and the subtropical convergence at 40°S the mean seabird biomass density was 1,6 kg/km² (range 0,40-2,92 kg/km²).

The sub-Antarctic zone (40°-50°S) mean biomass was 10,3 kg/km². The biomass was greatest around the islands (31,3 kg/km² near the Crozet archipelago and 27,2 kg/km² around Marion and Prince Edward islands) and lowest (2,90 kg/km²) in the vicinity of the subtropical convergence north of Kerguelen. The high biomass recorded near the islands was due largely to the abundance of larger species such as wandering albatross *Diomedea exulans*, white chinned petrels *Procellaria aequinoctialis* and giant petrels *Macronectes* spp. which gathered around the ship whenever it was stationary. Omitting counts made while the ship was stationary from the above estimates, mean biomass for the region was 7,7 kg/km². However, few penguins were recorded and they may be expected to contribute substantially to the overall biomass of the region.

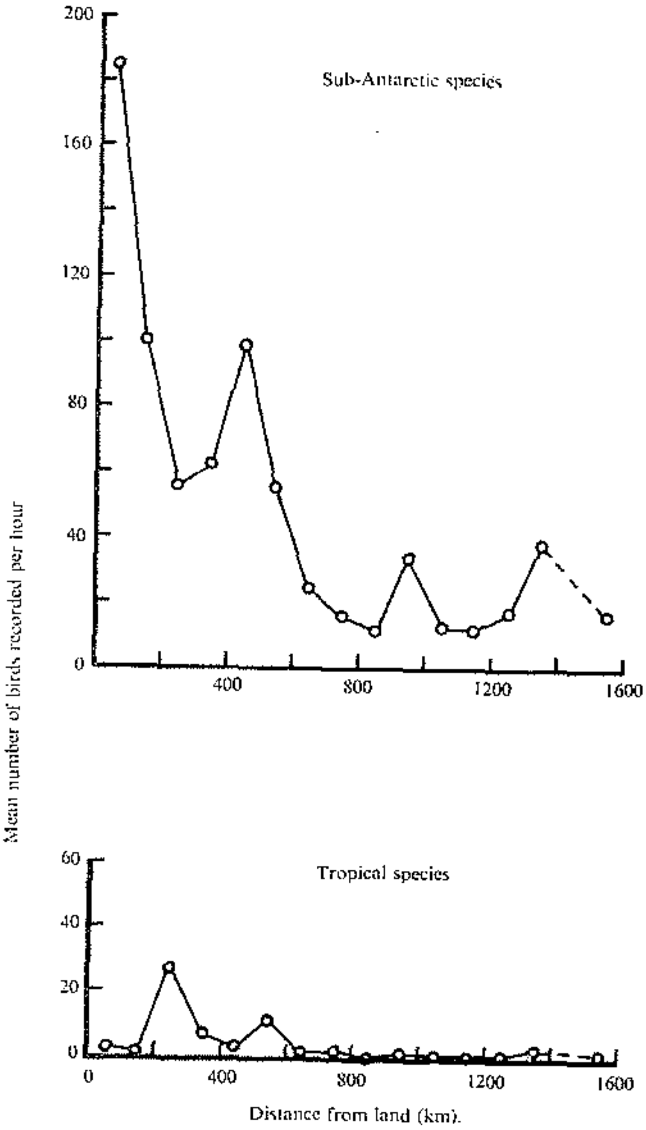

Fig. 3. The distribution of tropical and subantarctic seabirds as a function of distance from nearest land.

Distance from land

The greatest number of tropical seabirds was recorded from 200-300 km from land. (Fig. 3). This corresponds to the peak in abundance of seabirds (mostly sooty terns) recorded south of Madagascar. Few tropical seabirds occurred further than 550 km from land.

Peaks in the abundance of sub-Antarctic seabirds (Fig. 3) occurred within 100 km of the islands; from 400-500 km offshore, 900-1000 km and 1300-1400 km offshore. The abundance of birds close to land represents both those species which feed close to land as well as those which feed further away but which gather near the islands prior to returning to their nests. The peaks of birds occurring from 400-500 km and 900-1000 km offshore correspond to the concentrations of birds in the vicinity of the subtropical convergence north of the Crozets and Kerguelen respectively.

A crude indication of the distances offshore that a species most frequently occurs can be obtained from data on the percentage frequency of occurrence of each species (Table 1) and the mean number of individuals of each species sighted per hour at various distances offshore (Table 2). In the absence of observations on birds feeding at sea, these data may give some indication of the distance offshore that a species travels to feed, though two factors complicate the picture. Firstly, breeding birds must travel to and from their feeding grounds and so are as likely to be counted *en route* as they are to be counted on the feeding grounds. Secondly, it is seldom possible to distinguish non-breeders (failed breeders and immatures) from breeding birds at sea. Non-breeders are probably less constrained to remain near land and thus can range more widely over the ocean, a factor which tends to extend the measured distribution of the birds from land.

In spite of these complications it is possible to recognise four broad species-assemblages. These are: inshore species, occurring closer than 10 km; coastal species, confined largely to within 100 km from land; offshore species, occurring from 100-400 km from land; and pelagic species which range beyond 400 km (Table 3).

Discussion

Counts of birds at sea may be biased by many variables, including observer acuity, differences in the size and conspicuousness of different species, the movement and speed of the ship, movement of the birds relative to the ship, sea surface conditions, visibility and time of day (Gill 1967, Harris & Hansen 1974). Caution is needed therefore in analysing and interpreting data, and this attempt at quantification should be viewed as an aid to clarifying the pattern of seabird distribution and abundance observed during the cruise.

The data presented here show that seabird abundance and estimated biomass density in the southwest Indian Ocean in March-April varies considerably with latitude and that species tend to show reasonably distinct distributions with respect to distance from land. Seabird distribution and abundance is determined largely by the distribution and density of prey (Ashmole 1971, Nelson 1977), which in turn is related to surface water zonation, vertical and horizontal water movements, availability of dissolved nutrients and primary productivity (Murphy 1936, Ashmole 1971).

The distribution and abundance of seabirds in the subtropical zone of the Indian Ocean appears to reflect variations in oceanic productivity. Seabirds were most abundant along the Madagascar Ridge, a region of known high primary production (Koblentz-Mishke, Volkovinsky & Kabanova 1970). Conversely, there was a dearth of seabirds south of

Table 1

Percentage frequency of occurrence of different seabird species at various distances from land.[1]

Species	Distance offshore (km)							
	1–25	26–100	101–225	226–400	401–625	626–900	901–1225	1226–1600
Diomedea exulans	100	100	93	100	76	64	59	100
Diomedea melanophris	35	67	33	52	5	11	0	0
Diomedea chlororhynchos	9	27	0	5	19	25	25	0
Diomedea chrysostoma	61	80	73	57	24	0	0	0
Phoebetria fusca	70	40	67	90	62	32	8	0
Phoebetria palpebrata	78	93	40	14	5	4	0	0
Daption capense	35	47	13	0	0	0	0	0
Halobaena caerulea	43	67	27	38	19	0	0	0
Pachyptila spp.	100	100	100	100	81	25	6	0
Pterodroma lessoni	9	40	40	43	33	0	0	0
Pterodroma brevirostris	65	93	60	19	24	0	0	0
Pterodroma macroptera	70	93	73	81	81	36	49	86
Pterodroma mollis	83	87	93	100	86	75	68	100
Procellaria aequinoctialis	96	93	100	100	90	96	82	100
Procellaria cinerea	65	100	67	76	52	0	2	0
Oceanites oceanicus	48	67	20	0	33	54	33	43
Fregetta tropica	78	93	87	71	67	7	4	100
Pelecanoides spp.	87	93	67	10	14	0	0	0
Catharacta antarctica	52	60	27	43	5	3	2	0
Hours of observation	23	15	15	21	21	28	51	7

[1]Percentage frequency of occurrence of species $= \frac{\text{No. of hourly periods in which species was recorded}}{\text{Total number of hourly periods}} \times 100$

Table 2

Mean number of individuals of different seabird species recorded per hour at various distances from land.

	Distance offshore (km)							
Species	1–25	26–100	101–225	226–400	401–625	626–900	901–1225	1226–1600
Diomedea exulans	12,9	11,1	5,9	6,0	3,0	1,3	1,7	5,7
Diomedea melanophris	0,4	2,2	0,5	0,8	0,1	0,2		
Diomedea chlororhynchos	0,1	0,3		0,1	0,6	0,4	0,4	
Diomedea chrysostoma	1,5	2,1	1,5	1,0	0,5			
Phoebetria fusca	1,9	2,2	2,8	3,6	3,1	0,5	0,2	
Phoebetria palpebrata	1,7	2,5	1,2	0,3	0,1	0,1		
Daption capense	2,0	1,5	0,2					
Halobaena caerulea	5,4	36,3	0,3	0,5	0,2			
Pachyptila spp.	53,6	48,2	41,8	41,0	53,9	17,4	0,4	
Pterodroma lessoni	0,3	0,5	1,7	0,7	0,7			
Pterodroma brevirostris	6,4	10,3	2,6	0,2	0,4			
Pterodroma macroptera	4,3	3,2	3,1	3,7	3,5	0,7	1,2	2,1
Pterodroma mollis	6,4	4,3	9,2	8,2	15,0	2,8	3,8	6,8
Procellaria aequinoctialis	17,4	21,1	22,5	23,3	9,1	7,2	5,8	13,3
Procellaria cinerea	3,6	3,3	1,9	2,2	0,9			
Oceanites oceanicus	1,1	17,5	1,9		1,1	4,1	1,5	1,7
Fregetta tropica	9,6	9,6	8,1	8,8	6,8	0,2	0,1	
Pelecanoides spp.	23,7	13,5	1,5	0,1	0,2			
Catharacta antarctica	1,0	1,3	0,3	0,6	0,1	0,1	0,1	
Hours of observation	23	15	15	21	21	28	51	7

Table 3

Groupings of sub-Antarctic seabirds according to the distance offshore that they most frequently occur. Nestling periods are also given (see text for discussion).

Zone Species	Average[a] mass (kg)	Duration of [b] fledgling period (days)
Inshore (< 10 km)		
Phalacrocorax albiventer	2,200	75—80
Larus dominicanus	1,000	42
Sterna vittata	0,140	27—32
Coastal (10–100 km)		
Daption capense	0,450	48
Pterodroma brevirostris	0,334	60
Halobaena caerulea	0,209	56
Pelecanoides spp.	0,130	54
Oceanites oceanicus	0,036	60
Offshore (100–400 km)		
Macronectes spp.	4,400	114
Diomedea chrysostoma	3,600	141
Diomedea melanophris	3,500	135
Phoebetria palpebrata	2,700	143
Catharacta antarctica	1,600	49—59
Procellaria aequinoctialis	1,210	95
Procellaria cinerea	1,028	80—100
Pterodroma lessoni	0,750	102
Fregetta tropica	0,056	65—71
Garrodia nereis	0,032	?
Pelagic (> 400 km)		
Diomedea exulans	8,600	278
Phoebetria fusca	2,500	150
Diomedea chlororhynchos	2,000	130
Pterodroma macroptera	0,580	131
Pterodroma mollis	0,310	95
Pachyptila spp.	0,150	49—55

[a]Data on average body mass derived from various sources and detailed in a list of seabird weights housed at the FitzPatrick Institute

[b]Data on fledgling periods from Mougin (1975), Tickell & Pinder (1975) Watson (1975), Sagar (1978) and Williams (pers. comm.)

Réunion in waters over the Madagascar Basin, a region of low primary productivity (Koblentz-Mishke *et al.* 1970). A similar paucity of seabirds was found by Gill (1967) in the same region.

The abundance and biomass density of seabirds increased with increasing latitude, the increase being particularly marked south of the subtropical convergence at about 40°S. Large concentrations of seabirds were recorded in the vicinity of this convergence and around the sub-Antarctic islands. Productivity in sub-Antarctic waters is not uniform (Watson 1975) and the observed seabird distribution patterns correspond to the likely patterns in zooplankton productivity.

Plankton abundance in the vicinity of Marion Island and Ile aux Cochons (Crozets) was very high (Frost, Grindley & Wooldridge 1976) suggesting the presence of high concentrations of dissolved nutrients and enhanced primary productivity. These may be caused by upwelling near the islands and nutrient enrichment due to run-off from the large seabird colonies on the islands. Additionally, high numbers of seabirds near the islands probably reflect the concentration, near breeding grounds, of birds that feed further out to sea.

The abundance of seabirds in the vicinity of convergences is well known (Ashmole 1971, Watson 1975) and is primarily the result of the concentration of zooplankton in the surface layers as the cold, more productive, sub-Antarctic water sinks beneath the warmer subtropical water. Planktivores such as the prions *Pachyptila* spp. exploit this zooplankton which also attracts squids and fishes. These in turn are taken by albatrosses and the larger petrels.

Though large numbers of birds were recorded in the vicinity of the subtropical convergence in the southwestern Indian Ocean, the biomass was not as high as around the various islands or in intervening areas. This is largely because the most abundant birds in the convergence zone were the smaller petrels and prions which contributed little to overall biomass.

The biomass figures given here are similar to estimates for the southern ocean (Laws 1977), derived from projections of the biomass of seabirds (including penguins) breeding at various localities into the adjacent ocean. However, very few penguins were observed at sea during this cruise. King penguins *Aptenodytes patagonicus* and gentoo penguins *Pygoscelis papua* were only seen close to land, while the majority of adult macaroni and rockhopper penguins were moulting ashore. Prévost (1976) estimated that penguins constitute about 83 per cent of the biomass of all sub-Antarctic seabird stocks, so that when these moulting penguins are taken into account, the biomass of seabirds (at least within 300 km of the islands) is likely to be substantially higher than the estimates obtained during this study.

Few observations were made on birds feeding at sea, primarily because most species feed at night. This made it difficult to demarcate accurately species-specific feeding zones and more research needs to be carried out on this aspect, particularly as seabird distribution patterns are likely to fluctuate seasonally in response to changing spatial patterns of food availability.

Segregation of closely related species when feeding at sea might be inferred from some of the distribution patterns observed here. The two sooty albatrosses *Phoebetria fusca* and *Ph. palpebrata* provide a good example since they overlap extensively in their diets (Berruti 1977) but have segregated distributions when at sea. However, extending this conclusion to other species showing similar distribution patterns is not warranted at this juncture since few data are available on their diets.

The distance from land that a species feeds has an important influence on its breeding biology (Nelson 1977, Harris 1977). Some of the influences that distance to the feeding grounds has on seabird population and breeding biology are summarized in Table 4. The hypothesis is advanced that these features in turn influence the amount and rate of nutrient input to those island ecosystems where seabirds breed.

The amount of nutrient imported to an island by an adult seabird is dependent on its maintenance costs during the land-based phases of its breeding cycle and the energy required by its chick(s) for maintenance and growth. The growth rate of the young will depend on food delivery, food quality and the number of young in the nest (Pearson 1968). The rate at which parents supply food will be influenced by the distance to the feeding ground and the size and availability of food items. The rate of nutrient input to the breeding grounds therefore may be related to the frequency of visits to the island, the amount of food brought and the duration of the period in which the adult continues to feed the chick. Burger, Lindeboom & Williams (1978) have shown that seabirds which feed close to Marion Island and return daily to it, deposit more guano per kg body mass than do those species which feed further away and which return less frequently.

Obviously, the further that an adult must forage from the nest site, the relatively less frequently it can supply food. This can be expected to lead to a reduction in growth rate and an extension of the nestling period and is best illustrated in the gadfly petrels (Table 1). The small Kerguelen petrel *Pterodroma brevirostris* and the larger white headed petrel *P. lessoni* both remain relatively close to land. Nestling periods for these two species are 60 and 102 days respectively (Mougin 1975, Warham 1967) while the small soft-plumaged petrel *P. mollis* and the large great-winged petrel *P. macroptera*, both of which forage pelagically, have nestling periods of 95 and 131 days respectively (Mougin 1975, Despin, Mougin & Segonzac 1972), which are 37 per cent and 22 per cent longer than in *P. brevirostis* and *P. lessoni* respectively.

Table 4
Some influences that distance to food source has on seabird biology

Seabird biology	Inshore and Coastal feeders (0–100 km)	Offshore and Pelagic feeders (> 100 km)
Duration of foraging trip	Short	Long
Rate of food delivery to the nest	Rapid	Slow
Growth rate of chicks	Relatively rapid	Relatively slow
Length of breeding cycle	Relatively short	Relatively long
Size of feeding area	Restricted	Extensive
Population size	Relatively small	Relatively large
Food	Fish and crustaceans	Cephalopods and crustaceans

The duration of the nestling period and the rate of food delivery have two important influences on nutrient input. Firstly, a longer nestling period, with associated greater overall maintenance energy requirements of the chick would lead to greater faecal output on land. Secondly, because feeds are less frequent, the rate of food delivery to the chick is reduced and so nutrient input will be spread over a longer period of time.

A further factor influencing the amount of nutrient input is the population biomass of the different species. The amount of seabird biomass that can be supported by the oceans surrounding the breeding grounds is related to the productivity of the different ocean zones and their area. Species which feed close to land have less area to exploit than pelagic species and so are probably represented by a lower biomass (which in some cases is equivalent to a lower population as well).

To test this hypothesis requires more data on the spatial and temporal distribution of birds at sea, the location of their feeding grounds, the size and composition of their prey, and better information on the frequency of visits to nests and the energy requirements and growth of young. Such knowledge would be fundamental to a better understanding of those factors affecting the process of nutrient cycling.

Acknowledgements

I acknowledge the logistical support provided by l'Administration des Terres Australes et Antarctiques Francaises and the South African Scientific Committee for Antarctic Research during cruise MD-08 of the *Marion Dufresne*. Drs P.M. Arnaud, J-C. Hureau and J.R. Grindley, Cmdr. G. Duranton and M. Mercier are thanked for their cooperation at all times. A. Berruti, A.E. Burger and A.J. Williams provided valuable additional information. Professor G.L. Maclean, Dr P.R. Condy and an anonymous reviewer provided valuable criticism. The research was carried out while I held a postgraduate bursary from the Council for Scientific and Industrial Research.

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A note on winter seal observations in the South Atlantic pack ice

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A winter survey of seals in the marginal zone of the South Atlantic pack ice was carried out in July 1979. An area of 126,1 km² was surveyed from the S.A. Agulhas, *and only crabeater seals* Lobodon carcinophagus *and Kerguelen fur seals* Arctocephalus gazella *were encountered, and in very low numbers.*

'n Winter opname van robbe in die marginale gebied van die Suid-Atlantiese pakys is gedurende Julie 1979 uitgevoer. 'n Oppervlakte van 126,1 km² is vanaf die S.A. Agulhas *gedek en slegs krapvreterrobbe* Lobodon carcinophagus, *en Kerguelen pelsrobbe* Arctocephalus gazella *is in baie klein getalle teëgekom.*

Introduction

The winter cruise (08) of the *S.A. Agulhas* included a brief four-day penetration into the northern zone of the South Atlantic pack ice during July 1979. This brief survey was all that the ship's schedule allowed, and was made in order to obtain some idea of species distribution and density of Antarctic and sub-Antarctic seals in winter. Previous South African seal surveys in the Antarctic region had all been made in summer during January and February (Hall-Martin 1974, Wilson 1975, Condy 1976 and 1977) when the pack ice had retreated far south.

Methods

Pack ice was first encountered at 50°39'S, 09°32'W and the ship came out of the pack ice at 55°58'S, 03°42'W. Positions of the ship's route through the ice during the survey period are shown in Table 1. Observations were made from the ship's bridge 15 m above sea level and were conducted from 10h00 GMT on 27 July 1979 to 16h30 GMT on 30 July 1979. Observations were interrupted when the ship was stationary alongside icebergs while experiments were carried out by representatives of IFF (Icebergs For the Future) and during periods of poor visibility. During daylight steaming periods seals were censused using the same techniques of the previous surveys (strip width was 200 m either side of the ship) which were based on the technique described by Siniff, Cline and Erickson (1970). Ice cover (in tenths), floe size and floe surface nature (Hall-Martin 1974) were recorded at 20 minute intervals, and ship's position was monitored constantly by satellite navigation.