

Mineral and energy contributions of feathers moulted by penguins, gulls and cormorants to the Marion Island terrestrial ecosystem

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More than three million individual adult seabirds, belonging to six species, undergo their full annual moult on Marion Island. The estimated contribution to the island's ecosystem by their shed feathers is 428,7 t (dry weight). An area of 4 km² receives 76 per cent of the feather mass. Over the remaining 70 km² in which feathers are shed the average input is 13,7 kg ha⁻¹ yr⁻¹. The concentrations of selected mineral elements (Ca, Cd, Cu, K, Mg, Mn, N, Na, P, Sr, Zn) in the feathers were determined, and the total amount of mineral elements thus contributed to the ecosystem was calculated. The total amount of energy contained in the feathers is $9,03 \times 10^9$ kJ.

Introduction

Little is known about the role of birds in the transfer of mineral elements and energy from the sea to terrestrial ecosystems. Seabirds may be particularly important as transporters of essential plant nutrients to the nutrient-poor soils of sub-Antarctic islands. Preliminary studies of the role of seabirds as nutrient transporters are being made on Marion Island (46°54'S, 37°45'E) in the southern Indian Ocean (Siegfried, 1978).

Most species of birds undergo at least one moult of their entire body plumage each year. The present paper reports the amounts of energy and selected mineral elements combined in the feathers deposited on Marion Island by the populations of surface-breeding seabirds which complete their annual moult there. The species are: king penguin, *Aptenodytes patagonicus*; gentoo penguin, *Pygoscelis papua*; macaroni penguin, *Eudyptes chrysolophus*; rockhopper penguin, *E. chrysocome*; imperial cormorant, *Phalacrocorax albiventer*; and kelp gull, *Larus dominicanus*.

Materials and Methods

Penguins are unable to remain at sea during their annual moult and must pass the moult period, approximately one month, ashore. For the purpose of this paper it is assumed that the entire Marion Island population, excluding the fledglings of the year, moults on the island, and that all the feathers moulted are dropped on land.

A census of the numbers of breeding birds was taken by ground surveys, supplemented by aerial photography (Williams *et al.* 1979). The numbers of non-breeding imperial cormorants and kelp gulls were calculated by subtracting the numbers of breeding birds from the total population of each species (Williams *et al.* 1975). The total stock of Marion Island penguin populations, including breeding and non-breeding adults and the annual production of fledglings, was calculated by multiplying the number of breeding individuals by the appropriate 'Mougin co-efficient' given in Prévost (1976) namely: king penguin 1,83; gentoo penguin 2,30; macaroni penguin 2,31; rockhopper penguin 2,99. The number of non-breeding adults was obtained by subtracting

from the total stock the breeding population (Williams *et al.* 1979) and the annual fledgling production (Williams *et al.* 1978).

King, macaroni and rockhopper penguins which have bred, or attempted to breed, return to moult at their breeding colonies (Stonehouse, 1960; Warham, 1975) and gentoo penguins moult in the vicinity of their colony (personal observation). Penguins which, though adult, have not yet attempted to breed generally moult at the edge of their natal colony (Carrick, 1972) and on Marion Island only some king penguins moult away from breeding colonies. Imperial cormorants and kelp gulls retain their ability to fly throughout the annual moult, and their degree of movement at this time was not assessed. However, most of these birds breed and moult in the island's coastal zone. The distribution of the feathers shed during moult by the birds considered here was assumed to be the same as the distribution of the breeding populations, with the exception of the king penguin. To facilitate the plotting of the distribution of moulting birds on Marion Island, the island was divided into a series of 1 km² quadrats (Fig. 1).

Two methods were used in assessing the mass of feathers moulted by individual adult birds each year. Two imperial cormorants and a single adult kelp gull were collected and plucked. Penguin feathers cannot be plucked because they are too deeply embedded. Single specimens of king, gentoo and macaroni penguins were 'shaved', using scissors and scalpel. It is, however, impossible to shave off all the feather roots using this method. Feathers were also collected from live macaroni and rockhopper penguins during their moult. Five birds of each species were kept in cages, from the period before feather drop until all the old feathers had been shed. The moulted feathers were collected daily in trays placed under the wire mesh floors of the cages. These feathers were partially soiled with guano and had to be washed in distilled water.

The entire plumage of each individual bird was weighed after oven-drying at 60°C. Subsamples of feathers, representing, in the case of the imperial cormorant and kelp gull, actual proportions of flight, contour and down feathers, were cut into small pieces before grinding in a ceramic mortar and pestle. Energy values of the powdered subsamples were obtained using a Gallenkamp ballistic bomb calorimeter. Concentrations of mineral elements were, after treating the organic material as described by Watling and Watling (1975), determined by means of a Varian Techtron AA-6 atomic absorption spectrophotometer, using acetylene fuel and flame spectroscopy (Pringle *et al.* 1968). The concentrations of the following mineral elements were determined: copper, cadmium, potassium, magnesium, manganese, sodium, strontium and zinc. Total calcium was determined by EDTA titration using Erichrome Black T indicator (Vogel, 1939). Analysis for total phosphorus was by stannous chloride

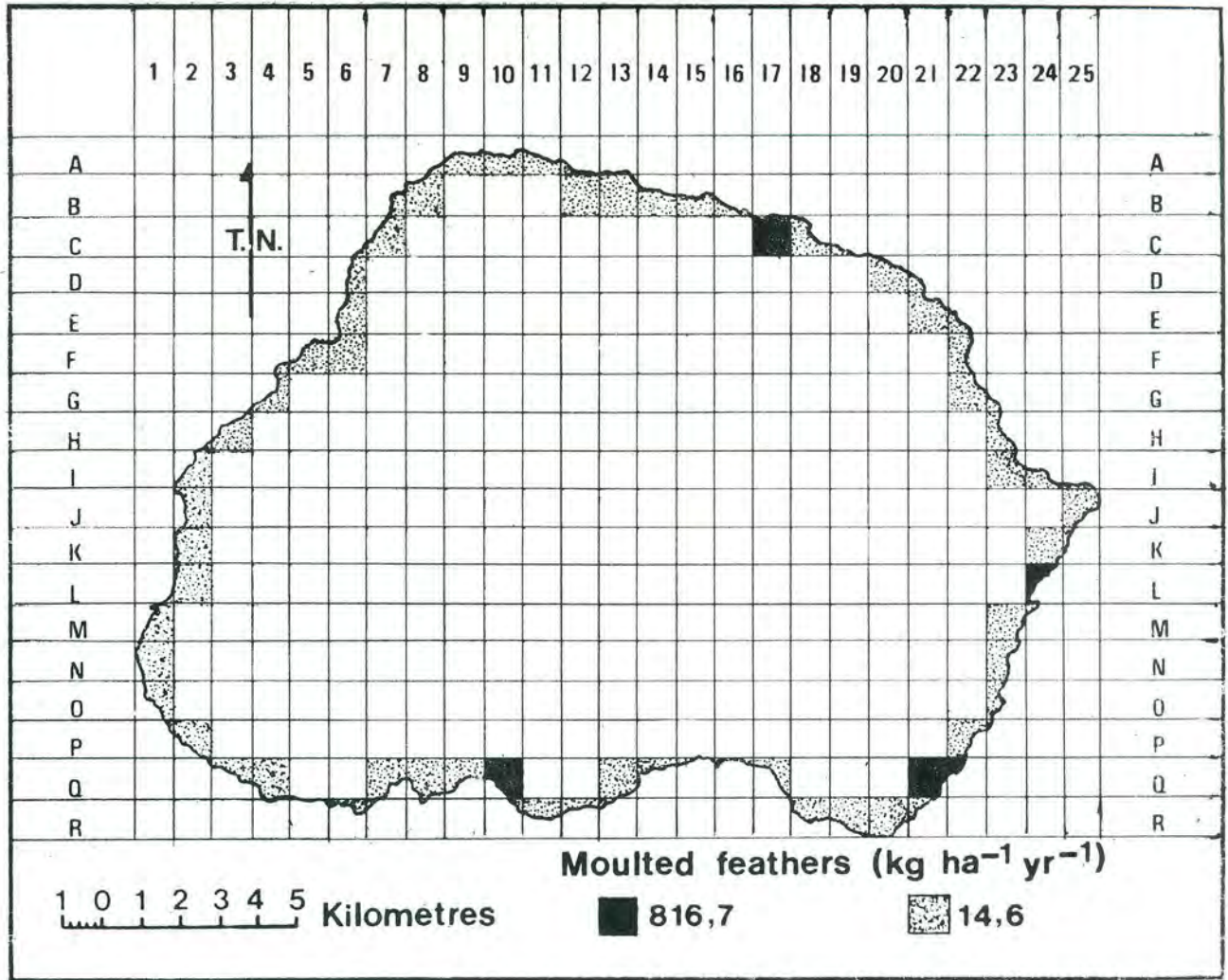


Fig. 1. Combined distribution of feathers moulted by penguins, gulls and cormorants on Marion Island, and the average level of input per quadrat.

procedure (Taras *et al.* 1971). Nitrogen was determined by standard Kjeldahl method (Grodzinski *et al.* 1975). Three determinations were made on each sample to give a mean value.

Results

More than three million adult birds belonging to the six species considered here moult each year on Marion Island: just under 1,5 million are breeding birds and over 1,5 million are immature birds (Table 1). The majority (99 per cent) of the moulting birds are penguins. Feathers from moulting birds are deposited on the island in eight months of the year, from October to May inclusive, but chiefly in February and March (Table 2).

The total mass of feathers estimated to be moulted by these birds annually is 428 700 kg (dry weight). Almost the entire amount is derived from penguins with 53,7 per cent contributed by macaroni penguins alone.

Feathers from moulting birds are deposited in 88 of the quadrats into which the island was divided (Fig. 1). Of the entire mass of feathers, 76 per cent is deposited in the five quadrats occupied by the largest king and macaroni penguin colonies. The input of feathers in this 4 km² area is 816,7 kg ha⁻¹ yr⁻¹. Over the rest of the area (70 km²) in which

feathers are shed, the annual input is 14,6 kg ha⁻¹, almost all being deposited within 100 m of the sea.

The mean energy content of the feathers of the six species was: king penguin 20,90 kJ g⁻¹ (dry weight); gentoo penguin 21,25 kJ g⁻¹; macaroni penguin 21,50 kJ g⁻¹; rockhopper penguin 22,15 kJ g⁻¹; imperial cormorant 21,85 kJ g⁻¹; and kelp gull 24,05 kJ g⁻¹. The total energy content in feathers moulted annually by these species is $9,03 \times 10^9$ kJ (Table 4).

The concentration of selected mineral elements in the feathers of the six species concerned here (Table 3) and the total feather mass (Table 1) enable calculation of the total mass of the selected elements which are contained in feathers moulted annually on Marion Island (Table 4).

Discussion

'Feathers are the only organ 100 per cent avian' (Mayr, 1959). It is therefore surprising that they have received so little study. The mass of plumage is known for only some 400 of the over 8 600 extant species of birds (Wetmore, 1936; Turcek, 1966); the mineral composition of feathers is known for only a handful of bird species and the potential contribution of feather energy and mineral contents to ecosystems has, as far as is known, not previously been studied.

There are shortcomings in the present materials and

Table 1

Number of seabirds which undergo full moult and the mass (kg dry weight) of feathers they shed annually on Marion Island.

| | Number of birds | | Mass of feathers | | Total mass of feathers | |
|--------------------|-----------------------|--------------|------------------|---------------------|------------------------|-------------------------|
| | Breeding ¹ | Non-breeding | Individual adult | Breeding population | | Non-breeding population |
| King penguin | 430 470 | 274 460 | 0,219 | 94 315 | 60 134 | 154 449 |
| Gentoo penguin | 2 690 | 2 760 | 0,201 | 540 | 555 | 1 094 |
| Macaroni penguin | 877 190 | 891 900 | 0,130 | 114 122 | 116 037 | 230 159 |
| Rockhopper penguin | 186 570 | 342 360 | 0,081 | 15 112 | 27 731 | 42 843 |
| Imperial cormorant | 570 | 77 | 0,108 | 61 | 8 | 70 |
| Kelp gull | 400 | 500 | 0,088 | 35 | 44 | 79 |
| | 1 497 890 | 1 512 057 | | 224 185 | 204 509 | 428 694 |

¹Williams *et al.* (1979)

Table 2

Monthly distribution of mass of feathers (kg dry weight) deposited annually by six species of seabirds which complete their body moult at Marion Island.

| | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | Jun.-Sep. |
|--------------------|--------|--------|--------|--------|--------|---------|--------|-------|-----------|
| King penguin | 57 920 | 38 610 | 57 920 | — | — | — | — | — | — |
| Gentoo penguin | — | — | — | 438 | 438 | 219 | — | — | — |
| Macaroni penguin | — | — | — | 19 340 | 77 360 | 87 810 | 45 650 | — | — |
| Rockhopper penguin | — | — | — | — | 13 870 | 13 870 | 12 090 | 3 020 | — |
| Imperial cormorant | — | — | — | — | 35 | 35 | — | — | — |
| Kelp gull | — | — | — | — | 20 | 40 | 19 | — | — |
| | 57 920 | 38 610 | 57 920 | 19 778 | 91 723 | 101 974 | 57 759 | 3 020 | 0 |

Table 3

Mineral element concentrations (ppm) in feathers of six species of seabirds moulting annually at Marion Island. Each concentration is the mean of three determinations.

| | Cu | Cd | Zn | Mn | Sr | Mg | K | Na | Ca | P | N |
|--------------------|------|------|-----|-----|------|-------|-------|-------|-------|-----|---------|
| King penguin | 18,0 | 0,13 | 111 | 1,8 | 2,3 | 546 | 1 250 | 4 200 | 770 | 340 | 86 570 |
| Gentoo penguin | 22,0 | 0,19 | 105 | 0,6 | 2,3 | 931 | 795 | 5 100 | 1 460 | 120 | 98 440 |
| Macaroni penguin | 22,7 | 0,42 | 115 | 1,3 | 6,6 | 870 | 1 310 | 5 200 | 1 150 | 380 | 108 020 |
| Rockhopper penguin | 16,0 | 0,09 | 128 | 2,5 | 4,0 | 749 | 575 | 1 400 | 3 080 | 240 | 82 230 |
| Imperial cormorant | 11,1 | 0,54 | 100 | 1,1 | 10,2 | 1 180 | 1 050 | 6 100 | 2 770 | 500 | 101 640 |
| Kelp gull | 8,4 | 0,24 | 112 | 0,4 | 1,2 | 177 | 775 | 2 100 | 1 300 | 260 | 115 960 |

Table 4

Total amounts of energy (kJ) and mineral elements (kg) contained in the annual production of feathers moulted by six species of birds on Marion Island.

| | Breeding population | Non-breeding population | Total |
|------------|-----------------------|-------------------------|-----------------------|
| Energy | 4,7 × 10 ⁹ | 4,3 × 10 ⁹ | 9,0 × 10 ⁹ |
| Copper | 4,54 | 4,17 | 8,72 |
| Cadmium | 0,06 | 0,06 | 1,12 |
| Zinc | 25,60 | 23,60 | 49,20 |
| Manganese | 0,36 | 0,33 | 0,69 |
| Strontium | 1,03 | 1,02 | 2,05 |
| Magnesium | 162,70 | 155,10 | 317,80 |
| Potassium | 276,60 | 243,60 | 520,20 |
| Sodium | 1 013,00 | 897,00 | 1 911,00 |
| Calcium | 251,40 | 266,10 | 517,40 |
| Phosphorus | 79,20 | 71,30 | 150,50 |
| Nitrogen | 21 798,00 | 20 081,00 | 41 879,00 |

methods used for calculating total feather production. Most obvious are the minimal sample sizes for plumage mass and the crude estimates for the number of non-breeding birds which moult on Marion Island. The plumage mass of the individual king and gentoo penguins is almost certainly too low. In the macaroni penguin, the single bird which was 'shaved' had a feather mass 6 per cent lower than the mean mass of feathers collected from birds moulting in cages. This is the result of not being able to shave off the roots of the feathers. A similar discrepancy must also apply to the shaved king and gentoo penguins.

In spite of these limitations, the calculated dry weight of feathers, 428,7 t, shed by the six species which complete their full annual moult on Marion Island exceeds the combined annual total weight of eggs and carcasses contributed to the island's ecosystem by the same species (Siegfried *et al.* 1978; Williams *et al.* 1978).

Feathers are also contributed to the island's ecosystem from other sources. Adults of at least three other species,

the lesser sheathbill, *Chionis minor* and northern and southern giant petrels, *Macronectes halli* and *M. giganteus*, undergo all or part of their annual moult at the breeding grounds. Adults of most species undergo partial moults associated with breeding: thus many species moult the feathers of the brood patch area prior to incubation; and the imperial cormorant has a partial moult to attain nuptial plumage. Chicks of all species have one or two plumages which are moulted before the definitive teleoptile plumage is attained. The total mass of feathers contributed from these sources is thought to be insignificant. However, a substantial mass of feathers is contributed when adult birds and chicks die on Marion Island. Penguins which die during moult contribute an estimated 3 281 kg (dry weight) of feathers and petrels (Procellariiformes) killed by feral cats, *Felis catus*, contribute an estimated 7 908 kg (dry weight) (Williams, 1978).

Feathers consist largely of inorganic material and have a low water content. The total amount of energy and of the analysed mineral elements contained in the moulted feathers is considerable (Table 4). However, the actual importance of feather contents to the ecosystem is dependent upon the transference of the energy and mineral elements in the ecosystem. Little is known about such fluxes. Feathers shed during moult may fall into vegetation, on to bare ground, or be blown off the island and into the sea. Feathers which fall into vegetation are likely to be trapped and to decompose *in situ*. Feathers which fall on to bare ground, especially within penguin colonies, may be trampled into the mud and guano. In neither case is the subsequent fate and breakdown of the feather material known. It is recommended that a study be made of the rate and way in which feathers decompose on Marion Island.

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