THE DISTRIBUTION AND ABUNDANCE OF BURROWING SEABIRDS (PROCELLARIIFORMES) AT BIRD ISLAND, SOUTH GEORGIA: I. INTRODUCTION AND METHODS

By I. Hunter, J. P. Croxall *and* P. A. Prince

Abstract. The habitats utilized by burrowing petrels at Bird Island, South Georgia are described and the habitat modifications induced by the activities of fur seals and other seabirds summarised.

The field methods for an investigation of the distribution and abundance of the nine species of burrow-dwelling petrels that breed on Bird Island are described in detail. About 40% of the 200 hectares of ground suitable for burrow excavation was investigated using a system of grid squares each 3 600 m^2 in area. In each square, two randomly located circular quadrats of area 36 m^2 were studied.

For each quadrat, aspect, slope, vegetation types and their cover, extent of fur seal influence and status of every burrow were recorded. Seven categories of both empty and occupied burrows were recognized and examination techniques (including use of tape-recorded calls to facilitate species identification) are described in detail. Over 5 000 burrows were examined, with dove prion the most abundant species.

There is increasing recognition of the general significance of the role of seabirds in Antarctic and sub-Antarctic ecosystems (Mougin and Prévost, 1980; Burger and others, 1978; Williams and others, 1978; Croxall, in press) and of their enhanced importance in certain locally rich areas such as South Georgia (Croxall and Prince, 1980, 1982).

To obtain quantitative data on the impact of seabirds as predators and on their role in providing nutrients for terrestrial communities, accurate information on their abundance and distribution is essential. At South Georgia, extensive data on seabird distribution have been obtained through the Breeding Bird Survey, conducted on the basis of a five-kilometre grid square, and information for surface-breeding species (especially penguins and albatrosses) is often fairly comprehensive (e.g. Croxall and Prince, 1979, 1980). This is particularly so at Bird Island, where various census and monitoring programmes have been operating for several years (Croxall and Prince, 1979). While considerable research has been done on many aspects of the biology of burrow-dwelling species (e.g. Payne and Prince, 1979; Prince, 1980), knowledge of their distribution and abundance is inadequate.

The difficulty of assessing the numbers of burrow-dwelling seabird species is well recognized and common to all areas where such species occur. More systematic approaches, particularly involving the use of random sampling, to estimating the abundance of burrow-dwelling species were developed by Nettleship (1976) and Harris and Murray (1981) for the puffin *Fratercula arctica*. The problem is more complicated in areas where several burrowing species co-occur and the only investigation of such a situation is that of Harris and Bode (1981) and Harris and Norman (1981) on islands in the Bass Strait, Australia. There, only four species were involved and only two occurred in the same habitat whereas nine species breed at Bird Island and four co-occur extensively. Furthermore, they do so in a habitat that is widely distributed throughout the island, which is topographically varied and has very few areas devoid of burrowing seabirds.

This project studied the distribution and abundance of the burrow-dwelling seabirds on Bird Island by investigating all burrows within quadrats randomly located within a fixed grid system covering all habitats and areas of the island. Field work was carried out in three successive field seasons, 1978–1981. This paper, the first of a series which will describe the results of this research, is concerned with the background to the study and the methods employed in the field.

Study Site and Species

South Georgia is a mountainous island 160 km long and up to 50 km wide rising to 2 935 m. It is situated 250 km south of the Antarctic Convergence, between latitudes 54° to 55°S and longitudes 36° to 38°W. Bird Island, off the north-western tip of South Georgia at 54°00′S 38°02′W (Fig. 1), is 6.5 km long and up to 1.5 km wide with a planar surface area of about 400 hectares (Figs 2–3).

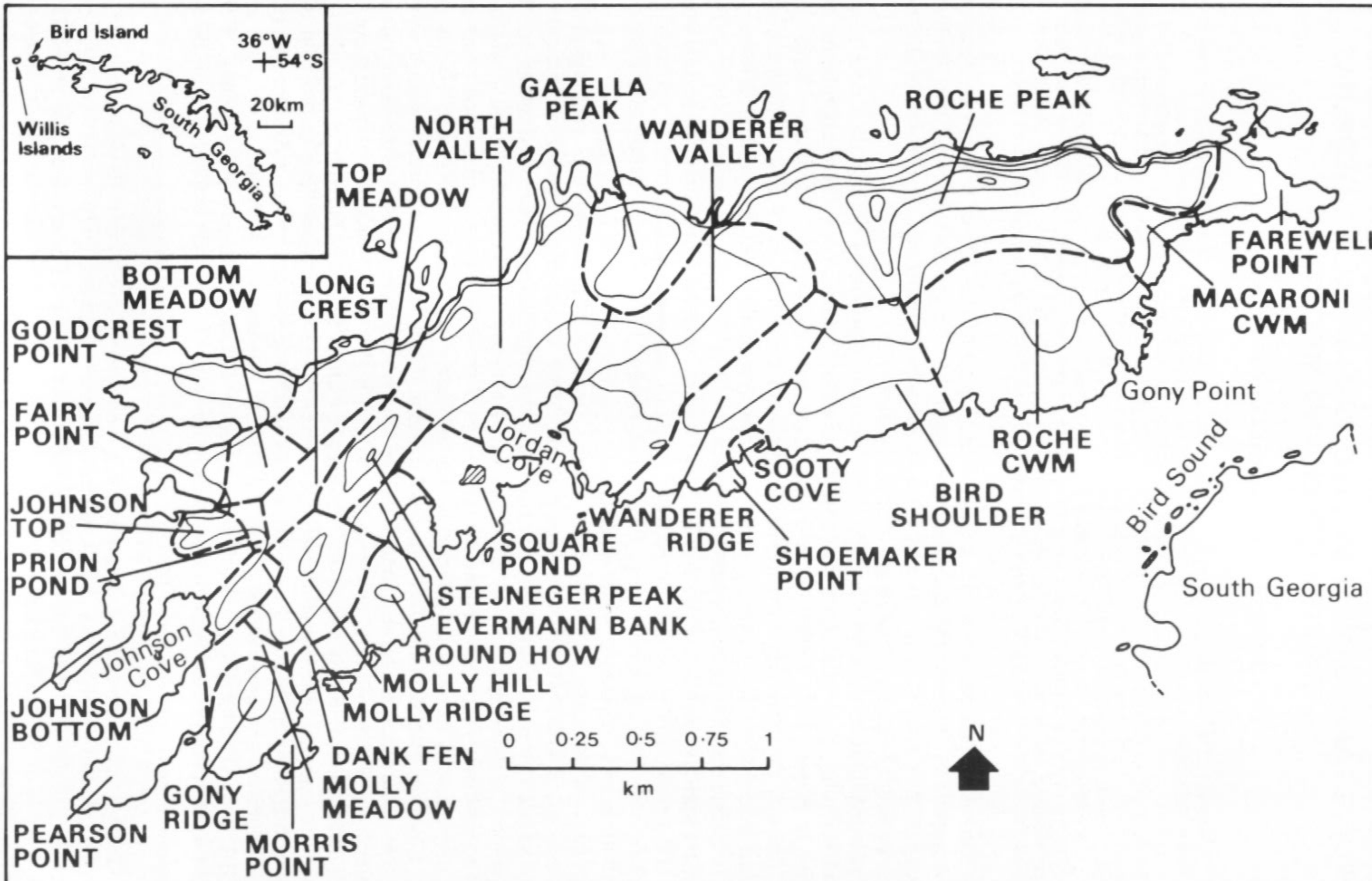

Fig. 1. Bird Island showing place-names mentioned in text and (inset) position in relation to South Georgia. Contour interval 200 feet.

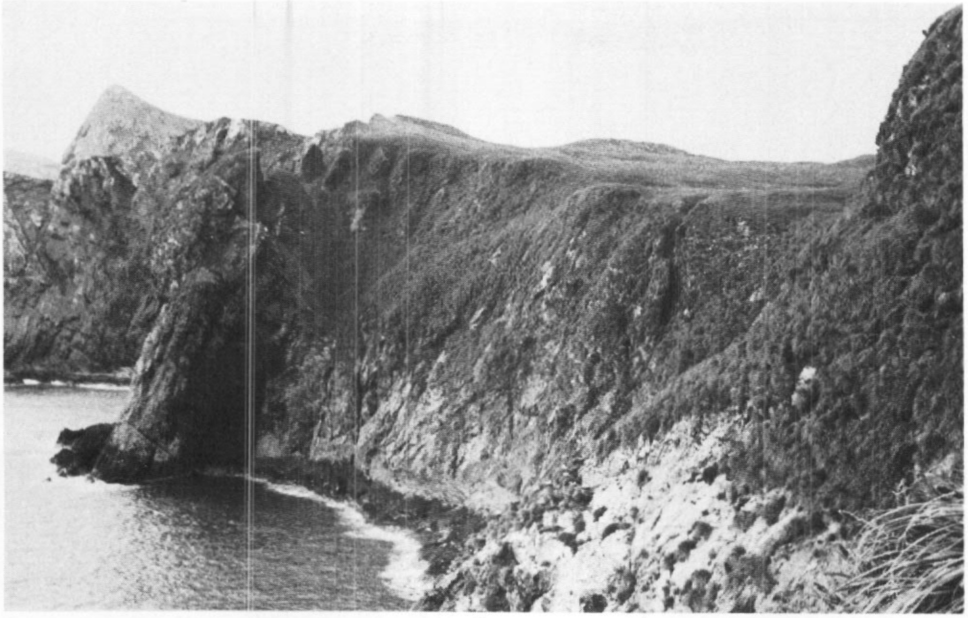

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Fig. 2. Bird Island. (a) view along north coast from Goldcrest Point. (b) view east from near Stejneger Peak to Roché Peak. Square Pond right foreground; Stejneger Peak left foreground.

The main ridge of Bird Island forms a backbone running approximately east–west. The eastern half reaches 365 m at Roché Peak. Its northern side forms precipitous cliffs, the southern side sloping more gently from scree to tussock covered slopes below 150 m. The ridge bisects the western half of the island reaching 190 m at Stejneger Peak. The southern side drops through

Fig. 3. Bird Island. (a) view south-west from Roché Peak. Gazella Peak at right, Stejneger Peak centre at top, Wanderer Valley foreground. (b) north coast to Farewell Point viewed from Roché Peak. (c) Roché Cwm.

steep tussock slopes to a series of bays and tussock covered hillocks. The northern side falls to a series of flat meadows, bordered by tussock, with four steep, tussock covered, promontories projecting seawards.

The climate is cloudy and windy with frequent precipitation. The temperature varies from −2°C to 9°C in summer and from −10°C to 3°C in winter (Richards and Tickell, 1968). Although snow and ice build up during the winter there is no permanent snow cover.

Natural Habitats

The approximate distribution of the main habitats on Bird Island is shown in Fig. 4 and their extent, estimated from planimetry of low altitude (300 m) aerial photographs, is summarized in Table I.

Poa flabellata is the only tussock-forming grass (Fig. 5), occurring between 0 and 150 m above sea level. The clumps may reach 0.5 to 1.0 m in diameter and 1.0 to 1.5 m in height. Greene (1964) described two distinct types of tussock community according to the density of the plants: 'closed' tussock, where plants are crowded together and there is little development of stools, and 'open' tussock which has a lower density of plants and well formed stools. Although he maintained that the dominant type on Bird Island was closed tussock, such areas, with no clump formation, are actually rare.

Meadows (Fig. 6) are characteristic of the flat, extensively waterlogged areas. The vegetation is dominated by the grass *Deschampsia antarctica,* with patches of *Colobanthus* spp. and *Callitriche antarctica. P. flabellata, Acaena magellanica* and *A. tenera* often encroach at the edges. Meadows may form large expanses such as Top Meadow and Bottom Meadow, or small patches, spread amongst tussock ridges, as on Wanderer Ridge.

Large banks of moss form on top of steep bare rock faces and in some closed tussock areas (Fig. 7). Some of these banks form a burrowable layer on otherwise unsuitable habitat.

The scree banks (Figs 3b, 8a) can be divided into two main types on the basis of the presence or absence of vegetation. The substrate also varies, according to the size of individual components, from a fine sandy texture through coarse but tightly packed gravel to very coarse rubble. On Bird Island fine scree, suitable for burrowing, occurs only at high altitude, above the tussock on south facing slopes from the top of North Valley and the base of Gazella Peak to the slopes of Roché Peak and the upper slopes of Roché Cwm. On the fringes of these screes moss becomes established. As a result other vegetation may also colonize and this may ultimately lead to the formation of swards of *Acaena*. Coarse rubble occurs on the north slopes of Stejneger Peak (Fig. 8b) and beneath Roché Peak.

Habitat Modifications by Seals and Seabirds

The tussock is sometimes considerably modified by the presence of seals and surface breeding seabirds (Fig. 9).

Both movement and resting of Antarctic fur seals *Arctocephalus gazella* flatten shoots and in areas of high activity cause extensive erosion of the stools and death of complete clumps (Fig. 10). The surface between the stools may also become firmly compacted or form thick mud. This type of habitat is becoming increasingly widespread as the seals, which are continuing to increase in numbers (Payne, 1977; Croxall and Prince, 1979), move farther away from the beaches.

Penguin colonies have a severe effect on the habitat, rapidly eroding the vegetation until only bare rock remains. This is the case for the gentoo penguin *Pygoscelis papua* colonies in Johnson Cove and at Gony Point and the macaroni penguin *Eudyptes chrysolophus* colonies at Goldcrest Point and Macaroni Cwm. The macaroni penguin colonies are probably still expanding as there is continuing erosion of tussock around the edge and these areas are now unsuitable for burrowing petrels. Smaller gentoo penguin colonies tend to change site from year to year and in these areas clumps are worn down and highly polished but usually still alive. The spaces in between fill with mud and none of these areas are suitable for burrowing.

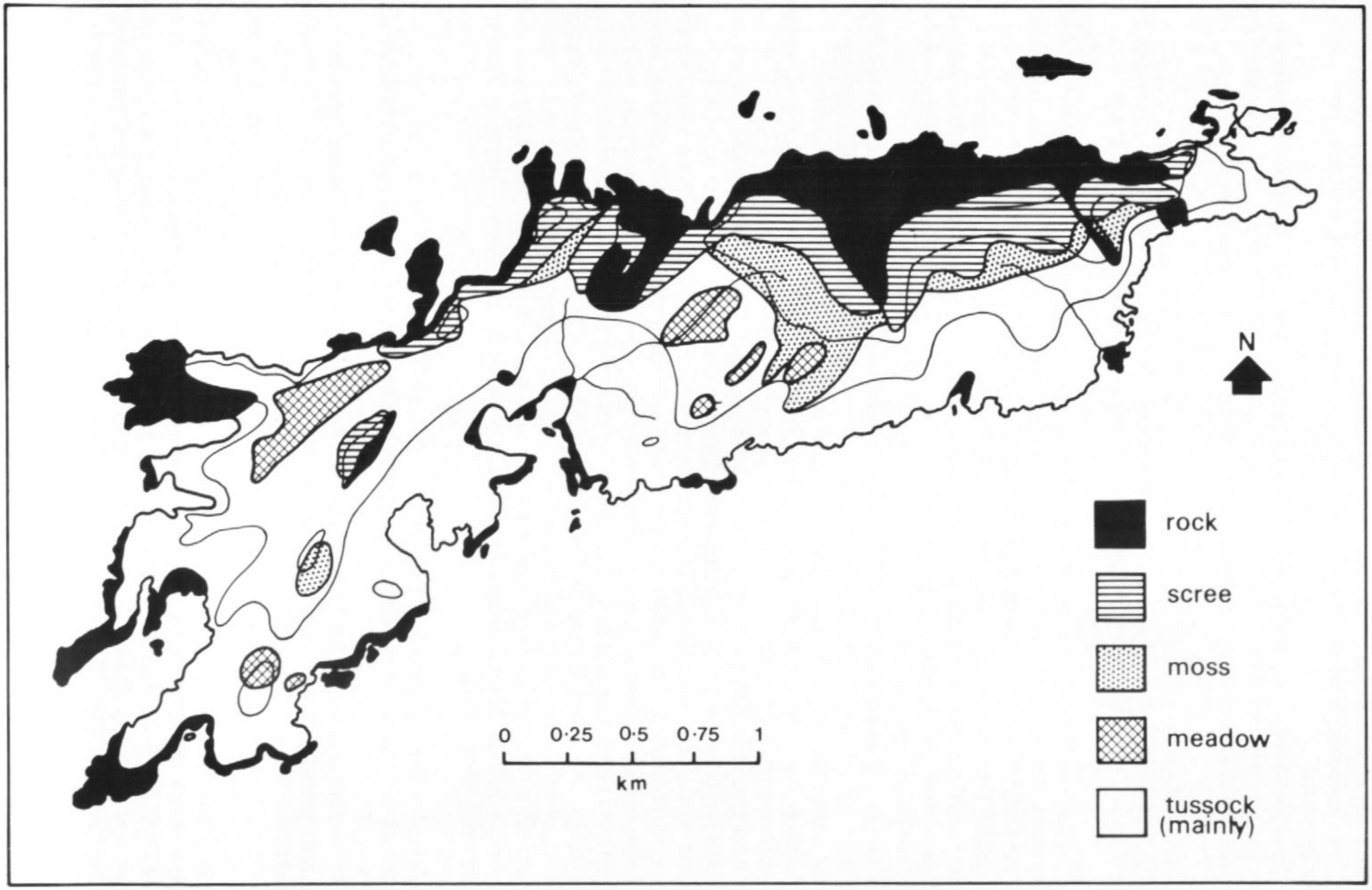

Fig. 4. Distribution and extent of major habitats on Bird Island. Contour interval 200 feet.

TABLE I. EXTENT OF MAJOR HABITAT TYPES AT BIRD ISLAND

Habitat	*Area (hectares)*
Tussock	190
Meadows	9
Moss	19
Coarse Scree	26
Fine Scree	21
Lakes	1
Rock	130

Colonies of black-browed albatrosses *Diomedea melanophris* and grey-headed albatrosses *D. chrysostoma* occur on the steep, tussock-covered hillsides. Within the flatter colonies the movement of these albatrosses (mollymawks) causes the formation of a muddy morass beween nests. In steeper sites they normally fly straight in and out of the colony and the area surrounding their nests does not become severely eroded.

Both penguin and mollymawk colonies have a beneficial effect on the growth of surrounding tussock (Fig. 11). This is due to bird faeces providing a rich supply of nutrients which results in a luxuriant growth of tussock and extensive stool formation, highly suitable for burrowing petrels. Drainage from mollymawk colonies results in especially dense tussock growth below the colony but as penguin colonies border the sea supplementary effects are limited to those from wind-blown nutrients.

The other surface-nesting species have much less effect on burrow-dwellers. Wandering albatrosses *Diomedea exulans* nest on flat or gently sloping ground. The nest is made from vegetation and soil removed from nearby areas. Even on the flat top of Gony Ridge, where burrowing species utilize tussock ridges, the albatrosses have no effect on burrowing petrels, apart from accidentally exposing some burrow entrances. Giant petrels *Macronectes halli* and *M. giganteus* are more widespread and *M. halli* also occurs on tussock slopes which are steep enough to allow easy take-off. Even here they use flat areas for the nest site and apart from exposing some burrow entrances have little effect on smaller petrels. In none of the above three species have burrows dug into the base of the nest been recorded.

Sub-Antarctic skuas *Catharacta lönnbergi* are important predators of burrowing petrels, e.g. 218 dove prion, 33 blue petrel and four diving petrel body remains were collected during one summer in the territory of a skua pair (with two chicks) on Johnson Bottom. Even so, occupied dove prion burrows were still present. Skuas also regularly dig into burrows to reach chicks, particularly near the end of the summer, when petrel chicks are large. The remaining surface-nesting species (see Prince and Payne, 1979) have no effect on burrowing petrels.

Study Species

Nine species of burrowing petrel have been recorded nesting on Bird Island (Table II). There are only two breeding records of the grey-backed storm petrel and fairy prions were not discovered until 1980–81, nesting in areas inaccessible to the present study.

Specimens of narrow-billed prion *Pachyptila belcheri* have been found in skua middens and, recently, in giant petrel food samples but no nest has been located.

METHODS

Quadrat Establishment

Sampling quadrats were located randomly within a fixed grid, 60 m × 60 m covering the island. Reference points for establishing the grid system in the field were determined from aerial photographs. At least one corner of each grid square was marked with a wooden stake, bearing a numbered tag painted white to show up against the predominantly green background.

a

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Fig. 5. Tussock-grass. (a) on steep slopes, north coast of Goldcrest Point. (b) luxuriant clumps with abundant petrel burrows, Goldcrest Point; 1-m pole for scale.

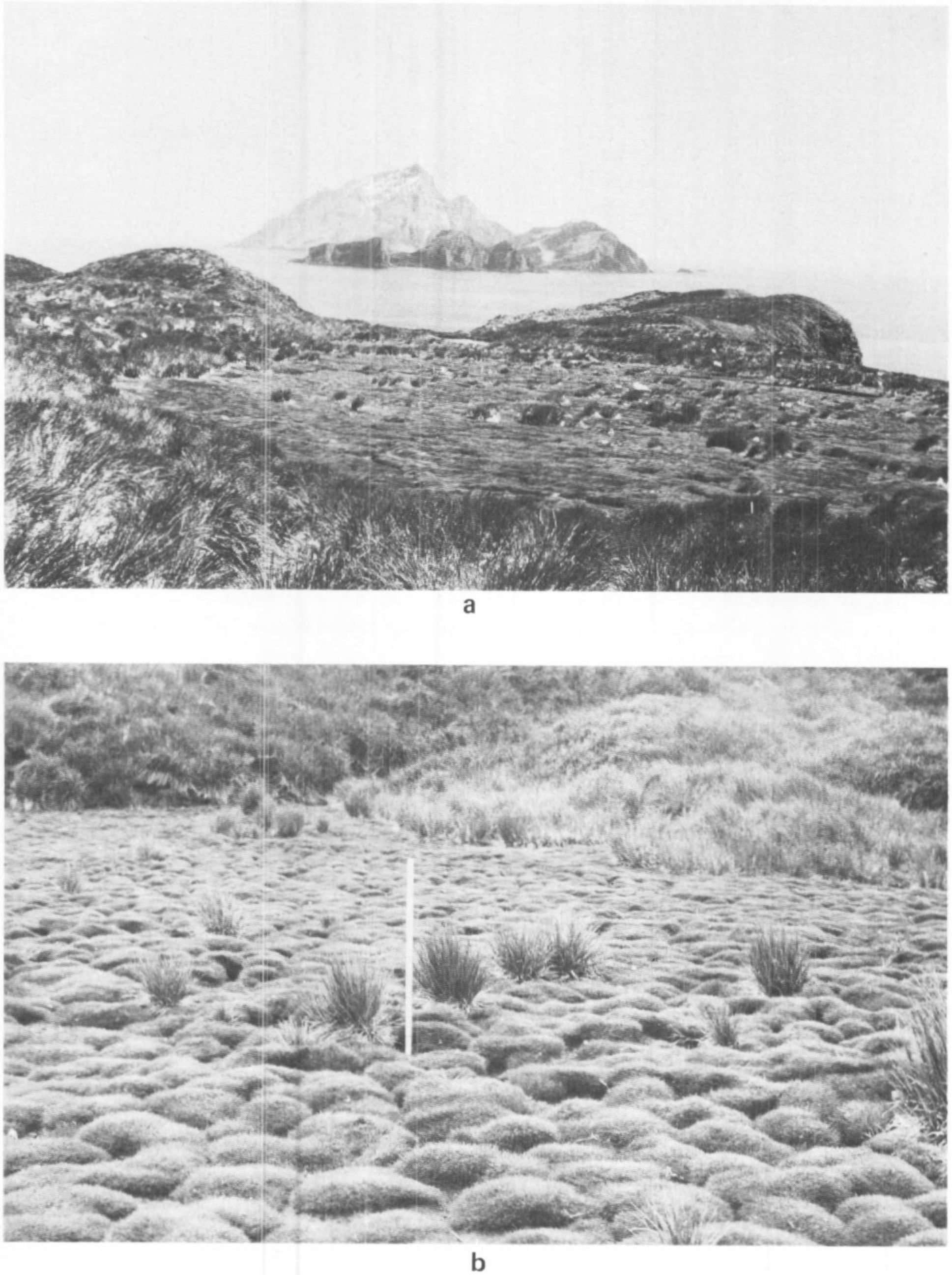

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Fig. 6. *Deschampsia* meadows. (a) Top Meadow, looking west to Willis Islands. (b) with a few isolated *Poa* clumps; 1-m pole for scale.

Fig. 7. Bank formed by various moss species. Typical breeding habitat of black-bellied storm petrel.

To locate the quadrats within each square, two adjacent sides of the square were divided into 4-m sections. Two numbers between 0 and 15 were selected randomly and these gave the co-ordinates of the centre of the quadrat.

Quadrats were circles of area 36 m^2. This was a compromise between the practicability of coverage by one person and a size sufficient to ensure adequate representation of burrows within a quadrat. Usually two quadrats were examined per square. A 30-m surveyor's tape measure and an orienteering compass were used to establish the position of the squares and quadrats. The quadrat was defined using orange nylon string cut to the radius of the circle (3.385 m) and attached at one end to a pole at the centre spot (Fig. 12). One string was anchored at its distal end to mark a starting line. Using other strings the quadrat was divided into four sectors to facilitate analysis.

Quadrat Analysis

To examine relationships between habitat features and burrow distribution and density, basic habitat information was recorded on data sheets.

The aspect and mean slope of the quadrat were measured with compass and inclinometer. The percentage area covered by each type of vegetation was estimated and the number and 'burrowable height' (i.e. height of the compact portion of the clump, ignoring the upper crown of loose shoots and leaves) of tussock clumps recorded.

The degree of fur seal activity was classified as:

0. Seals absent (no damage, faeces, etc.) from the quadrat and its vicinity.
1. Seals occasionally present in the vicinity and may pass through quadrat but no signs of damage to tussock.
2. Seals present nearby, signs of presence in quadrat, but no damage.
3. Some shoots permanently flattened.

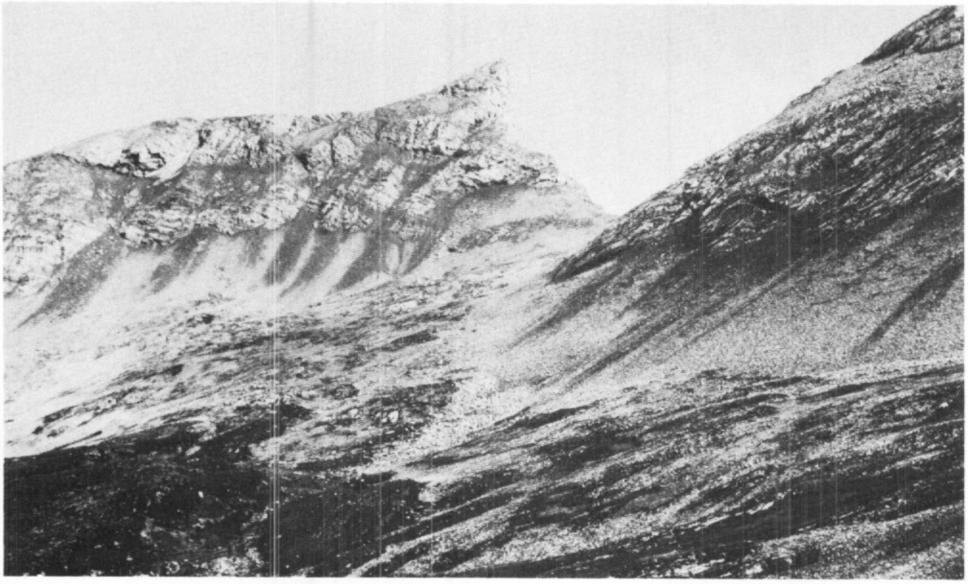

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Fig. 8. Scree and rock habitats. (a) coarse scree, with moss covered areas lower down, upper Bird Shoulder. (b) boulder scree beneath Stejneger Peak. Typical breeding habitat of Wilson's storm petrel.

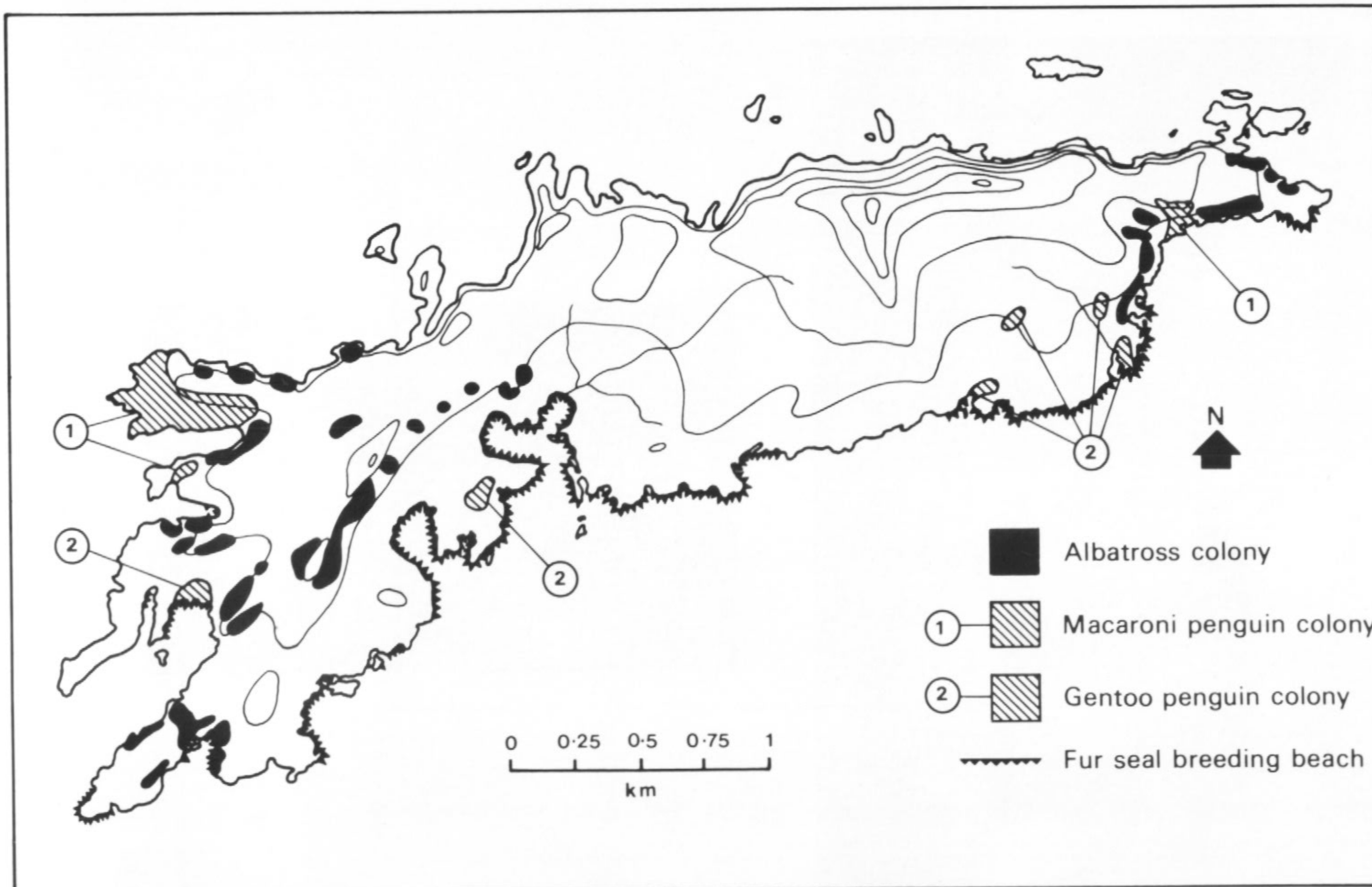

Fig. 9. Location of main concentrations of surface-breeding seabirds and fur seals at Bird Island. Contour interval 200 feet.

a

b

Fig. 10. Tussock damage by fur seals. (a) moderate damage (category 4), North Valley. (b) severe damage (category 6), Round How.

Fig. 11. Black-browed albatross colony. Long Crest. Note sparse tussock inside colony, rich growth below it.

4. Shoots flattened and some erosion of tussock crowns and between clumps.
5. Tussock crown erosion occurring on all clumps.
6. Heavy erosion on and between tussocks but active growth still occurs on the clump fringes.
7. Very heavy erosion, tussocks nearly or completely dead.

For each bird species the total number of burrows with entrances within the quadrat boundary was counted and the status of each burrow classified as follows:

1. Empty.
   (a) Incomplete, only part of the tunnel excavated.
   (b) Unused but suitable for breeding.
   (c) Unused due to icing of the tunnel or chamber.
   (d) Unused due to flooding of the tunnel or chamber.

TABLE II. TIMING OF THE BREEDING SEASON IN ALL BURROWING PETRELS THAT BREED AT BIRD ISLAND

Species	*Laying date*		*Hatching date*		*Fledging date*		*Reference*
	Mean	*Range*	*Mean*	*Range*	*Mean*	*Range*	
Dove prion *Pachyptila desolata*	16 Dec ± 3 (n = 12)	6–25 Dec	30 Jan ± 1 (n = 12)	22 Jan–14 Feb	20 March ± 1 (n = 15)	6–30 March	Pers. obs.
Fairy prion *Pachyptila turtur*		3 Nov–5 Dec	31 Dec ± 5 (n = 425)	18 Dec–19 Jan	20 Feb ± 4	16 Feb–10 Mar	Richdale, 1965 (southern New Zealand)
Blue petrel *Halobaena caerulea*		*c.* 23–31 Oct	11 Dec (n = 14)	8–20 Dec	27 Jan (n = 10)	22 Jan–4 Feb	Pers. obs.
White-chinned petrel *Procellaria aequinoctialis*	24 Nov	22–30 Nov	17 Jan	12–22 Jan	19 April	16–25 April	Pers. obs.
South Georgia diving petrel *Pelecanoides georgicus*	12 Dec ± 7 (n = 10)	7–31 Dec	28 Jan ± 11 (n = 20)	4–30 Jan	14 March ± 10 (n = 18)	4 Mar–2 April	Payne and Prince, 1979
Common diving petrel *Pelecanoides urinatrix exsul*		20 Oct–7 Nov	18 Dec ± 4 (n = 18)	14–31 Dec	9 Feb ± 3 (n = 16)	4–14 Feb	Payne and Prince, 1979
Wilson's storm petrel *Oceanites oceanicus*		27 Dec–20 Jan[1] 22 Dec[2]		6 Feb–Mid-March[1]		2nd week April–mid-May[1] 19 Mar[2]	(1) Beck and Brown, 1972 (Signy Island) (2) pers. obs. (Bird Island)
Black-bellied storm petrel *Fregetta tropica*		25 Dec–31 Jan		3–16 Feb		12–19 April	Beck and Brown, 1971 (Signy Island)
Grey-backed storm petrel *Garrodia nereis*		Early-mid Dec		Mid-late Jan		Late Mar–early April	Prince and Payne, 1979

All data for Bird Island unless otherwise indicated.

Fig. 12. Quadrat analysis. The pole marks the quadrat centre; the strings are radii. Burrow investigation in the left-hand quadrant is complete.

(e) Unused due to collapse or blockage of the tunnel or chamber.
(f) No indication of breeding but signs of use this season.
(g) Unused this season but indications of breeding activity in previous season (old fragments of egg or chick skeleton).

2. Occupied.
(a) Adults alone.
(b) Incubated egg.
(c) Cold egg.
(d) Broken egg.
(e) Live chick or signs of chick presence (e.g. layer of faeces or down or waxy feather sheaths on floor of chamber).
(f) Dead chick.
(g) Nest excavated by a skua.

Burrow Examination Techniques

To establish whether a bird was present in a burrow a tape recording of appropriate calls was played at the burrow entrance. This often meant that the occupant did not have to be extracted for identification, reducing disturbance. The size of the burrow entrance dictated which call was played first. Dove prions and blue petrels have similar sized burrow entrances (although blue petrels often dig longer tunnels) which are smaller than those of white-chinned petrels but larger than those of common diving petrels. Incubating adults (and non-breeding birds) readily replied to their own call, except for black-bellied storm petrel (which may have been due to the only available recording being of a young bird in the hand). Dove prions would also respond to blue petrel calls and vice versa, particularly in areas where both occurred. With white-chinned petrel burrows the calls of the other species were played because these sometimes occurred in tunnels branching off the main burrow. Once the species was identified a piece of broad gauge wire, which could be bent to fit the shape of the burrow, was inserted into the nest chamber, to double-check any burrows where no reply to the tape was detected or to determine whether an egg or chick was present. The wire had a small loop at its distal end to prevent damage to any occupant and to increase sensitivity by giving a larger area of contact.

If a chamber was inaccessible from the entrance, due to the distance involved or complex turns and branches, the approximate position of the chamber was estimated and a sharp knife used to dig down to it. The compact nature of tussock peat permitted its removal in blocks and once the chamber contents were identified the hole could easily be refilled. Unoccupied burrows were identified on the basis of size of burrow entrance. Blue petrel and dove prion burrows could not be distinguished. In areas where they occurred together sampling was done when blue petrels were incubating and repeated later when dove prions were incubating.

Non-random Sampling and Quadrats

White-chinned petrel, blue petrel and common diving petrel occurred most densely in relatively restricted areas and habitats, including very steep tussock cliffs which were extremely difficult to sample effectively. Some additional quadrats were deliberately located in areas considered to represent the optimum habitat for a particular species.

For a few species the routine sampling methods were inappropriate. The South Georgia diving petrel nests in only fine scree banks and their moss covered fringes. Except for a few dove prions in the mossy areas it is the only species in this habitat. Because there is no vegetation to obscure burrow entrances it is possible to count the total number of burrows and thus to estimate directly the size of the breeding population of this species.

TABLE III. DISTRIBUTION AND CONTENT OF QUADRATS AT BIRD ISLAND

Area	*Number of quadrats*	*Number of quadrats*		*Percent of quadrats with burrows*
		Without burrows	*With burrows*	
Macaroni Cwm	8	6	2	25
Roché Cwm	42	0	42	100
Bird Shoulder	48	31	17	35
Wanderer Ridge	19	5	14	74
Wanderer Valley	13	9	4	31
North Valley	76	45	31	41
Square Pond	7	0	7	100
Stejneger Peak	9	0	9	100
Long Crest	6	0	6	100
Top Meadow	21	8	13	62
Goldcrest Point	18	1	17	94
Bottom Meadow	14	3	11	79
Fairy Point	10	0	10	100
Prion Pond	2	0	2	100
Johnson Bottom	30	5	25	83
Molly Ridge	14	0	14	100
Molly Hill	22	0	22	100
Molly Meadow/Dank Fen	3	1	2	67
Pearson Point	8	0	8	100
Gony Ridge	41	3	38	93
Morris Point	5	0	5	100
Round How	17	0	17	100
Evermann Bank	14	0	14	100
Molly Meadow	1	1	0	0
Sooty Cove	6	2	4	67
Shoemaker Point	6	0	6	100
Total	460	120	340	

Wilson's storm petrel nests mainly in screes of coarse rubble where it was impossible to see the burrows or to excavate without causing severe disturbance and destruction of burrows. At Bird Island the black-bellied storm petrel is a very local nesting species of moss banks and steep coastal debris slopes and was not found during the quadrat sampling. Counts were made by detailed examination of suitable areas. No grey-backed storm petrel nests were located during any form of sampling.

Results

The results of this research will appear as a series of papers dealing with each of the main species involved. It is only appropriate here briefly to note the extent of the sampling coverage of the island that was achieved. Table III records the number of quadrats examined in each part of the island (refer to Fig. 1 for the location of these areas). The total of 460 quadrats represents sampling in 230 grid squares, covering an area of 83 hectares. As Bird Island only has some 200 hectares of ground suitable for burrowing petrels (other than South Georgia diving petrels and storm petrels which were assessed separately), this means that over 40% of the suitable habitat was sampled. The magnitude of the effort involved is perhaps better reflected by noting that the contents of well over 5 000 burrows were examined, three-quarters of these belonging to dove prions, and the remainder to blue petrels, common diving petrels, white-chinned petrels and South Georgia diving petrels, in order of abundance.

Acknowledgements

M. P. Harris provided helpful advice at the start of this study and constructive criticism of the manuscript. S. McInnes assisted with the planimetry.

MS received 26 January 1982; accepted in revised form 1 March 1982

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