THE INFLUENCE OF SOUTHERN ELEPHANT SEALS <u>MIROUNGA LEONINA</u> (LINNAEUS) ON THE COASTAL TERRESTRIAL ECOLOGY OF MARION ISLAND.

by

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ABSTRACT

A survey of the 36 moulting sites along the coast and adjacent areas of Marion Island, reveals that moulting elephant seals prefer vegetated areas with smooth and gently sloping access areas. Usage of wallowing areas has declined, with 31 of 36 areas being used at present, representing a decrease of 13,9 % since 1974. Seal moulting sites had a typical Poa Cookii-Cotuletum Plumosae association with *Poa cookii* ,*Poa annua* and *Cotula plumosa* predominating in such areas. Observations at the two study sites revealed that individual movements due to social and climatic factors, gregariousness of the different age-classes of seals, and the high degree of synchronisation in their haul-out pattern result in a seasonal degeneration and regeneration of vegetation in these areas.

Analyses of soil samples at the two study sites suggest that mineral concentrations increased progressively closer to the moulting areas. Increasing use of such areas by seals was characterised by higher levels of the total forms of N , Ca , K , Mg and the available forms of Ca , Na , Mg and NH_4 . The effects of defecation and urination by the seals is reflected in the

higher concentrations of total P , and Ca , available P, Ca and NH_4.

The principal input of material by elephant seals at their moulting sites were through, faeces, urine, skin and corpses. Urine contained greater amounts of N , P , Mg , Na and NO_3 than faeces which contributed greater quantities of K , Ca and the available forms of N . The addition of high levels of nutrients in localised areas throughout the moulting sites appears to be one of the principal factors affecting plant distribution, with trampling and salt spray influencing the distribution of specific species.

Trampling by seals resulted in the characteristic hollow-hummock feature of moulting sites with vertical and horizontal compression within a particular wallow influencing growth and regeneration of plants. Invertebrate numbers within moulting sites are affected by the intensity of seal utilisation. Differential survival of different size classed individuals was directly related to the effects of trampling. The most prominent components of the soils within these sites were springtails (Order Collembola) and Oribateid mites (Order Acarina).

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CHAPTER 1

INTRODUCTION AND OBJECTIVES OF THE STUDY

A study of the influence of southern elephant seals (*Mirounga leonina*) on the coastal terrestrial ecology of Marion Island (46° 53'S, 37° 52'E) was proposed in order to provide detailed information on the effects of the elephant seals on the ecosystem of the island. This included relationships between seal activities on land and the resultant changes in the environment. **The specific objectives of the study were to establish:**

1. The most characteristic and easily quantified features of moulting areas.
2. The total area of new and old moulting areas, and the extent to which they are increasing or decreasing.
3. The time it takes for a unit virgin area to assume the characteristics of a unit moulting area, and vice versa.
4. How many elephant seals, and the duration and frequency of occupation of the unit area which are necessary to create and maintain the characteristics of a moulting area.
5. The major mineral and energy pathways operative in moulting areas.
6. The role moulting areas play in the terrestrial ecology of Marion Island.

Apparently sealers commenced operations on Marion Island thirty years after the discovery of the island by the French sailor Marion Defresne (from dated rock carvings,G.I.H. Kerley pers.comm.).

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They virtually exterminated the southern elephant seals, fur seals and penguins during the next one hundred and thirty years (Marsh 1948) Sealing was discontinued in 1930, after which no further attempts to resume sealing have been made (Marsh 1948, Rand 1955, 1956). The elephant seal population then recovered to an estimated 10 000 individuals by 1951 (Rand 1955), but the population subsequently declined at an estimated mean rate of 4,85 % per year between 1951/52 and 1975/76, possibly due to a below population maintenance level of recruitment to the female third year age class (Condy 1977). An analysis of the data for the period 1973 to 1982 showed that the adult bull, adult cow and pup components decreased at rates of 11,0; 8,0 and 8,0 % per year respectively (Skinner & van Aarde, 1983).

The present study was directed at the effect of moulting elephant seals on the soils, the vegetation and the insect component of moulting areas, in order to obtain an insight into such effects.

CHAPTER 2

TOTAL AREA UTILISATION AND GENERAL SURVEY OF THE VEGETATION OF ELEPHANT SEAL MOULTING SITES

INTRODUCTION

The local distribution of elephant seal moulting sites correlates with the accessibility of sites that may be used by moulting elephant seals (Rand 1962, Csordas & Ingham 1965, Condy 1977). A general survey of the vegetation of elephant seal moulting sites was undertaken in order to identify all such moulting sites and assign these to vegetation complexes during the period of the study.

METHODS

The elephant seal moulting sites were located and their surface areas determined by triangulation using a range-finder and compass. The moulting sites (Boulder and Trypot) were also surveyed using a plane table.

Assessment of the vegetation of each site was based on line transects and a more detailed method of partial-random sampling at the study areas. Other features which were recorded include: general slope of the area to the sea, accessibility of the site, number of seal impacted areas, features in the topography that could limit the movements of seals, use of the area by other species of bird and mammal and whether the areas were presently occupied or abandoned.

Each site was assigned to a particular plant community/complex following Gremmen (1981). The sites were assigned depending on the dominant species, and placed in more than one complex, where a number of community-complexes or transitions between these and the vegetation affected by seals occurred.

An indication of seal utilisation of each moulting site was based on counts of the number of seal impacted areas (areas where the vegetation cover was completely destroyed). These were then related to the size of the moulting site.

RESULTS

Areas utilised

The 36 moulting areas of elephant seals on Marion Island ranged in size from approximately 400m to 36 298m^2. The boundaries of these sites are recognisable, as abrupt changes in the vegetation and presence of wallows (weathered depressions) occur between these and the adjacent areas.

The location and relative size of presently occupied and unoccupied moulting sites are shown in Fig. 1 and Table 1. The smallest wallowing site (King Penguin East Wallows (25); 400,95m^2) occurs on the north of the island, and the largest on the south, (Watertunnel Wallows (13); 36 297,69m^2). Detailed assessments of the individual moulting sites are provided in Appendix 1 and the floristic composition of each site is presented in Table 2. Floristic lists, based on Gremmen's classification, are given, with the most important seal affected vegetation in these sites shown in Table 3. Only the dominant and characteristic species are shown and companion species (see Gremmen 1981) are omitted.

Areas impacted by seals remain visible for a few months following their departure and individual areas ranged from 3,4m^2 to 36,4m^2. The number of seal impacted areas for each site appear in

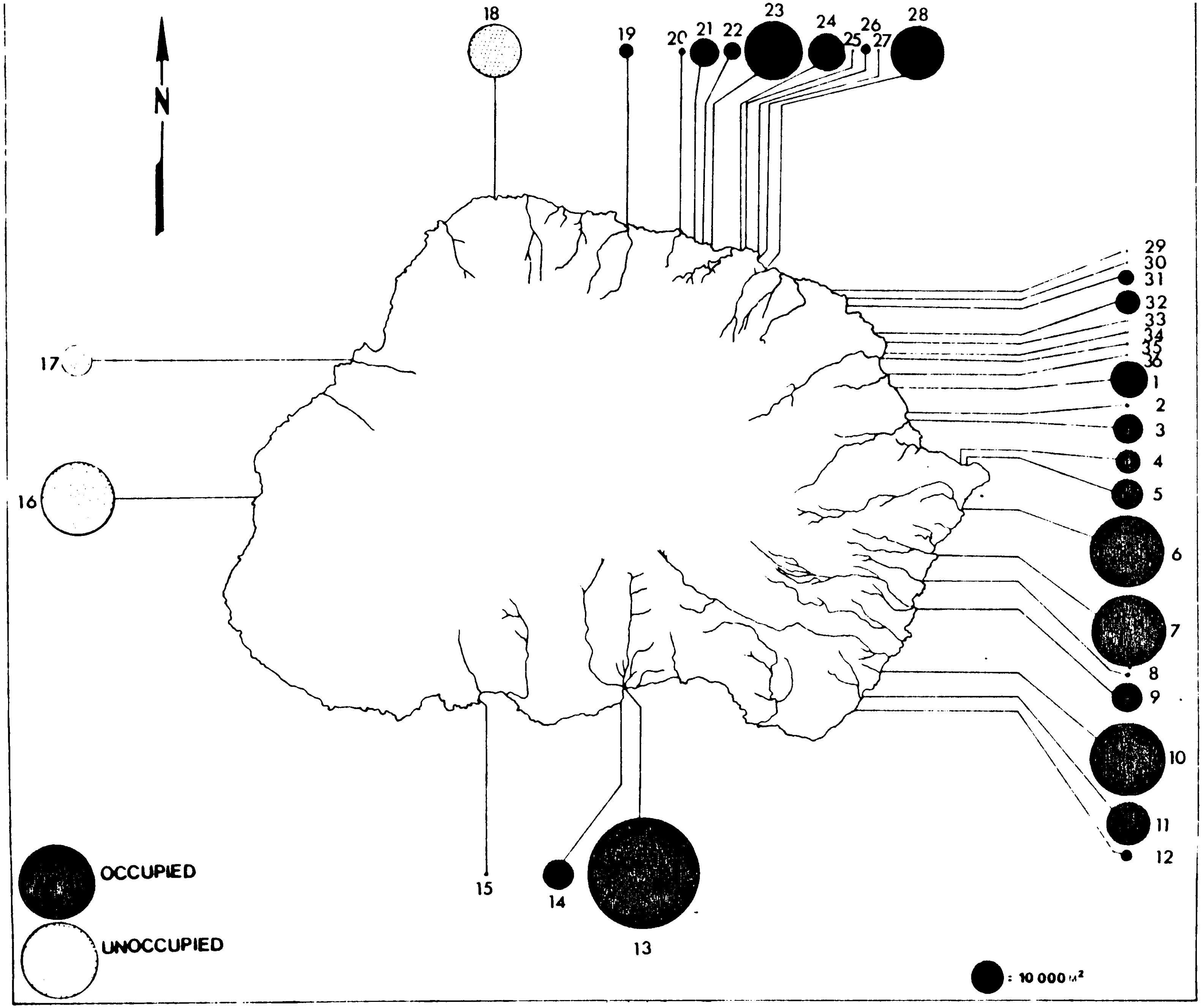

Figure 1. Location and relative size of elephant seal moulting sites on Marion Island. Numbers correspond to those in Table 2.

Table 1. Location and total areas (m^2) of elephant seal moulting sites on Marion Island.

NUMBER	MOULTING SITE	LATITUDE	LONGITUDE	AREA (m^2)
1	Boulder Beach	46°52,7'S	37°51,7'E	11613,9
2	Trypot North	46°53,1'S	37°52,1'E	1455,2
3	Trypot Beach	46°53,2'S	37°52,1'E	5989,5
4	Archway Beach	46°54,1'S	37°53,6'E	7201,3
5	Archway East	46°54,0'S	37°53,8'E	8710,6
6	Hansen Point	46°54,7'S	37°53,5'E	12252,0
7	Bullard West	46°59,5'S	37°52,9'E	11999,5
8	Killerwhale Cove	46°56,0'S	37°52,5'E	1282,7
9	Waterfall Cove	46°56,5'S	37°52,4'E	10037,9
10	Kildalkey North	46°57,6'S	37°51,5'E	26508,7
11	Kildalkey Beach	46°58,1'S	37°51,1'E	15563,7
12	Hooker Cove	46°58,3'S	37°50,9'E	2937,1
13	Watertunnel	46°57,9'S	37°45,1'E	36297,6
14	Watertunnel South	46°58,0'S	37°45,0'E	9727,8
15	Goodhope West	46°58,1'S	37°41,4'E	866,1
16	Kaalkoppie Beach	46°54,5'S	37°36,0'E	23884,3
17	Mixed Pickle	46°52,2'S	37°38,3'E	9575,3
18	Sealers Beach	46°49,5'S	37°42,0'E	17579,5
19	Storm Petrel Bay	46°49,9'S	37°45,2'E	4185,5
20	Goney Beach	46°50,0'S	37°46,5'E	2354,2
21	Log Beach	46°50,2'S	37°46,8'E	8948,9
22	Log Beach South	46°50,3'S	37°47,0'E	4529,9
23	King Penguin West	46°50,3'S	37°47,3'E	19627,2
24	King Penguin Bay	46°50,3'S	37°48,0'E	10115,9
25	King Penguin East	46°50,3'S	37°48,1'E	400,9
26	Sea Elephant Point	46°50,4'S	37°48,4'E	3886,6
27	Sea Elephant Bay	46°50,5'S	37°48,3'E	600,0
28	Sea Elephant Beach	46°50,7'S	37°48,5'E	19219,4
29	Sealers Beach	46°51,0'S	37°50,2'E	3749,1
30	Sealers South	46°51,2'S	37°50,5'E	565,8
31	Ships Cove	46°51,3'S	37°50,5'E	4907,9
32	King Bird Head	46°51,8'S	37°51,3'E	7851,1
33	Duikers Point	46°51,9'S	37°51,5'E	1158,3
34	Rockhopper North	46°52,1'S	37°51,5'E	1169,8
35	Rockhopper Beach	46°52,2'S	37°51,4'E	1360,8
36	Rockhopper South	46°52,5'S	37°51,5'E	1332,2
	Total Area Utilisation			312447,9

Table 2. Plant communities at elephant seal moulting sites at Marion Island.

		CRASSULA MOSCHATA COMPLEX		CALLITRICHE ANTARCTICA - POA COOKII COMPLEX			
Number	Moulting site	Cotulo plumosae-Crassuletum moschatae	Crassula moschatae-Azorelletum selaginis	Montio fontanae-Callitrichetum antarctica	Callitriche antarcticae-Poetum annuae	Poa cookii-Cotuletum plumosae	Leptodon prolifer. Poetum cookii
1	Boulder Beach				x	x	
2	Trypot North	x					
3	Trypot Beach			x	x	x	
4	Archway Beach				x	x	
5	Archway East	x					
6	Bansens Point					x	
7	Bullard West						x
8	Killerwhale Cove				x		
9	Waterfall Cove					x	
10	Kildalkey North				x	x	
11	Kildalkey Beach					x	
12	Booker Cove					x	
13	Watertunnel	x			x	x	
14	Watertunnel South				x	x	
15	Goodhope West				x		
16	Kaalkoppie Beach	x					
17	Mixed Pickle		x				
18	Sealers Beach			x			
19	Storm Petrel Bay	x					
20	Goney Beach	x					
21	Log Beach					x	
22	Log Beach South	x				x	
23	King Penguin West					x	
24	King Penguin Bay					x	
25	King Penguin East					x	
26	Sea-elephant Point					x	
27	Sea-elephant Bay					x	
28	Sea-elephant Beach				x	x	
29	Sealers South					x	
30	Sealers Beach			x		x	
31	Ships Cove				x	x	
32	King Bird Head				x		
33	Duikers Point			x			
34	Rockhopper North	x					
35	Rockhopper Beach				x		
36	Rockhopper South				x		

Appendix 1. These were linearly related to size of the moulting site ($r_{31}=0,65; p<0,001$). Areas of high densities of moulting elephant seals (large moulting sites) which possibly have the greatest impact in terms of vegetation cover and addition of nutrients within these, are also shown in Fig.1.

Habitat preferences

Access to moulting areas (Appendix 1) in terms of slope and hence ease of approach to the areas ranged, from 4° (Watertunnel South) to 17° (Log East). Seals were however able to manoeuvre up a 35° slope (Rockhopper). The boundaries of these wallowing sites were clearly demarcated as an abrupt end to the wallows and then a gradual change in the vegetation when compared to the immediate adjacent areas. Hills with slopes of $\geqslant 25^{\circ}$ and waterlogged mires seemed to restrict the movements of seals and where the areas were relatively flat (Watertunnel Stream, Kaalkoppie, Cape Davis, Boulder Beach), moulting areas were large with well defined boundaries.

Vegetation associations

Elephant seal moulting sites on the island were categorised into two community complexes and six associations (Table 2). More than one association occurred within a single site, with the Callitricho antarcticae - Poa cookii complex and the Poa cookii - Cotuletum plumosae association occurring within 20 (56%) of the moulting sites (Table 2). Thirteen sites (36%) consisted of the Callitricho antarcticae - Poetum annuae association and eight sites (22%) consisted of Cutulo plumosae - Crassuletum moschatae

Table 3. Floristic composition of plant communities occurring within elephant seal moulting sites at Marion Island.

Plant species	CRASSULA MOSCHATA COMPLEX		CALLITRICHE ANTARCTICA - POA COOKII COMPLEX			
	Cotulo plumosae-Crassuletum moschatae	Crassula moschatae-Azorelletum selaginis	Montio fontanae-Callitrichetum antarctica	Callitricho antarcticae-Poetum annuae	Poa cookii-Cotuletum plumosae	Leptodontio proliferi-Poetum cookii
Crassula moschata	x	x				
Cotula plumosa	x	x		x	x	x
Callitriche antarctica		x	x	x	x	x
Azorella selago	x	x				
Poa annua			x	x	x	x
Poa cookii			x	x	x	x
Montia fontana			x	x	x	x
Agrostis magellanica			x	x	x	x
Juncus scheuchzeroides						
Agrostis stolinifera			x	x	x	x
Acaena magellanica				x	x	x
Marchantia bertoroana			x			x
Eriopus apiculatus	x					
Clasmatocolea vermicularis						x
Colobanthus kerguelensis	x	x				
Campylopus cavifolius		x				
Racomitrium crispulum		x				
Plagiochila neterodonta		x				
Brachythecium rutabulum				x		x
Drepanocladus uncinatus				x		x
Lophocolea randii					x	x
Leptodontium proliferum					x	x
Lophozia cylindriformes						x
Mielichoferia campylocarpa						x

association, which is the typical coastal vegetation (Gremmen 1981). Four areas (11%) consisted of the Montio fontanae - Callitrichetum antarctica association.

DISCUSSION

Beaches along the east and north coasts consisting of flat, even profiles with smooth, rounded rocks and boulders are used extensively by breeding elephant seals (Condy 1977,1978).

The distribution of occupied sites during the moult and the breeding cycles during the 1950's (Rand 1962, Condy 1977) were assumed to have remained the same until 1974 (Condy 1977, 1978). Following the decline in the number of elephant seals (Condy 1977, Skinner & van Aarde 1983), five former breeding and moulting sites were unoccupied . The former west coast breeding and moulting sites, Kaalkoppie Beach wallows and Mixed Pickle wallows, had recently been abandoned, the former as a direct result of volcanic activity in 1980 , blocking access to the beach and vegetated moulting area, while the latter seems to have been abandoned shortly after 1974, and has since been occupied by large numbers of fur seals (Arctocephalus tropicalis). Although the wallowing site on the north coast, Sealers Beach wallows, was occupied during the present study by nine moulting elephant seals, these occurred on the extreme edge of the site and the site was considered as being in the process of being abandoned by elephant seals. The beach and wallowing site is now extensively utilised by fur seals (A. tropicalis and A. gazella) and these seemed to maintain the typical hollow/hummock topography of these areas. The two unoccupied sites on the east coast, Duikers

Point and Rockhopper North, although not located by Rand (1962), but identified as moulting sites by Condy (1977, 1979), seem to have been abandoned since 1974, the areas being small with no seals utilising them during the present study.

The number of unoccupied sites (5) represented a decline of 13,9% in site utilisation since 1974, with an overall area utilisation of 312 447,96m^2. Further declines in habitat utilisation were observed in the two study areas (see Chapter 4).

Apparent preference for the vegetated areas by moulting elephant seals has been shown by shifts in distribution between the moulting and breeding seasons (Condy 1978), with large numbers occurring within drainage lines of rivers (Fig. 1). The change in habitat selection applied to all age classes of elephant seals and has been shown to occur at Gough Island (Bester 1980), Macquarie Island (Carrick 1962) and Marion Island (Condy 1977, 1981).

Interspecific competition during the breeding season between fur seals and elephant seals is largely reduced to a minimum by spatial, temporal (Condy 1977, 1978, 1979) or behavioural separation (Ling 1979). During their extended moulting season, the elephant seal haul out coincided with the haul out of breeding populations of fur seals (Condy 1978) early in the season and with moulting fur seals later in the season (Kerley, pers. comm.) as well as with large numbers of moulting King penguins, <u>Aptenodytes patagonica</u> (see Appendix 1). Interspecific overlap occurred mainly with fur seals at 14 moulting sites, and at nine and three sites with King and Gentoo penguins (Pygoscelis papua) respectively. Although many examples of interspecific relationships between the pinnipeds have been cited in the literature (Scheffer 1958, Orr 1965, Rice, Kenyon & Lluch 1965, Ling 1969, Condy 1979), and interspecific competition for space has been shown to be minimal. However, competition for space in areas of similar habitat preferences may occur.

On Marion Island, large numbers of moulting King penguins occupied the beaches as well as limited areas within the moulting sites during the moult of the elephant seals, although King penguins preferred gentle sloping pebble beaches, while elephant seals sought vegetated areas. The presence of large numbers of penguins on these beaches appeared to restrict the movement of the elephant seals, with seals moving along areas adjacent to these colonies onto moulting areas, or taking a number of days to move through the colonies. The mere presence of large numbers of fur seals on the beaches and moulting sites seemed to act as a deterrent to elephant seals moving through such areas.

Although Huntley (1968) referred to the complex of plant communities owing their floristic and physiognomic characters to the influence of seals and birds as the Biotic Complex with the Cotula plumosa herbfield forming part of the complex, he made no reference to the distribution of these communities around the island. Salt spray is a major factor affecting the island's coastal vegetation (Huntley 1968, Gremmen 1981). Huntley (1968) recognised two noda in the Salt Spray Complex, the Tillea moschata halophytic herbfield, almost continuous along the west coast (with the sea's influence being mainly mechanical and physiological), and the Cotula plumosa herbfield, occurring inland within the vicinity of seal wallowing grounds. Plant communities occurring in areas influenced by sea-water or salt-spray were grouped together in the Crassula moschata complex (Gremmen 1981) and their composition is considered to be determined by the intensity of salt-spray deposition and by the water regime of the soil. The moulting sites of elephant seals consisting of the typical coastal vegetation (Crassula moschata complex) occur on two sites presently unoccupied (Kaalkoppie and Rockhopper North) while three small moulting areas, strongly affected by salt-spray occur on the north coast (Table 2), three on the east coast and one on the south coast.

It therefore seems that the trampling and manuring by the seals resulted in a more complex plant community type (Callitrche antartica- Poa cookii complex), the majority of the wallowing sites having typical Poa cookii - Cotuletum plumosae associations. These larger wallowing areas were situated along the east coast. The single moulting site belonging to the Crassula moschatae - Azorelletum selaginis association - the Mixed Pickle wallowing site (Table 2, Fig. 1) on the west coast, is exposed to wind and more adverse environmental conditions and this was reflected in the amount of bare soil (Gremmen 1981) present. In addition, bare soil resulted from large numbers of fur seals using the area.

The Bullard West moulting site, the only one on the east coast, consists of the Leptodontio proliferi - Poetum cookii assocation (Fig.1), with the predominant species being Poa cookii, Marchantia bertoroana and Leptodontium proliferum (Table 3) .This association is found on well drained soils and generally on slopes (Gremmen 1981). The Poa cookii tussock found present seemingly result from extremely high manuring by both seals and penguins.

The predominant species comprising the two associations within most of the moulting sites show a similarity in vascular species in the associations, differing only in the two predominant species. Brachythecium rutabulum and Drepanocladus uncinatus in the Callitricho antarcticae - Poetum annuae association, and Lophocolea randii and Leptodontium proliferum in the Poa cookii - Cotuletum plumosae association, with Cotula plumosa being the differential and dominant species in the latter association (Gremmen 1981). Poa annua together with Callitriche antarctica formed the Callitricho antarcticae - Poetum annuae association.

CONCLUSION

The survey of areas utilised by the moulting elephant seals and the resultant plant communities found in such areas suggest that elephant seals previously occupied all accessible vegetative areas. The vegetation of such areas differs from that of adjacent coastal sites. The preference for smooth, gentle sloping access areas leading to preferred vegetated areas resulted in the particular selection of moulting sites on the island. In turn the utilisation of these areas by seals has resulted in a plant community consisting of fewer species depending on the amount of seal utilisation and salt-spray. Sites on the north and east coast had the greatest species diversity. In areas where salt-spray seems to be the major factor in modifying plant communities, utilisation by seals apparently enhances the vitality of plants with an increase in the number of species found present (ie. Callitriche antarctica, Ranunculus biternatus).

As a result of the activity of seals, differences between sites and between the plant communities of moulting sites and adjacent areas do exist. Earlier workers (Huntley 1967, 1968, 1970, 1971; Smith 1976, 1977, 1978; Gremmen 1981) postulated that trampling and the addition of nutrients had been responsible for such differences.

CHAPTER 3

THE STUDY AREAS

The proximity of the Boulder Beach and Trypot Beach moulting areas to a laboratory, their relatively large areas of seal-affected vegetation, differences in their physiographical features and the availability of total counts of elephant seals within these areas since 1973 resulted in their being selected as study areas to determine to what extent the elephant seals affect soil properties.

BOULDER BEACH MOULTING SITE

Boulder Beach moulting site, situated approximately 600m from the meteorological station (Fig. 2) is relatively flat with the highest point 9,3 m above sea level and gently slopes from west to east and from south to north to Gentoo lake 3,3 m above sea level . The study area is illustrated in Fig.3. An indication of the variation in topography is given in Fig.4, showing both height above sea level and soil depth.The boundaries of this site can be easily distinguished from the surrounding areas by abrupt changes in vegetation or the abrupt end of the wallowing site.

Vegetation

The Boulder Beach site has a typical coastal vegetation (Gremmen 1981) with transition areas in the extreme west of the site, an area little used by elephant seals, and consisting of a Juncus scheuchzeroides - Blepharidophyllum densifolium complex (Gremmen 1981) with *Clasmatocolea humilis* dominant in this area. *Clasmatocolea humilis* is the character species with *Blepharidophyllum densifolium* and occasional stands of *Agrostis*

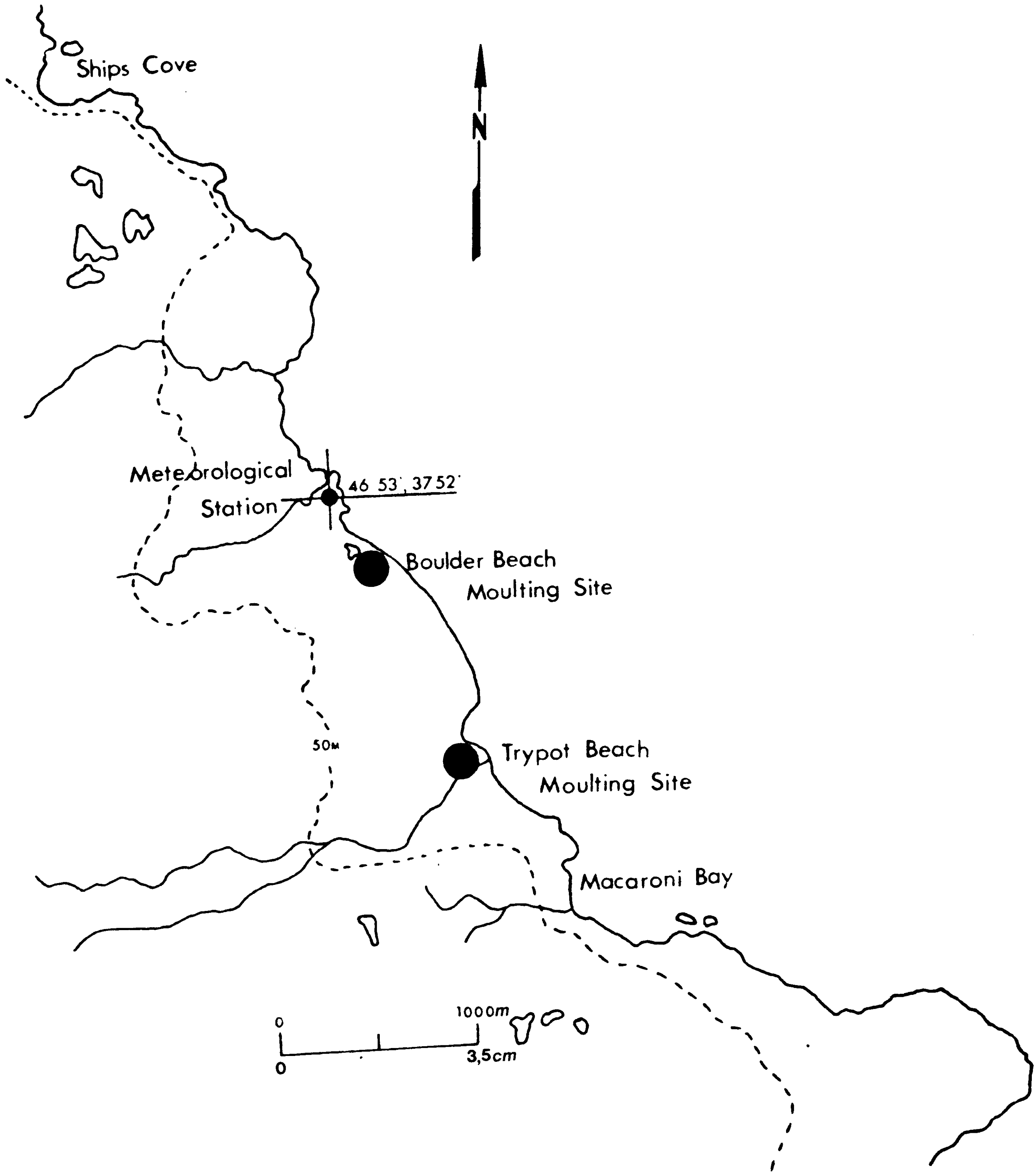

Figure 2. Locations of the Boulder Beach and Trypot Beach study areas.

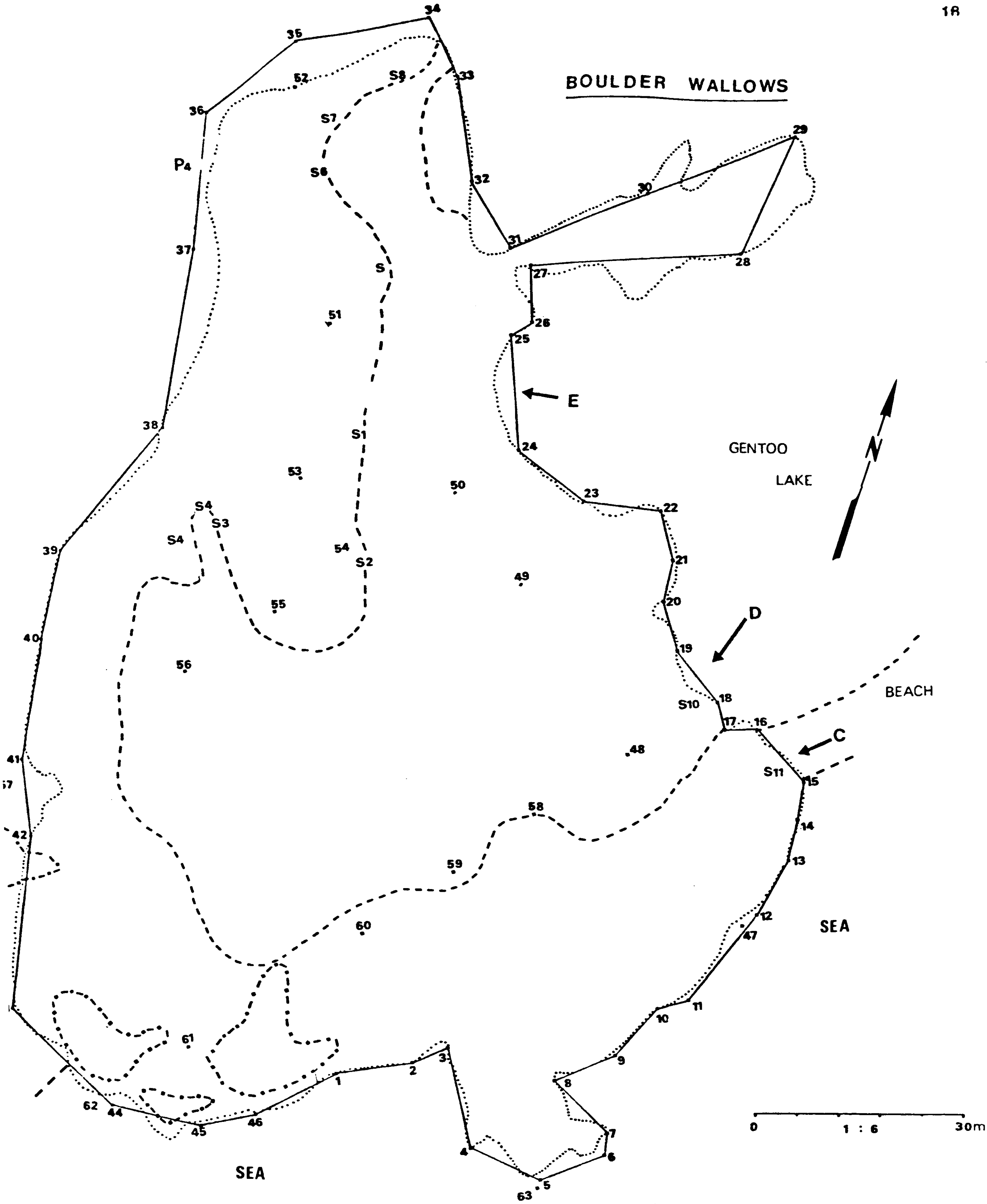

Figure 3. Boundaries (indicated by dotted lines) of the Boulder Beach moulting area. Broken lines indicate contour lines within the area. Arrows show seal access points. Numbers represent surveyed points.

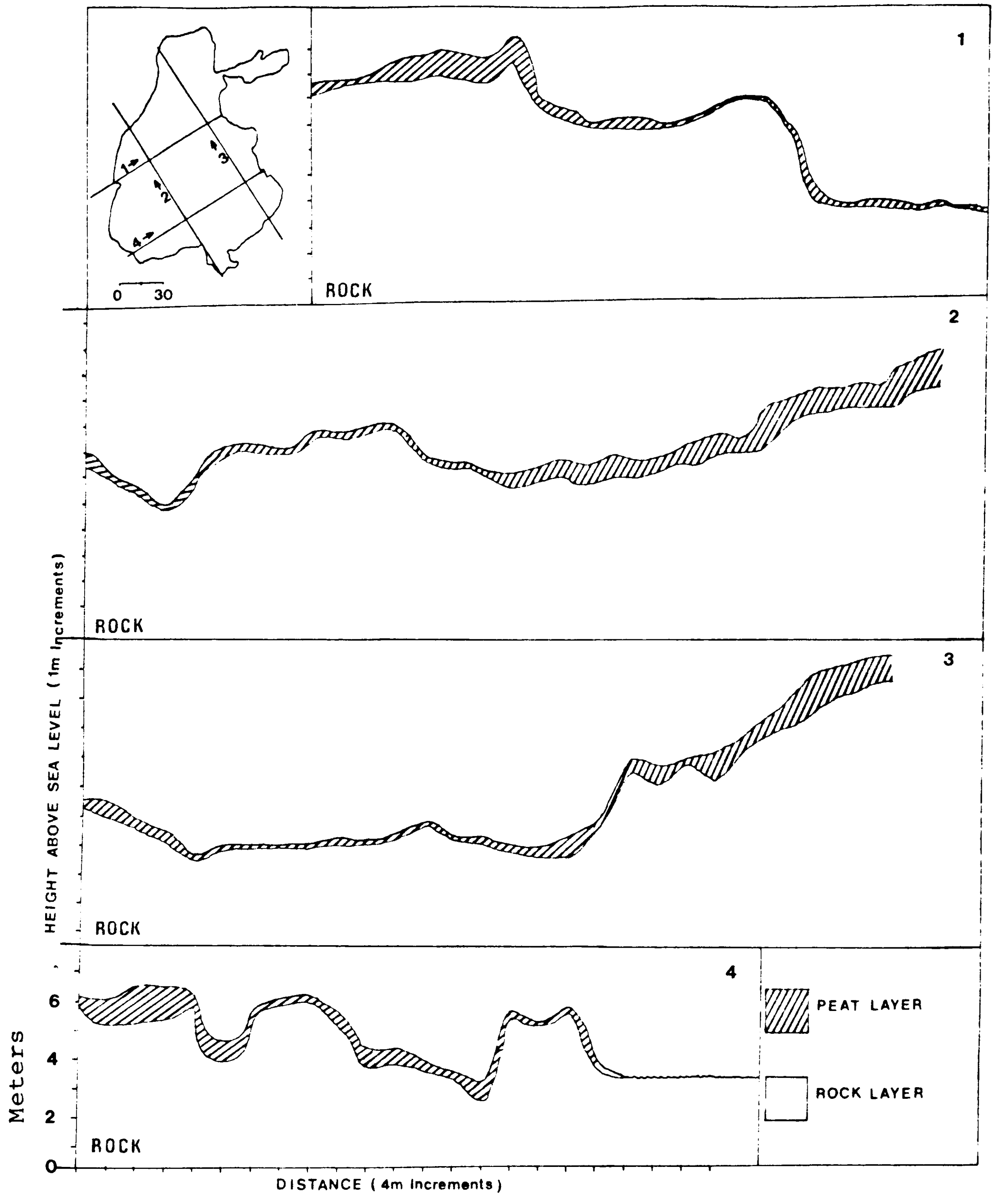

Figure 4. Profile diagram of the Boulder Beach wallowing area, showing height above sea level and soil depth. Locations of each cross-section shown in map-inset.

magellanica occurring. On the south edge of the site, stands of Jamesionella grandiflora occur, with Agrostis magellanica dominating the herb layer. On the eastern side of the moulting site, Crassula moschata has been completely eliminated. The area consisted of stands of Poa annua and Agrostis stolinifera and the introduced plant Sagina apetala.

Blechnum penna-marina occurred on the northern edge of the moulting site, bordering Gentoo lake, with occasional individual plants of Acaena-ascendens found present. No seal activity occurred on steep slopes forming the northern edge of the moulting site.The areas which were mostly used by seals, are relatively flat and adjacent to sloping access points. The vegetation was dominated by Poa cookii, Poa annua, Agrostis stolinifera and Sagina apetala, whilst Poa cookii occurred on the hummocks. Depending on the extent of seal activity, plants such as Poa annua, Agrostis stolinifera, Ranunculus biternatus, and Callitriche antarctica were dominant within individual wallow depressions.

TRYPOT BEACH MOULTING SITE

Trypot Beach moulting site, situated approximately 1,500 m south of the meteorological station (Fig. 2), was characterised by hollow depressions within the moulting area. The limits of the area were set by an abrupt ending of wallows with the highest point 9,47m and the lowest 0,97m above sea level. Seals had four access points to this moulting area (Fig. 5). However, utilisation of the area by elephant seals is at present reduced,

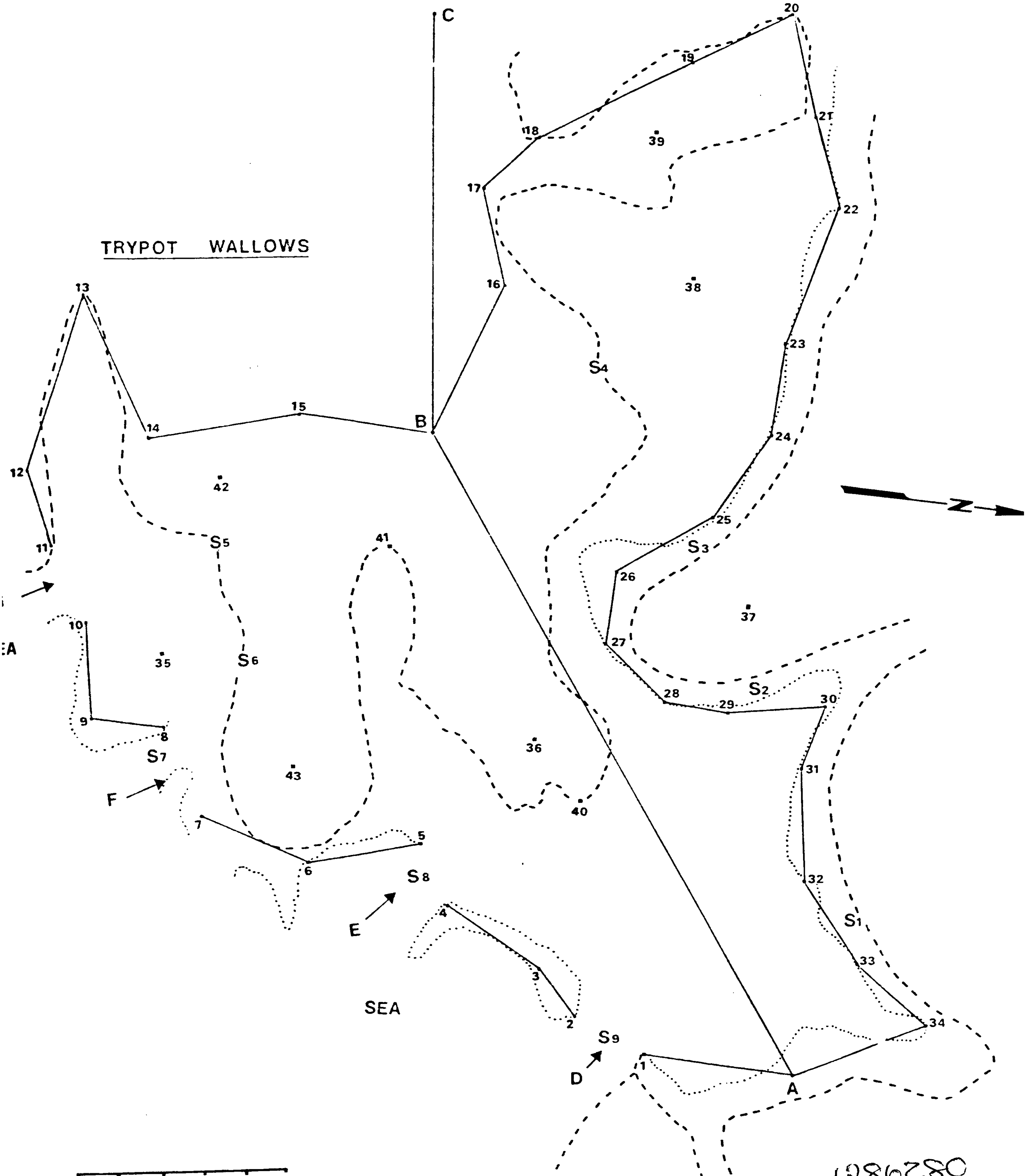

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Figure 5. Boundaries (indicated by dotted lines) of the Trypot Beach moulting area. Broken lines indicate contour lines within the area. Arrows show seal access points. Numbers represent surveyed points.

with seals being concentrated in two areas.

Vegetation

The areas at present heavily utilised by the elephant seals were dominated by Poa annua and Agrostis stolinifera with Poa cookii occurring on the hummocks. The northern extremity of the site was colonised by Cotula plumosa while the northern and eastern facing slopes of the western edge consist of stands of Blechnum penna-marina and Acaena ascendens .Natural depressions in the unused areas consisted of almost pure stands of Poa annua and Agrostis magellanica on the northern slopes, while the Crassula moschata complex, occurred on top of the slopes. The areas leading from the two southern access sites and which are used to a limited extent by the seals, had a vegetation type similar to the Cotulo plumosae-Crassuletum moschatae association (Gremmen 1981). Poa annua, Callitriche antarctica and Ranunculus biternatus occurred in the wallows.

CHAPTER 4

ELEPHANT SEALS: HAUL OUT BEHAVIOUR AND SPATIAL DISTRIBUTION

Condy (1977,1978) described the synchronised seasonal haul out pattern of the different age and sex classes of M. leonina on Marion Island. From this it was apparent that in order to assess the effects of elephant seals on their moulting sites (on the vegetation and soil nutrient levels), censuses of seals hauling out at both the study sites had to be undertaken.

METHODS

The Boulder Beach moulting area was subdivided into 15m grids using steel poles ("droppers") (Fig. 6). These were colour-coded and numbered to allow the precise placing of seals and mapping of wallows. Counts of seals and their precise location were determined five times a day (07h00, 10h30, 13h00, 16h00, 18h00) from 22 November 1980 to 28 February 1981.

The Trypot Beach wallowing area was demarcated by bamboo posts into 13 distinct areas (Fig. 7) and counts and utilisation by seals in the different areas were determined each day (22 November to 28 February).

TOTAL COUNTS: Elephant seals encountered in the study areas were grouped into four age categories: juveniles, sub-adults, adult cows and bulls, following Laws (1953) and Condy (1977). Juveniles included the pups of the present as well as the previous pupping season, corresponding to Condy's yearling class, and may have included second year animals. Sub-adults (male and female) represent those in their third to fifth year, while adult

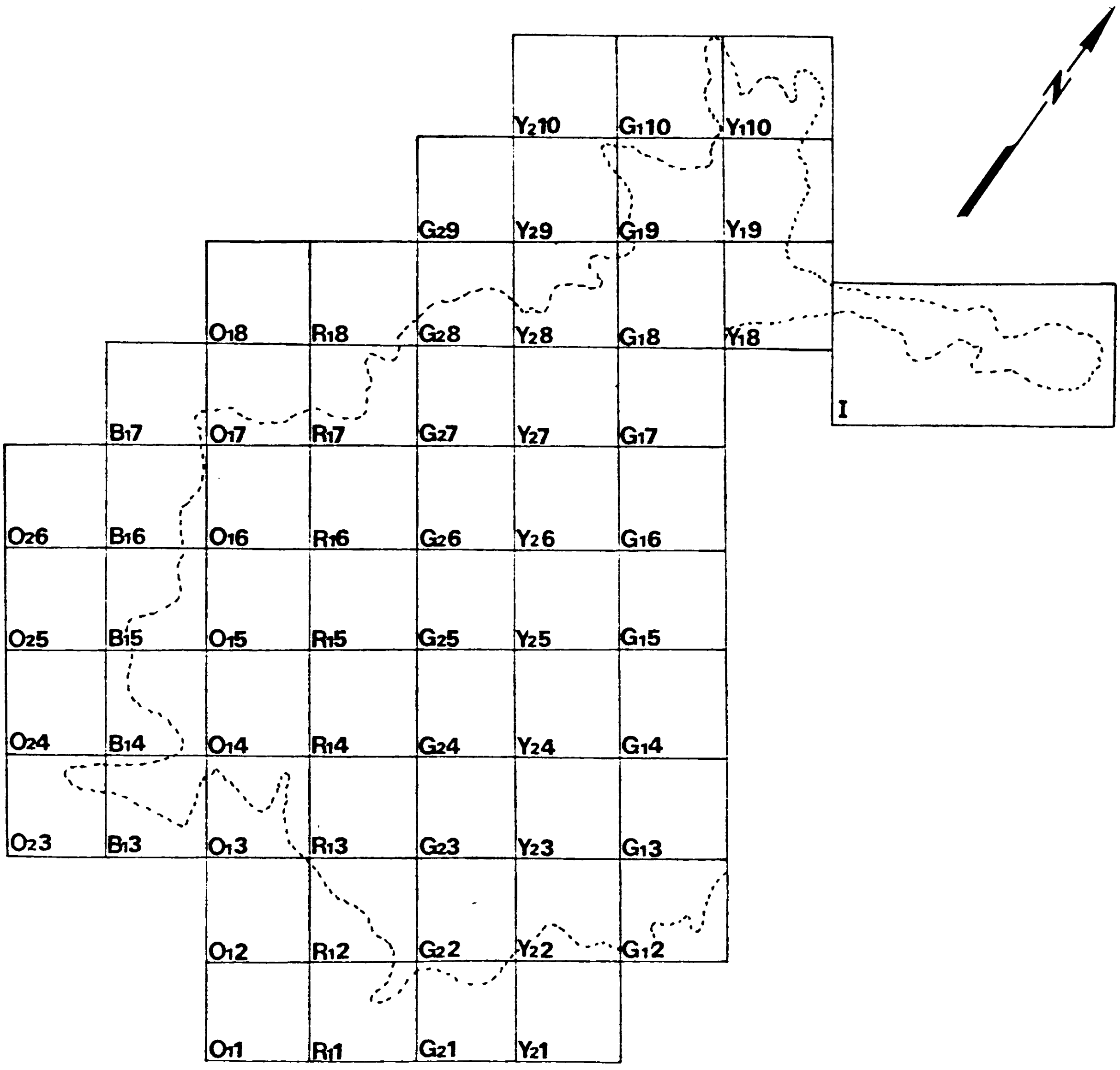


Figure 6. Grid system used at the Boulder Beach study site, with identifiable blocks numbered in the lower left-hand corner.

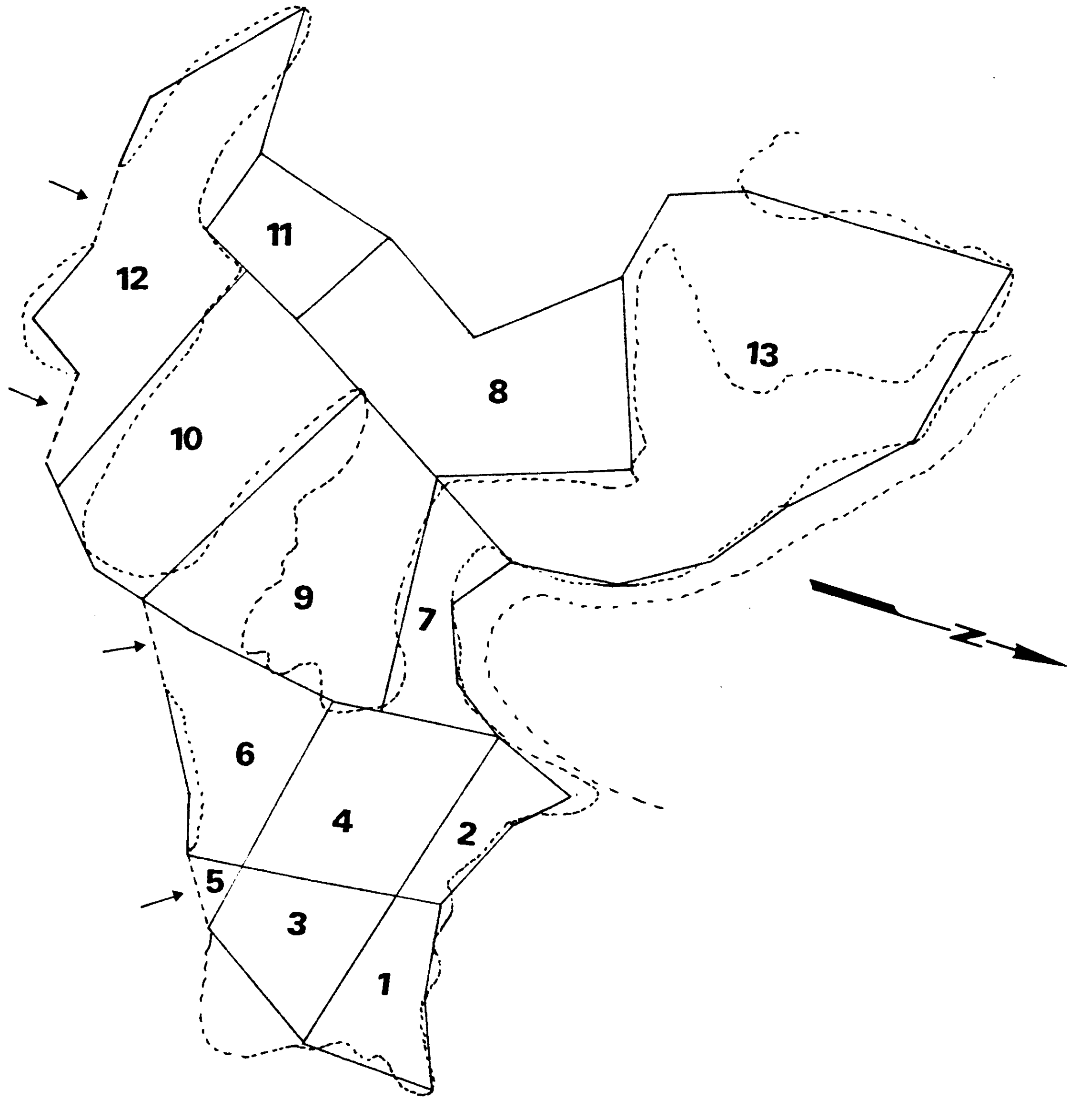


Figure 7. Trypot Beach study site showing thirteen selected areas with corresponding numbering system.

cows and bulls are in their sixth year or older.

LOCAL MOVEMENT. Seven seals were paint-marked in order to assess the extent of movement within the moulting site, since tagging proved unsuccessful due to inability to read tags.

CLIMATIC ASSOCIATIONS: Climatological data were obtained from the meteorological station and in addition temperatures were recorded at Gentoo lake using a portable digital thermometer (Kane-May), 1 m from the edge of the lake. Least square linear regressions were calculated to show the relationship between group size and the number of seals hauling out during different times of the day. Spearman rank correlations between weather variables and the total numbers of seals hauled out were computed. A detailed assessment of the data was carried out during the cow haul-out period (22 December to 30 January) so as to minimise the overall effect of the two-way movement of seals, departing and arriving at the site. The sample size depended on the number of days on which all observations were carried out at the appropriate times.

UTILISATION INDEX: See appendix 2

RESULTS

An analysis of the counts of seals of the different age classes confirms the patterns described by Condy (1977,1978,1979,1981),and is shown in Fig.8. The first peak in population numbers occurred on 23 October, and pup numbers

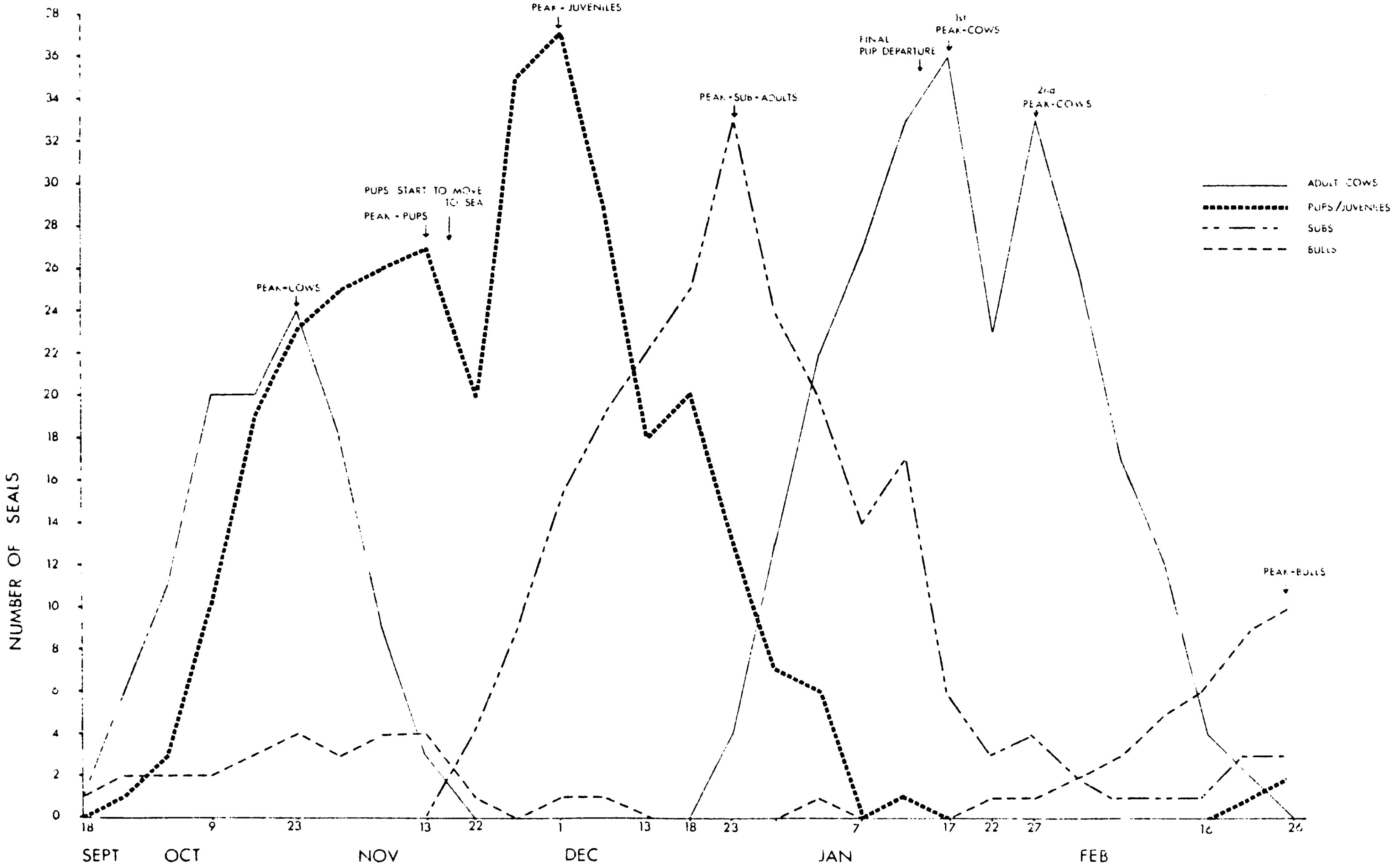


Figure 8. Population cycle for southern elephant seals on Marion Island, from September 1980 to February 1981. Numbers of seals represent the mean number of seals at the Trypot and Boulder study beaches.

peaked on 13 November. Local movement of pups to other beaches starts on 17 November, with pups becoming pelagic on 17 January. The first population peak in numbers during the moulting season occurred on 1 December with juveniles (the previous year's pups) peaking, followed by peaks in the sub-adult population (both females and males) on 23 December. The haul out pattern of the adult cow component was characterised by two distinct peaks, the first occurring on 17 January, and was believed to consist of cows in their first pregnancy and sub-adult cows in their fourth year(Condy 1978). The second peak occurred on 27 January, and was thought to consist of adult cows. Bull numbers increased towards the end of Feburary, peaking on 26 February.

The seasonal haul-out pattern of elephant seals of each age and sex at Marion Island (Condy, 1977, present study), and the part of elephant seal biomass hauled out each month on the island (Condy, 1981) suggests that seals of different age classes will have different effects on the areas where they occur. The percentage of the total number of seals hauled out (5-day intervals) over the moulting period from 22 November to 28 February in the two study areas is shown in Fig. 9 and 10. The mean values for the two sites are shown (Fig. 11). The actual numbers and percentages are given in Appendix 4. Although considerable overlap exists between the seals of particular age-classes, the period that 50% or more haul-out (calculated as a percentage of the total number hauled out) shows a distinct separation of the age-classes. The haul out period for juveniles extended from 22 November to 3 December, peaking on 26 November;

Table 4. Maximum number of adult cows and bulls hauled out at Trypot and Boulder Beach, 1973 - 1981.(Data 1973-1980 from unpublished records, Mammal Research Institute)

	TRYPOT BEACH						BOULDER BEACH					
	COWS		BULLS		MOULTING NO.s / BREEDING NO.s %		COWS		BULLS		MOULTING NO.s / BREEDING NO.s %	
	Breeding	Moulting	Breeding	Moulting	Cows	Bulls	Breeding	Moulting	Breeding	Moulting	Cows	Bulls
1973/1974	77	45	4	6	58,4	150,0	16	60	3	1	375,0	33,3
1974/1975	62	40	2	3	64,5	150,0	18	33	4	4	183,3	100,0
1975/1976	67	31	1	4	46,3	400,0	11	34	2	6	309,1	300,0
1976/1977	37	70	1	6	189,2	600,0	5	45	2	7	900,0	350,0
1977/1978	45	33	2	4	82,5	200,0	18	39	5	5	216,7	100,0
1980/1981	40	45	3	6	112,5	200,0	12	27	1	7	225,0	700,0

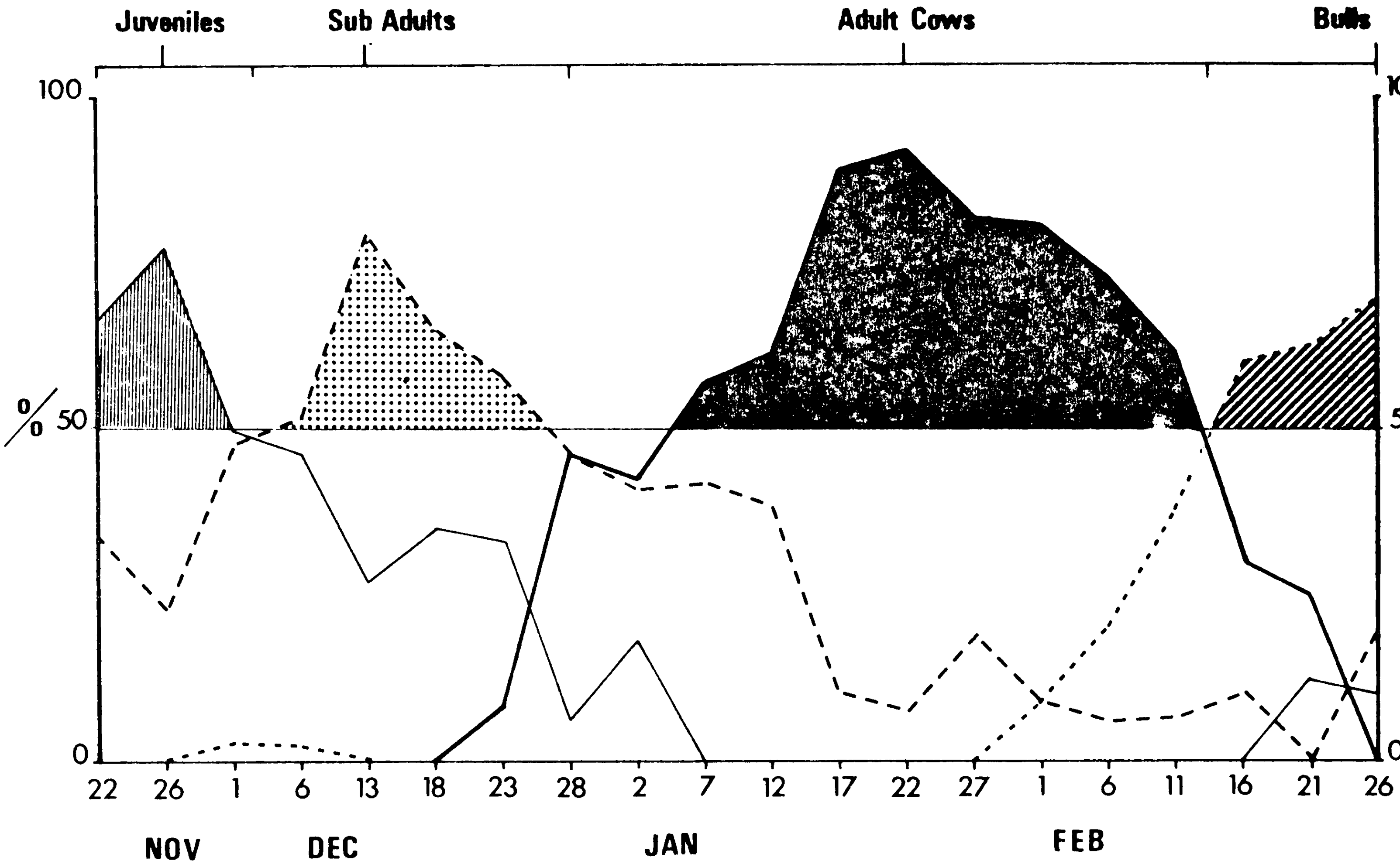


Figure 9. Percentages of seals of each age class hauled out at the Boulder Beach site from November 1980 to February 1981.

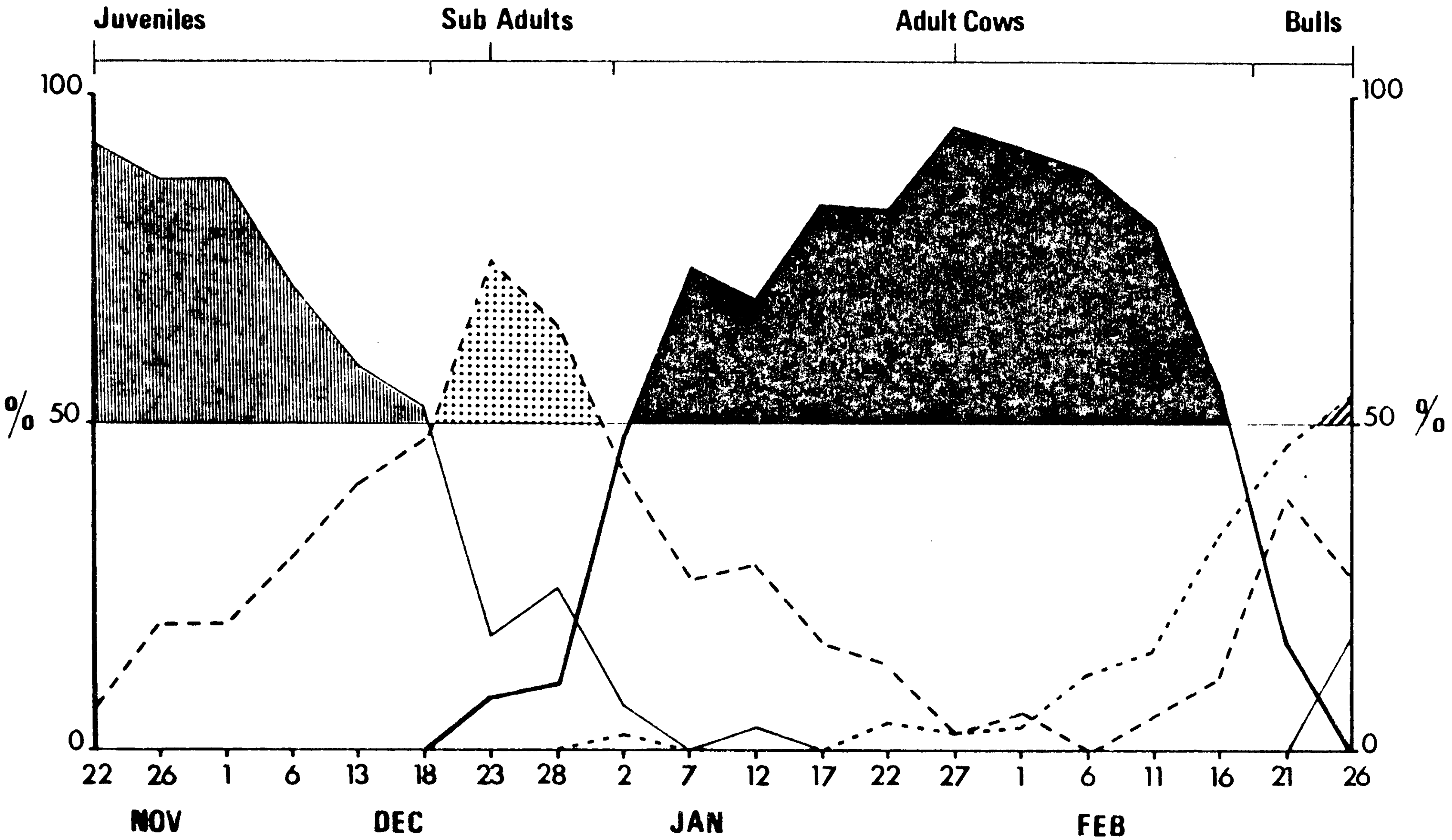


Figure 10. Percentages of seals of each age class hauled out at the Trypot Beach study site from November 1980 to February 1981.

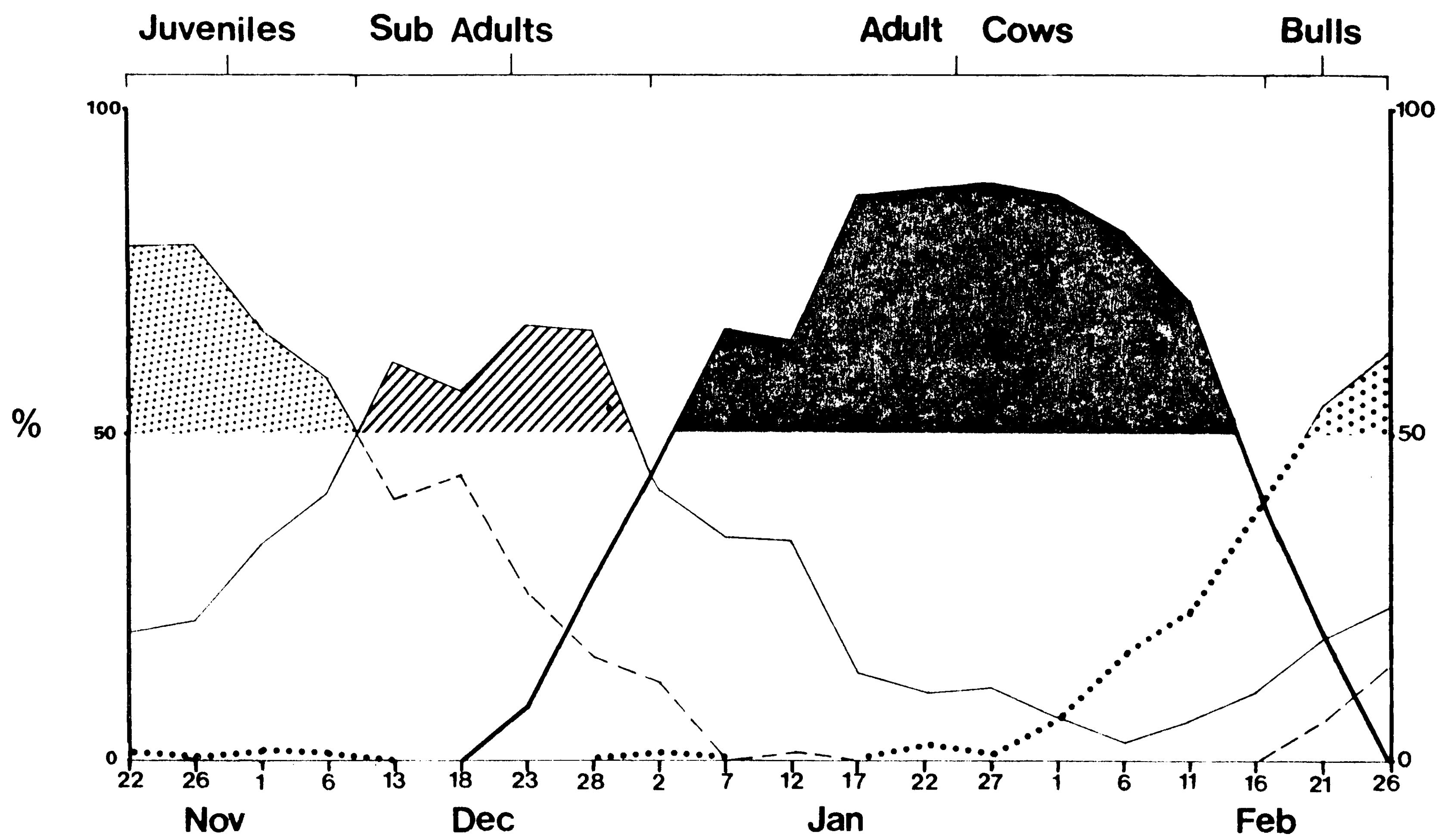


Figure 11. Mean percentage of each age class of elephant seals hauled out at the Trypot and Boulder Beach study areas. November 1980 to February 1981.

the sub-adult age-class, from 4 December to 21 December peaking on 13 December; the adult cow age-class from 22 December to 30 January, peaking on 22 January; and the adult bulls from 31 January to 28 February, peaking on the 26 February.

Duration of the haul out periods during the moult has been determined by Condy (1977), and this period the seals spend on the island is likely to have the greatest trampling impact on the moulting sites. During the moult bulls were present for 19 weeks (36,5%) of the year, while cows occupied the island for 12 weeks (23,1%) with sub-adults and yearlings spending 26,9% and 19,2% respectively, of the year moulting.

The time spent when 50% or more of a particular age-class had hauled out (Fig. 11) was 34, 20, 44 and 12 days for juveniles, sub-adults, cows and bulls respectively.

Space utilisation

The present boundaries to the two moulting sites, are shown in Fig. 12 together with the present utilisation of the Boulder Beach moulting site, and the different areas which were occupied during the 1980/1981 moulting season at the Trypot Beach moulting site. The areas of these study sites and the decrease in use is given in Table 5. The decrease of 32,6 and 37,7% at the Boulder and Trypot site respectively represents an average decrease in area utilisation of 35,2%.

TABLE 5. Total and present areas utilised by elephant seals at the Boulder and Trypot moulting sites.

Moulting site	Total area(m^2)	Present area utilised (m^2)	% Decrease
Boulder	11613,91	7827,78	32,6
Trypot	8989,57	5600,50	37,7

Areas close to access points were used more intensively than areas further from the coast. These represented easily accessible, gently sloping vegetated areas, and although fewer seals were using a smaller area, apparent site preferences occurred. The Utilisation Index (UI) of each 225 m^2 in the case of Boulder and in each of the 13 areas at Trypot is shown in Fig. 12 & 13. At Boulder Beach, the UI ranged from 0,01 to 4,78. Blocks showing high UI values (1,21-4,78) represent areas where seals grouped and remained in the wallows for long periods of time. The effect of trampling and the addition of soil nutrients were the greatest in these areas. Figure 12 indicates the identification code in the lower left corner, with the value for each block indicated (UI) in the centre of each.

Wallows generally occurred within the lee of the contour line in the area, and seem to indicate that seals prefer areas which provide protection from the westerly winds. The mean UI over the whole area was 0,48 which approximates 48 seal occupation days throughout the period (see Appendix 2). At the Trypot site differences existed between areas, with seals utilising areas to

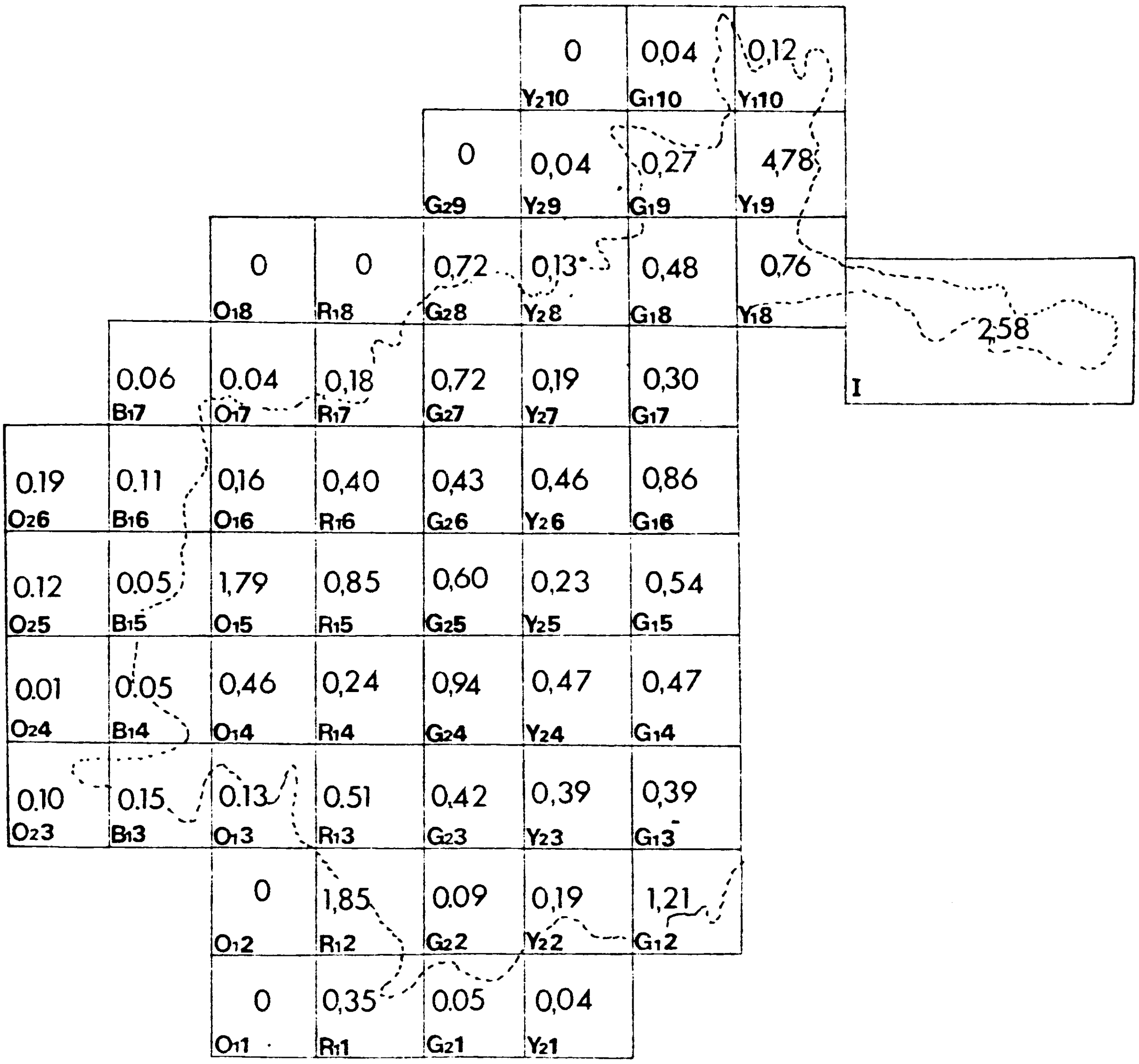


Figure 12. Past and present utilisation (1980/1981) of the Boulder Beach moulting site. Figures represent the Utilisation Index (indicated in the centre) for each 225m^2 block.

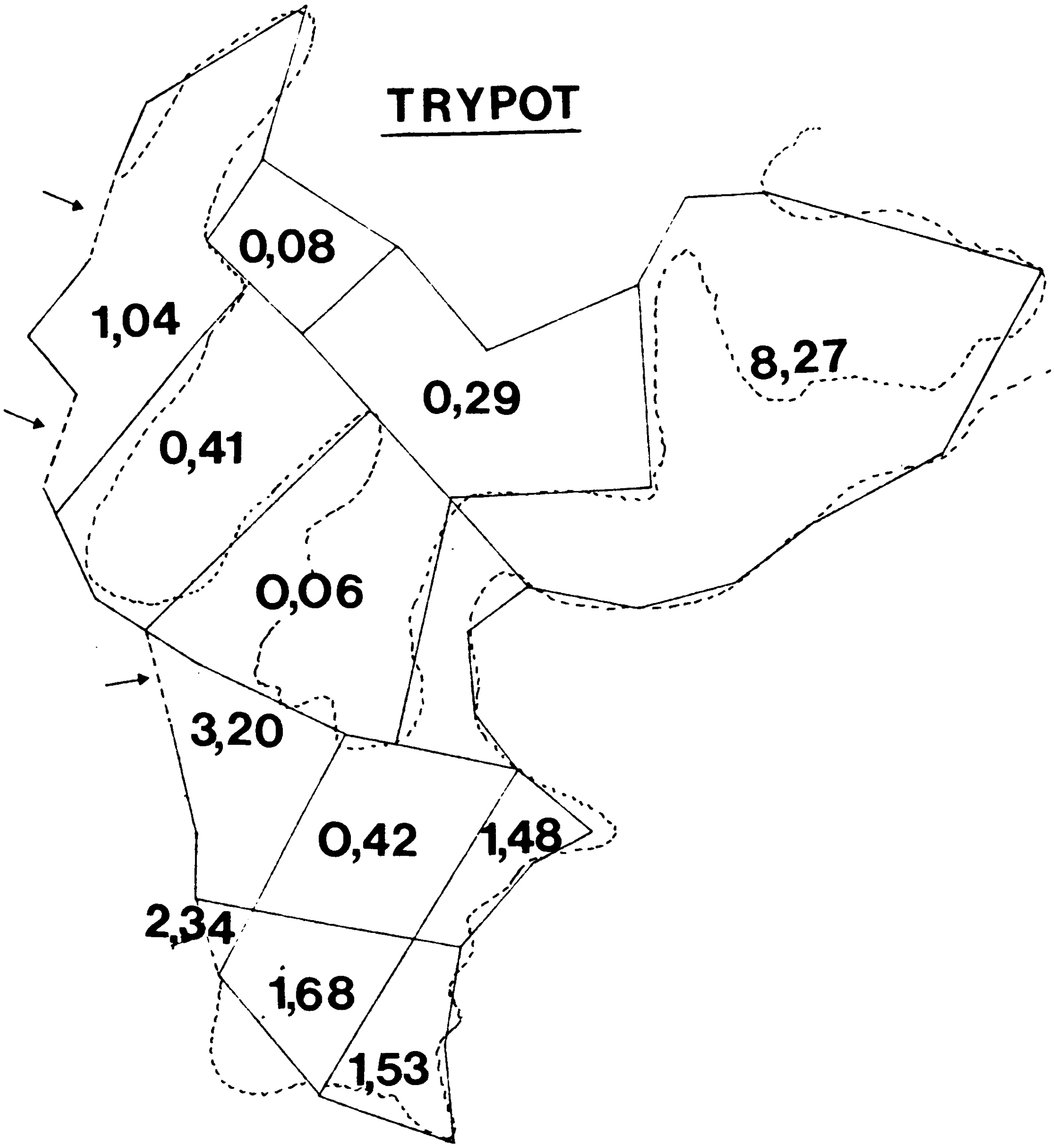


Figure 13. Present (1980/1981) utilisation of the Trypot Beach moulting site. Figures represent the Utilisation Index (indicated in the centre) of each area.

in close proximity to access sites as well as areas on the edges of the old moulting sites. Some areas (area 4) were largely avoided by the seals and were only used as thorough fares to other areas. Area 4 was also utilised by King penguins, resulting in the complete destruction of the peat layer.

Individual movement of seals

The distances a number of paint-marked seals moved each day are shown in Fig. 14. Sub-adults A and B (Fig. 14) moved 9,7 and 22,7 m/day (Table 6), spending approximately one day at each location (wallow). Adult bulls C, D and G (Fig. 14) spent more time within wallows, not moving within the area as sub-adults. Distances moved per day varied from 3,7 to 14,1 m/day (Table 6).

Climatic associations

Observations during the 1980/1981 moulting season revealed a diurnal pattern of utilisation by the elephant seal populations at these sites. The number of moulting seals increased towards midday and decreased to their lowest numbers towards evening when they moved to the nearby freshwater lake at the Boulder site and to the sea at the Trypot site.

During the moulting cycle the number of elephant seals hauled out each day fluctuated considerably. No relationship existed between the maximum numbers of seals hauled out at a site and the mean air temperatures (r_{30}= 0,04). It was apparent that seals hauling out to moult at the Boulder Beach site had a diurnal haul-out rhythm, with seals moving back and forth between the moulting area and Gentoo lake. The mean number of seals in the

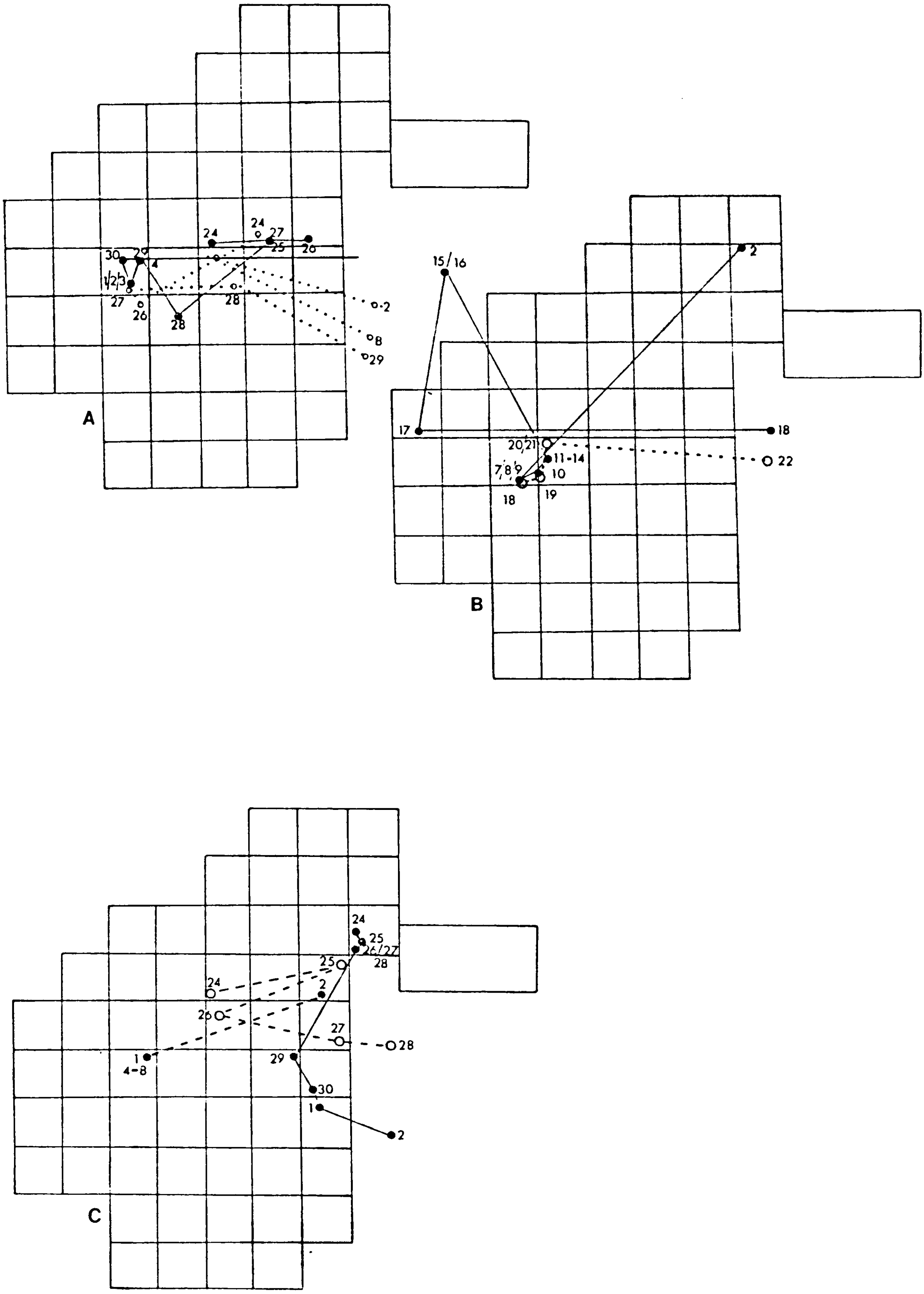


Figure 14. Movements of paint-marked individuals within the Boulder Beach moulting site. A: sub-adult male o———o(24/11/80 to 1/12/80); sub-adult male o·····o(24/11/80 to 4/12/80). B: adult bull o———o(2/2/81 to 18/2/81); adult bull o·····o(20/2/81 to 6/3/81). C: juvenile female o———o(24/11/80 to 2/12/80); juvenile male o·····o(25/11/80 to 2/2/81); adult bull o———o(1/12/80 to 92/12/80).

Table 6. Distances moved per day by marked elephant seals during periods in the moulting season.

Individual		Period of observation (days)	Distance moved (m/day)
Sub-adult male	A	7	9,7
Sub-adult male	B	11	22,7
Adult bull	C	16	14,1
Adult bull	D	14	3,7
Juvenile female	E	8	31,6
Juvenile male	F	7	68,9
Adult bull	G	1	8,1

moulting site over a 45 day period is given in Fig. 15. Seal numbers peaked at 10h30, and decreased to a trough at 18h00. Daily trends in numbers, furthermore, corresponded with daily trends in temperatures, with the highest temperature recorded at 10h30, these decreasing slightly towards early afternoon, reaching a minimum after 18h00 (Fig. 15). Daily variation in the number (maximum and minimum) of seals at the Boulder Beach site for a sampling period of 15 days from 15 to 30 January is shown in Fig. 16. Fluctuations in the total number of seals hauled out were significantly related to: maximum dry bulb temperatures (r_s = 0,43 ; $p < 0,01$), maximum humidity (r_s = 0,53; $p < 0,001$), minimum cloud cover (r_s = 0,48; $p < 0,01$) and maximum wind speeds (r_s = 0,69; $p < 0,001$). Temperature, cloud cover and humidity are strongly correlated to each other. Spearman rank correlations suggest that maximum temperatures and humidity, and maximum humidity and maximum cloud cover are positively related (r_s = 0,44; $p < 0,01$ and r_s = 0,91; $p < 0,001$ respectively). Moulting elephant seals thus tend to haul out on days when temperatures, humidity and hence cloud cover are high.

The mean number of groups formed at the five time periods and the mean air temperatures for each time period over 15 days from 15-30 January is shown in Fig.17. The number of groups decreased with an increase in temperature and increased with a decrease in temperature.

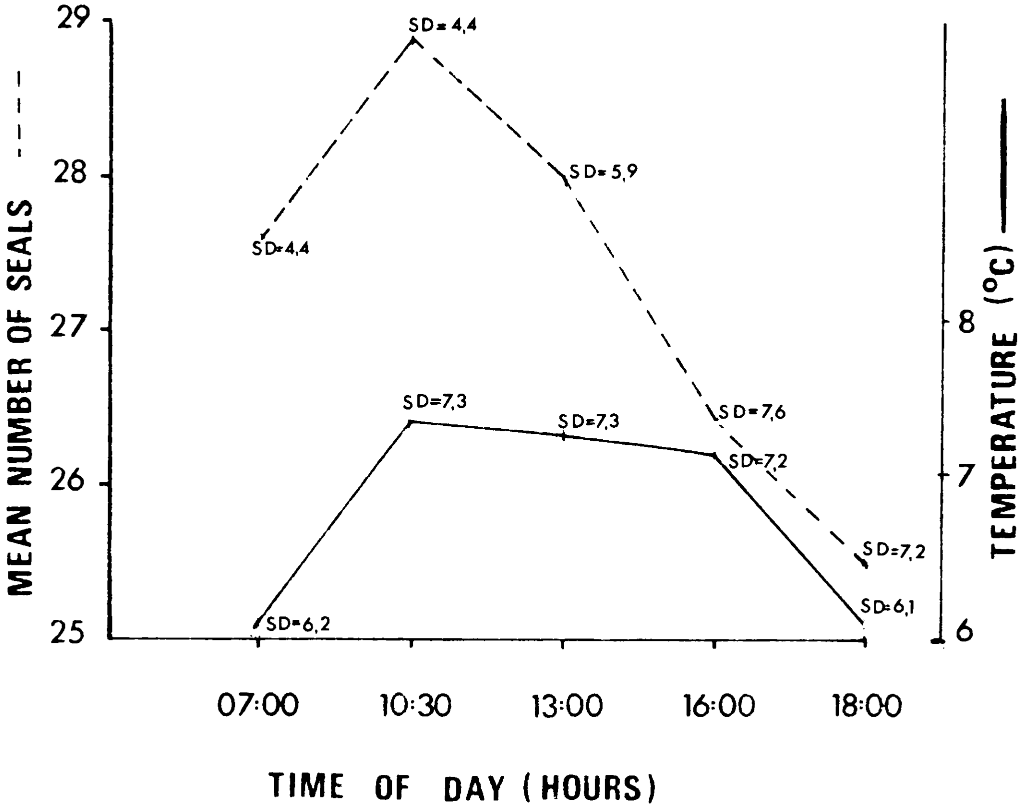


Figure 15. Mean number of elephant seals and mean air temperatures at different times over a 45 day period (S.D. - standard deviation).

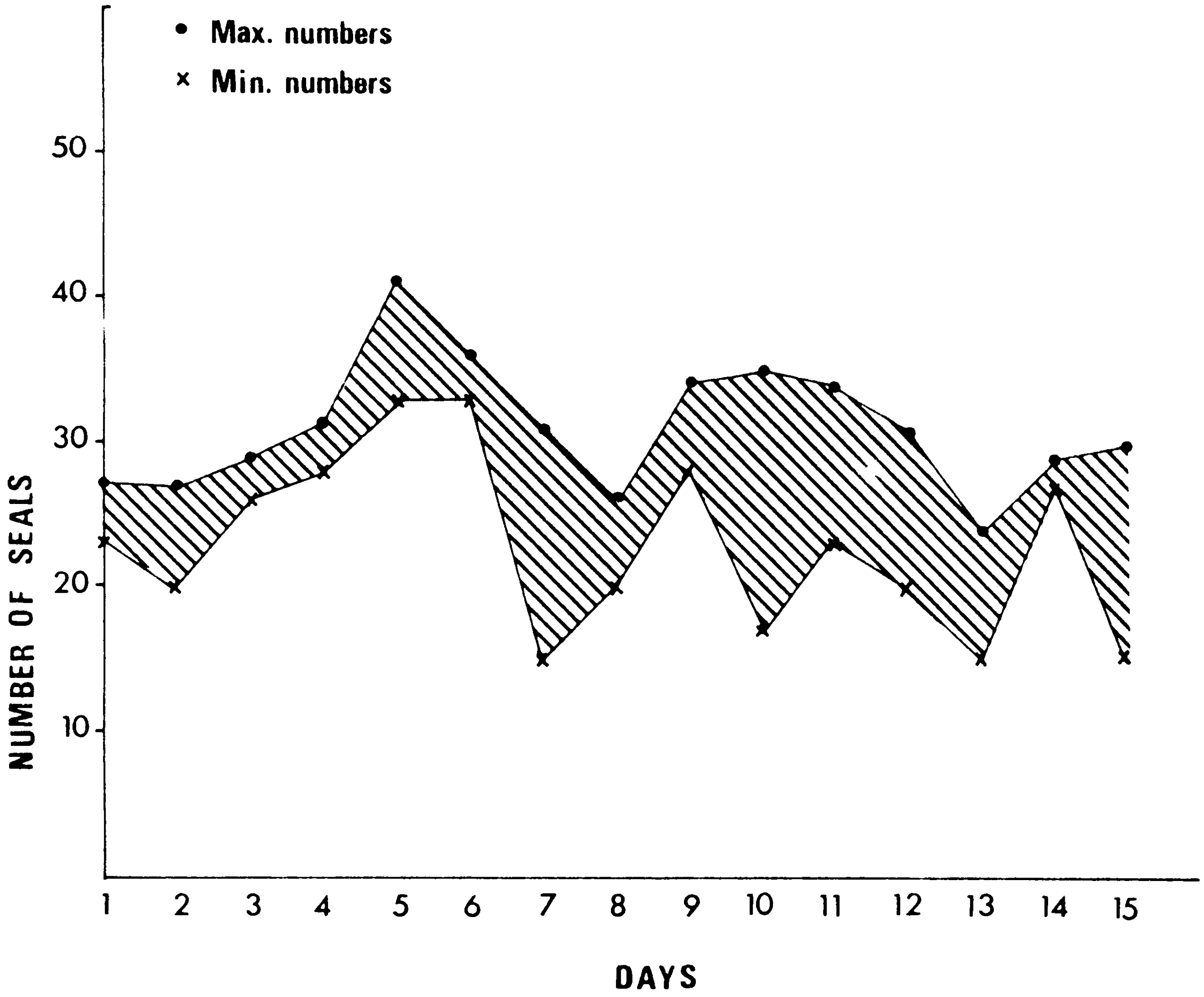


Figure 16. Daily variation in the number of seals at the Boulder Beach moulting site for a 15 day period from 15-30 January 1981.

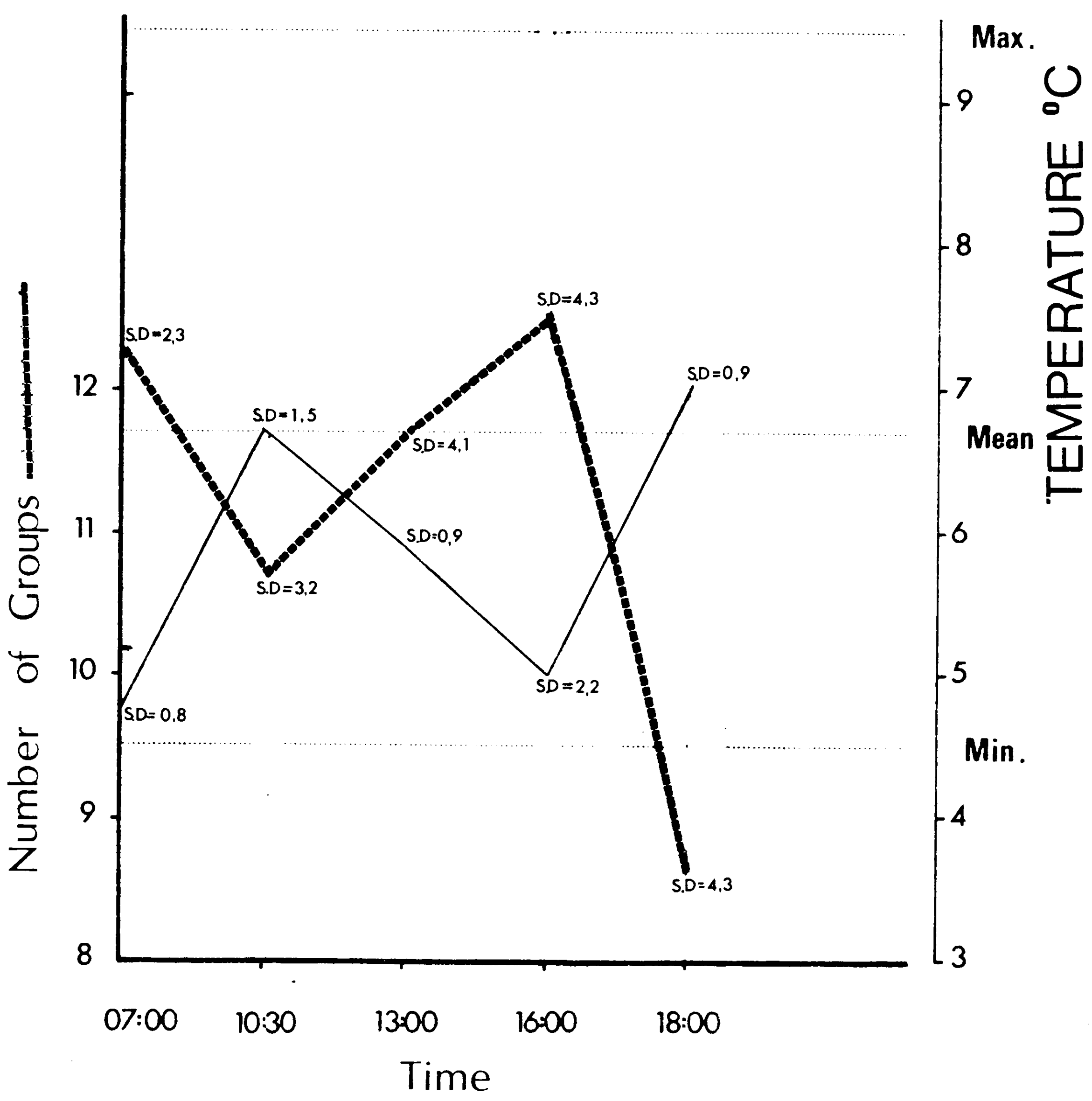


Figure 17. Daily variation in the number of groups of moulting elephant seals and air temperatures for the period 15-30 January 1981 at the Boulder Beach Moulting site (S.D. - standard deviation).

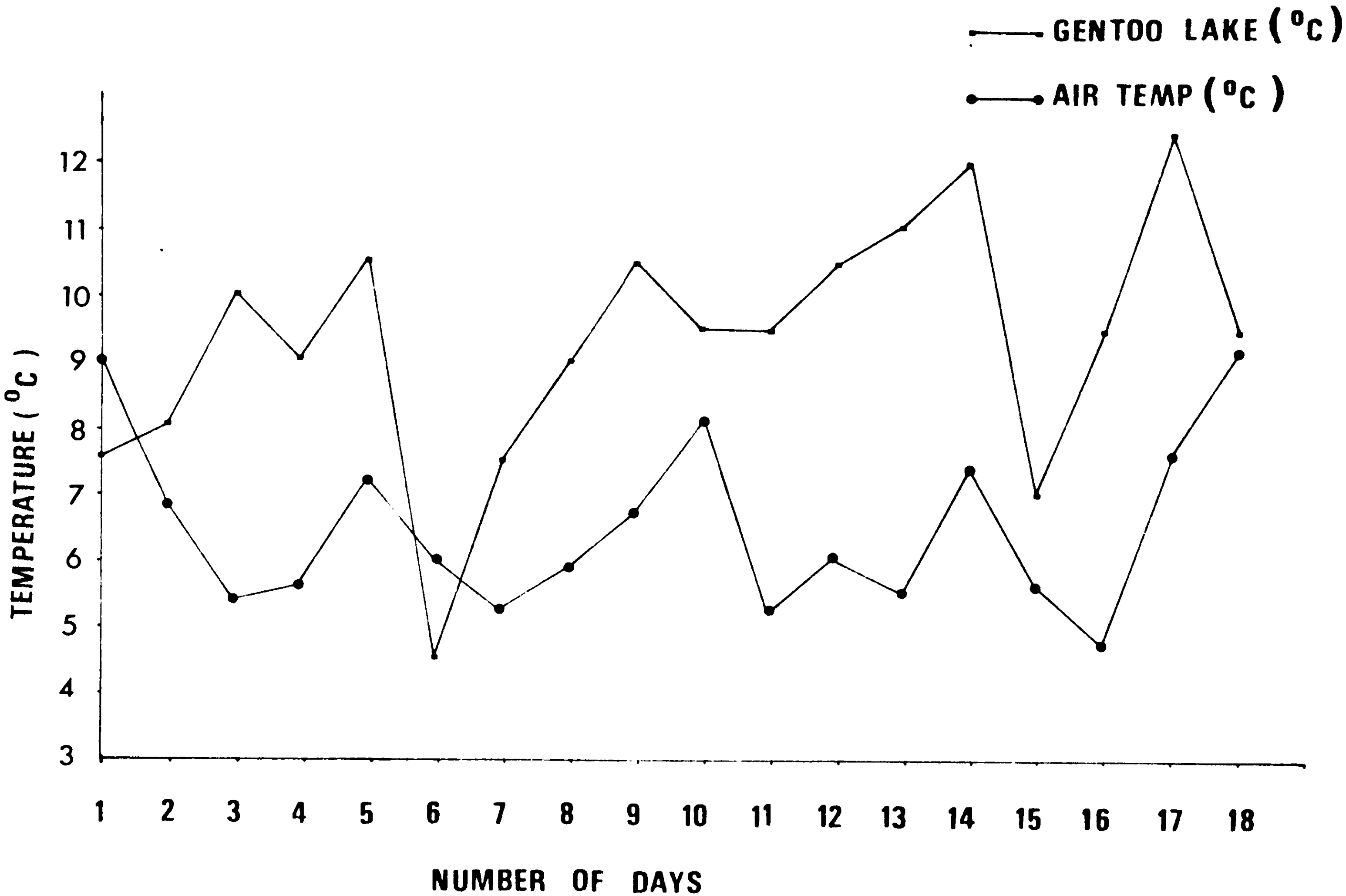


Figure 18. Differences between the air and water temperatures of Gentoo Lake for a 18 day period from 15 January to 3 February 1981.

DISCUSSION

The peak in the number of adult females hauled out to moult occurred on 25 January at Macquarie Island (Carrick,Csordas & Ingham 1962b), 26 January at Signy Island (Laws 1956), end of January at Heard Island (Carrick,Csordas &Ingham 1962b), late December and during January at Campbell Island (Sorenson 1950) and 22 January (Condy 1977) and 27 January (present study) at Marion Island. This peak occurs at similar times at all islands in the southern ocean and the proximate factor initiating hauling out to moult is therefore probably daylength (Laws 1960, Ling 1972). The sequence of the haul-out in which the immatures of both sexes moulted before the adult females which are followed by the adult males in order of increasing size and age (Carrick,Csordas & Ingham 1962b; Condy 1977, 1978) differs from the sequence followed by the the northern elephant seal (Le Boeuf 1972) where the immatures of both sexes moulted after the adult females.

Seals hauling out to moult preferred certain areas, with individual movement of seals varying according to age and size. The degree of association between the different groups and the spacing of these groups at various times and positions resulted in the destruction of the vegetation with addition of nutrients occurring in localised areas. The greater degree of gregariousness of the females during the moult is an indication that they have the greatest impact on the island.

The degree of association between individuals depends on the tolerance between different age classes. Adult cows on Marion

Island seemed to be the most tolerant, dispersing when bulls associated with them. The number of seals associating together depended not only on the tolerance within the group but the maximum group size may also depend on the microclimate, a factor mentioned by Laws (1960) and Ray & Fay (1968). Individual movements of seals as well as the formation of groups are therefore influenced by climatic factors during the period of moult. The effects of moulting seals in terms of vegetation destruction and addition of nutrients in localised areas will therefore vary from season to season.

CHAPTER 5

SOIL PROPERTIES : SOIL ANALYSIS WITHIN MOULTING SITES

INTRODUCTION

Studies on the effects of animals on sub-Antarctic islands have been concerned with the effects of grazing and erosion by rabbits (Gillham 1956), the influence of reindeer grazing on the vegetation at South Georgia (Lindsay 1973, Knightley & Smith 1976), the trampling and manuring effects of birds and elephant seals at Macquarie Island (Gillham 1961) and their modifications on the island's flora. Studies on Marion Island have been concerned with the manuring influences of birds on soil-nutrient levels (Smith 1976, 1977, 1979; Huntley 1971), and the trampling and subsequent erosion of the peat layer due to penguin activities (Hall & Williams, 1981).

It has been postulated that trampling by elephant seals and the addition of nutrients are the major factors responsible for differences between the vegetation of elephant seal moulting sites and adjacent areas(Huntley 1967, 1970, 1971; Smith 1976, 1977, 1978; Gremmen 1981).

MATERIALS and METHODS

Soil samples were collected at monthly intervals from December 1980 from both sites when the number of juvenile seals peaked until March 1981 when all the seals (in all the age classes) had departed following the completion of their moulting cycle.

Soils were sampled at 33 different wallows at the Boulder Beach site, as well as systematically along the permanent quadrats within both sites. At all sampling points the utilisation of the area by the seals was determined.

The layout of the permanent quadrats, blocks and sub-blocks within the two moulting sites is illustrated in Fig. 19. A permanent sampling quadrat (96 x 2 m at Boulder Beach; 76 x 2 m at Trypot Beach site) was marked out at each site. The selected permanent quadrats represent a gradient of utilisation by the seals, and extend from an area immediately adjacent to the moulting areas, towards the centre of these areas. Samples were collected and measurements taken at the points shown in Fig. 20. Values obtained were plotted to illustrate trends following elephant seal utilisation. The systematic sampling within the permanent quadrats is shown in Fig. 20 and 21 for the Boulder and Trypot sites respectively.
Sampling points were spaced four metres apart throughout the permanent quadrats. Sampling occurred within a 2 x 2 m block (1-23 sampling points), and each block was sub-divided into four 25 x 25 cm sub-blocks (Fig. 19). The following samples were collected from the sub-blocks:

Sub-blocks 1 and 2: A core of soil to determine percentage moisture; a sub-sample from the above to determine pH; a soil core for bulk density determinations; two soil cores for the extractions of insects, (an additional core 4cm deep, taken on the dominant plant species occurring within one metre radius of the sampling location for extraction of insects), and for

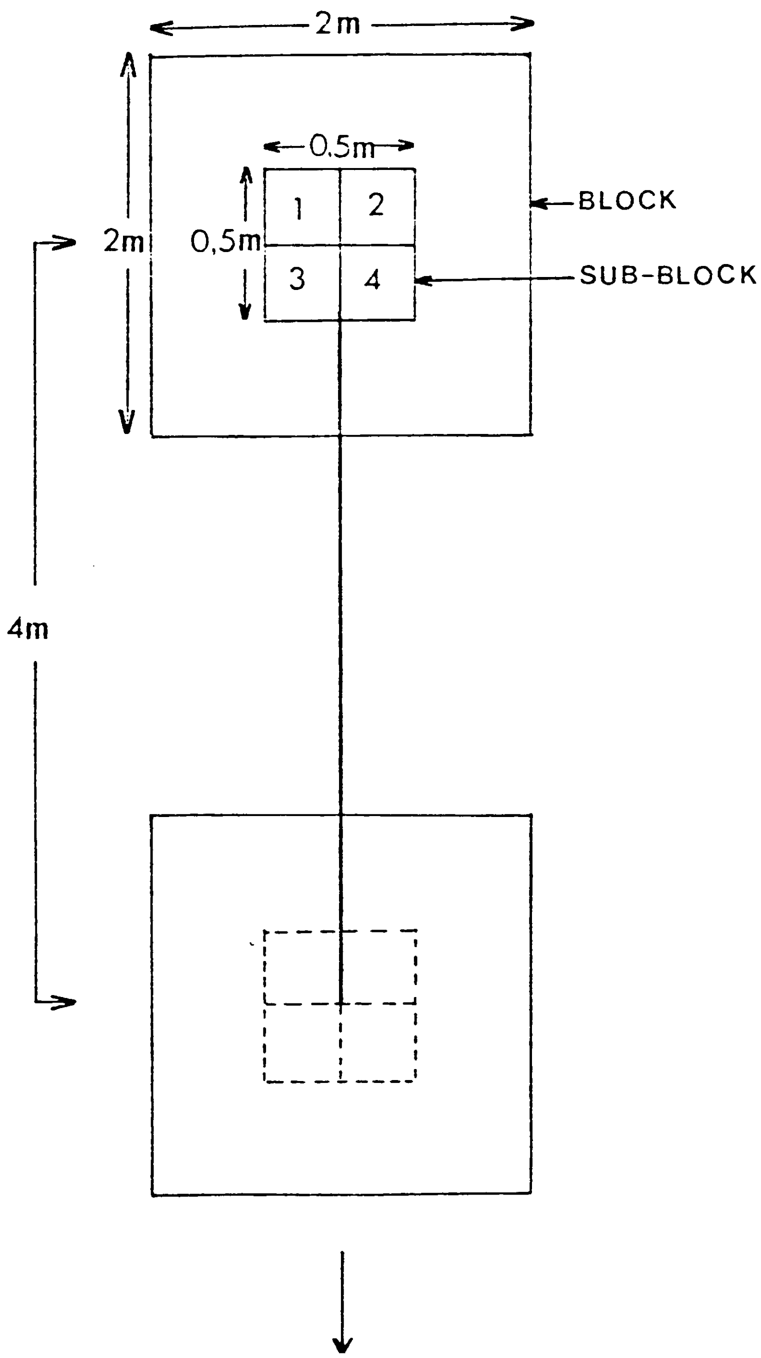


Figure 19. Layout of the permanent quadrats, blocks and sub-blocks within the two study sites.

chemical analyses. Soil temperatures were measured at a depth of 15 cm.

Sub-blocks 3 and 4: Two frozen soil cores for determination of ammonia and nitrate. Soil depth and penetrometer readings were taken from all sub-blocks.

Soil cores and readings within wallows were taken towards the centre of these depressions. Where soil was not available all measurements were taken on the edge (lengthwise) of the wallow. The soil readings taken and the chemical analyses carried out were assessed using the methods outlined in Appendix 2.

Coefficients of correlation between 15 chemical properties, 10 physical measurements, number of plant species (within 4,0 m), the percentage bare ground (estimated) and the seal utilisation index (UI) within the Boulder Beach permanent quadrat and Boulder Beach wallows were determined (Appendix 5a,c).

A principal component analysis ordination (SPSS) of all the chemical variables within 13 sampling locations at the Trypot site was carried out. This site was chosen as a large number of seals were present during the moulting period.The eigenvalues and eigenvectors were extracted from the correlation matrix, and those components with eigenvalues greater than 1,0 were taken to be of practical significance (see Jeffers 1967).

TRAMPLING EFFECTS BY ELEPHANT SEALS: The extent of compaction, namely bulk densities and soil penetration resistance as well as soil moisture content of the soils as a result of trampling by seals were determined within all the wallow sites and within the permanent quadrats of the two study sites. The methods are described in Appendix 2. Correlation coefficients and the corresponding levels of significance between soil bulk density, soil penetration resistance and soil moisture content were determined.

RESULTS

Soil properties at the Boulder Beach moulting site.

The mean values for these sampling locations for each of the three areas are given in Tables 7, 8, 9. Actual values for each location are given in Appendix 4a and 4b.

The results for the wallows sampled at the Boulder Beach site and the seal utilisation of these areas (Fig. 20), show the following: an increase in the concentrations of total-N, Ca, available Ca, with obvious increases in total K, NH_4 and available Na with an increase in utilisation of wallows by the seals. In the permanent quadrat at Boulder Beach (Fig. 21, Appendix 4b, c) nutrient levels show considerable variation, with most of the soil nutrients generally higher in those areas where seals have occurred. Seal utilisation increases towards the end of the quadrat (higher sampling numbers). There seem to be higher levels in total P, available P, total Ca and percentage ash, with increased seal use (higher UI). The higher levels are due to the direct effects of urination and defecation by the seals. The high ash contents in areas intensively used by seals, are due to the removal of the peat layer, decreasing the overall organic matter in these areas. The area shows high levels of total N, total K, available Ca, total Mg, available Mg and total Na; low values of chlorides, NO_3 and available K, factors which may be innate properties of the soil.

The mean values of the soil properties for the Boulder Beach wallows and sampling points within the permanent quadrat are given in Tables 7 and 8. The mean utilisation index of 0,20 at the Boulder permanent quadrat was higher than for the Boulder Beach wallows sampled, with similar values for available Na, total N, total P, total K, total Na and chlorides. Higher values for available P, available Ca, available Mg, available Na, total Ca, NH_4, NO_3 and percentage ash also occurred within the wallows that were sampled. These increased values, are due to the greater range of seal use of the individual wallows.

Soil properties at the Trypot Beach moulting site.
The results for the soil samples within the permanent quadrat at the Trypot Beach site and the utilisation index are shown in Fig. 22. High values were obtained for available Ca, total Mg, available Mg and ash content of the soils utilised by seals. Minerals such as available Na, chlorides, available P, NH_4 and NO_3 - do not seem to increase with increasing seal use.
The increases in NH_4 at the Boulder site, but not at the Trypot site, indicate an overall lower use of the area in combination with greater surface runoff. Although on closer examination the figures indicate a decrease in total N with increasing use by seals in the area, this was actually a direct result of the

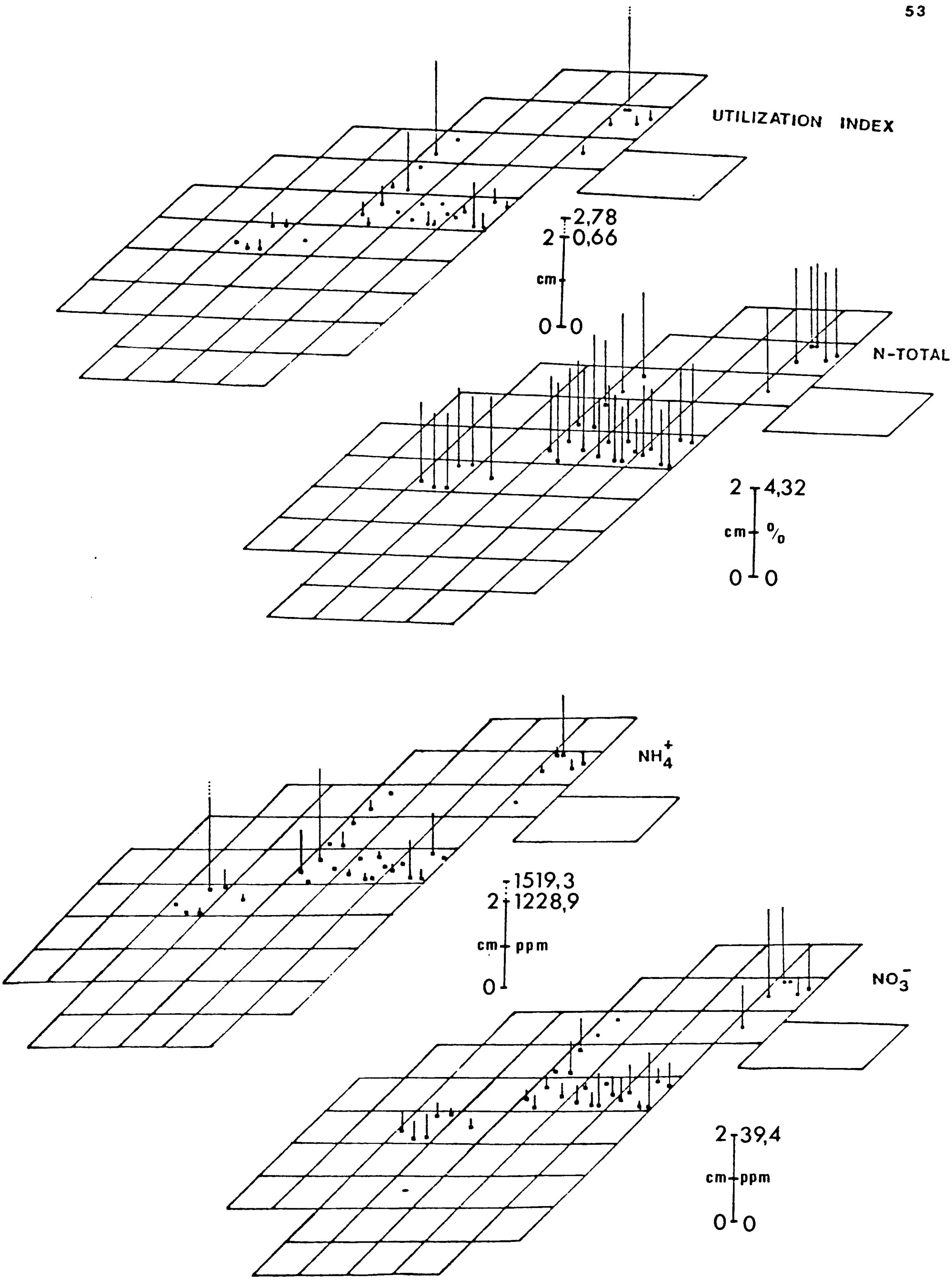
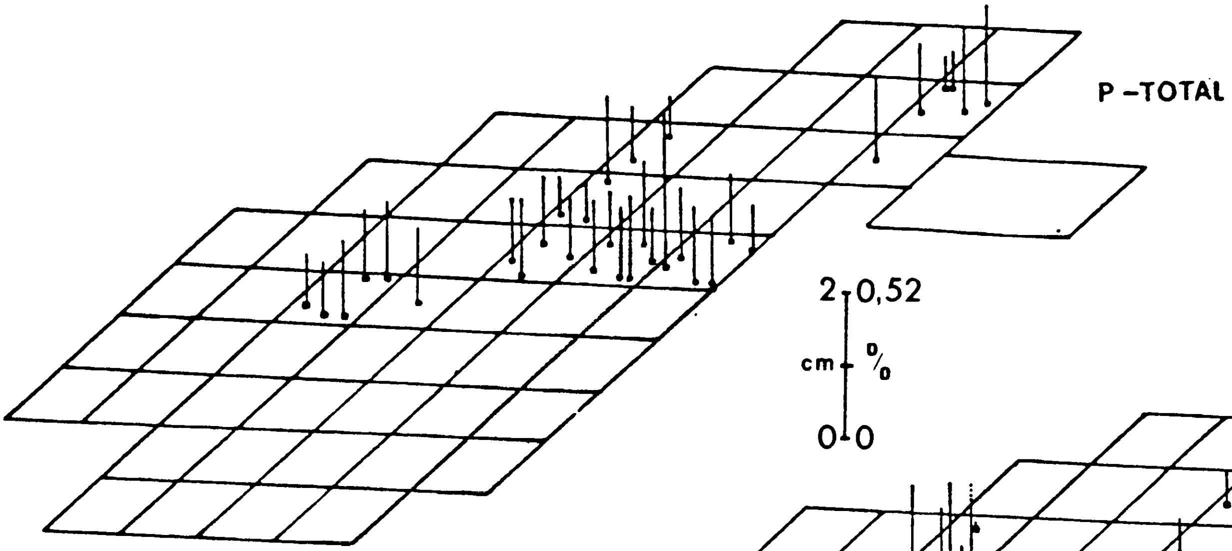


Figure 20. Soil properties sampled at the Boulder Beach wallows, December and January. Actual sampling locations are shown.


P -TOTAL
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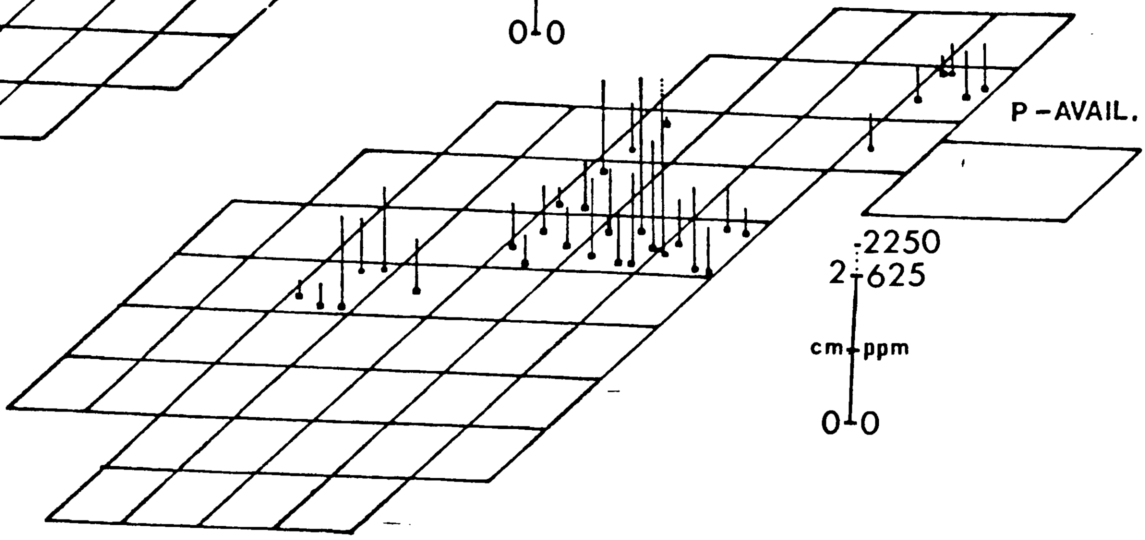
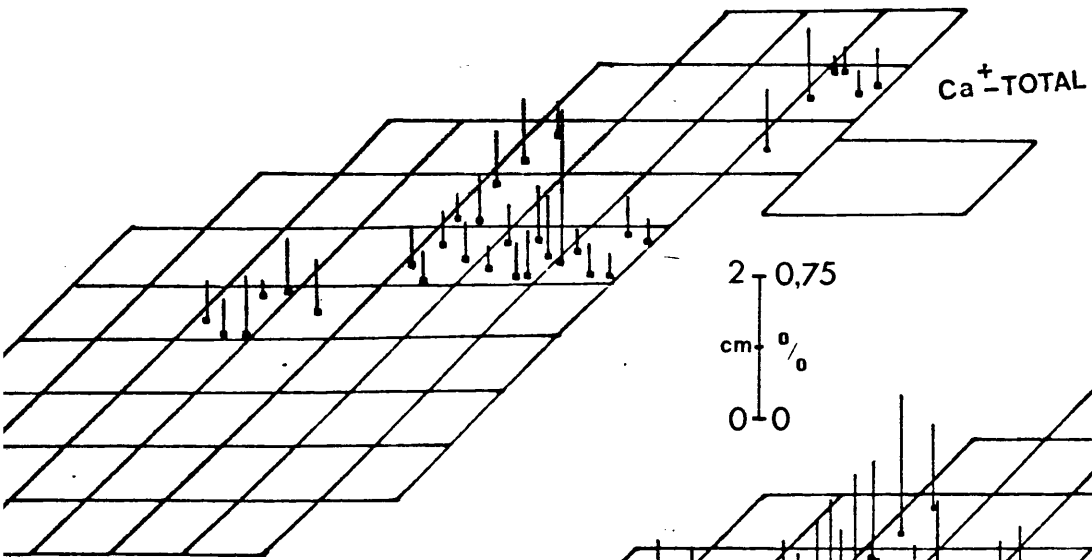
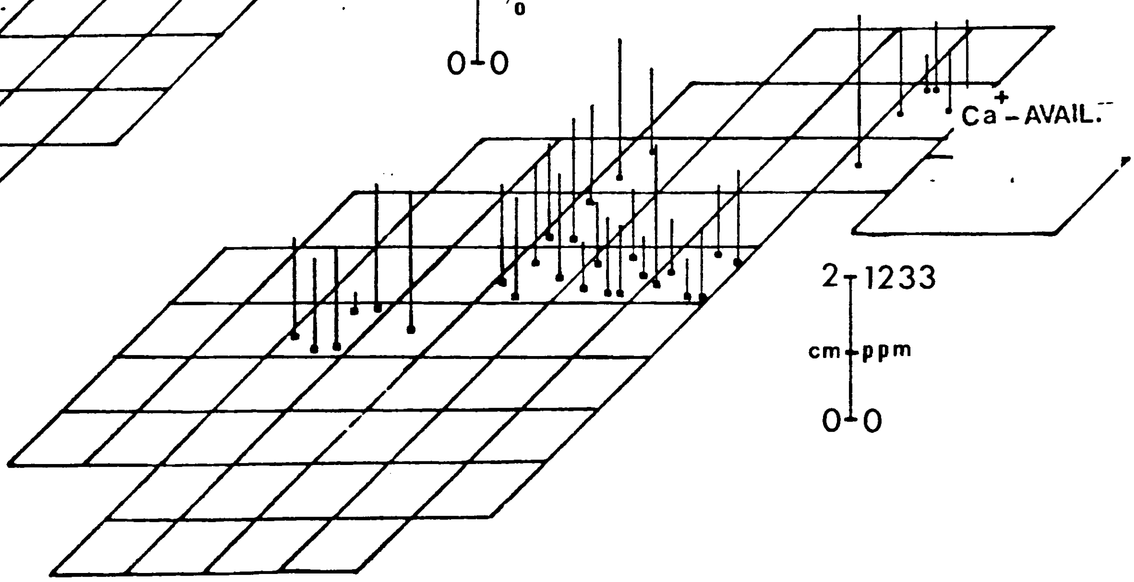
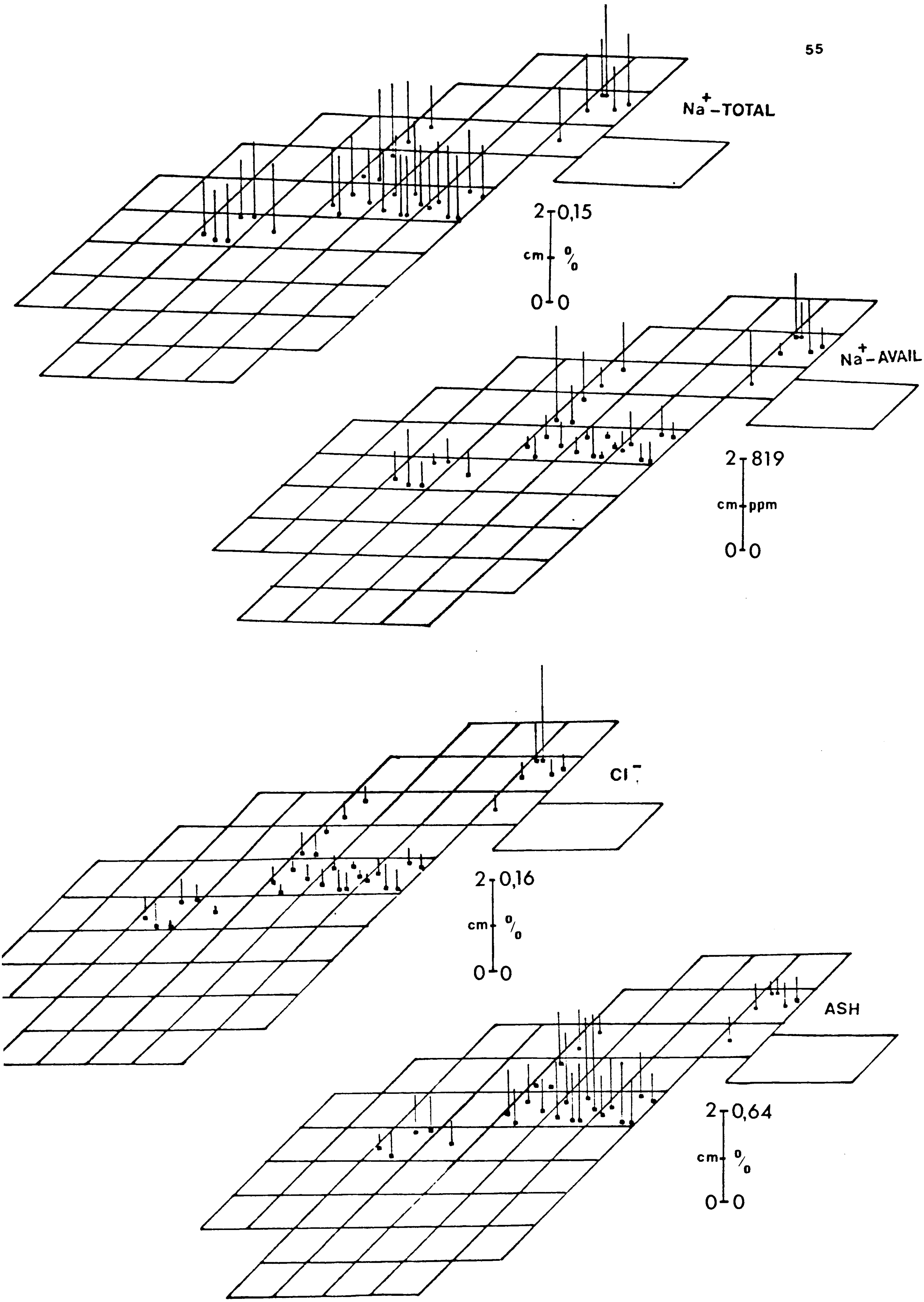
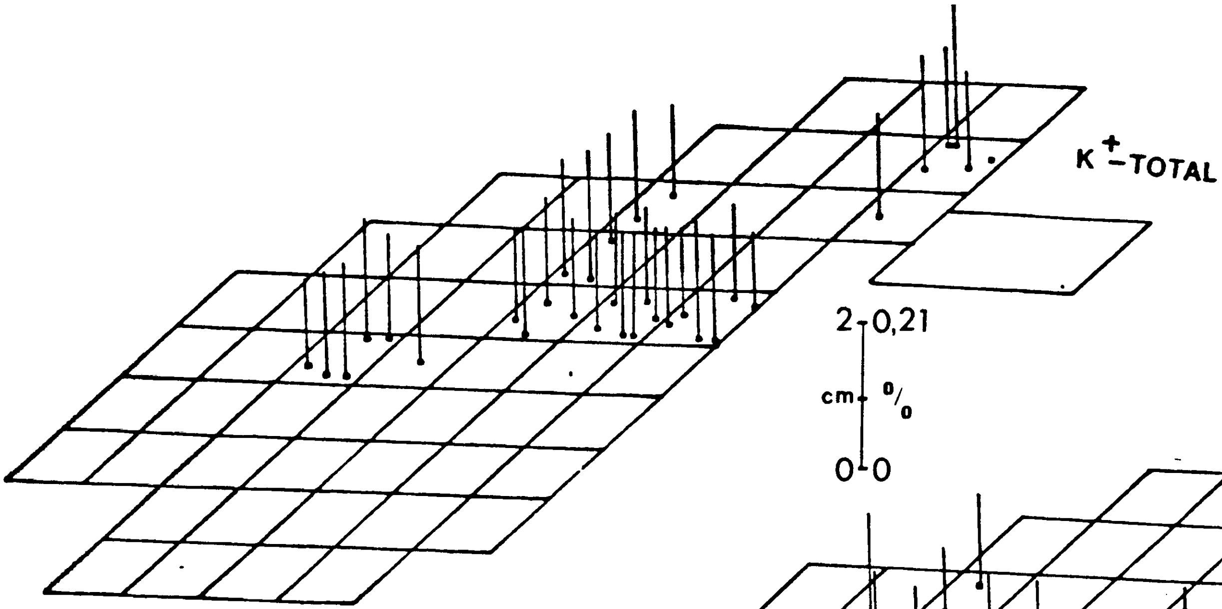
cm %
0 0

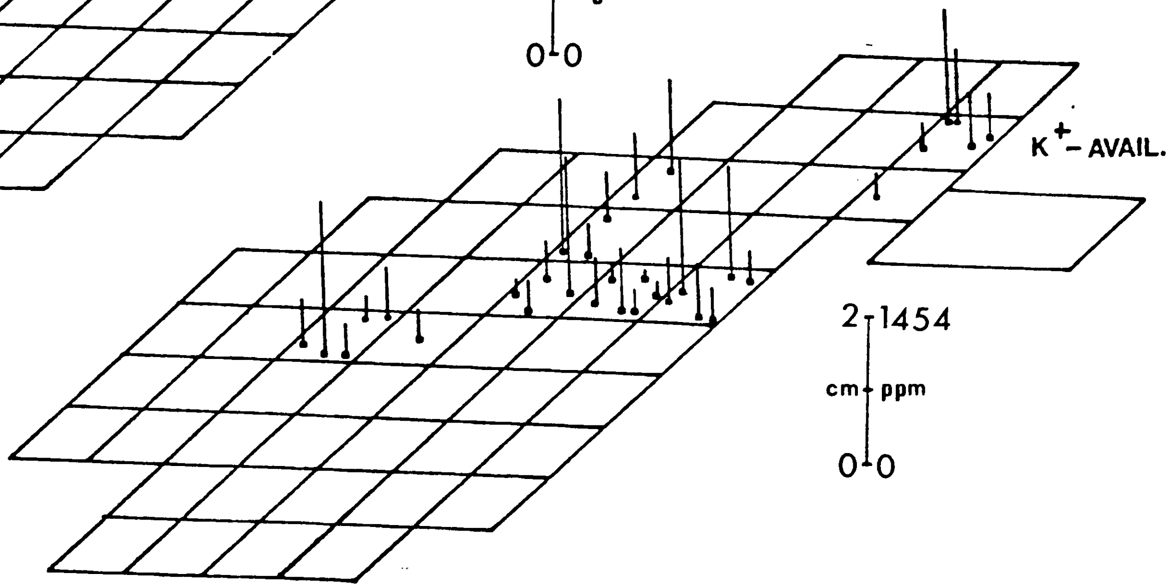

P -AVAIL.
2250
2 625
cm ppm
0 0

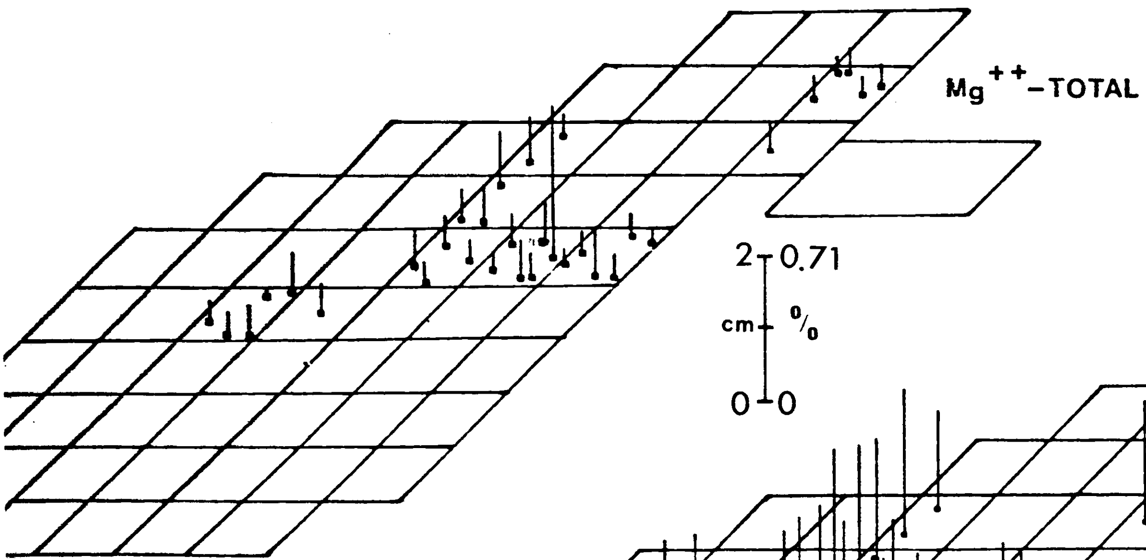

Ca+-TOTAL
2 0,75
cm %
0 0


Ca+-AVAIL.
2 1233
cm ppm
0 0


Na+ -TOTAL
2 0,15
cm %
0 0
Na+ -AVAIL
2 819
cm ppm
0 0
Cl−
2 0,16
cm %
0 0
ASH
2 0,64
cm %
0 0


K + -TOTAL
2 0,21
cm %
0 0


K + - AVAIL.
2 1454
cm ppm
0 0


Mg ++ -TOTAL
2 0.71
cm %
0 0

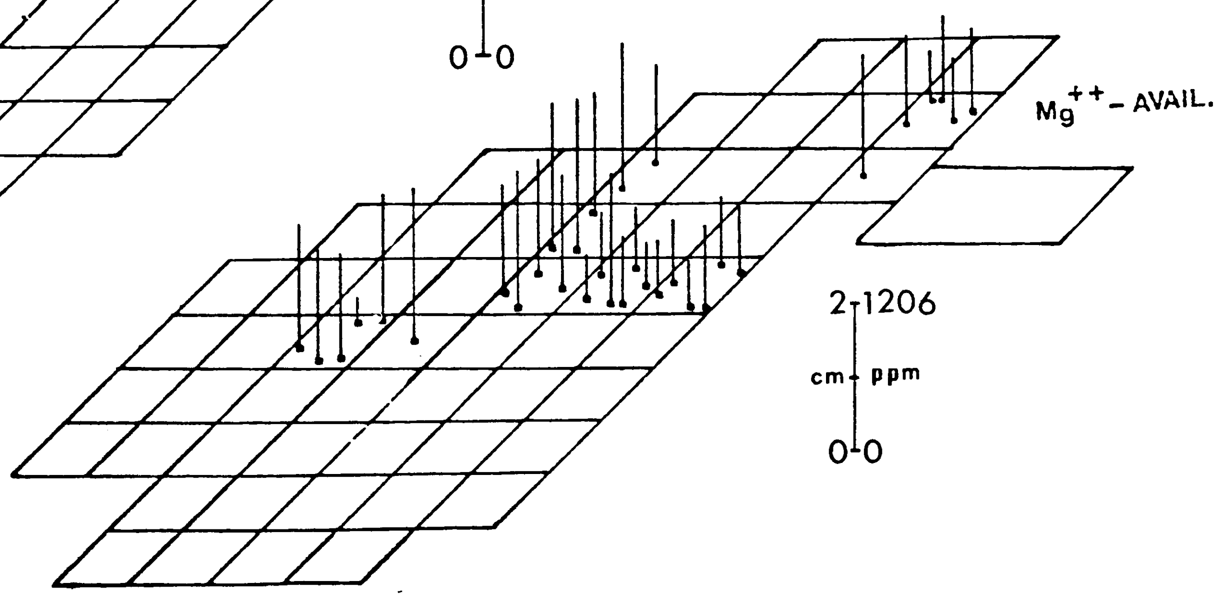
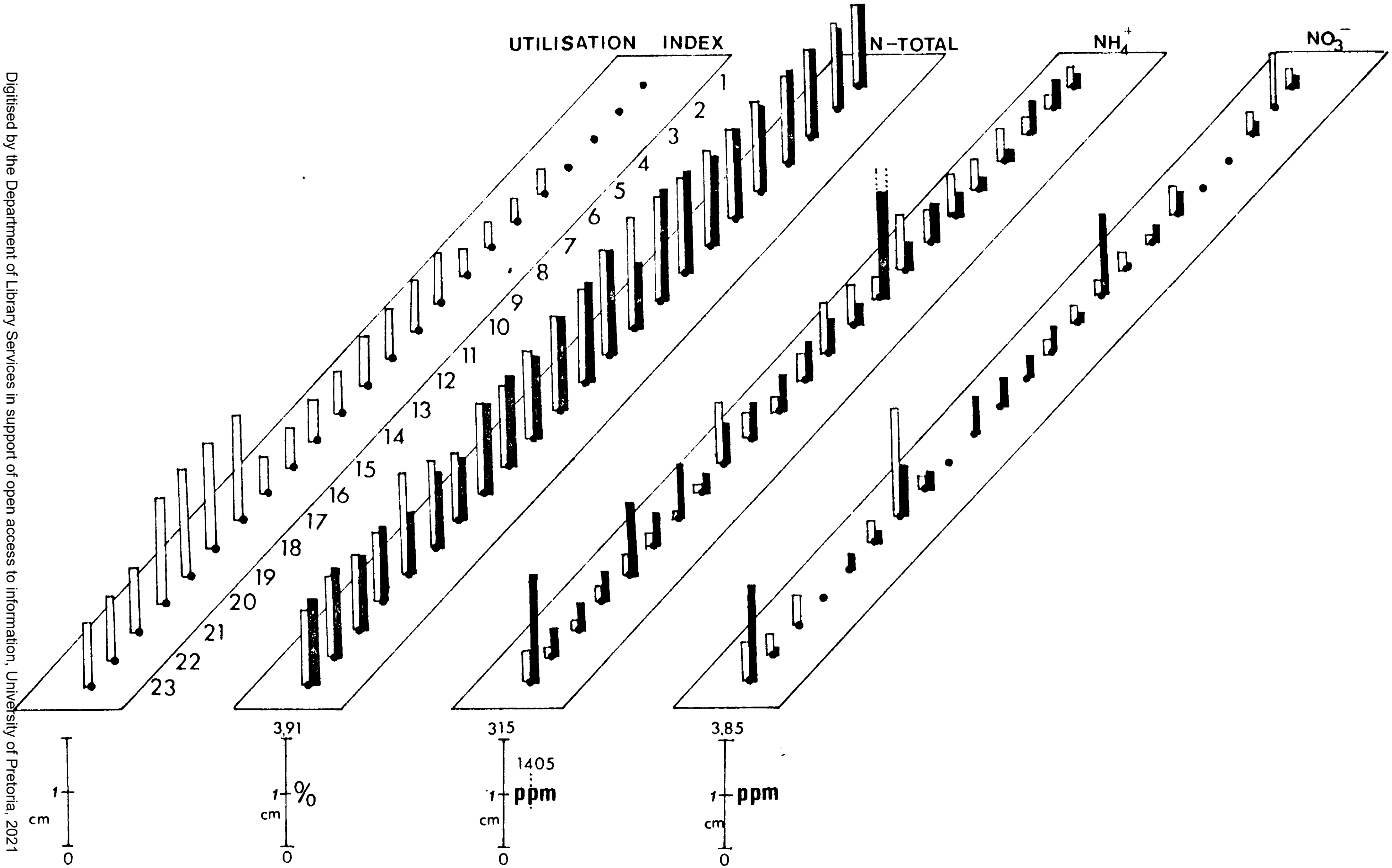
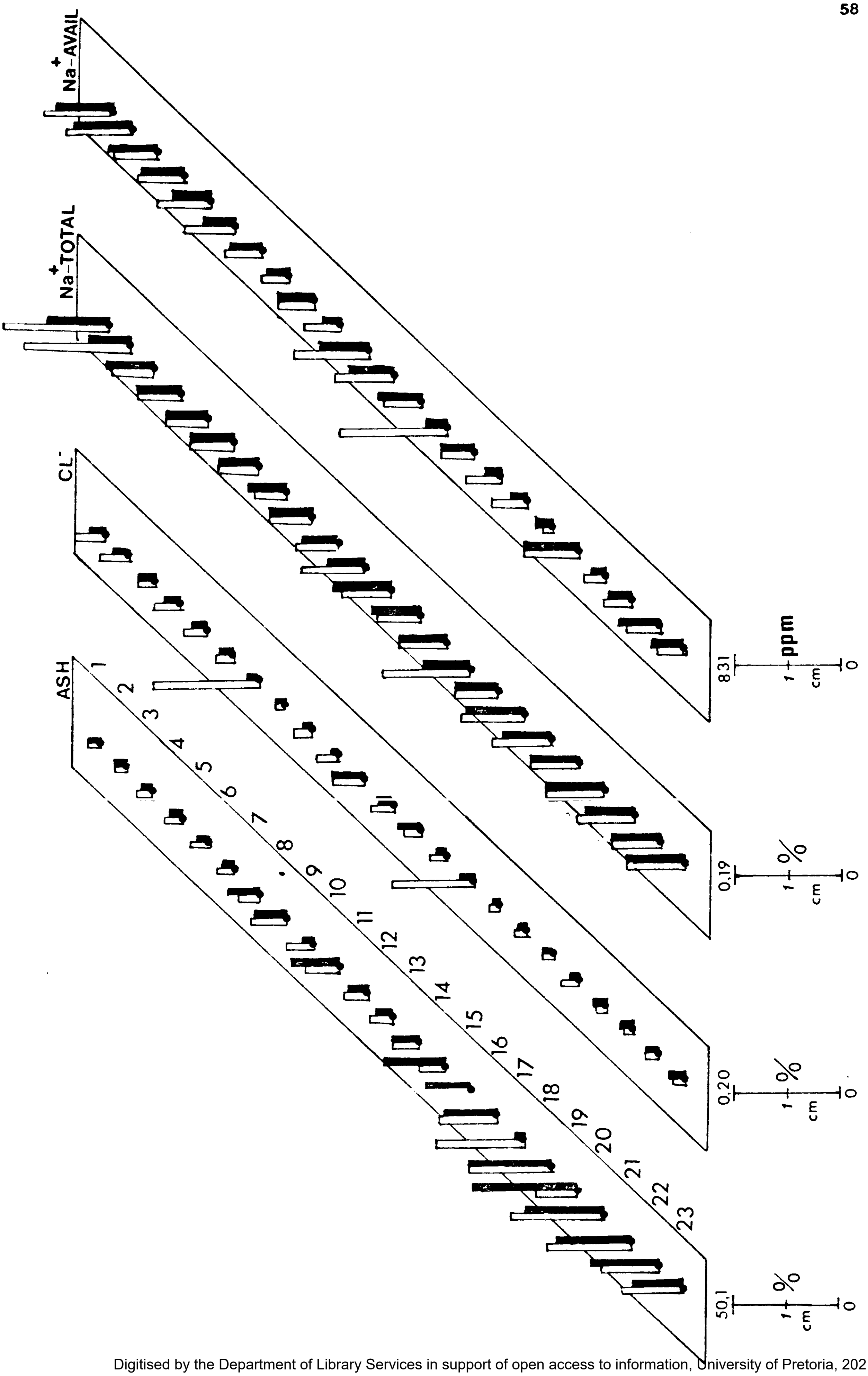
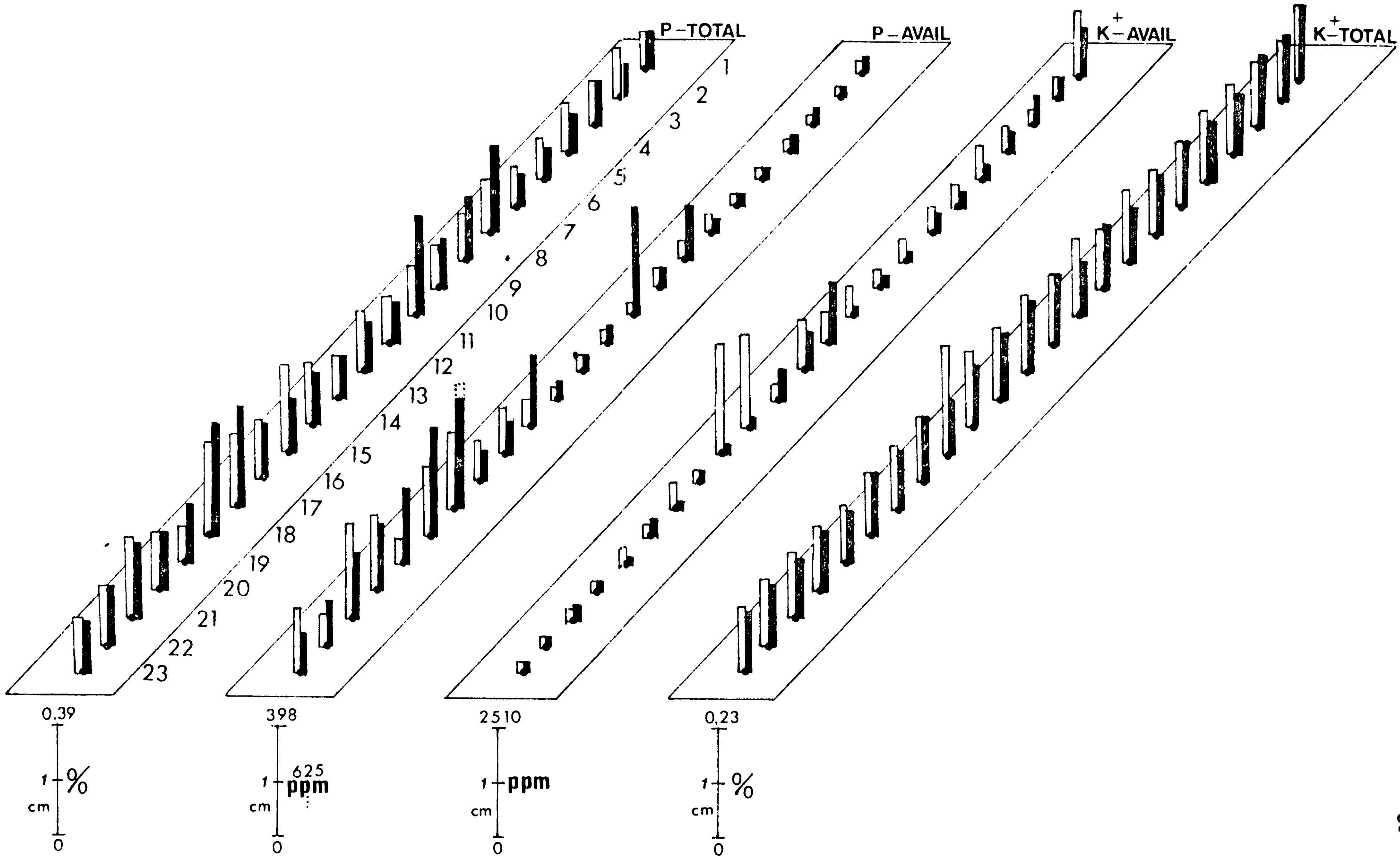
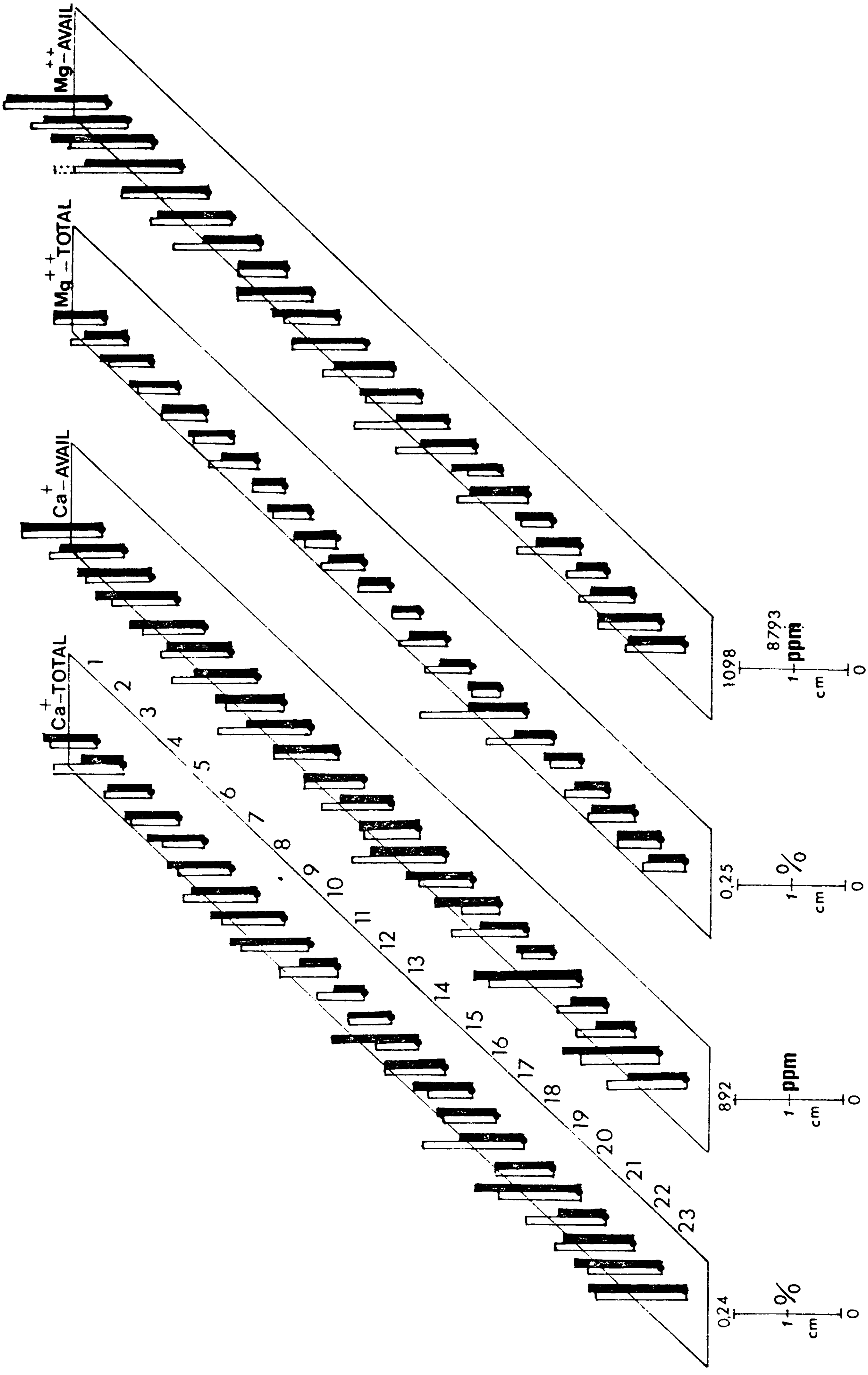

Mg ++ - AVAIL.
2 1206
cm ppm
0 0

Figure 21. Variation in soil properties sampled at the Boulder Beach permanent quadrat. White bars - January, black bars - March.




ASH
CL⁻
Na⁺-TOTAL
Na⁺-AVAIL
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
50,1
1
%
cm
0
0,20
1
%
cm
0
0,19
1
%
cm
0
8,31
1
ppm
cm
0


P-TOTAL
P-AVAIL
K+-AVAIL
K+-TOTAL
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
0,39
1 cm
%
0
398
625
ppm
1 cm
0
2510
1 cm
ppm
0
0,23
1 cm
%
0



Ca^{+}-TOTAL
Ca^{+}-AVAIL
Mg^{++}-TOTAL
Mg^{++}-AVAIL
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
0,24
1 cm
%
0
892
1 cm
ppm
0
0,25
1 cm
%
0
1098
8793
1 cm
ppm
0

Table 7. Mean values, range and standard deviations for soil properties sampled at the Boulder Beach wallows, December 1980- January 1981.

	MEAN ($\bar{X}$)	RANGE	STANDARD DEVIATION (SD)
Utilisation Index	0,29	0,02-0,66	0,21
Distance to sea	110,2	66,2-154,2	27,13
Aspect (°)	112,7	0-350	120,3
Slope(°)	10,2	0-32	9,00
Percentage moisture	736,6	155,11-1193,90	285,00
Temperature (°C)	5,7	4,0-15,0	1,82
Log penetrometer impacts	-1,04	-23,9-4,0	1,82
Bulk density	0,13	0,66-0,21	0,41
pH	5,29	4,57-7,03	0,50
Soil depth (cm)	46,2	7,8-100,0	32,2
P-avail (ppm)	114,0	40-338	96,12
K-avail (ppm)	685,3	206-2510	606,16
Ca-avail (ppm)	562,7	253-771	137,54
Mg-avail (ppm)	1048,4	310-8793	470 ,91
Na-avail (ppm)	337,3	49-730	157,7
N-total (%)	3,19	2,55-3,91	0,37
P-total (%)	0,20	0,13-0,23	5,28
K-total (%)	0,15	0,13-0,23	0,02
Ca-total (%)	0,14	0,09-0,23	0,04
Mg-total (%)	0,10	0,01-0,25	0,04
Na-total (%)	0,10	0,06-0,19	0,03
Chlorides (%)	0,04	0,01-0,15	0,03
Ash (%)	18,6	4,6-44,0	13,27
NH_4^+ (%)	73,4	15-189	50,54
NO_3^- (%)	0,64	0-3,85	0,87

Table 8. Mean values, range and standard deviations for soil properties sampled at the Boulder Beach permanent quadrat, December 1981.

	MEAN ($\bar{X}$)	RANGE	STANDARD DEVIATION (S
Utilisation index	0,16	0-2,78	0,49
Distance to sea	110,6	8,16-153,8	0,80
Aspect (°)	126,0	0-360,0	143,29
Slope (°)	4,0	0-17,0	5,17
Percentage moisture	541 622,5	327 748 - 934 894	155 336,93
Temperature (°C)	10,9	4,8-23,0	3,56
Log penetrometer impacts	0,10	-0,52-0,63	0,26
Bulk density	0,16	0,08-0,24	0,04
pH	6,1	4,63-8,80	1,04
Soil depth (cm)	13,0	0-35,0	9,57
P-avail (ppm)	282,4	35-2250	349,42
K-avail (ppm)	607,4	101-1454	420,17
Ca-avail (ppm)	950,9	147-4885	931,44
Mg-avail (ppm)	751,0	172-1932	368,31
Na-avail (ppm)	359,2	22-1279	306,57
N-total (%)	3,43	1,47-4,73	6,41
P-total (%)	0,23	0,11-0,52	0,08
K-total (%)	0,16	0,11-0,24	0,03
Ca-total (%)	0,25	0,08-1,08	0,21
Mg-total (%)	0,14	0,04-0,71	0,11
Na-total (%)	0,12	0,07-0,45	0,77
Chlorides (%)	0,03	0,01-0,16	0,03
Ash (%)	22,2	0-66,4	14,38
NH_4^+ (%)	194,3	4,3-1519,3	318,2
NO_3^- (%)	10,2	0-39,4	9,83

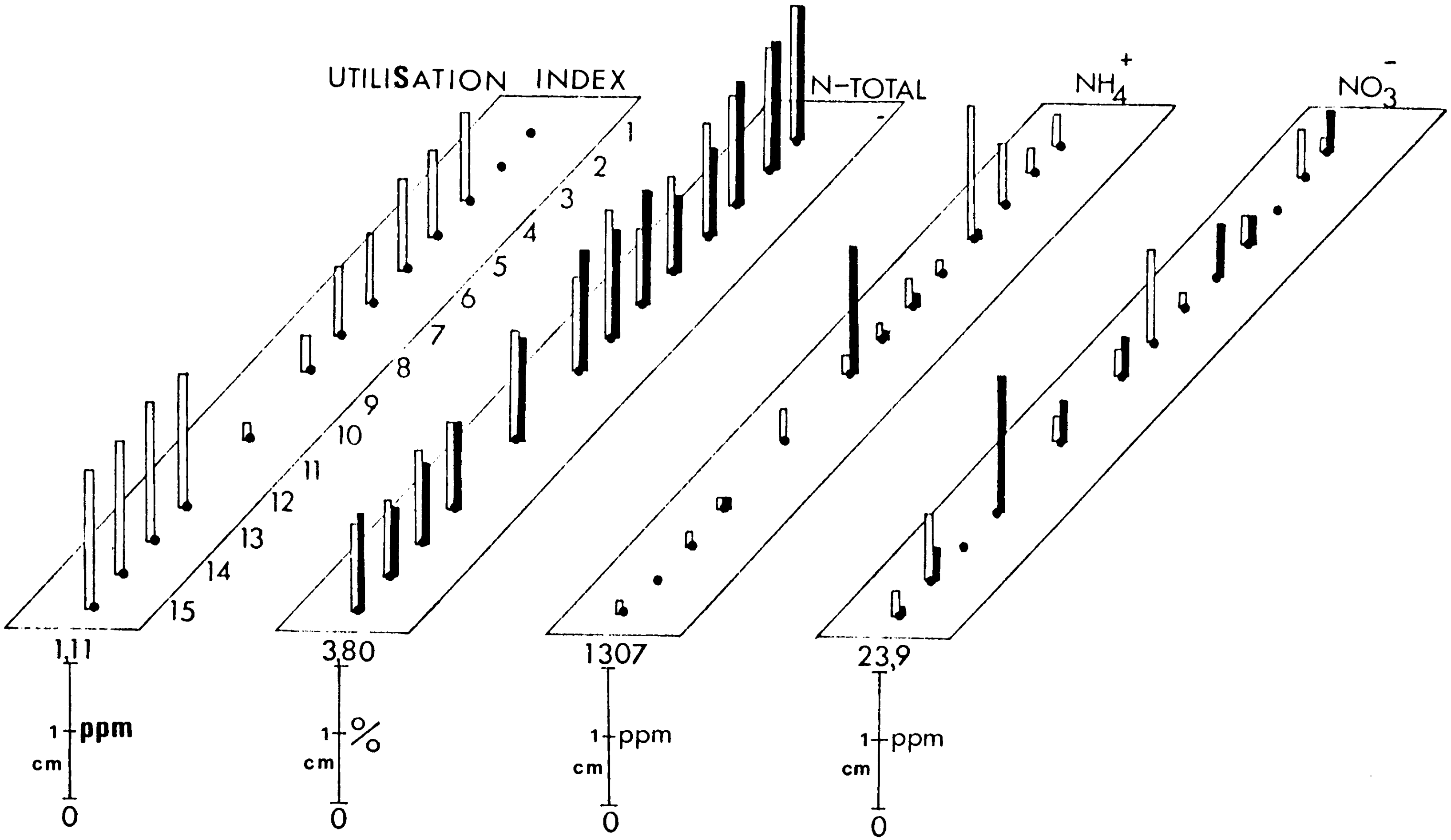
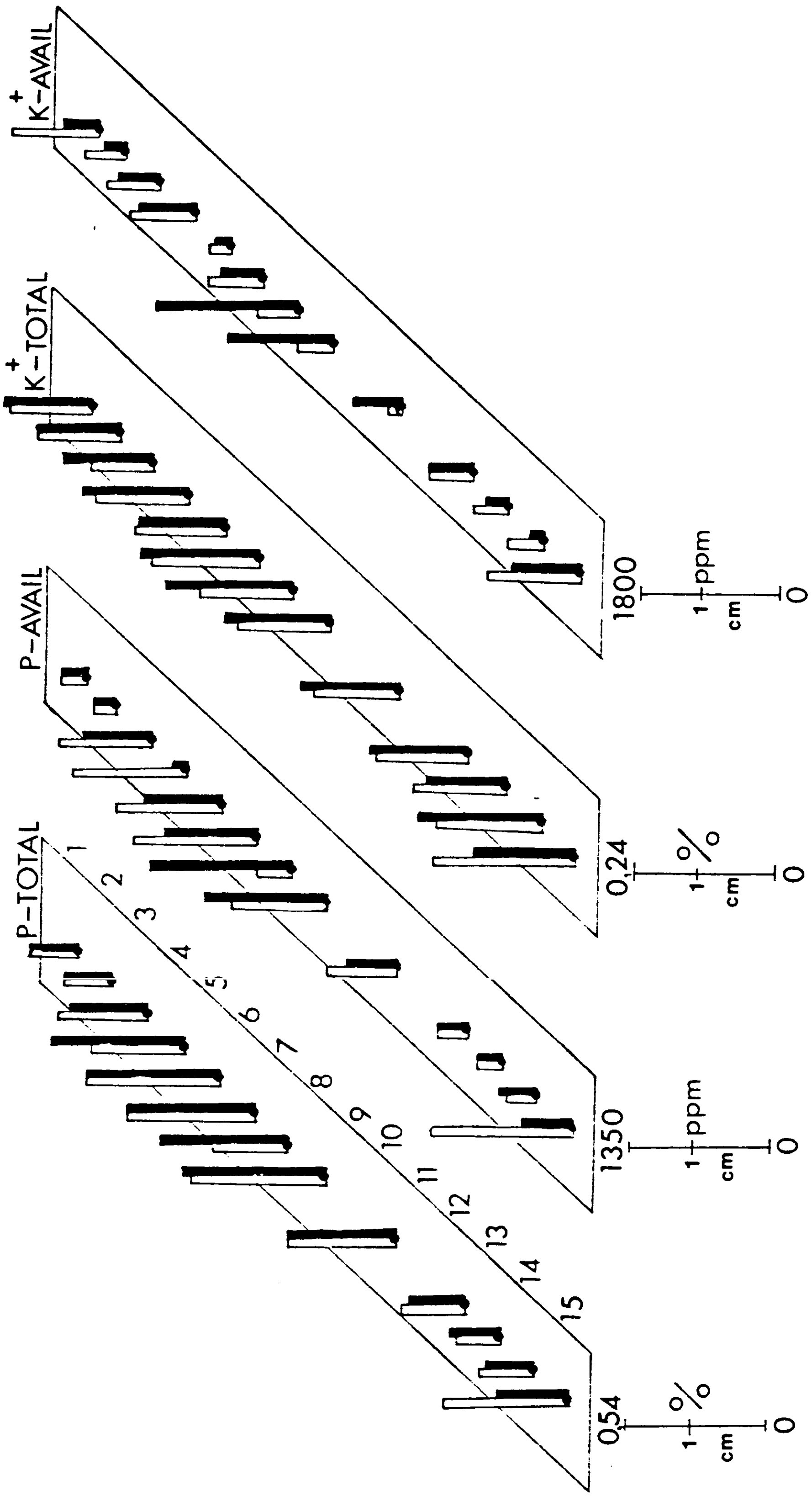
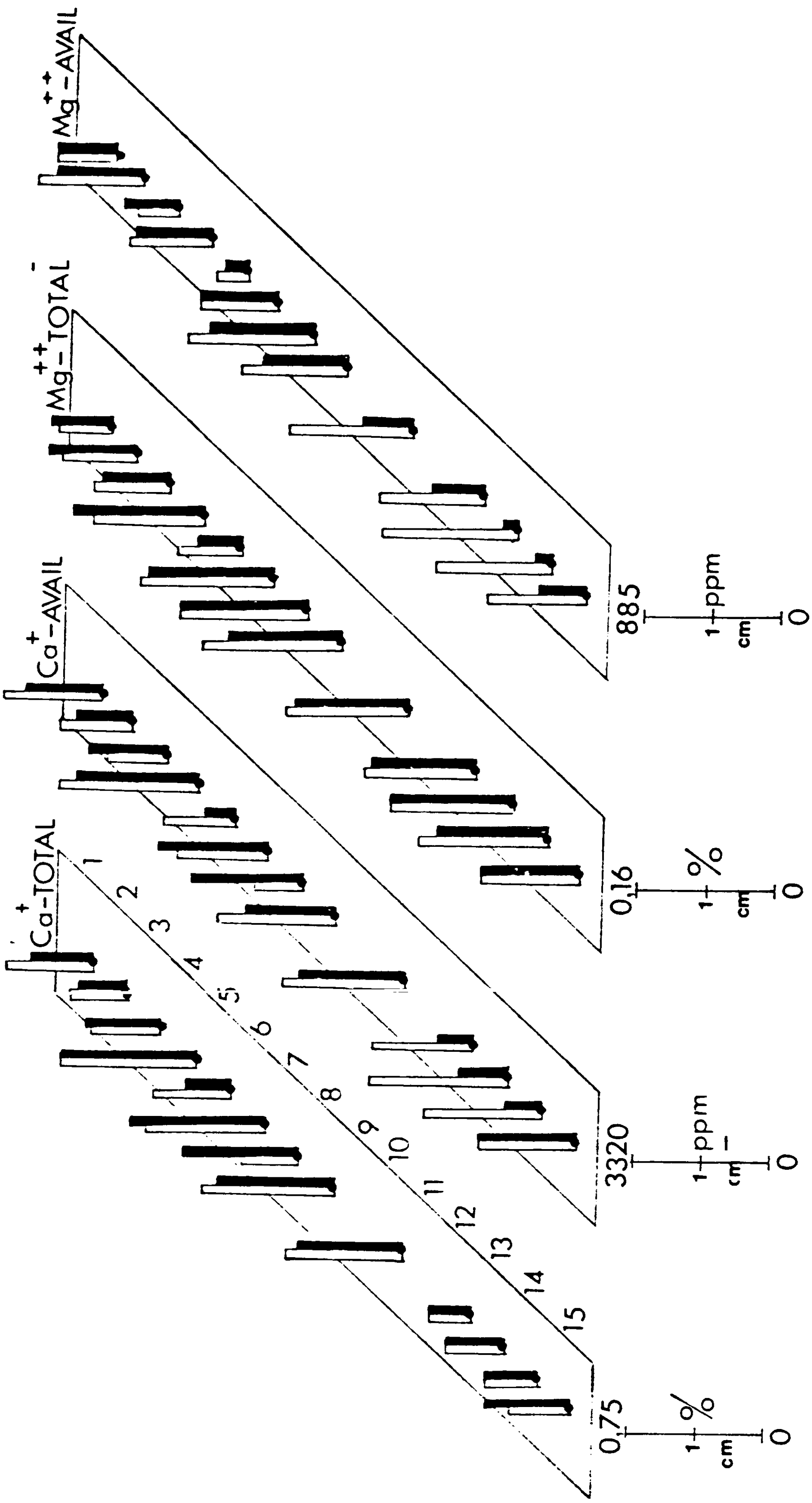


Figure 22. Variation in soil properties sampled at the Trypot Beach permanent quadrat. White bars - January, black bars - March.


P-TOTAL
P-AVAIL
K^+-TOTAL
K^+-AVAIL
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0,54
1350
0,24
1800
1 cm
%
ppm
0


Ca^{+}-TOTAL
Ca^{+}-AVAIL
Mg^{++}-TOTAL
Mg^{++}-AVAIL
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0.75
3320
0.16
885
1 cm
%
ppm
0

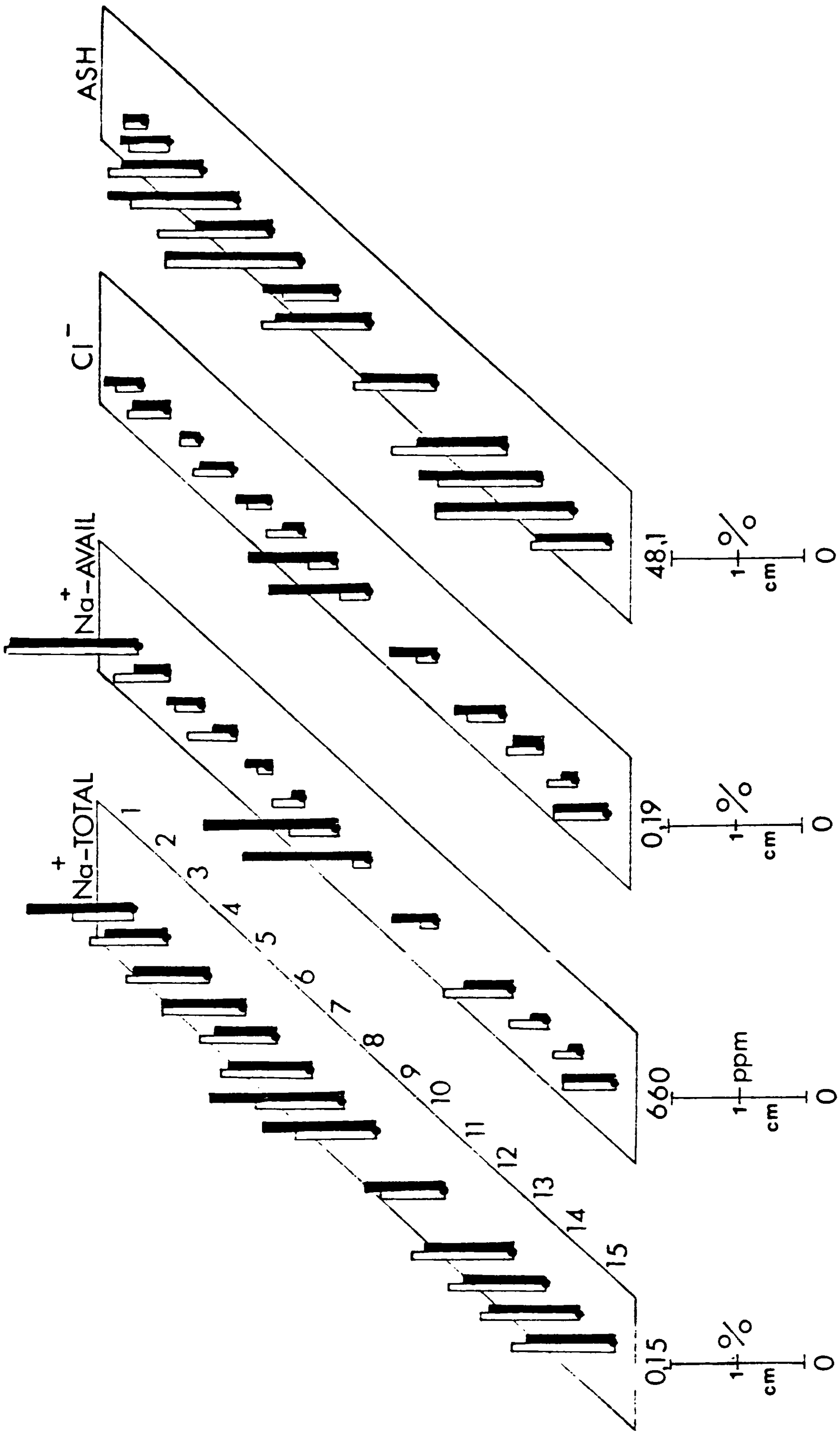

Na+-TOTAL
Na+-AVAIL
Cl−
ASH
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0,15
1 cm
%
0
660
1 cm
ppm
0
0,19
1 cm
%
0
48,1
1 cm
%
0

Table 9. Mean values, range and standard deviations for soil properties sampled at the Trypot Beach permanent quadrat, January 1981.

	MEAN ($\bar{X}$)	RANGE	STANDARD DEVIATION (SD)
Utilisation index	0,62	0-1,11	0,43
Distance to sea	34,4	27-42,7	5,22
Aspect (°)	58,5	0-200	91,86
Slope (°)	5,9	0-25	10,29
Percentage moisture	517,0	220,04-851,84	181,19
Temperature (°C)	8,58	7,0-12,0	1,47
Log penetrometer impacts	0,04	-0,2-0,4	0,158
Bulk density	0,14	0,09-0,20	0,036
pH	5,88	4,7-7,7	0,83
Soil depth (cm)	14,8	3,8-38,3	9,49
P-avail (ppm)	644,2	176-1350	418,65
K-avail (ppm)	614,5	221-1168	293,94
Ca-avail (ppm)	1858,2	830-3320	801,46
Mg-avail (ppm)	595,85	195-885	212,59
Na-avail (ppm)	200,6	23-660	164,22
N-total (%)	2,86	2,0-3,8	0,54
P-total (%)	0,34	0,15-0,52	0,13
K-total (%)	0,16	0,11-0,24	0,03
Ca-total (%)	0,44	0,24-0,75	0,18
Mg-total (%)	0,12	0,06-0,16	0,03
Na-total (%)	0,09	0,07-0,11	0,02
Chlorides (%)	0,05	0,03-0,08	0,01
Ash (%)	32,4	8,2-47,1	12,06
NH_4^+ (%)	269,8	30-1307	344,45
NO_3^- (%)	4,55	0-17,30	5,22

erosion of the peat layer decreasing the soil depth and hence the organic layer present. The mean values, range and standard deviations for the Trypot permanent quadrat are summarised in Table 9. Soil nutrient levels show lower values of available P, available Ca, total P, total K, total Ca, total Mg, ash, ammonia and nitrate compared to the Boulder site. Higher values of available K, available Mg and total Na occurred at the Trypot site.

DISCUSSION

Both areas showed increases in mineral concentrations progressively from the adjacent to the core moulting areas. Increased use of these areas by seals is characterised by higher levels of the total forms of N, Ca, K, Mg and the available forms of Ca, Na, Mg and NH_4. Although differences did occur between the sites these were probably related to the degree of exposure to salt-spray, surface erosion and runoff within the areas. At the Trypot site where surface runoff seems to be the greatest, no increases in the available forms of Na, P, NH_4 or NO_3, nor in chlorides occurred with increases in seal use. These effects are also shown by the lower concentrations of these factors compared to the Boulder site.

The seasonal use of moulting sites by the moulting elephant seals has resulted in a high level of nutrients occurring throughout such areas. Abrupt changes, especially in the concentrations of NO_3, available P and Mg and the percentage ash seem to occur between seal moulting sites and the immediately adjacent areas.

RELATIONSHIPS BETWEEN VARIABLES

Boulder Beach moulting site

The intervariable correlation matrix between 15 chemical properties, 10 physical measurements, the total plant species (within 4 m^2), the percentage bare ground (estimated) and the seal utilisation (UI) within the Boulder Beach permanent quadrat and Boulder Beach wallows are, given in Appendix 5a,c. The corresponding significance levels between all the variables are illustrated in Fig. 24,25 and 26.

Boulder Beach permanent quadrat :

Increased seal use of the area resulted in highly significant positive correlations between, available P ($p < 0,001$), percentage ash ($p < 0,001$) and total Ca ($p < 0,05$) which are possibly a direct result of the manuring and trampling effects by the seals. The correlation matrix (Appendix 5a) indicates the following trends: significant positive correlations ($p < 0,01$) between percentage ash, total and available P, available K, Cl and total K. Significant negative correlations existed between the percentage moisture and percentage ash, and total N and available P and available Na. Correlations ($p<0,05$) occur between total K, Ca, NO_3, Cl, available Ca, and total P.

Factors such as NH_4 , NO_3 , total Ca, available Ca and total Na are largely independent of one another with the available forms also being independent of the total quantities, while the forms of total Ca, total Na (as a result of manuring influences by the seals), show little intervariable correlation (Fig.23,24).

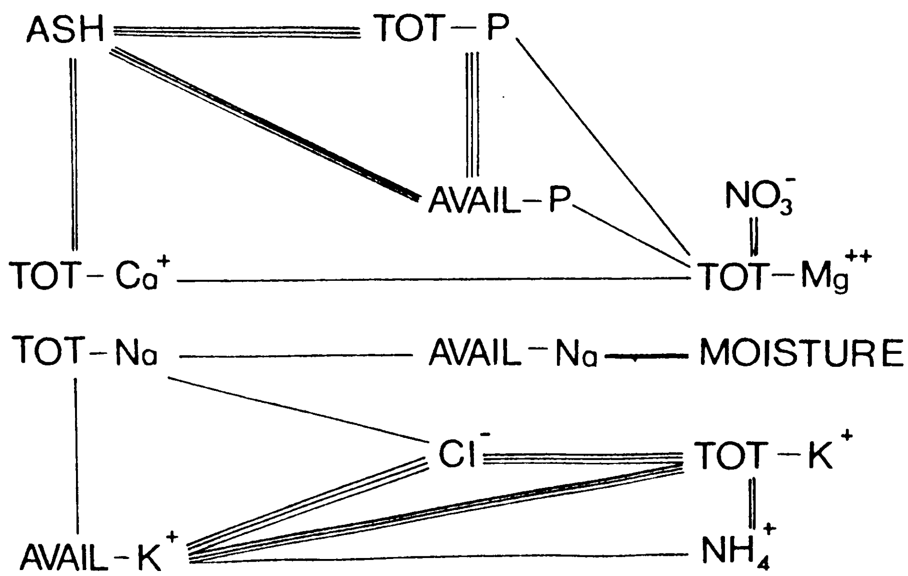


Figure 23. The levels of significance of the positive correlation coefficients for the permanent quadrat at Boulder Beach moulting site.(−,= and ≡ indicates significance at 5%, 1% and 0,1% respectively).

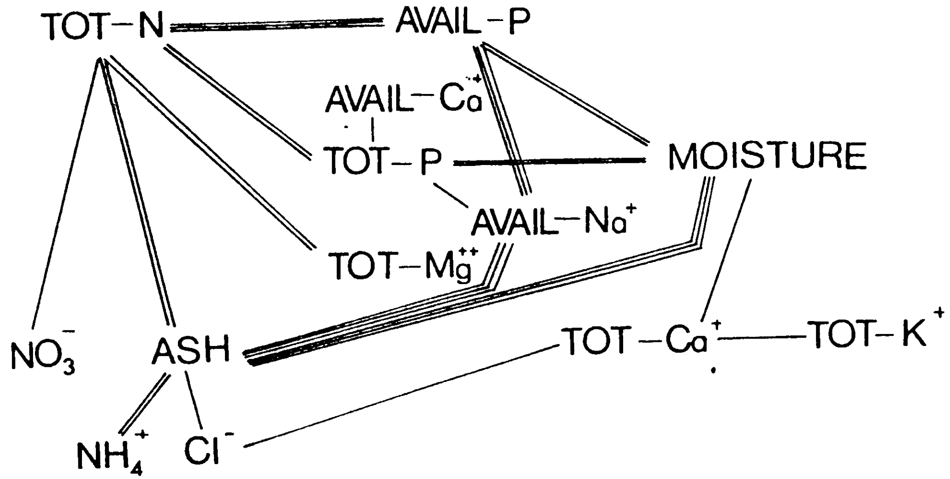
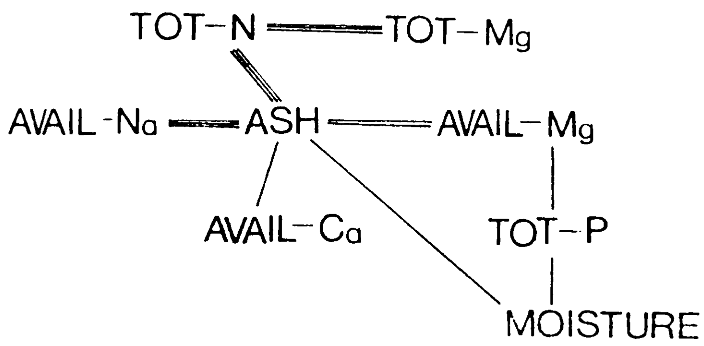
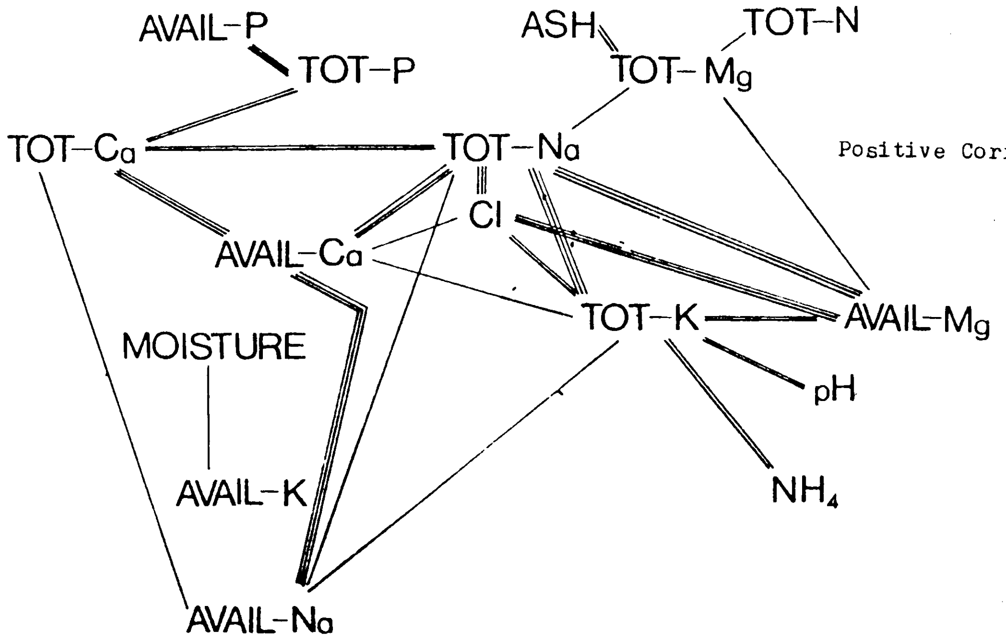


Figure 24. The levels of significance of the negative correlation coefficients for the permanent quadrat at Boulder Beach moulting site. (-, = and ≡ indicates significance at 5%, 1% and 0,1% respectively) .



Negative Correlations



Positive Correlations

Figure 25. The levels of significance of the positive and negative correlation coefficients for the Boulder Beach wallows. (-, = and ≡ indicates significance at 5%, 1% and 0,1% respectively).

Boulder Beach wallows

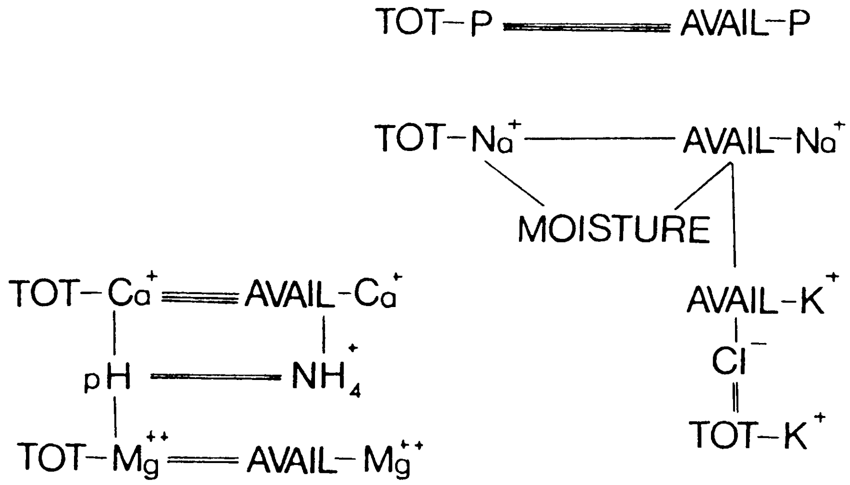
The seal utilisation index (UI), within the 33 seperate wallows sampled, is significantly correlated ($p<0,001$) with total K, NH_4, available Na, total Ca, and available Ca and at the 5% level with total N. Total N is negatively correlated with total Mg, ash and available Na. NO_3 is not correlated to any other factor and appears to be determined by the soil organic matter content and the breakdown of ammonia.

Trypot Beach moulting site

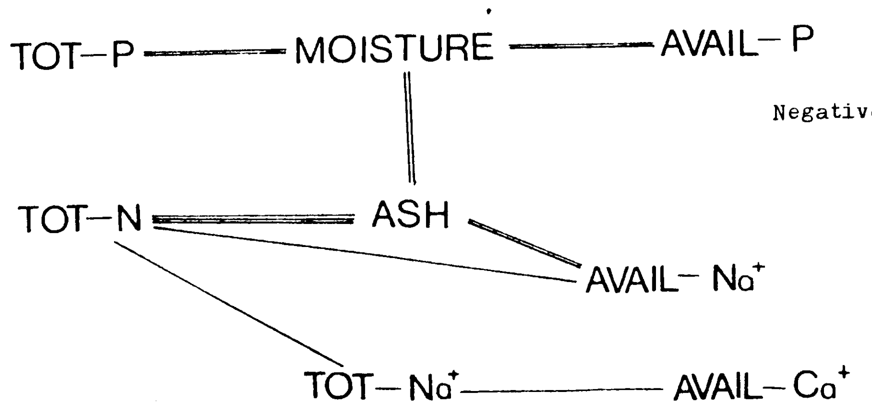
An increase in use of the Trypot site by seals is indicated by a strong positive correlation with total Na ($p<0,001$) and a negative correlation with total N ($p<0,05$). The inter-variable correlations (positive) show three independent groups of chemical nutrients being correlated (Fig.26).

A principal component analysis ordination (SPSS) of all the chemical variables within the 13 sampling locations at the Trypot site was carried out. The eigenvalues and eigenvectors extracted from the correlation matrix are given in Table 10 and 11. The first four components account for 82,5% of the total variability, with the last five components not supplying any additional information. The first 11 components account for 100 percent of the observed variability. The components with eigenvalues greater than 1,0 (Table 10) are thought to be of practical significance (see Jeffers 1967).

The first factor accounts for 27,1 % of the variability, giving high positive weighting to the percentage ash, total Mg, total Na



Positive Correlations



Negative Correlations

Figure 26. The levels of significance of the positive and negative correlation coefficients for the permanent quadrate at Trypot Beach moulting site.(-, = and ≡ indicates significance at 5%, 1% and 0,1% respectively.

and total K and may be regarded as maritime influences largely as a result of salt spray. The second factor accounts for 24,8 % of the observed variability, giving high weight to total P, total Ca, available P, available Ca and NH_4, all of these being measures of the extent of manuring by the seals. Factor three which accounts for 18,2 % of the variability gives high weight to the total and available forms of K and Cl. These minerals seem to be unrelated to each other, their concentrations in the soil were unaffected by increasing seal use and possibly give a measure of the degree of weathering and the subsequent release of these minerals. Factor four accounts for 12,4 % of the variability and is possibly a combined measure of the degredation of ammonia to nitrate and the influence of salt spray.

A clear distinction is shown between the first and second components which account for 51,9 % of variability of all the chemical variables (Table 10). The first component is interpreted as a general index of salt spray, and possibly has a major effect on soil nutrient levels of the site. The second component, an index of seal manuring, indicates the overall influence manuring has on the soil nutrient levels, and becomes more important in areas of heavy seal use. The computed values of the first two components (Table 11) are presented in Fig. 27 and suggests that there are two major groups recognisable by their concentrations of nutrients, which show clear differences. The remaining variation is relatively unimportant.

Table 10. Eigenvalues of the correlation matrix of the chemical properties.

COMPONENT	EIGENVALUE	PERCENTAGE OF VARIABILITY	
		COMPONENT	CUMULATIVE
1	4,06023	27,1	27,1
2	3,72321	24,8	51,9
3	2,73302	18,2	70,1
4	1,85460	12,4	89,9
5	1,10895	7,4	89,9
6	0,69276	4,6	94,5
7	0,43504	2,9	97,4
8	0,23680	1,6	99,0
9	0,08240	0,5	99,5
10	0,05827	0,4	99,9
11	0,01256	0,1	100,0
12	0,00216	0,0	100,0
13	0,00000	0,0	100,0
14	-0,00000	-0,0	100,0
15	-0,00000	-0,0	100,0

Table 11. Eigenvectors for the first five components of the chemical variables.

VARIABLE	EIGENVECTOR FOR COMPONENT				
	1	2	3	4	5
Total N	-0,91	-0,00	-0,06	0,27	-0,11
Total P	0,45	0,72	0,05	-0,09	-0,47
Ash	0,85	0,21	-0,19	-0,20	0,35
Total K	0,51	-0,04	0,77	0,11	-0,27
Total Ca	0,06	0,83	-0,14	0,48	0,09
Total Mg	0,74	-0,11	-0,17	0,58	0,15
Total Na	0,66	-0,49	0,39	-0,05	0,29
Total Cl	0,13	-0,40	0,87	0,21	0,09
NH_4	-0,28	0,56	0,14	0,23	0,57
NO_3	0,01	-0,46	-0,09	0,57	-0,42
Available P	0,40	0,78	0,35	-0,10	-0,20
Available K	-0,35	0,16	0,86	0,01	0,04
Available Ca	-0,23	0,79	-0,08	0,51	0,04
Available Mg	0,28	-0,62	-0,04	0,67	0,02
Available Na	-0,74	-0,20	0,48	0,04	0,14

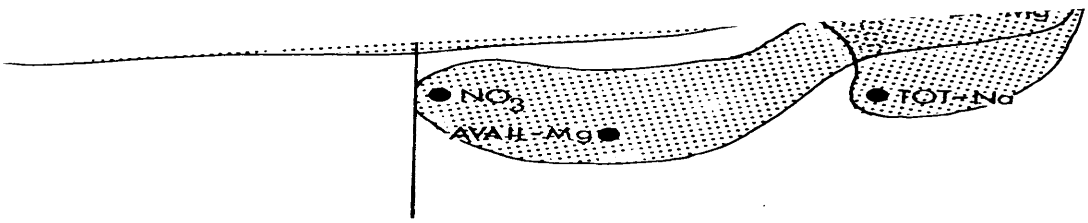


Figure 27. Computed values of the first two components of measurements taken at the Trypot Beach site, the first component is plotted on the horizontal and the second component on the vertical axis.

TRAMPLING EFFECTS BY ELEPHANT SEALS : PHYSICAL CHARACTERISTICS OF SOILS

The two direct effects of soil compaction, namely an increase in bulk density and soil penetration resistance (Liddle 1973) both show considerable variation within the wallows sampled (Table 7) and within the permanent quadrats of the two study sites (Table 8, 9). The mean bulk densities for the Boulder Beach wallows are Ø,16 $g.cm^{-3}$ and within the Boulder Beach permanent quadrat Ø,13$g.cm^{-3}$ and Ø,15 $g.cm^{-3}$ for the Trypot Beach permanent quadrat (Tables 7,8,9). The soil penetrometer resistance shows similar trends, Ø,1Ø log penetrometer impacts (L.P.I.) at the Boulder Beach wallows and -1,Ø4 and Ø,Ø4 at the Boulder and Trypot Beach permanent quadrats respectively.

The interrelationships between bulk density, log penetrometer resistance and moisture content are summarised in Appendix 5a,b and c. Bulk density and log penetrometer impacts were not significantly related (r=Ø,3) and neither were percentage moisture and log penetrometer impacts (r=-Ø,16; p>Ø,Ø5) at the Boulder Beach wallows. The percentage moisture content is negatively correlated to bulk density (r=-Ø,77; p<Ø,ØØ1). The permanent quadrats at the Boulder and Trypot study sites show a positive correlation between bulk density and log penetrometer impacts at the Ø,1 % (r=Ø,68) and the Ø,Ø1% (r=Ø,7Ø) level of significance respectively. Appendices 5a,b and c indicates that the seal utilisation is related to percentage moisture (p<Ø,ØØ1) and positively related to log penetrometer impacts (p<Ø,ØØ1) and bulk density (p<Ø,ØØ1). The percentage moisture content of the soils shows strong negative correlations (Appendix 6) with bulk

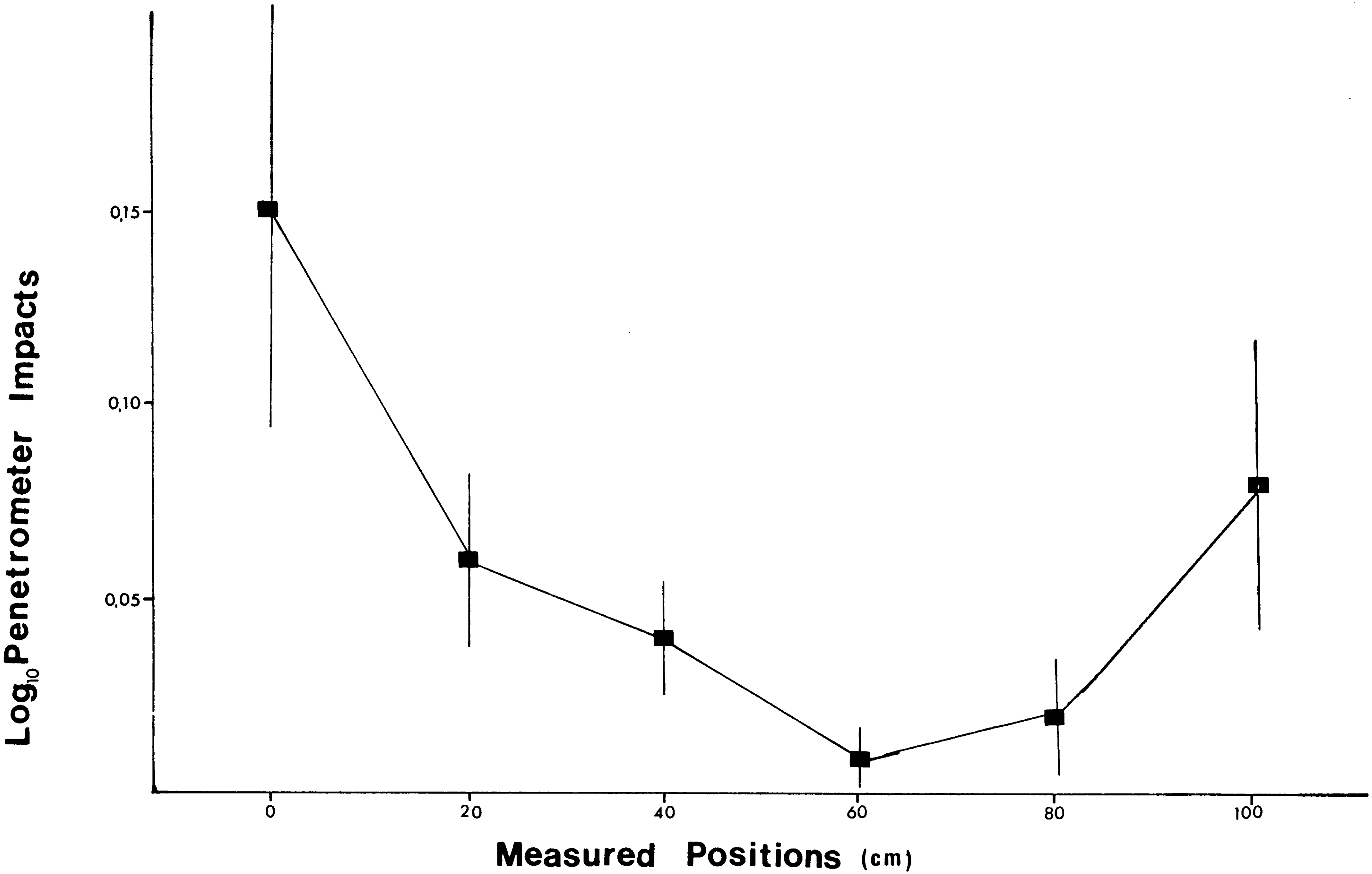


Figure 28. Changes in log penetrometer impacts at 20 cm intervals from the centres of 30 wallows used by elephant seals.

densities and with log penetrometer impacts except at the Boulder Beach wallows sampled.

The L.P.I. taken from the centre of 30 randomly chosen wallows, and spaced over 20 cm for 1 m are shown in Fig. 28. Compression was greatest in the centre of the wallows as a direct result of the vertical force exerted by the seals, and decreased in compression towards the edge of the wallows, and increasing again along the sides and towards the top of the wallow. The seals therefore exert both vertical and horizontal forces within particular wallows. These effects are likely to have an influence on the growth and regeneration of plants occurring within the wallows.

DISCUSSION

Defecation and urination by the large numbers of moulting elephant seals resulted in a considerable enhancement of the available forms of the major plant nutrients , N,P and Ca. Defecation and more importantly urination does increase concentrations of the available forms of Ca,Na,Mg and N. The increases in the total and available forms of Ca in the soils were unexpected and Gillham (1956) could detect little effect of guano on the soil Ca values.

Gehu & Gehu-Franck (1961) concluded that defecation by birds led to an enhancement of soil organic matter levels. This was not evident from the present study where defecation and urination by seals did not enhance the soil organic levels.

Smith (1977) showed the importance of manuring by burrowing bird species on the nutrient status of the soils. In addition areas not influenced by manuring contained low amounts of inorganic N mainly in the NH_4 form. The present study has shown that abrupt changes in soil nutrients especially in the concentrations of NO_3, available P and Mg and the percentage ash, seem to occur between adjacent and seal moulting sites.

Defecation has always been considered a factor of particular significance in determining vegetative cover around sea-bird colonies (Sobey 1975), plants having to cope with varying amounts of faeces. A similar situation has been found at Marion Island, where groupings of seals resulted in the addition of nutrients in localized areas.

Trampling by elephant seals was thought to be the factor of greatest significance in the modification of the Macquarie Island flora (Gillham 1961) where the effects of trampling were more likely to affect the plants because of the vulnerability of the merisermatic zone (Gillham 1956). Soil changes which most commonly occurred due to trampling are an increase of bulk density resulting in a reduction in pore space (Liddle 1973). Studies by Huntley (1971) on the vegetation of Marion Island have shown the extent of the influence of salt spray on the distribution of plant communities, while Smith (1976, 1979) has emphasised the manuring influences affecting the distribution of plant species. Few studies have been carried out on the effects of trampling on wet peatlands (Slater & Agnew 1977),and the effects on the soil properties and vegetation of these areas.

Because of the seasonal haul-out pattern of seals and the tendency of the seals to make use of the same moulting areas the same effects, trampling , defecation and urination, are repeated year after year. Not only would the rate of defecation and urination affect the soil-nutrient levels, and hence the plants, but trampling by seals does affect the plants, both beneficially and detrimentally. Plants growing in these areas are apparently adapted to cope with such factors.

CHAPTER 6

MINERAL AND ENERGY CONTRIBUTIONS OF THE MOULTING POPULATIONS OF ELEPHANT SEALS

Various authors have commented on the manuring effects of birds and seals on soil nutrient levels (Russell 1940,Wilson 1959, Gillham 1956,1961,Longton 1967, Northover 1967, Smith 1976,1978,1979, Huntley 1971). In addition to manuring and urination effects, the addition of shed hair and whole carcasses of elephant seals result in a considerable quantity of energy and nutrient material being introduced to the vegetated areas used by the seals during their moult.

MATERIALS and METHODS

A reinforced cage was designed to restrain sub-adult and adult female seals in the field in order to determine urine and faecal output and to obtain samples for the estimation of chemical and calorific outputs. Urine was collected every 12h for the determinations of total excretion rates, and samples kept frozen until analysed for their chemical composition. The hydrogen ion concentration (pH) of sub-samples of freshly collected urine was determined using a portable pH 800 meter.

Faecal samples were air-dried, sub-samples were frozen and kept for ammonia and nitrate analyses. The analitical methods used are outlined in Appendix 2. The energy content of sub-samples (0,3g) of fresh faeces and urine (1ml) was determined using a Gallenkamp ballistic bomb calorimeter. Since priming with alcohol results in complete combustion and eliminates the need to dry samples, 0,2g of 96% alcohol were burned with the sample. The energy value of the alcohol (28,9kJ/g) was subtracted from the gross energy value.

The total mass of hair shed by the seals was determined by calculating area to mass values for air dried hair samples collected randomly from moulting seals. These were extrapolated to cover the total surface area of the seals,calculated for each of the age-classes, by using girth and length measurements following Bryden (1972). Samples of hair were ground in a Wiley mill before chemical and energy values were determined. Two elephant seals, an adult female and a sub-adult female, were cropped towards the end of the moult, frozen and returned to Pretoria, where they were minced in a Wolfking grinder and sub-sampled. Calorific determinations were carried out on freeze-dried samples, while the chemical determinations were carried out on fat-free, freeze-dried samples.

The total urine and faecal contribution of the seals during the moulting period was determined by extrapolating the data obtained from the caged individuals to the entire population. The urine output was calculated as follows: the mean body mass of bulls was taken as 2 300kg, 390kg for adult cows and 157,5kg for sub-adults and juveniles (Bryden 1972). The faecal and urine output was determined from the caged individuals and applied to the above mass values for each size class. These values were multiplied by the total number of seals from each age class to give the total output for the population for one day, and multiplied by the durations of haul out for each age class to give total output for the entire moult period.

RESULTS

Urine samples from the three different age-classes of elephant seals exhibited a wide range in nutrient contents (Table 12). Adult bull elephant seals had higher values of total N, Na and NO_3 than the other age and sex classes. Values of P, K, Ca, Mg and Cl were lower in the bulls. The urine of adult females is higher in K, P and Cl.

The nutrient contents of faecal samples collected, are given in Table 13. Values for total N range from 4,65 to 9,35 % with a mean of 8,04%. The values for P, K and Ca, Na and NH_4 are high, while low values of Mg, Cl and NO_3 occurred. Only a small proportion of the total N content was in the available form (1,62% wet sample) while the greater part was in the total form (8,04%).

Mean total N values of 14,37 and 12,90% for hair and whole carcasses respectively (Table 14) were obtained. High values of Ca and P occurred in the carcass samples (Table 14).

The daily volume of urine excreted by caged adult and sub-adult females varied considerably and volumes produced ranged from 0,0 to 1102,5 ml per day for adult cows, with a mean value of 461,8 and 216,4 ml per day for cows and sub-adults respectively. A fasting adult elephant seal cow (279,7 kg) produced 1,65 ml/kg/day and a sub-adult (133,3 kg) 1,78 ml/kg/day. A single sample of 1270 ml urine was collected from an adult bull in the field. The moisture content of faeces as well as energy contents (kJ/g) for faeces, urine, hair and whole carcasses of elephant

Table 12. Concentrations of mineral elements (mg/l) in the urine of four age-classes of elephant seals.

	n	pH	Total N	Total P	Total K^{+}	Total Ca^{++}	Total Mg^{++}	Total Na^{+}	Chlorides	NH_4^{+}	NO_3^{-}
Adult cow	1.	6,01	30880	2400	186	68	289	1133	325	194	910
Adult cow	1.	6,09	31290	1800	86	63	316	1295	248	317	1071
Adult bull	1.	6,47	44380	2080	0	31	111	1473	311	212	1708
Sub-adult female	1.	6,89	20930	70	2	88	213	421	122	105	875

n = Number of samples

Table 13. Mean concentrations (%) of mineral elements in the faeces of adult cows and bulls.

FAECES	Total N	Total P	Total K	Total Ca	Total Mg	Total Na	Cl^-	Dry sample NH_4	Dry sample NO_3	Wet sample NH_4	Wet sample NO_3
Mean ($\overline{X}$)	8,04	0,45	0,53	0,39	0,04	1,21	0,36	0,91	0,05	1,62	0,26
Range	4,65-9,35	0,36-0,54	0,30-0,64	0,22-0,55	0,06 0,18	1,01-1,36	0,26-0,55	0,17 1,25	0-0,08	0,23-2,78	0,10 0,17
Standard deviation	2,26	0,10	0,15	0,18	0,06	0,16	0,13	0,50	0,04	1,05	0,30

Table 14. Concentrations (%) of mineral elements in hair and whole carcasses of seal samples.

	Total N	Total P	Total K	Total Ca	Total Mg	Total Na
HAIR						
Mean	14,37	0,11	0,09	0,08	0,08	0,16
Range	13,8- 14,8	0,10- 0,12	0,07- 0,11	0,07- 0,10	0,07- 0,10	0,11- 0,22
S.D.	0,51	0,01	0,02	0,02	0,02	0,06
n	4					
WHOLE CARCASS						
Mean	12,90	1,41	0,57	1,62	0,07	-
Range	12,71- 13,08	1,10- 1,71	0,54- 0,59	1,19- 2,05	0,06- 0,08	-
S.D.	0,26	0,43	0,04	0,61	0,01	-
n	4					

S.D. = Standard Deviation

n = Number of samples

seals are given in Table 15.

The data given in Tables 12,13,14 and 15 were used to calculate the total mineral and energy contribution to the island's terrestrial system by the population of moulting elephant seals. The total numbers of seals of each age-class, based on known rates of decrease (Skinner & van Aarde, 1983) and population counts, were 46 adult bulls, 682 adult cows and 1690 sub-adults and juveniles. Chemical and energy values were extrapolated using these figures and are presented in Table 16.

TABLE 15. Percentage faecal moisture content and calorific values of urine, faeces, hair and whole carcasses of elephant seals during their moulting cycle.

		Energy contents (kJ/g)			
	Faeces %moisture	Urine	Faeces	Hair	Whole seals
Mean	121,2	11,76	17,70	25,65	31,67
Range	133,2-96,7	10;96-12,93	10,71-32,26	20,42-32,84	29,79-37,07

The greatest contribution of total N was via the urine (approximately 5 000kg) followed by faeces (approximately 900 kg) and approximately 100 kg was contributed by moulted hair. Urine, with the the exception of the whole seals, contributed greater amounts of N, P, Mg, Na and NO_3. Faeces contributed greater quantities of K, Ca and available forms of N than the total urine excreted. Relatively high values of total N occurred in the hair shed, with low quantities of all the other minerals (Table 16).

DISCUSSION

The large daily volume of urine excreted by the seals was the principal route by which nutrients and energy were added to the system. Although differences may be expected to occur between the various age-classes of seals due to possible differences in the amount of food consumed , the values presented (Table 12) are assumed to be representative of the total population. The contribution of faeces to the vegetation and soil nutrient levels was limited as seals fast (food and water) during their moult. Defecation rates are likely to be greatest immediately following haulout, decreasing during the subsequent fast. The faeces are usually evacuated as a brown to yellow-brown liquid covering seals as they huddle together or on top of each other. In addition, large vegetative areas become covered with faeces, with the extermination of some plant species, an effect also mentioned by Gillham (1956) at the Pembrokeshire Islands.

Chemical elements contained in avian products deposited annually by 13 species of sea-birds in the coastal lowland of Marion Island amounted to 569,9 tons of N , 194,4 tons of Ca , 96 tons of P , 79,6 tons of K , 55,2 tons of Na and 20,1 tons of Mg (Burger, Lindeboom & Williams 1978, Siegfried, Williams, Burger & Berruti 1978, Siegfried 1981, Williams & Berutti 1978) These amounts are much greater than those deposited by elephant seals.

Table 16. Estimated amounts of energy (kJ) and minerals (kg) in the moulting elephant seal population on Marion Island. November 1980 to February 1981.

	Energy kJ	Total N	Total P	Total K	Total Ca	Total Mg	Total Na	Chlorides	NH_4^+	NO_3^-
Whole seals	$9,6x10^{10}$	82316,6	899,74	3637,2	10337,4	466,7		-	-	-
Urine	$1,2x10^{8}$	5737,8	334,4	16,0	11,7	58,7	240,6	46,1	58,9	198,9
Faeces	$5,4x10^{6}$	945,3	52,9	62,3	45,8	10,6	142,3	42,3	107,0	5,9
Hair	$2,2x10^{9}$	699,2	5,4	4,38	3,9	3,9	7,78	-	-	-
Total	$9,8x10^{9}$	89698,9	1292,4	3719,9	10398,8	539,9	390,1	88,4	165,9	204,8

No relevant values for fur seals have been determined. Manuring by penguins was associated with the production of peat which they may later erode (Lindeboom 1979, Hall & Williams 1981). The intense trampling , especially by penguins results in the total erosion of their habitats and is likely to adversely affect sloping areas resulting in large amounts of nutrients being washed into the sea. Although intense trampling occurs within elephant seal moulting sites, only partially localised erosion seems to occur within such areas. The minerals added to these vegetated moulting areas are therefore largely retained with little leaching to the sea. As a result the seals mineral and energy contributions to the terrestrial system are magnified in specific areas.

CHAPTER 7

DISTRIBUTION OF PLANT SPECIES AT THE TWO STUDY SITES

Trampling and manuring by elephant seals probably has as great an effect on the vegetation of Marion Island than manuring by birds. High P and N levels in the animals excreta may influence the occurrence of plant species (Smith 1976, 1979, Gremmen 1981). Trampling and manuring are generally associated, and areas influenced by animals differ from the immediate adjacent areas (Gremmen 1981).

METHODS

BOULDER BEACH.

Plant cover was recorded in each of 10 (1,0 m^2) quadrats placed randomly within each 225m^2 block. The percentage plant cover in each block was estimated by using the 1-10 Domin scale (Bannister 1966). The vegetation in the permanent quadrat (2 x 96 m) was assessed using a 40 point quadrat method (Brown 1964). Pins were spaced five cm apart, across the width of the permanent quadrat, and results were expressed as a percentage of 40 points. Frequency of occurrence of plants, using the point quadrat method, was determined every 4 m along the quadrat.

Plant samples for chemical analyses were collected within each 4,0 m^2 block. Plant cover in all the wallows at the Boulder Beach site was assessed using Domin ratings (Bannister 1966). Only plants which occurred within the depressions created by the seals were recorded.

TRYPOT BEACH. The coverage of all the plant species within the 13 separate areas (Fig.32) was recorded in each of ten 1,0m^2 quadrats placed randomly within each area. Plant samples for chemical analysis were collected within each 4,0 m^2 block.

Chemical analyses of plant tissue were carried out as described in Appendix 2. Samples collected from the permanent quadrats were grouped in order to reduce the number of analyses. Samples were grouped as follows: at the Boulder site, quadrats 1-4; 5-8; 9-12; 13-16; 17-20; 21-23; and at the Trypot site, quadrats 1-2; 3-4; 5-6; 7-8; 10-12; 13-15.

The method proposed by Liddle (1973,1975) was used to compare the vulnerability of different vegetation types to the effects of trampling.

Seedlings of Callitriche antarctica, Ranunculus biternatus, Cotula plumosa, Poa annua and Agrostis magellanica were collected from the same localities. Soil was collected on 29 January 1981 from a pure stand of Poa annua 50m south of the Boulder Beach site (Soil-1); from an unused wallow where Callitriche antarctica predominated (Soil-2); within a wallow, soon after it had been abandoned by seals and where no plants occurred (Soil-3); from a coastal salt spray community dominated by Crassula moschata and Cotula plumosa (Soil-4); in a stand where Agrostis magellanica predominated with a bryophyte layer of Clamatocolea humilis (Soil-5) and on a slope with a pure stand of Blechnum penna-marina (Soil-6). Fifteen seedlings of each plant species were placed in a plastic tray (25 x 15 cm) and each seperate tray filled with a specific soil type. Trays were placed in an outside hot-house, where the temperature was uncontrolled ,and the seedlings allowed to grow for 70 days. The plants were then cropped, measured, oven-dried and weighed. The soils were air-dried and kept for chemical analysis.

RESULTS

Boulder Beach Moulting Site

The plant cover estimates of all the vascular plants and selected bryophytes throughout the moulting area are shown in Fig. 28. Poa cookii, Poa annua (introduced), and Agrostis stolinifera, (naturalised alien; Gremmen 1975) cover the whole moulting area, with the greatest values for cover in the areas presently used by seals. P. annua and A. stolinifera were restricted to the hollows (wallows), while seedlings of P. annua occurred together with the faster growing A. stolinifera. P. cookii tussock was here entirely restricted to the hummocky parts of the area. Cover values for Cotula plumosa, a prominent species in areas strongly influenced by salt spray and on nitrogenous soils (Huntley 1971, Gremmen 1981), were highest in areas close to the sea and occurred in patches throughout the area. C. plumosa did not occur in areas intensively used by seals.

The plant species whose presence was attributed to high manuring effects by birds and seals, namely Callitriche antarctica, Montia fontana and Ranunculus biternatus (Huntley 1971, Smith 1978, Gremmen 1981) occurred throughout the area. C. antarctica had high cover values in areas not intensively used by the seals. Pure stands of C. antarctica occurred within wallows previously intensively used by the seals and where the vegetation

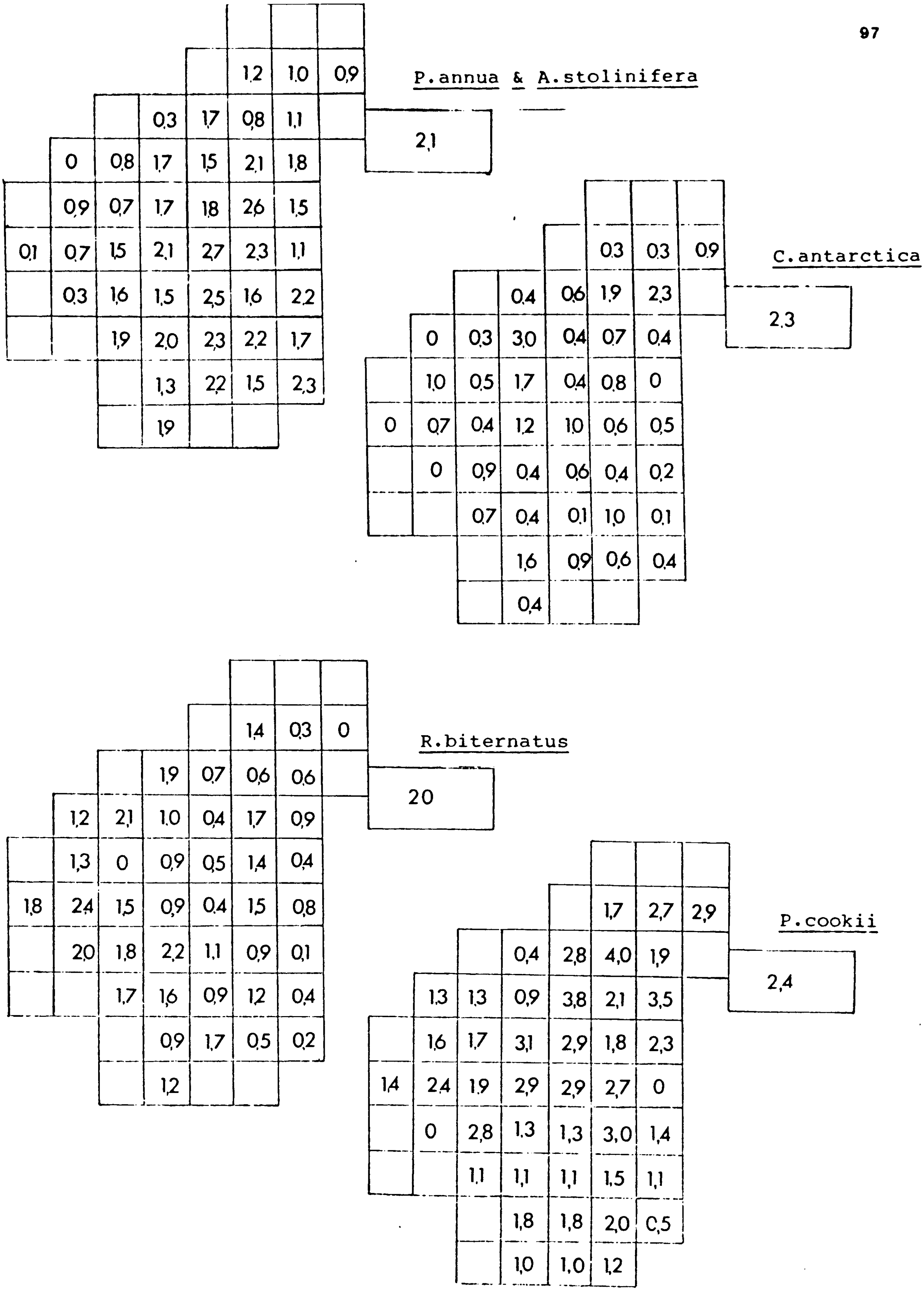
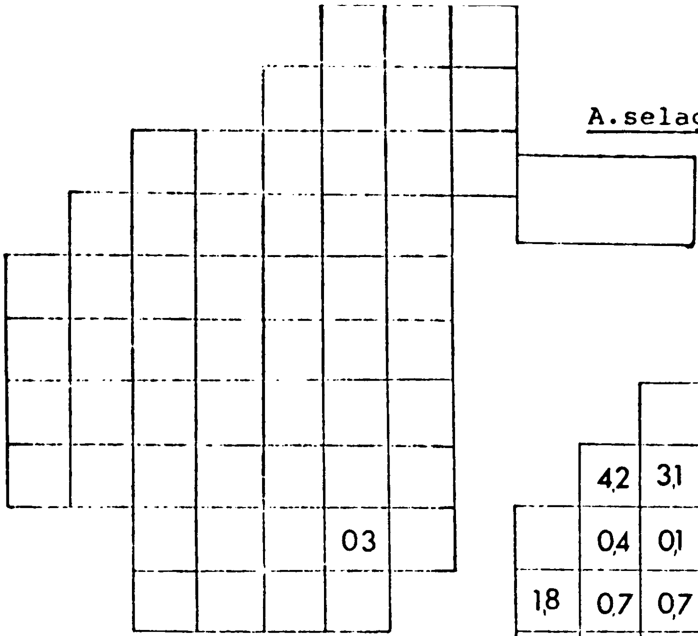
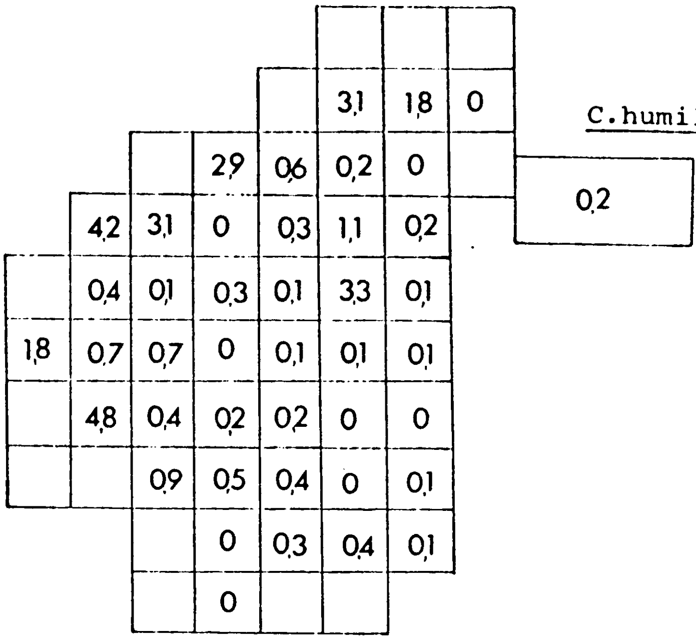


Figure 29. Plant cover values (transformed domin values) within each 225m² block at the Boulder Beach moulting site.


A.selago
03


C.humilis
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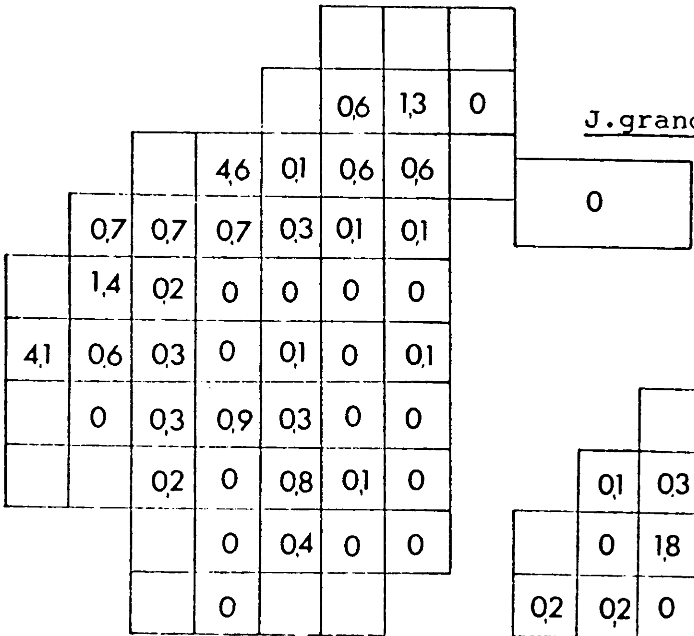
2,9 0,6 0,2 0
4,2 3,1 0 0,3 1,1 0,2
0,4 0,1 0,3 0,1 3,3 0,1
1,8 0,7 0,7 0 0,1 0,1 0,1
4,8 0,4 0,2 0,2 0 0
0,9 0,5 0,4 0 0,1
0 0,3 0,4 0,1
0
0,2


J.grandiflora
0,6 1,3 0
4,6 0,1 0,6 0,6
0,7 0,7 0,7 0,3 0,1 0,1
1,4 0,2 0 0 0 0
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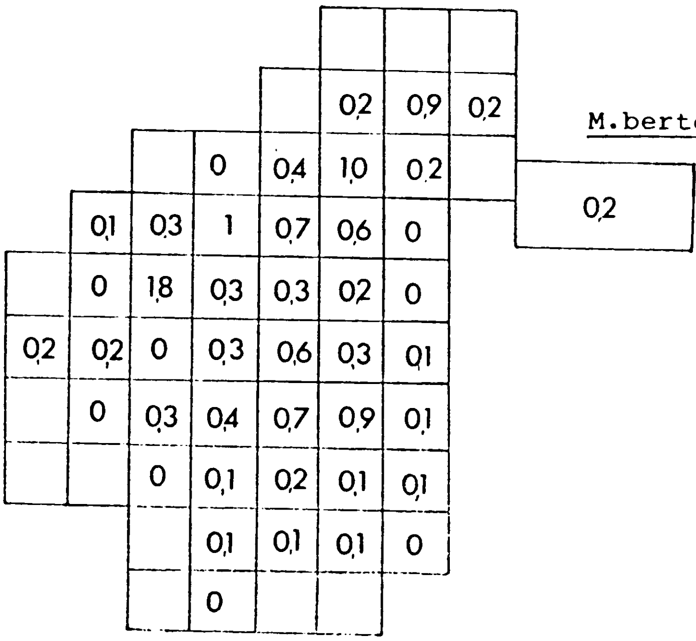
0 0,4 0 0
0
0


M.berteroana
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0 0,4 1,0 0,2
0,1 0,3 1 0,7 0,6 0
0 1,8 0,3 0,3 0,2 0
0,2 0,2 0 0,3 0,6 0,3 0,1
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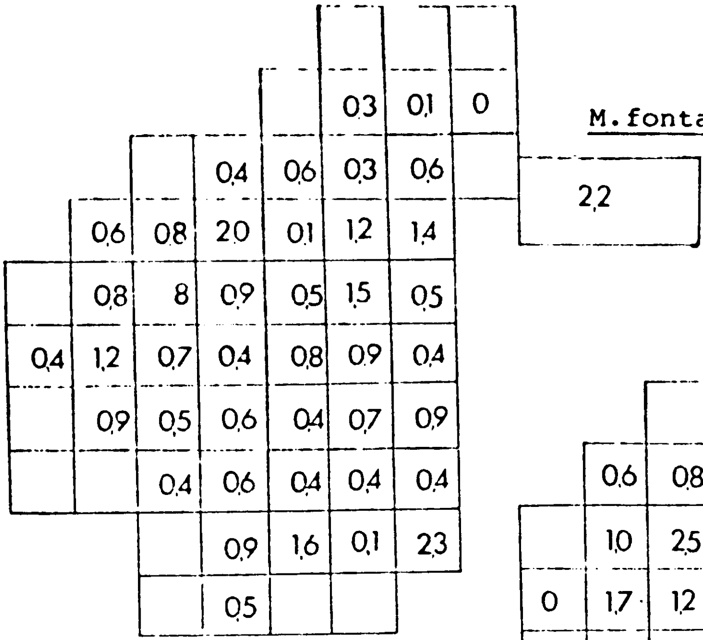
0
0,2


M.fontana
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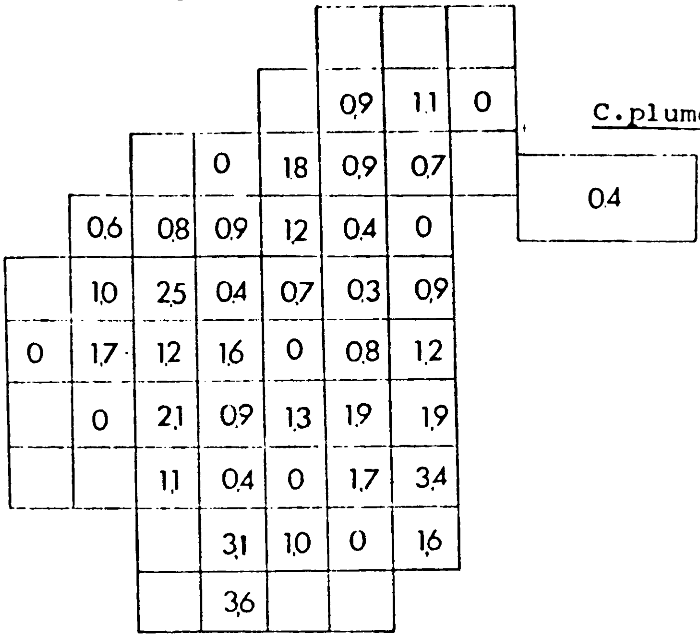
0,4 0,6 0,3 0,6 ; 2,2
0,6 0,8 2,0 0,1 1,2 1,4
0,8 8 0,9 0,5 1,5 0,5
0,4 1,2 0,7 0,4 0,8 0,9 0,4
0,9 0,5 0,6 0,4 0,7 0,9
0,4 0,6 0,4 0,4 0,4
0,9 1,6 0,1 2,3
0,5


C.plumosa
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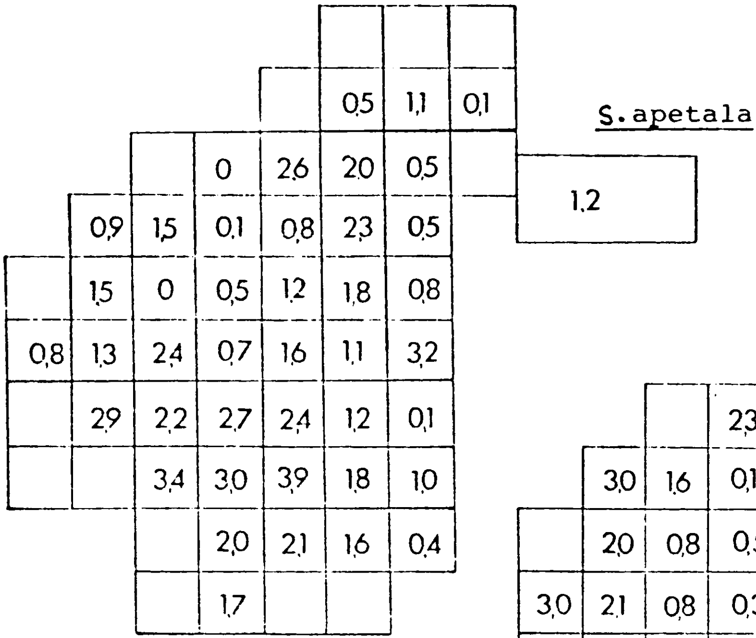
0 1,8 0,9 0,7 ; 0,4
0,6 0,8 0,9 1,2 0,4 0
1,0 2,5 0,4 0,7 0,3 0,9
0 1,7 1,2 1,6 0 0,8 1,2
0 2,1 0,9 1,3 1,9 1,9
1,1 0,4 0 1,7 3,4
3,1 1,0 0 1,6
3,6


S.apetala
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0 2,6 2,0 0,5 ; 1,2
0,9 1,5 0,1 0,8 2,3 0,5
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0,8 1,3 2,4 0,7 1,6 1,1 3,2
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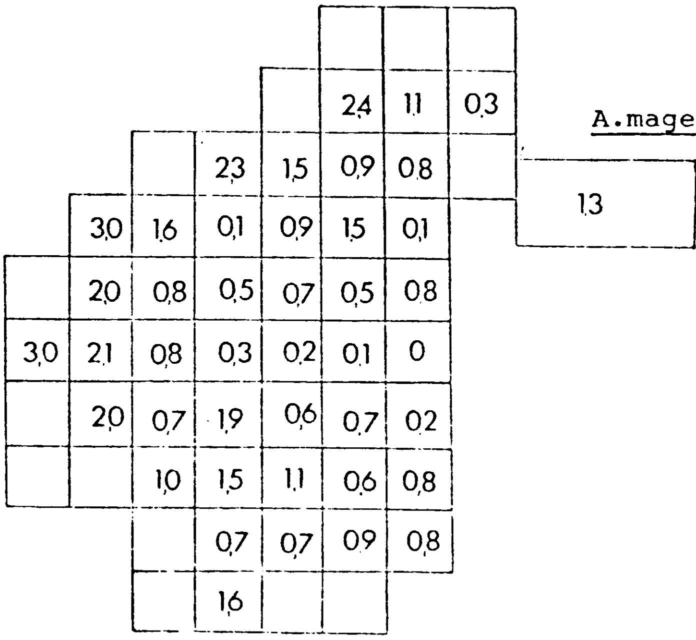
1,7


A.magellanica
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2,3 1,5 0,9 0,8 ; 1,3
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3,0 2,1 0,8 0,3 0,2 0,1 0
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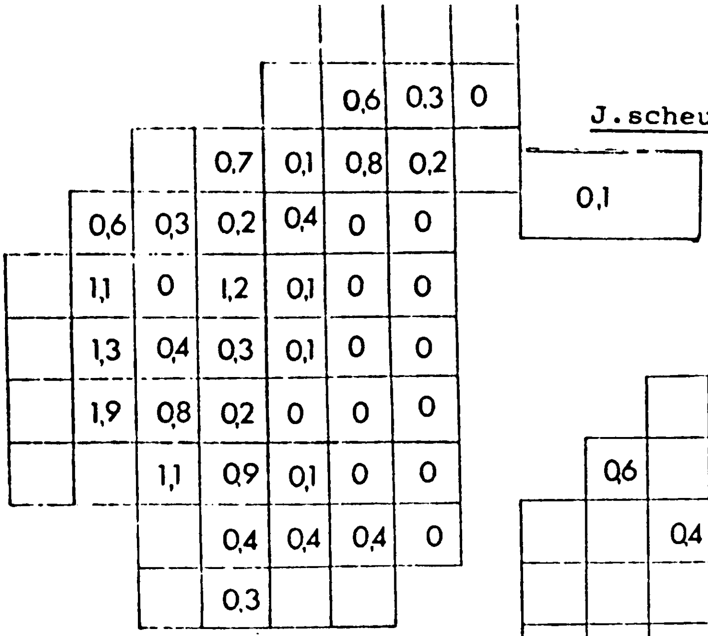
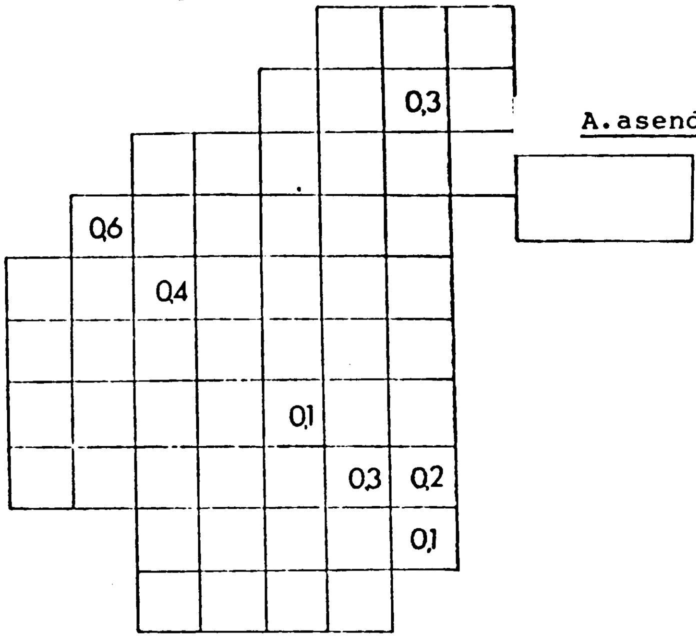
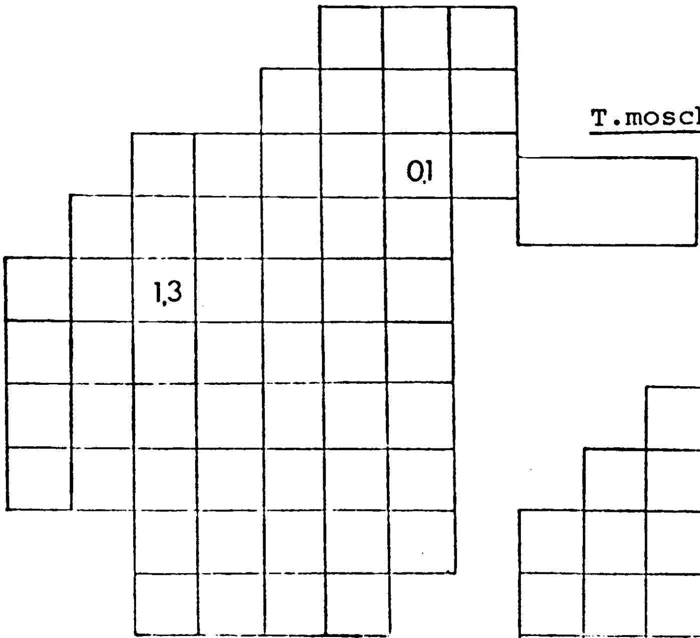
1,6



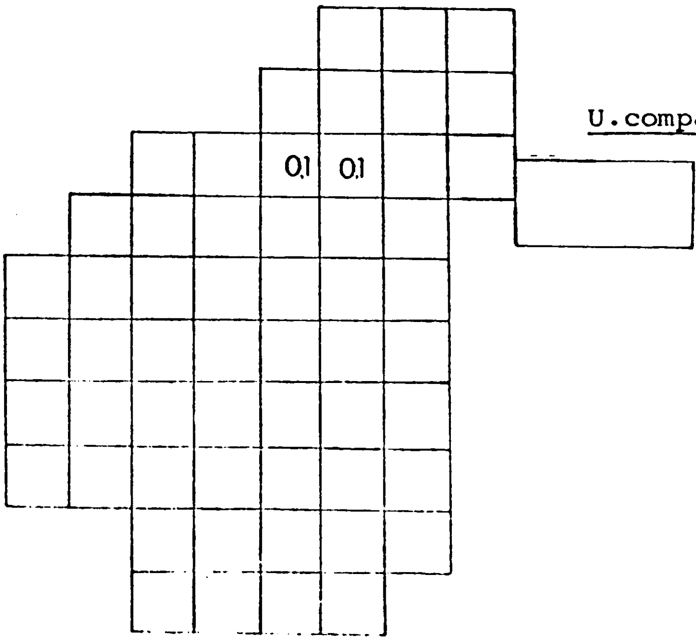
J.scheuchzeroides



A.asendens



T.moschata



U.compacta

had been destroyed. P. annua and A. stolinifera occasionally grew in association and eventually dominated old unused wallows. The cover values for R. biternatus showed a gradient with low values towards the centre of the area and higher values towards the boundary of the moulting site. The cryptophyte Montia fontana had a patchy distribution pattern. M. fontana usually grew in areas disturbed by seals. The grass species Agrostis megellanica, which is the most resistant to human trampling on paths on Marion Island (unpublished data) occurred at low cover values within the moulting site. Higher cover values were found towards the edge of the site although individual plants occurred on hummocks within the moulting site which were free from seal disturbance. The introduced weed Sagina apetala, a naturalised alien with a wide distribution (Gremmen 1975), had high cover values throughout the moulting site, forming dense carpets, excluding all other plant species.

The vegetation records for the 23 sampling locations are shown in Figure 30. The areas not used by seals, and hence not trampled supported stands of Clasmatocolea humilis, P. cookii and A. magellanica, and generally consisted of fewer plant species. Species such as P. annua, S. apetala, M. fontana, R. biternatus, C. antarctica and C. plumosa occur with increased seal use of the areas with stands of P. annua and A. stolinifera being dominant in areas of heavy seal use.

The vegetation at elephant seal moulting sites was extremely vulnerable to trampling with vegetation cover decreasing with an increase in the seal utilisation index (Fig.31).

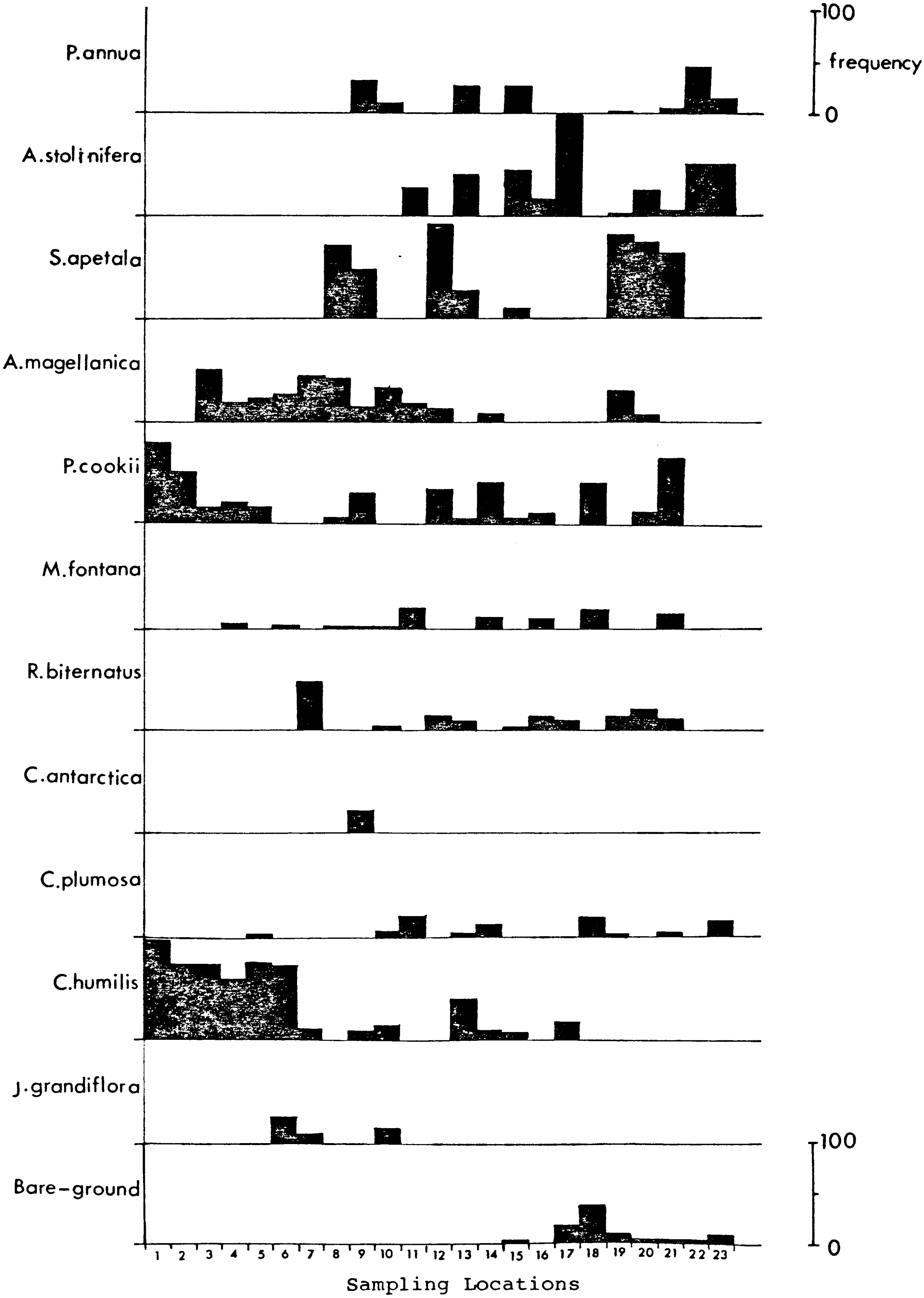


Figure 30. Spatial distribution of the plant species at each sampling location within the permanent quadrat at the Boulder Beach moulting site.

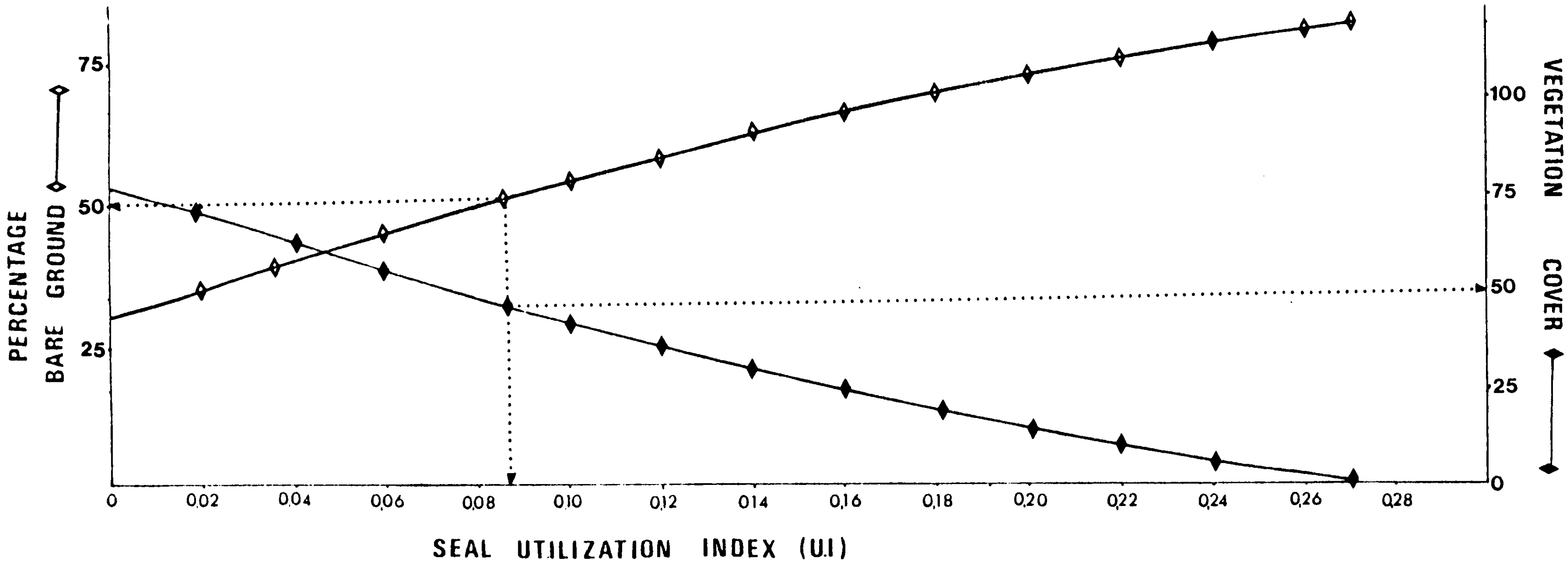


Figure 31. The relationships between ground cover(%) and seal utilisation index and between plant cover (%) and seal utilisation index. Curves were fitted through curvilinear regression analyses.

The level at which 50% of the vegetation remains occurred at an utilisation index of about 0,09, which approximates a seal using a wallow for nine days.

Trypot Beach Moulting Site

Plant cover values (transformed domin values) for seven vascular plant species within the 13 areas at the Trypot Beach moulting site are shown in Fig. 32. A. stolinifera and P.annua are dominant followed by P. cookii tussock. C. antarctica occurs in areas intensively used by seals. The distribution of C. plumosa does not seem to bear any relation to the pattern in seal activity and is restricted to areas in the immediate vicinity of the salt spray zone.

The frequency of occurrence of plant species at each sampling area within the permanent quadrat is shown in Fig. 33. Areas not intensively used by seals supported dense stands of C. plumosa with Stellaria media and A. stolinifera found occasionally. P. annua was restricted to the four quadrats (Fig.33) and A. stolinifera did not occur here.P. cookii tussock occurred among the stand of P. annua. The remaining area, which was heavily eroded by seals, supported a dense stand of A. stolinifera, with C. antarctica and R. biternatus found occasionally. The estimated percentage of bare ground represented the degree of seal activity and was clearly related to the distribution of particular plant species. The introduced weed S. apetala, widespread over the coastal eastern sections of the island (Gremmen 1975, 1981), was absent at the Trypot site.

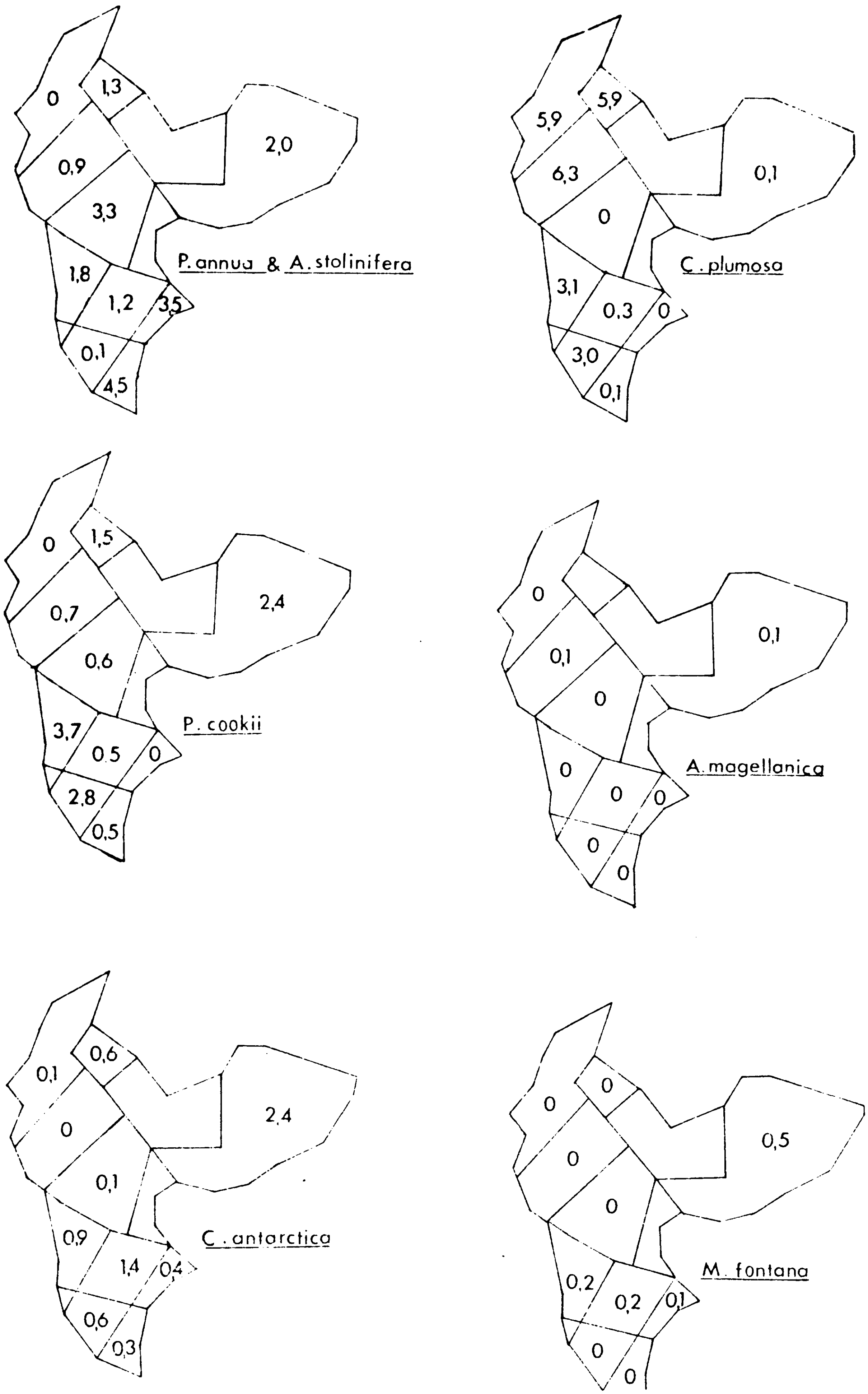


Figure 32. Plant cover values (transformed domin values) for seven vascular plant species within the 13 areas at the Trypot Beach moulting site.

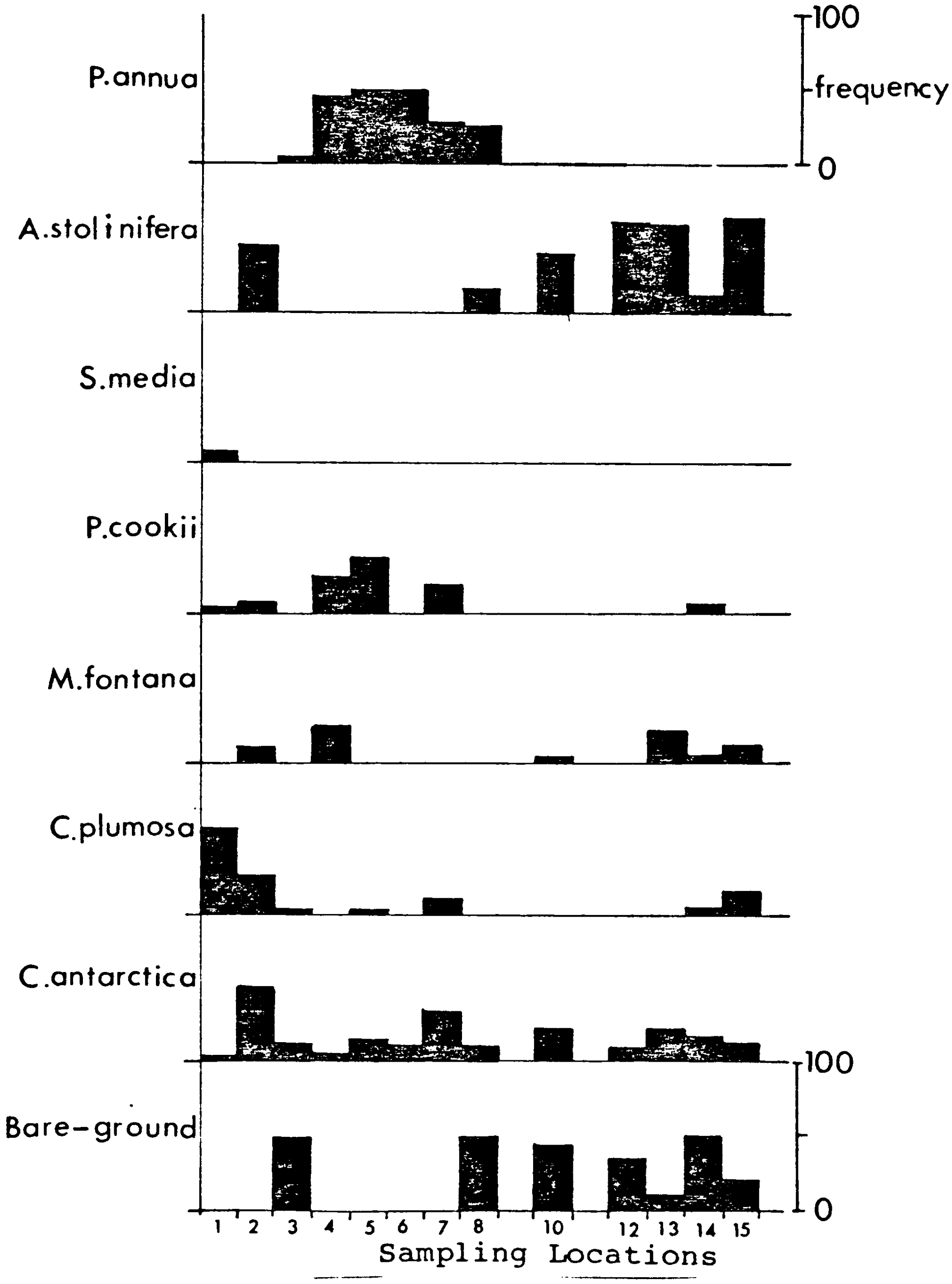


Figure 33. Spatial distribution of the plant species at each sampling location within the permanent quadrat at the Trypot Beach site.

PLANT TISSUE ANALYSIS

The concentration of mineral elements in the plant matter of the various island communities has been determined by Smith (1977). Plants in areas influenced by manuring had higher levels of N and P and to a lesser degree of K, Fe and Na than plants in areas not affected by manuring (Smith 1976b, 1978c). The concentrations of elements in the leaves of the plant species dominant in the wallow area fall within the ranges given (Smith 1976b, 1977b, 1978c) (Table 21) where the cation Na predominated over K in C.plumosa, M. fontana and C. antarctica. In C. humilis, S. apetala, A.magellanica, P. annua, A. stolinifera and P. cookii, K predominates over Na. The Ca content of C. antarctica and C. plumosa was higher than in all the other plants occurring within the area.

GROWTH OF VARIOUS PLANT SPECIES ON SOILS OF DIFFERENT SOIL FERTILITY

All the plant species grew and survived in the various soils. P. annua followed by C. antarctica, A. magellanica, R. biternatus and C. plumosa all produced the greatest biomass on soil 3 (collected from a wallow after it had been abandoned by seals)and 4 (from the coastal salt spray community),followed by soils 2 (soils from an unused wallow) and 5 (soil collected where A.magellanica was dominant) and less on soil 1 (soil where a pure stand of P.annua grew)and 6 (from a slope where Blechnum penna-marina grew) (Table 18). A. magellanica had the greatest length on soil 5 and similar lengths on soils 1 and 6 (Fig 34). C. antarctica did not show any clear distinction between its growth

Table 17. Mineral concentrations of leaves of selected plant species collected from the two study beaches, January 1981.

PLANT SPECIES		*n*	% Total N	% Total P	% Total K	% Total Ca	% Total Mg	% Total Na
P. cookii	Mean	11	2,18	0,29	0,97	0,16	0,14	0,68
	Range		1,50-3,14	0,23-0,42	0,14-1,20	0,12-0,52	0,09-0,46	0,10-3,52
			0,39	0,06	0,20	0,12	0,11	0,95
A. stolonifera	Mean	6	3,19	0,46	1,19	0,32	0,33	0,74
	Range		2,60-4,30	0,33-0,61	0,87-1,86	0,09-0,41	0,26-0,51	0,47-1,06
	SD		0,68	0,11	0,60	0,55	0,09	0,20
P. annua	Mean	5	3,73	0,57	1,43	0,45	0,38	1,30
	Range		3,20-3,96	0,35-0,65	1,19-1,86	0,19-0,92	0,31-0,47	0,9-4,06
	SD		0,31	0,28	0,17	0,25	0,06	0,33
A. magellanica	Mean	3	1,72	0,28	1,29	0,17	0,30	0,62
	Range		1,64-1,88	0,27-0,29	1,08-1,66	0,09-0,28	0,20-0,51	0,35-1,11
	SD		0,14	0,01	0,32	0,26	0,18	0,42
Sagina apetala	Mean	5	2,22	0,31	0,69	0,26	0,38	0,91
	Range		1,82-2,64	0,22-0,36	0,45-0,96	0,21-0,35	0,34-0,42	0,41-1,16
	SD		0,38	0,06	0,21	0,05	0,03	0,33
Clasmatocolea	Mean	2	1,40	0,16	1,04	0,24	0,28	0,15
	Range		1,24-1,56	0,14-0,17	0,92-1,16	0,18-0,29	0,26-0,30	-
	SD		0,23	0,02	0,17	0,08	0,03	-
Cotula plumosa	Mean	4	2,19	0,30	1,16	0,72	0,31	3,13
	Range		2,14-2,28	0,17-0,40	0,86-1,86	0,08-1,01	0,10-0,47	0,37-4,83
			0,07	0,10	0,23	0,43	0,14	1,96
Montia fontana	Mean	3	3,04	0,58	1,02	0,54	0,43	2,07
	Range		2,76-3,44	0,54-0,61	0,83-1,19	0,39-0,77	0,28-0,52	1,72-2,30
	SD		0,36	0,04	0,18	0,20	0,13	0,31
Callitriche antarctica	Mean	2	2,80	0,57	1,02	0,76	0,39	1,90
	Range		2,32-3,28	0,54-0,57	0,99-1,04	0,46-1,06	0,32-0,46	1,80-1,99
	SD		0,68	0,04	0,04	0,42	0,10	0,13

S.D. = Standard Deviation

n = Number of Plant Samples

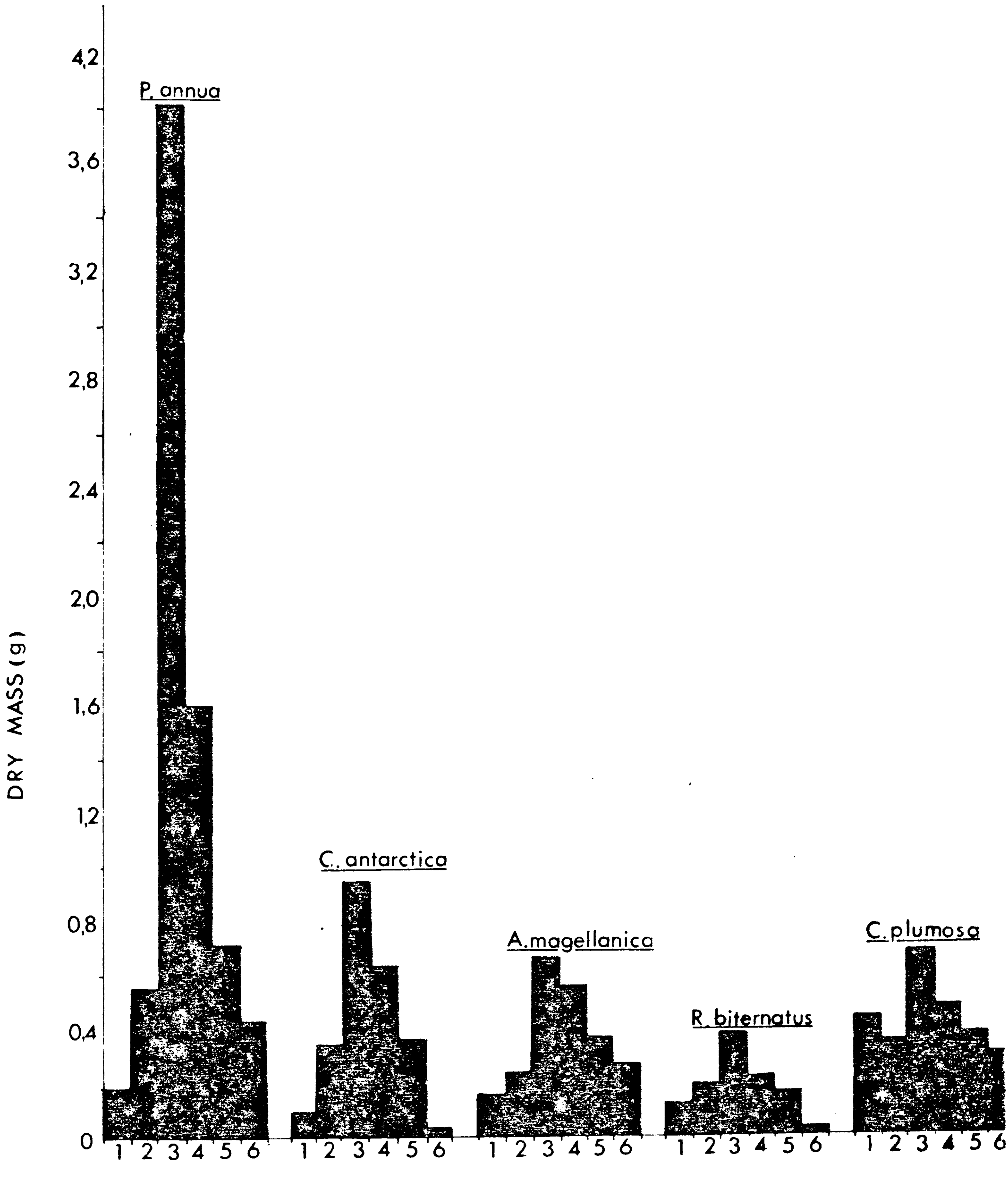


Figure 34. Biomass of the five plant species grown on the six different soil types.

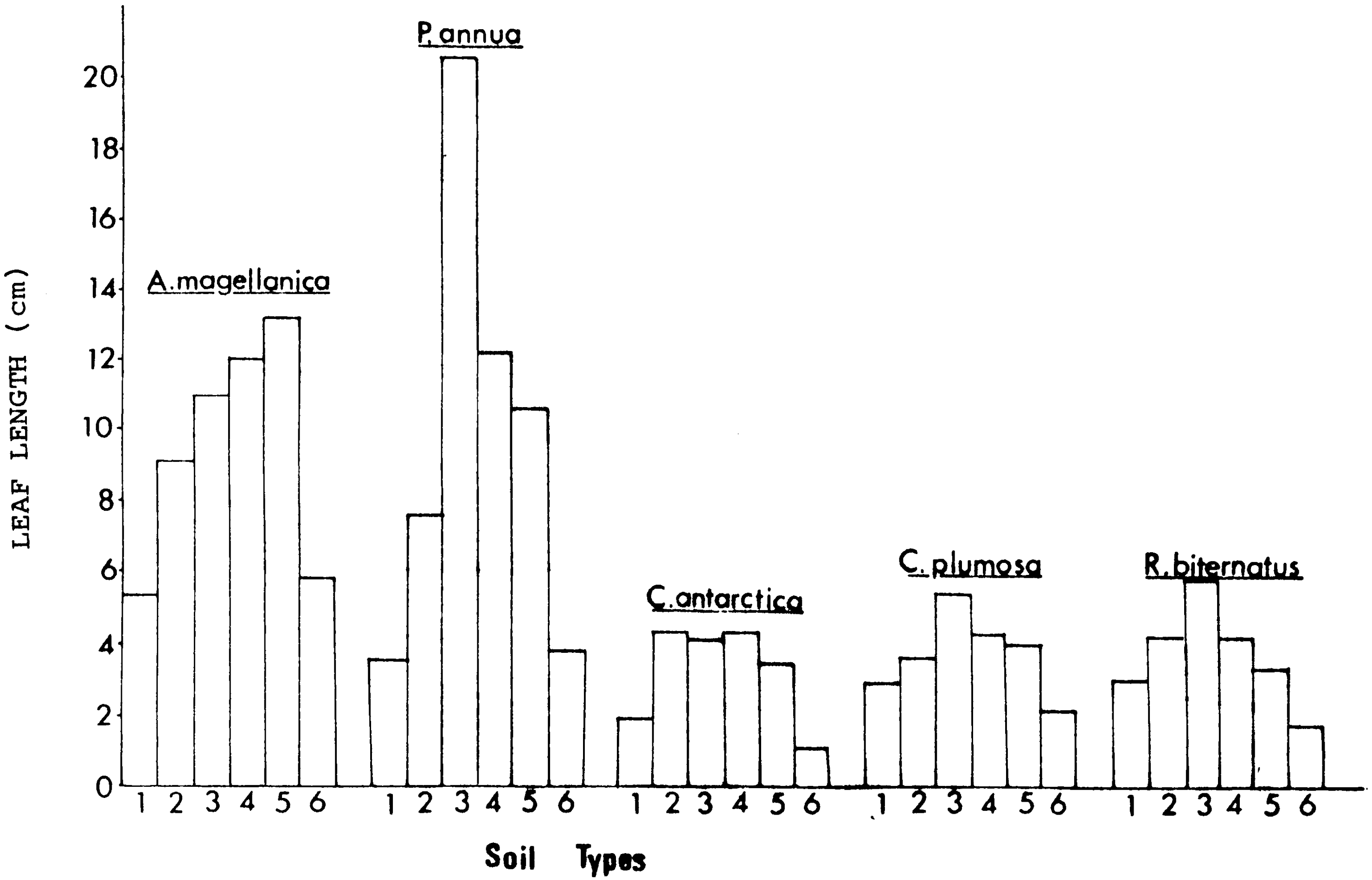


Figure 35. The mean leaf length (cm) of five plant species grown on six different soil types.

Table 18. Chemical analysis of the six soils used in the plant experiments.

SOIL	Avail P	Avail K	Avail Ca	Avail Mg	Avail Na	Total N	Total P	Total K	Total Ca	Total Mg	Total Na	Cl	Ash	pH
1	12	2100	600	613	541	1,93	0,19	0,21	0,17	0,10	0,09	0,02	25,6	5,64
2	43	448	4696	2184	1330	3,15	0,12	0,25	1,14	0,70	0,40	1,28	10,8	5,90
3	109	2300	825	770	498	3,75	0,16	0,26	0,22	0,12	0,11	0,02	23,8	6,08
4	69	2301	1035	1154	259	3,80	0,15	0,26	0,20	0,15	0,10	0,05	18,1	5,80
5	81	612	994	1089	257	3,05	0,25	0,20	0,17	0,13	0,10	0,05	7,2	5,73
6	124	2001	2041	1823	578	1,99	0,12	0,22	0,52	0,33	0,08	0,02	5,9	4,84

on soils 2, 3, 4 and is possibly related to the large variation in leaf size occurring within each tray. All the plants with the exception of A. magellanica and C. plumosa exhibit the lowest dry mass (Fig 35).

The soils showed a marked degree of variation in mineral concentrations with soils 3 and 4 having the higher concentrations of available K, total N and total K, and these factors were possibly of importance to the plants in terms of growth.

DISCUSSION

The distribution of the plant species at the Boulder and Trypot site was related to the gradient in seal activities. Areas towards the centre of the wallowing site were covered by almost pure stands of A.stolinifera and P.annua within the wallows , with P.cookii growing on the hummocks between wallows. These species seemed to be the most resistant to seal disturbance (i.e.trampling). Where soil fertility was at its greatest C.antartica occurred, indicating areas previously impacted by seals. A.magellanica occurred at greater cover values towards the edges of the wallowing site in areas where seal activity was minimal.

Factors other than those brought about by seals that play a role in the distribution of the various plant species included salt spray, which resulted in dominant stands of C.moschata and C.plumosa occurring on areas closer to the sea. This suggests that sea-spray deposition was the factor determining their distribution. The island's plants possessed a high Mg content

(Smith 1976), which was a response to the low soil Ca status and to influx of Mg from the sea. The highest concentrations occurred in the leaves of M. fontana, C. antarctica, S. apetala and P. annua. The high Na concentrations in the leaves of C. plumosa, M. fontana and C. antarctica reflected the concentrations in the soil solutions, a factor resulting from manuring by the seals, as these plant species attained optimum vigour in nitrogenous soils (Smith 1978, Gremmen 1981).

The experiment designed to determine the importance of the chemical and physical effects of the seals, predictably indicated that defecation and urination by the seals did enhance the level of soil nutrients and that the plants growing on the soils richer in nutrients had a higher nutrient concentration in their tissues. The high N concentrations in the leaves of C.plumosa , M.fontana and C.antartica reflected the concentrations in the soil solutions , as the plants obtained optimum vigour in nitrogenous soils.
Certain plant species responded more favourably than others in the greenhouse experiment , and the fact that all the plants thrived in the soils on which they did not normally occur implies that edaphic factors cannot be entirely responsible for the observed distributions. The greatest biomass was produced by P.annua, followed by C.antartica and A.magellanica. The absence of A.magellanica in areas heavily used by seals , and its prevalence in areas along the perifery of wallowing sites indicated the role of interspecific competion for space between the plants and was also possibly related to its vulnerability to

trampling by seals. *P. annua* seemed to be the most tolerant to high nutrient levels , with the remaining species such as *A.magellanica*, *R.biternatis*, and *C.plumosa* being more sensitive to high nutrient levels.

CHAPTER 8

BIOMASS AND ABUNDANCE OF TERRESTRIAL INVERTEBRATES IN ELEPHANT SEAL MOULTING SITES AT MARION ISLAND

Studies on the invertebrates on Marion Island have been for taxonomy collections (van Zinderen-Bakker, Winterbottom & Dyer 1971), to determine the occurrence, biomass and energy contents of insects (Burger 1978, 1980) and to study their role in the diet of Mus musculus (Gleeson 1981). Luxuriant plant growth, resulting from manuring by elephant seals was found to support the greatest invertebrate biomass in all the months of the year (Burger 1978).

MATERIALS AND METHODS

Invertebrates were extracted from soil samples collected within the two moulting sites from December to March in order to determine the total biomass and occurrence of the various groups. Soil samples were collected within the permanent quadrats at the Boulder and Trypot Beach moulting sites (see Fig.19). The samples were obtained with a core-sampler, 5,0 cm in diameter, 15,0 cm deep and 215,0 cm^3 in volume. Two soil cores (15,0 cm deep) were collected every 4,0 m intervals with an additional core (4,o cm) taken on the dominant plant species which occurred within one metre radius of the sampling location. Arthropods were extracted using steep sided Tullgren Funnels. Intact soil samples were inverted on the mesh screen (1,5 mm) and the animals were collected directly in sampling bottles containing 70% alcohol. A light bulb (60 watts) was used as a source of heat and suspended directly above the soil samples. Samples were removed after three days and all the meso-fauna removed by hand. The efficiency of the method was not tested. The permanent quadrats were sampled at the Boulder site during December and at both sites during January, February and March.

Individual mass of the Oligochaetae, Lepidoptera (Pringleophaga marioni) larvae and Curculionidae (weevil) larvae were determined on chemical balances. A mean weight loss of 65,3% of the three species perserved in 70% alcohol occurred after 10 months. Weight loss was calculated from differences in mean figures between wet mass (obtained during the present investigation) and dry mass supplied by Burger (1978). Wet mass of the samples was adjusted accordingly before regression coefficients were determined. Groups of microfauna were weighed and the mean individual mass (g) was determined for the most abundant groups (i.e. Collembola, aphids and mites). Due to the low numbers of Dipterans, spiders and slugs in the samples, mean dry mass supplied by Burger (1978) are used. A number of "indicator" species/groups of invertebrates were chosen (Table 19) and the results are given separately for these (Table 20).

Table 19. Species list of invertebrates on Marion Island showing the separation of groups and individuals for the purpose of this study.

	Indicator species/group
ARANEIDA	
1. Myro paucispinosus	
2. M. kerguelenensis	
3. Engona vagans	
4. Porrhomma antarctica	
LEPIDOPTERA	
1. Pringleophaga marioni	ADULTS & LARVAL FORMS
2. P. kerguelensis (only on Prince Edward Is.?)	
3. Embryonopsis halticella	
COLEOPTERA	
1. Palirhoeus eatoni	CURCULIONIDAE
2. Mesembriorrhinus parvulus	ADULT & LARVAL FORMS
3. Bothrometopus randii	
4. Antarctonesiotes elongatus	
5. Ectemnorrhinus similis	
6. Antarctophlosus atriceps	ADULTS
7. Meropathus randii	
DIPTERA	
1. Limnophyes pusillius	ADULTS & LARVA
2. Lelmatoscopus albipuntatus	
3. Paractora jeanelli	
4. P. drauxi	
5. Apetenus litoralis	
6. Listriomastax litorea	
7. Fannis camcularis	

HEMIPTERA

1. Rhopalosiphum podi
2. Neomyzus circumflexus
3. Macrosiphum euphorbiae
4. Brachycaudus helichrysi

APHIDIDAE

ADULTS & YOUNG GROUPED TOGETHER

PSOCOPTERA

1. Antarctopsocus jeanneli

OLIGOCHAETA

1. Microscolex kerguelen
2. Dendrobaena rubida

HYMENOPTERA

1. Kleidotoma icarus

EUCOILIDAE

ORIBATEI

1. Liochthonium c.f. fimbriatissimus
2. Hermanniella sp.
3. Albodamaeus sp.
4. Macquarioppia striata
5. Oppia crozetensis
6. Podocarus aubenti aubenti
7. Alaskozetes antarcticus
8. Alaskozetes bouvetoyaensis
9. Halozetes marinus devilliersi
10. Halozetes edwardensis
11. Halozetes crozetensis
12. Halozetes belgicae spp A
13. Halozetes belgicae spp B
14. Halozetes marionensis
15. Halozetes fulvus

16.	Antarctozetes crozetensis	
17	Porokalumna rotunda	
18..	Dometorina marionensis	
19.	Tototabes marionensis	
20	Zygoribatula subantarctica	

COLLEMBOLLA

1.	Cryptopygus antarcticus travei	ISOTOMIDAE
2.	C. caecus	
3.	C. dubius n. sp.	
4.	C. tricuspis	
5.	Tsotomurus cf. palustris	OTHERS
6.	Tsotoma notabilis	
7.	Sorensia marionensis	
8.	Sminthurinus cf. granulosus	
9.	S. cf. kerguelensis	
10.	Magelothorax cf. minimus	
11.	Ceratophysella cf. denticulata	
12.	Phpogastrura cf. viatica	
13.	Tulbergia bisetosa	

Species list was compiled from data supplied by van Zinderen Bakker Sr, and others (1971); Trave (1976); Wallwork (1963, 1970); Engelbrecht (1974, 1975).

RESULTS

Size Distribution and Abundance

Size distribution of E. similis (weevil) larvae, P. marioni (lepidopteran) larvae and the Oligochaetae (earthworms) are shown in Figures 36, 37,38 for the months December 1980 March 1981 respectively. The size class (0-0,4 cm) for E. similis was greater than the rest in all the months except March (Fig. 32), where the maximum percentage occurrence was the size group 0,6 cm. Size class 0,5 cm showed decreasing percentage occurrence for the months of December to February, increasing again in March. The percentage occurrence of P. marioni, size class 1,0 cm is highest in December, but low in all other months, with the greatest size class (2,4 cm), increasing from zero in December to 13% in March. The percentage occurrence of the Oligochaetae showed a similar trend in that the smallest size class group (1,0 cm) was greatest in December (30,5%) and decreased to March (17,6%). The second size class group (1-1,5 cm) was high for all the months, peaking in March (34%). The third size class group (1,6-2,5 cm) was generally high in all the months, greatest in March (38,5%). E. similis and the Oligochaetae showed distributions typical of species in which few individuals survived long after reaching maximum size (Satchell, 1971). The monthly densities, range and the coefficient of variations (Vx) for all the animals for the months January 1981 to March 1981 at the two sites are given (Table 22). The Trypot moulting site showed a greater density of meso-fauna (1,0 cm), namely earthworms (4743,0/m^2), Lepidopterean larva (365,5/m^2) and

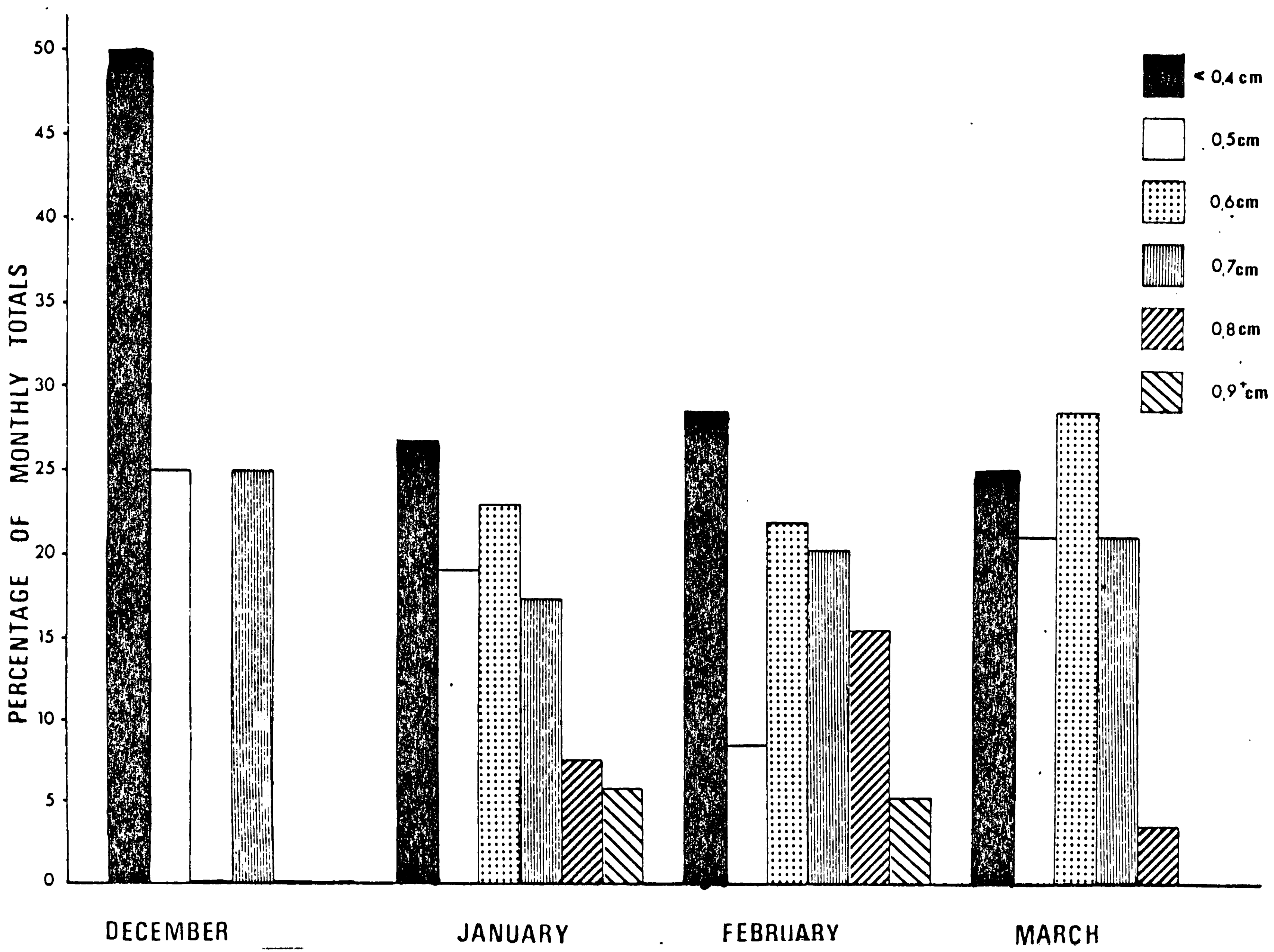


Figure 36 Frequency distribution of size classes for the monthly collections of Ectemnorrhinus similis (weevil) larvae. December 1980 to March 1981.

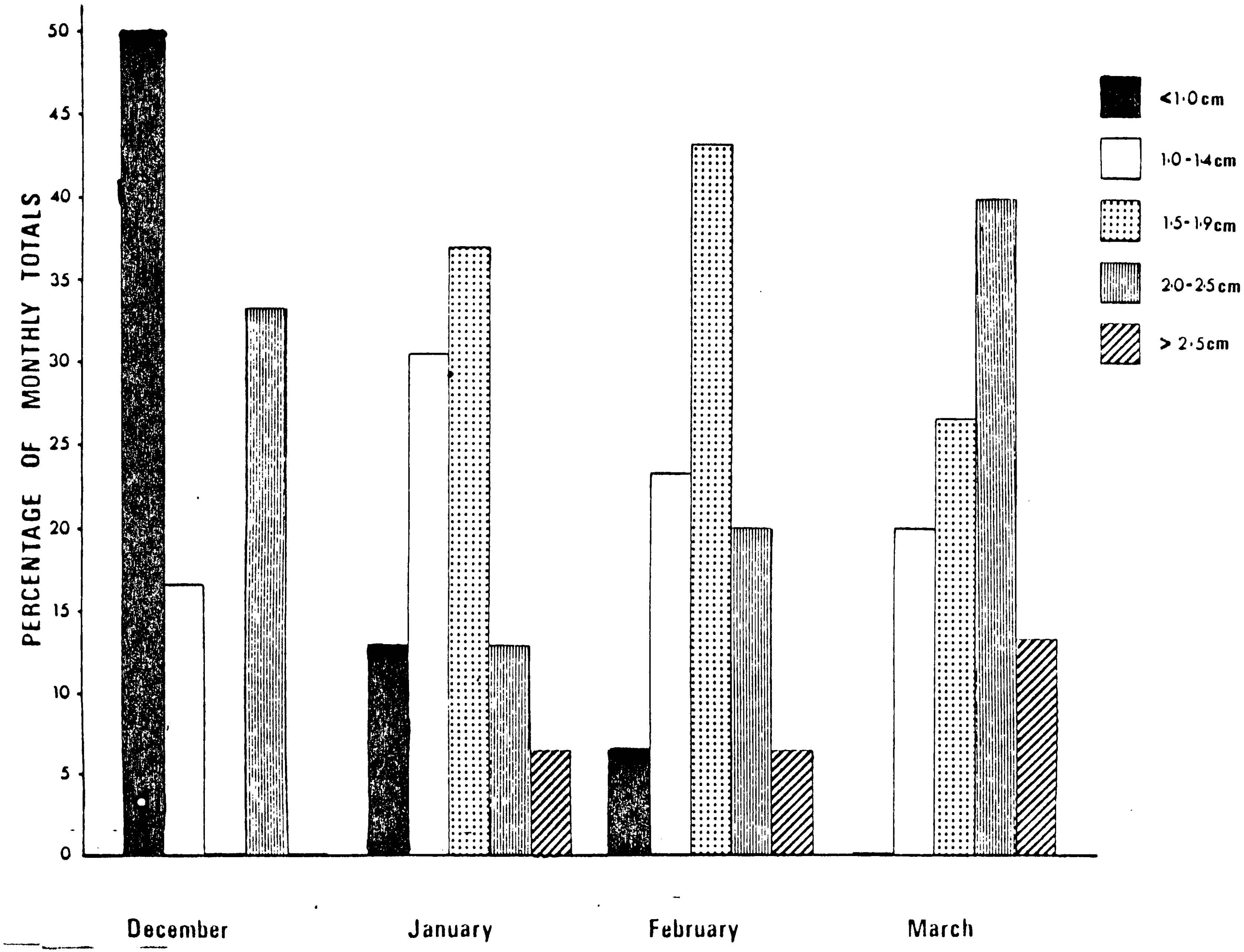


Figure 37. Frequency distribution of size classes for the monthly collections of Pringleophaga marioni larva. December 1980 to March 1981.

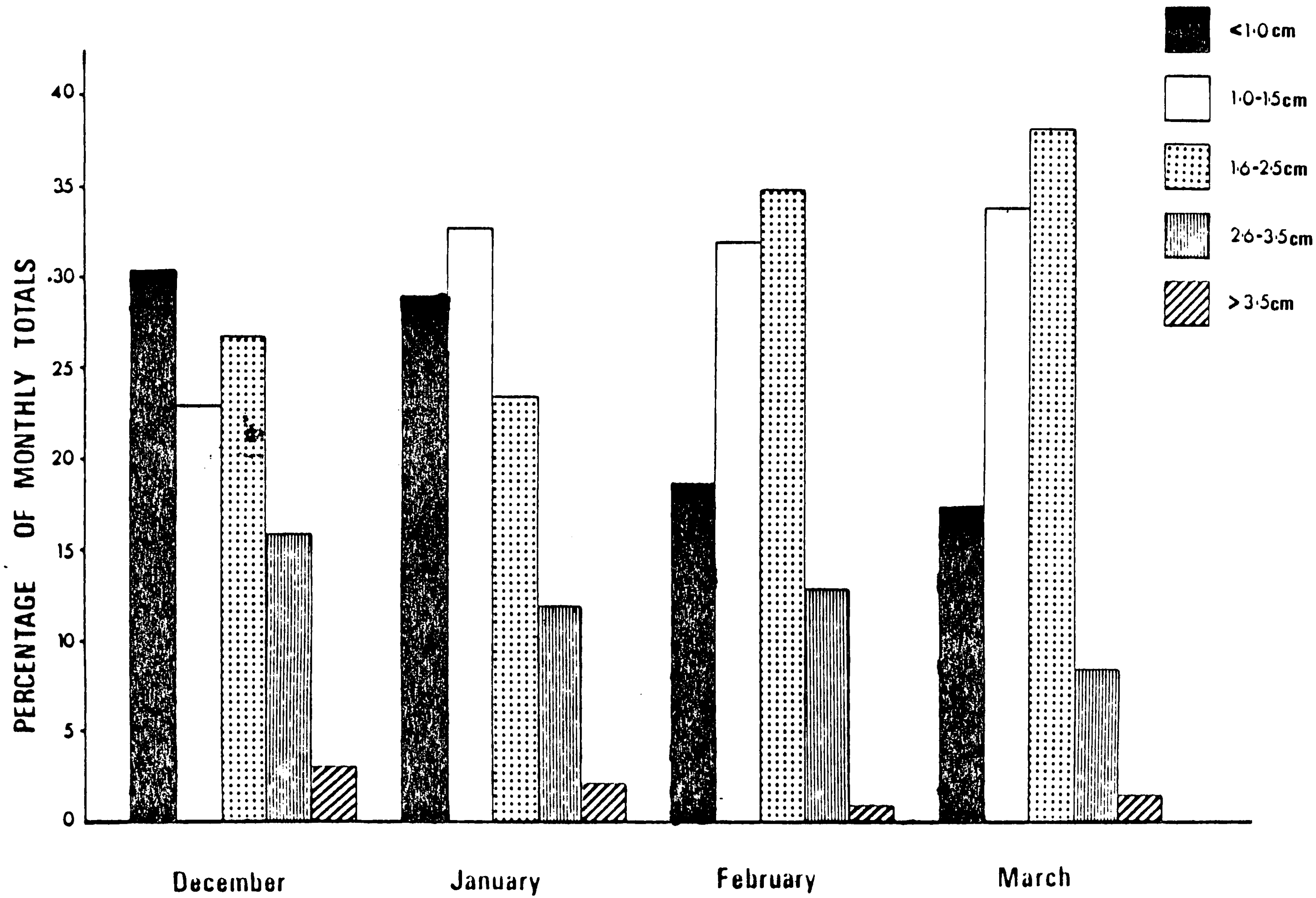


Figure 38. Frequency distribution of size classes of Oligochaeta. December 1980 to March 1981.

Table 20. Mean monthly values (numbers/m^2) range and coefficient of variation (Vx) of invertebrates for Trypot and Boulder Beach moulting sites.

TRYPOT

INSECT SPECIES		JANUARY Mean	JANUARY Range	JANUARY Vx	FEBRUARY Mean	FEBRUARY Range	FEBRUARY Vx	MARCH Mean	MARCH Range	MARCH Vx
OLIGOCHAETAE:		474,3	0-11050	72,0	1582,7	0-7310	116,5	654,5	0-1700	82,8
LEPIDOPTERA: Pringleophaga marioni	(adults)	-	-	-	-	-	-	-	-	-
" "	(larva)	365,5	0-1530	111,89	144,5	0-680	158,9	91,8	0-510	179,7
Embryonopsis halticella	(adults)	-	-	-	-	-	-	-	-	-
" "	(larva)	195,5	0-340	77,9	25,5	0-170	244,1	78,2	0-340	143,1
COLEOPTERA : Curculionidae	(adults)	39,1	0-340	259,6	-	-	-	-	-	-
:	(larva)	144,5	0-850	172,9	130,9	0-510	120,5	64,6	0-340	199,7
Staphylinidae	(adults)	105,4	0-340	105,7	117,3	0-680	199,0	25,5	0-170	244,1
DIPTERA	(larva)	248,2	0-1190	159,5	91,8	0-510	180,0	195,5	0-1190	183,3
	(adults)	-	-	-	91,8	0-510	179,7	39,1	0-340	259,6
ARACHNEIDA		25,5	0-170	244,1	52,7	0-170	156,2	25,5	0-340	360,6
LARVAL SPECIES[x]		13,6	0-170	360,6	-	-	-	-	-	-
HEMIPTERA APHIDAE		204,0	0-1530	220,5	195,5	0-1360	196,5	144,5	0-340	116,7
ORIBATEI (TOTAL)		46478,0	680-269110	151,9	14201-5	170-39780	90,0	21537,3	850-119000	151,9
HALOZETES spp		2771,0	170-7310	88,0	1137,3	0-3740	104,1	1072,7	170-4080	116,4
HYADESIA spp		36159,0	850-252450	186,6	8853,6	0-33320	112,6	8277,3	170-47940	162,0
'OTHERS'		7548,0	340-22950	104,8	4210,9	170-18530	121,7	12187,3	340-113900	257,6
COLLEMBOLA (TOTAL)		3617,0	510-31620	76,5	6590,9	680-17170	81,7	5217,3	0-27200	135,6
TULLBERGIA antarctica		11713,0	340-31620	81,9	5701,8	680-13260	72,7	2104,6	0-6630	97,0
ISOTOMIDAE		13,6	0-170	360,6	-	-	-	-	-	-
'OTHERS'		1922,7	0-15470	215,9	889,1	0-8160	252,4	3190,9	0-20570	171,5
SLUGS		-	-	-	-	-	-	-	-	-

BOULDER

INSECT SPECIES		JANUARY Mean	JANUARY Range	JANUARY Vx	FEBRUARY Mean	FEBRUARY Range	FEBRUARY Vx	MARCH Mean	MARCH Range	MARCH Vx
OLIGOCHAETAE:		1174,7	0-3570	91,8	821,1	0-3060	104,7	746,3	0-2210	97,5
LEPIDOPTERA: Pringleophaga marioni	(adults)	-	-	-	-	-	-	6,8	0-170	479,6
" "	(larva)	88,4	0-340	113,7	73,1	0-510	181,2	66,3	0-340	184,6
Embryonopsis halticella	(adults)	-	-	-	-	-	-	-	-	-
" "	(larva)	96,9	0-510	167,2	73,1	0-680	217,4	119,0	0-850	222,8
COLEOPTERA : Curculionidae	(adults)	-	-	-	37,4	0-340	238,5	6,8	0-170	479,6
:	(larva)	192,1	0-1190	128,8	185,3	0-510	91,6	198,9	0-510	104,8
Staphylinidae	(adults)	6,8	0-170	479,6	22,1	0-170	264,0	15,3	0-340	479,6
DIPTERA	(larva)	494,7	0-6630	323,5	57,8	0-510	264,0	147,9	0-1020	206,0
	(adults)	214,2	0-1870	200,4	73,1	0-340	181,2	51,0	0-340	183,6
ARACHNEIDA		66,3	0-850	275,0	37,4	0-340	275,9	59,5	0-510	222,8
LARVAL SPECIES[x]		51,0	0-510	231,0	44,2	0-510	264,0	22,1	0-340	350,9
HEMIPTERA APHIDAE		243,1	0-2720	234,8	686,8	0-6800	207,0	2927,4	0-1598	158,2
ORIBATEI (TOTAL)		6001,0	170-18020	89,0	3666,9	0-12070	100,2	4552,6	0-19550	122,4
HALOZETES spp		2556,8	0-9690	112,1	1479,0	0-6460	124,5	1796,9	0-13430	171,8
HYADESIA spp		1898,9	0-10200	156,2	872,1	0-3910	141,2	516,8	0-57800	244,4
'OTHERS'		1545,3	0-6970	100,8	1315,8	0-8670	164,4	2150,5	0-14620	158,8
COLLEMBOLA (TOTAL)		59632,6	5780-408680	162,9	58124,7	4590-206550	84,6	107128,9	12750-620160	147,7
TULLBERGIA antarctica		554,2	0-6460	249,7	695,3	0-5270	186,3	229,5	0-1870	188,0
ISOTOMIDAE		50304,7	510-389130	187,4	48716,9	0-189210	91,7	88576,8	2890-564910	169,4
'OTHERS'		8773,7	680-26180	84,3	8714,2	340-32130	95,2	19397,4	510-69700	109,8
SLUGS		22,1	0-510	479,6	-	-	-	-	-	-

x UNIDENTIFIED LARVAL SPECIES.

Halticella larva ($195,0/m^2$) than the Boulder site (Table 1) during the month of January. The Boulder site contained increased densities of spiders ($66,3/m^2$), weevil larvae ($192,1/m^2$) as well as dipterans and slugs values, 214,2 and $22,10/m^2$ respectivley for January. No lepidopteran adults or slugs were found at the Trypot site (Table 24). The mean total numbers $/m^2$ for micro-fauna showed differences at both sites. The most abundant group was the Oribatei ($46478/m^2$) at the Trypot site (Table 24) and the Collembola ($59632,6/m^2$) at the Boulder site for the months January to March. The mean densities for the Aphidae were highest at the Boulder site.

The table of variance (Table 21) indicates that significant differences existed for the monthly mean values of Oligochaetae (earthworms) at the Trypot site ($p < 0,001$), but not at the Boulder site, with significant differences occurring between their densities at the two sites (T.E. vs B.E. : $p < 0,001$) (Table 21). A similar trend is shown with the Lepidoptera (Pringleophaga marioni) larvae, with significant differences between the monthly mean values at the Trypot site ($p < 0,05$) and between the two sites (T.P.L. vs P.P.L. $p < 0,01$). The Curculionidae larvae showed significant differences between the two sites (T.E.c vs. B.E.c : $p < 0,05$). Significant differences occurred for the monthly values for the Aphididae ($p < 0,01$) and the Collembola $p < 0,05$) for the Boulder and Trypot site respectively. Significant differences occurred for the total mean values found between the two sites for the Aphidae, Oribatei and the Collembola (Table 22).

Table 21. Analysis of variance table for monthly values of invertebrates sampled at the Boulder and Trypot sites.

	DF.	TOTAL SUM OF SQUARES	TREATMENT MEAN SQUARE	F
Trypot E.	2	10526,31	2071,46	11,68 ***
Boulder E.	2	1934,20	41,80	1,49 N S
Te vs Be	1	14183,44	1722,92	14,66 ***
Trypot Pl.	2	121,74	9,56	3,36 *
Boulder Pl.	2	33,07	0,10	0,20 N S
T.Pl vs P.Pl.	1	168,10	13,29	9,10 **
Trypot Ec.	2	44,67	1,20	0,66 N S
Boulder Ec.	2	101,83	1,54	0,03 N S
T.Ec vs B.Ec.	1	151,85	1,38	3,88 *
Trypot Ap.	2	151,9	0,41	0,10 N S
Boulder Ap.	2	27406,96	1646,22	6,00 **
A.Ap vs B.Ap.	1	22616,10	1057,25	5,20 *
Trypot Ob.	2	283965,36	128748,64	1,79 N S
Boulder Ob.	2	210868,43	2780,52	0,89 N S
T.Ob vs B.Ob	1	3540366,92	442881,49	16,20 ***
Trypot Coll.		96081,08	9122,54	4,22 *
Boulder Coll.		29321130,87	618057,92	1,45 N S
T.Coll. vs B.Coll.		33228647,67	3811435,72	13,73 ***

E = Earthworms; Pl = Pringleophaga marioni (larva); Ec = Ectemnorrhinus similis (larva); Ap = Aphidae; Or = Oribatei; Coll = Collembola; T = Trypot; B = Boulder. * p<0,05; ** p<0,01; *** p<0,001; N S = not significant.

Percentage occurrence and biomass

The percentage composition and biomass of the samples from each area are given in Table 22. There were no distinct differences between the proportions of the various groups in the monthly samples. The Oligochaetae showed a decrease from January to March at both the sites. Similarities existed between the two sites in terms of the different groups, with E.halticella larvae being of a similar order in the two areas, as well as Curculionidae larvae, Staphylinidae, Diptera, Aphidae and Oribatei (Halozetes spp). Lepidoptera and Coleoptera adults and slugs did not occur in any of the samples. The percentage occurrence of Oribatei (36,8%) was greatest at the Trypot site, followed by the Collembola (10,8%) and Oligochaetae (3,8%). At the Boulder site, the percentage occurrence of the Collembola was greatest (44,55%), followed by Oribatei (4,5%) and Oligochaetae (0,9%).

The mean individual biomass (dry mass) of earthworms collected at both sites is shown in Fig. 39. The biomass increased to a peak during January (2130,1g) decreasing to 527,0 g during March, and corresponded to the increased size class (1-1,5 cm) (Fig. 38).

DISCUSSION

A total of 698292,0 arthropods/ m^2 were found in the soil cores collected in the monthly samples at the two study sites. The mean monthly population of arthropods was $116382,1/m^2$. The most prominent components of the soils within these sites were the

Table 22. Percentage monthly representation and biomass (g/m^2) of invertebrates sampled at the two elephant seal moulting sites.

		% OCCURRENCE						BIOMASS (g)	
		TRYPOT			BOULDER			TRYPOT	BOULDER
		JAN	FEB	MARCH	JAN	FEB	MARCH		
OLIGOCHAETAE		3,8	3,6	1,2	0,9	0,7	0,3	2,44	2,47
LEPIDOPTERA:									
Pringleophaga marioni	(adults)	0	0	0	0	0	0	-	-
	(larva)	0,3	0,3	0,2	0,1	0,1	0	2,11	0,80
Embryonopsis halticella	(adults)	0	0	0	0	0	0	-	-
	(larva)	0,2	0,1	0,1	0,1	0,1	0,1	N/D	N/D
COLEOPTERA:									
CURCULIONIDAE	(adults)	0	0	0	0	0	0	-	-
	(larva)	0,1	0,3	0,1	0,1	0,1	0,1	0,17	0,29
STAPHYLINIDAE	(adults)	0,1	0,3	0	0	0	0	N/D	-
DIPTERA	(larva)	0,2	0,2	0,4	0,4	0,1	0,1	0,24	0,32
	(adults)	0	0,2	0,1	0,2	0,1	0	N/D	N/D
ARACHNIDA		0	0,1	0	0	0	0	0,12	0
HEMIPTERA APHIDAE		0,2	0,4	0,3	0,2	0,5	1,3	0,02	0,13
ORIBATEI (Total)		36,8	32,2	39,2	4,5	2,9	2,0	9,26	6,92
Halozetes spp		2,2	2,6	2,0	1,9	1,2	0,8	1,22	1,43
Hyadesia spp		28,6	20,1	15,1	1,4	0,7	0,2	4,12	0,25
"Others"		6,0	9,6	22,2	1,2	1,0	0,9	3,92	0,82
COLLEMBOLA. (Total)		10,8	15,0	9,5	44,5	46,2	47,0	10,53	32,84
Tulbergia antarctica		9,2	13,0	3,8	0,4	0,6	0,1	8,71	0,66
ISOTOMIDAE		0	0	0	37,6	38,8	38,9	0	22,9
"Others"		1,5	2,0	5,8	6,6	6,9	8,1	1,55	9,28
SLUGS		0	0	0	0,02	0	0	0,27	0

N/D = not determined

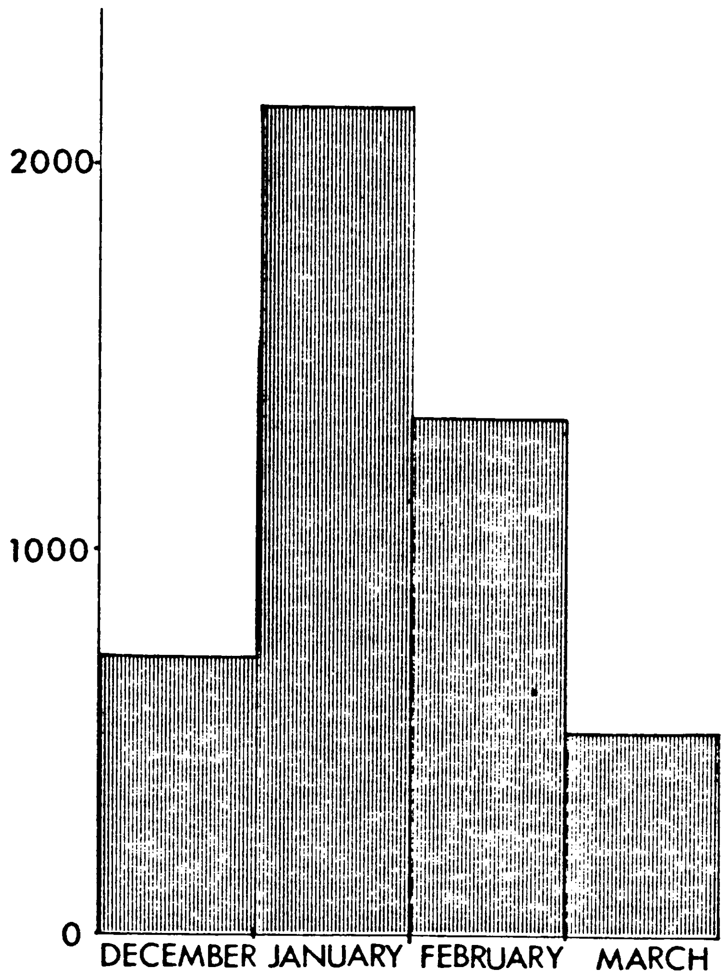


Figure 39. Total biomass (g) for the monthly collections of Oligochaeta at the two study sites. December 1980 to March 1981.

Collembola and the Acari. The Acari were the most numerous with a maximum of 119000 / m^2 at the Trypot site while the Collembola were most abundant at the Boulder site with a maximum of 620160 individuals /m^2. The majority of the Oribatei at the Trypot site belonged to the Hyadesiidae (Hyadesia spp.) with the Podocaridae (Halozetes spp) occurring in large numbers. The majority of the Collembola at the Boulder site belong to the Isotomidae with low numbers of Onychiuridae (Tullbergia antarctica) occurring. No other studies on numbers or biomass for these groups have been carried out at other sites on Marion Island. Burger (1978), using sticky traps, found that mites accounted for 83% and Collembola 8% of all the animals caught in coastal areas. High numbers of mites (59%) and Collembola (37%) occurred in samples at Isles Kerguelen (Trave 1976). The highest values for the elephant seal sites determined during the present study were 39,2% for mites and 47% for the Collembola. These two groups are generally thought of as being one of the most common free-living invertebrates in the Antarctic (Gressit 1967). No adult forms of P. marioni, Curculionidae (weevils) or slugs occurred within the two sites. Low numbers of P. marioni larvae, E. halticella larva, Dipterean adults and larva, Curculionidae (weevil) larva and Arachnida occur (Table 20).

The analysis of variance (Table 21) show differences between the monthly values in absolute numbers of the various groups, especially at the Trypot Beach site. Significant differences occurred between all the selected groups of invertebrates at both sites. Although monthly decreases occurred in all the groups

(December to January), significant monthly differences occurred only at the Trypot site. No clear trends in the monthly changes in the invertebrate biomass and proportions occurred in the meso-fauna sampled by Burger (1978), with biotically influenced areas supporting the greatest invertebrate biomass in all the months.

A similar situation was found by Gleeson (1981) although the present systematic sampling procedure has shown differences not only in monthly values but between the two sites. The differences between the two sites seemed to be related to the greater seal utilisation of the Boulder Beach site. Although this was likely to lead to a greater manuring effect, trampling effects were also likely to increase. The high coefficient of variation values obtained by Burger (1978) within the different vegetation types were possibly related to micro-habitat preferences and were similar to values obtained in the present study within each of the moulting sites (Table 20). These high values were most probably related to the trampling effects of the elephant seals within the site. The gregarious nature of the seals and the tendency to form groups resulted in localised areas being used with subsequent complete destruction of the vegetation.The biomass of the meso-fauna, 5,3 g/m^2 and 3,9 g/m^2 for the Trypot and Boulder sites respectively, was much lower than the value of 16,9 g/m^2 obtained by Burger (1978), and possibly attributed to the direct effects of elephant seal trampling. Factors such as soil porosity (Haarlov, 1955), moisture, pH and bulk density (Weil & Kroantje 1979) as well as the effect of interactions of other groups (Janzen & Schoener

1968) have been shown to affect the densities and occurrence of different taxa. Manuring is likely to have an effect on total numbers although little attention has been paid to this aspect.

The total biomass (g) for the Oligochaetae for the monthly collections (Fig. 35) showed maximum values during January (2130,1 g) and February (1351,5 g) and corresponded to the increase in numbers of seals hauling out to moult within these two sites.

The size class structure of P. marioni larva, Curculionidae larvae and Oligochaetae is shown in Figures 35, 36 and 37 and indicates some variation between the four monthly sampling dates. Although the size classes are arbitrary and expressed in lengths (cm) the histograms illustrate the following : The histogram for the Oligochaetae and Curculionidae larva are typical of species in which few individuals survive long after reaching the average maximum size (Satchell 1971), while the P. marioni larvae show the opposite trend with a large percentage of the monthly totals of large individuals (72,5 cm) increasing and peaking in March. The size class (1-1,4 cm) peaks in January followed the trend of total biomass (Fig. 34) and the general haul-out pattern of the moulting elephant seals. The size class (0,5 cm) of the Curculionidae larvae and to a lesser degree the Oligochaetae (1,6-2,5 cm) showed the opposite trend with their percentage occurrence decreasing during January. No data are available on the life histories of the various insect species on Marion Island, although data for Curculionidae on Heard Island (Brown

1964) indicated that larval forms were present for longer periods than the adults, while P. kerguelensis at Kerguelen (Paulin 1953) had a larval stage lasting several years while the adult stage lasted for only three weeks, and possibly explains the large proportions of individual P.marioni (≥2,5 cm) during March (Fig. 36). The differential survival of different size classed individuals as a result of varying degrees of trampling by elephant seals is likely to be of major importance and could explain the relatively low numbers of meso-fauna found present within these sites.

CHAPTER 9

SUMMARY

Trampling by seals results in the typical hollow-hummock feature of moulting sites and these effects are long lasting. Trampling is of particular importance since the complete elimination of all the species of plants particularly in wallows, leads to large areas of bare soil , these being suitable for invasion by those species which are fast growing, prolific seed producers which thrive in conditions where disturbance is maintained. Species that were able to rapidly colonise wallow areas were *P.annua*, *A.stolinifera* and *P.cookii*, and the latter being almost entirely restricted to the hummocks of moulting sites where soil depth was at its greatest. Trampling also had an effect on the soil properties of the moulting sites. Soil compaction showed considerable variation within the sites and, being correlated with soil moisture, was likely to have an influence on the growth and regeneration of plants occurring within individual wallows. Factors such as bulk density were likely to have a direct mechanical effect on plant roots and could have resulted in anaerobic conditions. Plants which were able to withstand a certain amount of trampling included *P.cookii* because of its tussock growth form, and *P.annua* , *A.stolinifera* and *S. apetala* because of their rapid growth and propagation.

The effect of trampling by seals on the invertebrate fauna showed considerable variation within and between wallow areas. The most prominant components within the sites being the Collembola and Acari and these also seemed to be the most susceptible to trampling pressure. Decreases in all the insect populations occurred during the months of December and January, which corresponded to the peak haul-out of seals and was related to the greater seal utilisation of the areas. The trampling affected soil properties such as soil porosity, moisture and bulk densities which in turn affected the density and occurrence of the various invertebrate forms.

The importance of other seal activities such as defecation and urination cannot be ignored . Defecation and more importantly urination did lead to an enhancement of soil nutrient levels, and plants growing within the moulting areas had to cope with enhanced nutrient levels. Urination was thus likely to be of direct importance and would affect the performance of most plants which came into contact with higher soil nutrient levels. If a plant species was to colonise an elephant seal moulting site successfully a necessary attribute was not only an ability to cope with the disturbing and destructive activities of the seals, but also to withstand the high nutrient levels and competition from other plant species.

The seasonal and regular use of moulting sites would eventually result in increases in the concentrations of many of the nutrients throughout the site , although the extent of leaching due to the high rainfall was not known. The high defecation and urination effects also had an influence on the biomass of invertebrate fauna occurring in these sites since the greatest biomass of invertebrates occurred within these biotically influenced areas. Although their total numbers and biomass increased due to the large levels of nutrients and energy available to them, when the seals' haul-out peaked during their moult, invertebrate numbers were physically decreased by the direct effects of trampling by the seals. Invertebrates that existed in these areas had to adapt to this activity.

Salt spray seemed to be of particular importance in determining the distribution of certain plant species within some moulting sites along the west coast of the island. Where salt deposition was particularly heavy it overrode the effects of the seals and resultant high nutrient levels. Plants such as C.plumosa, T.moschata and A.selago dominanted on these areas but were absent from moulting sites where high soil nutrient levels and low salt spray deposition occurred. Plants which were vulnerable to trampling included A. magellanica, those tolerant of high nutrient levels included P.annua and A.stolinifera while those that were more sensitive to high nutrient levels included A.magellanica, R.biternatis and C.plumosa.

The principal ecological consideration of the study had been to discover the relationships between the seals and the various components of the system. This has been achieved and the significance of the seals on the islands terrestrial ecology has been estimated.

OPSOMMING

Vertrapping deur robbe, wat langblywende effekte het, gee aanleiding tot die heuwelagtige voorkoms van die vervellingsterrein. Vertrapping is van besondere belang aangesien die algehele verwydering van al die plantspesies veral in rolplekke aanleiding gee tot groot kaal gebiede. Sulke toestande is geskik vir plantsoorte wat vinnig groei, baie sade produseer en onder omstandighede van versteuring kan voorkom.

Spesies wat vinnig in rolplekke groei is P.annua , A. stolinifera en P. cookii , alhoewel laasgenoemde feitlik geheel en al beperk is tot die heuweltjies van die vervellingsterrein waar die grond die diepste is.

Die vertrapping deur robbe het ook 'n uitwerking op die grondeienskappe van die vervellingsterrein. Die mate van samepakking van die grond in die terrein varieer geweldig. Aangesien dit saamhang met die voggehalte van die grond, kan dit dalk 'n invloed op die groei en regenerasie van die plante hê. Faktore soos massadigdtheid kan 'n direkte meganiese effek op die wortels van plante hê en'n anaerobiese toestand veroorsaak. Plante wat 'n sekere hoeveelheid vertrapping kan weerstaan is P.cookii as gevolg van sy groeivorm; en P.annua, A.stolinifera en S.apetela wat vinnig groei en versprei. Die robbe se vertrapping van invertebraat fauna binne en tussen die rolplekke verskil. Die mees prominente invertebraat komponente binne die terrein is die Collembola en Acari .Hierdie is ook die mees gevoelig vir die druk wat die robbe se vertrapping uitoefen.'n Afname van die totale insektebevolkings kom gedurende Desember en Januarie voor. Dit stem ooreen met die spitstyd wanneer robbe land toe kom en wat klaarblyklik verband hou met die groter gebruik wat robbe in hierdie tydperk van die terreine maak.

Die effek van vertrapping op grondeienskappe soos poreusheid, vog en massadigtheid beinvloed die digtheid en voorkoms van die veskillende invertebraat soorte.

Die belang van ander rob-aktiwiteite soos ontlasting en urineering mag nie onderskat word nie. Ontlasting en meer belangrik urineering , lei tot 'n verhoging in die voedingstofvlakke in die grond . Die plante wat binne die vervellingsgebied groei moet dit kan weerstaan. Urineering is van besondere belang en beinvloed die plante wat in kontak kom met die hoër grond voedingsvlakke.
As 'n plantspesie suksesvol in 'n olifantrob vervellingsterrein is, is 'n noodwendige vereiste die vermoë om aan te pas by die verontwrigtende en vernietigende aktiwiteite van die robbe en om die hoë voedingsstofvlakke te weerstaan asook enige inter-spesifiese kompetisie tussen die verskillende plantspesies.

Die seisoenale en reelmatige gebruik van vervellingsterreine kan uiteindelik 'n verhoging van die konsentrasie van baie van die voedingstowwe in die terrein veroorsaak. Die omvang van uitloging as gevolg van die hoë reënval is egter nie bekend nie.

Die groot effek van ontlasting en urineering beinvloed ook die invertebraat fauna op die terrein, soos bewys word deur die feit dat die biomassa van invertebrate binne hierdie bioties beinvloede terrein verhoog. Alhoewel die getal en biomassa styg as gevolg van hoë vlakke van voedingstowwe en energiebronne, verminder die aantal invertebrate fisies deur die direkte effek van vertrapping deur robbe tydens die piek in landwaardse beweging.

Soutsproei is van belang om die verspreiding van plantspesies binne vervellingsplekke soos langs die weskus van die eiland, te bepaal. Waar soutneerslae besonder swaar is oorheers dit die effek van die robbe en hoë voedingstofvlakke. Plante soos C.plumosa T.moschata en A.selago domineer. Die twee laasgenoemdes kom nie voor in die vervellingsterreine waar daar hoe voedingstofvlakke en lae soutneerslae is nie. Plante wat gevoelig vir vertrapping is, is A.magellanica; die wat hoe voedingstofvlakke tolereer, P.annua en A stolinifera terwyl A.magellanica, R.biternatis en C.plumosa meer gevoelig is vir hoe voedingstofvlakke.

Die belangrikste doel van die studie was om die verwantskap tussen robbe en die verskillende komponente van die sisteem vas te stel. Dit is bereik en die beduidende rol van die robbe op die eiland se terrestriële ekologie is uitgewys.

REFERENCES

BANNISTER, P. 1966.
The use of subjective estimates of cover abundance as the basis for ordination. J. Ecol. 54: 665-559.

BARTHOLOMEW, G.A. 1952.
Reproductive and social behaviour in the northern elephant seal. Univer. Calif. Publ. Zool. 47: 369-472.

BESTER, M.N. 1980.
The southern elephant seal Mirounga leonina at Gough Island. S. Afr. J. Zool. 15: 238-239.

BRODY, S. 1968.
Bioenergetics and growth. Hofner Publ. New York. 1023p.

BROWN, D. 1954.
Methods of surveying and measuring vegetation. Commonwealth Agricultural Bureau. Commonwealth Bureau of Pastures and Field Crops, no. 42. Farnham Royal, Bucks, England.

BROWN, K.G. 1964.
The insects of Heard Island. Aust. Nat. Antarct. Res. Exped. Rep., B(1) 1-39.

BRYDEN,M.M. 1972.
Body size and composition of elephant seals (Mirounga leonina): Absolute measurements and estimates from bone dimensions.J.Zool.,Lond.167:165-276.

BULLOUGH, W.S. & RYTOMAA, T. 1965.
Mitotic homeostasis. Nature Lond. 205: 573-578.

BURNS, J.J. & HARBO, S.J. 1972.
An aerial survey of ringed seals, northern coast of Alaska. Arctic. 25: 279-290.

BURGER, A.E. 1978.
Terrestrial invertebrates : a food resource for birds on Marion Island. S. Afr. J. Antarct. Res. 8: 86-98.

BURGER, A.E. 1979.
Sampling of terrestrial invertebrates, using sticky traps at Marion Island. Polar Rec. 19: 618-620.

BURGER, A.E., LINDEBOOM, H.J. & WILLIAMS, A.J. 1978.
Mineral and energy contributions of guano of selected species of birds to the Marion Island terrestrial ecosystem. S. Afr. J. Antarct. Res. 8: 59-70.

CARRICK, R., & INGHAM, S.E. 1962a.
Studies on the southern elephant seal, Mirounga leonina (L.). I Introduction to the series. CSIRO Wildl. Res. 7: 89-101.

CARRICK, R., & INGHAM, S.E. 1962.b.
Studies on the southern elephant seal, Mirounga leonina (L.). V. ✓Population dynamics and utilisation. CSIRO Wildl. Res. 7: 198-206.

CARRICK, R., CSORDAS, S.E., INGHAM, S.E. & KEITH, K. 1962a.
Studies on the southern elephant seal, Mirounga leonina (L.). III. The annual cycle in relation to age and sex. CSIRO Wildl. Res. 7:119-160.

✓CARRICK, R., CSORDAS, S.E., & INGHAM, S.E. 1962b.
Studies on the southern elephant seal, Mirounga leonina (L.). IV. Breeding and development. CSIRO Wildl. Res. 7:161-197.

CLARKE, J.R. 1981.
Physiological problems of seasonal breeding in eutherian mammals. In: Oxford Reviews of Reproductive Biology ed: C.A. Finn, 3: 244-312.

COLOVAS, N.F., KEENER, H.A., KEENER & DAVIS, H.A. 1957.
Errors in drying silage and faeces for protein and energy determinations. Improved procedures. J. Dairy Sci. 40: 173-179.

CONDY, P.R. 1977.
The ecology of the southern elephant seal Mirounga leonina ✓(Linnaeus 1758), at Marion Island. D.Sc thesis, University of Pretoria.

CONDY, P.R. 1978.
The distribution and abundance of southern elephant seals Mirounga leonina (Linn.), at the Prince Edward Islands. S. Afr. J. Antarct. Res. 8:41-47.

CONDY, P.R. 1979.
The annual cycle of the southern elephant seal Mirounga leonina (Linn.), at Marion Island. S. Afr. J. Zool. 14: 95-102.

CONDY, P.R. 1981.
Annual food consumption and seasonal fluctuations in biomass of seals at Marion Island. Mammalia 45: 23-30.

ENGELBRECHT, C.M. 1974.
The genus Halozetes (Oribatei : Acari) on Marion Island. Navors. nas. Mus., Bloemfontein 3: 1-25.

ENGELBRECHT, C.M. 1975.
New Ameronothroid (Oribatei : Acari) taken from the R.S.A. and the islands of Gough and Marion. Navors. nas. Mus., Bloemfontein. 3: 53-87.

FAY, F.H., RAY, C. 1968.
Influence of climate on the distribution of walruses, Odobenus rosmarus (Linnaeus). I. Evidence from thermoregulatory behaviour. Zoologica 53: 1-18.

FELTZ, E.T. & FAY, F.H. 1967.
Thermal requirements in vitro of epidermal cells from seals. Cryobiology 3: 261-264.

FERTILIZER SOCIETY OF SOUTH AFRICA. 1980.
Soil analysis. Manual of methods. Publication no. 74.Pretoria.

FISHER, R.A., CORBET, A.S., & WILLIAMS, C.B. 1943.
The relation between the number of species and the number of individuals in a random sample of an animal population. J. Anim. Ecol. 12: 42-57.

GEHU,J.N and GEHU-FRANCK,J. 1961.
Recherches sur la vegetation at le sol da la reserv.de lile des Landes (I.et V), et de quelques ilots de la cote Nord-Bretagne Incidences Ie L'avifaune marine sur la flora. Bull.Labor.Marit.Dinard. 47:19-57.

GENTRY, R.L. 1975.
Comparitive social behaviour of eared seals. Rapports et. Proces - Verbaause des Reunions. Conseil International pour l'Exploration de la mer. 1969: 188-194.

GILLHAM, M.E. 1956.
Ecology of the Pembrokeshire Islands V. Manuring by the colonial sea-birds and mammals, with a note on seed distribution by gulls. J. Ecol. 44: 429-454.

GILLHAM, M.E. 1961.
Alteration of the breeding habitat by sea-birds and seals in Western Australia. J. Ecol. 44: 429-454.

GLEESON, J.P. 1981.
The Ecology of the House Mouse, Mus musculus Linnaeus, on Marion Island.M.Sc.thesis,University of Pretoria.

GREMMEN, N.J.M. 1975.
The distribution of alien vascular plants on Marion and Prince Edward islands. S. Afr. J. Antarctic. Res. 5: 25-30.

GREMMEN, N.J.M. 1981.
The vegetation of the Subantarctic Islands Marion and Prince Edward. Junk publishers, Hague.

GRESSIT, J.L. 1967.
Entomology of Antarctica, Antarctic research series, 10. American geophysical Union, Washington,D.C.

HAARLOV, N. 1955.
Vertical distribution of mites and collembola in relation to soil structure In Soil Zoology (DKM Kevan Ed) pp 167-179. Academic Press, New York.

HALL, K.J. & WILLIAMS, A.J. 1981.
Animals as agents of erosion at Sub-Antarctic Marion Island. S. Afr. J. Antarct. Res. 10/11 : 24-26.

HUNTLEY, B.J. 1967.
A preliminary account of the vegetation of Marion and Prince Edward islands. S. Afr. J. Sci. 63: 235-241.

HUNTLEY, B.J. 1968.
A floristic and ecological account of the vegetation of Marion and Prince Edward islands, South Indian Ocean. M.Sc. thesis, University of Pretoria. 145pp.

HUNTLEY, B.J. 1971.
Vegetation In: Marion and Prince Edward Islands; report on the South African biological and geological expedition 1965-1966. E.M. van Zinderen Bakker (Sr.), J.M. Winterbottom & R.A. Dyer (eds). A.A. Balkema. Cape Town, pp 98-160.

HUNTLEY, B.J. 1970.
Altitudinal distribution and phenology of Marion Island vascular plants. Tyds. Natuurwet. 10: 255-262.

JANZEN, D.H., & SCHOENER, I.W. 1968.
Differences in insect abundance and diversity between wetter and drier sites during a tropical dry season. Ecology 49: 96-110.

JEFFERS,J.N.R. 1967.
Two case studies in the application of principal component analysis.Appl. Statist.16:225-236.

KNIGHTLEY,S.P.J & SMITH,R.I.L. 1976.
The influence of reindeer on the vegetation of South Georgia:I.Long - term effects of unrestricted grazing and the establishment of exclosure experiments in various plant communities.Bull. Br. Antarct. Surv. 44: 57-76.

LAWS, R.M. 1953.
The elephant seal (Mirounga leonina Linn.) I. Growth and age. Scient. Rep. Falkl. Isl. Depend. Surv. 8: 1-62.

LAWS, R.M. 1956.
The elephant seal (Mirounga leonina Linn.). II General, social and reproductive behaviour. Scient. Rep. Falkl. Isl. Depend. Surv. no. 13, 1-88.

LAWS, R.M. 1960.
The southern elephant seal (Mirounga leonina Linn.) at South Georgia. Norsk. Hvalfongst-Lidende. 10 & 11: 466-476; 520-542.

LE BOEUF, B.J. 1972.
Sexual behaviour in the northern elephant seal, Mirounga angustirostris. Behaviour. 41: 163-176.

LIDDLE, M.J. 1973.
The effects of trampling and vehicles on natural vegetation. Ph.D. thesis Univ. College of North Wales, Bangor.

LIDDLE,M.J. 1975.
A selective review of the ecological effects of human trampling on natural ecosystems. Biol.Conserv.7: 17-36.

LINDEBOOM, H.J. 1979.
Chemical microbiological aspects of the nitrogen cycle on Marion Island (sub-Antarctic) Ph.D. thesis University of Groningen.

LINDSAY, D.C. 1973.
Effects of reindeer on plant communities in the Royal Bay area of South Georgia. Bull. Br. Antarct.Surv. 35:101-109.

LING, J.K. 1969.
A review of ecological factors affecting the annual cycle in island populations of seals. Pacific Science 23: 399-413.

LING. J.K. 1972.
Adaptive functions of vertebrate moulting cycles. Am. Zoologist 12: 77-93.

LING, J.K. 1965.
Hair growth and moulting in the southern elephant seal, Mirounga leonina (Linn.). In: Biology of the skin and hair growth. Eds. A.G. Lyne, B.F. Short. pp 525-544. Angus and Robertson, Sydney.

MARSH, J.H. 1948.
No pathway here. H.B. Simmens, Cape Town. 200 pp.

McLAREN, I.A. 1958.
The biology of the ringed seal (Phoca hispida Schreber) in the eastern Canadian Arctic. Fish. Res. Board. Can. Bull. 118.

MURRAY, M.D. & NICHOLLS, D.G. 1965.
Studies on the ectoparasites of seals and penguins. I. The ecology of the louse Lepidophthirus macrorhini. Enderlein on the southern elephant seal Mirounga leonina (L.). Aust. J. Zool. 13: 437-454.

ORITSLAND, N.A., & RONALD, K. 1978.
Aspects of temperature regulation in harp seal pups evaluated by in vivo experiments and computer simulations. Acta. Physical. Scand. 103: 263-269.

ORR, R.T. 1965.
Interspecific behaviour among pinnipeds.Z.Saugetierk.30: 163-171.

PANAGIS, K. 1981.
Mapping of the Boulder Beach and Trypot Beach moulting sites at

Marion Island. Unpublished report. University of Pretoria.

PAULIN, P. 1953.
Notes biologiques sur le Pringleophaga kerguelensis. End. Rev. Franc. Ent., 20: 45-47.

PETERSON, R.S. 1968.
Social behaviour in pinnipeds with particular reference to the northern fur seal. pp 3-53 In: the behaviour and physiology of Pinnipeds. Eds. R.J. Harrison, R.C. Hubbard, R.S. Peterson, C.E. Rice, and R.J. Schusteman. Appleton - Century - Crafts, New York.

PIEROTTI, R. & PIEROTTI, D. 1980.
Effects of cold climate on the evolution of pinniped breeding systems. Evolution 34: 494-507.

RAND. 1962.
Elephant seals on Marion Island. Afr. Wildl. 16: 191-198.

RAND, R.W. 1955.
Marion Island - home of South Africa's elephant seal. Afr. Wildl. 9: 7-9.

RAND, R.W. 1956.
The Cape Fur Seal: Its general characteristics and moult. Div. Fish. Invest. Rep. 21: 1-52. Pretoria.

RAY, C. & FAY, F.H. 1968.
Influence of climate on the distribution of walruses, Odobenus rosmarus (Linnaeus) II. Evidence from physiological characteristics. Zoologica 53: 19-32.

RICE,D.W.,KENYON, K.W. & LLUCH,D.B.1965 Pinneped populations at Islas Guadalupe San-Benito and Cedros, Baja, California.Trans.Santiago Soc. Nay. Hist.14:73-84.

RIDGEWAY,S.H. 1972.
Mammals of the sea. Charles.C.Thomas,Springfield.

SATCHELL, J.E. 1971.
Earthworms. In: Quantitative soil ecology methods of study in populations, production and energy flow Ed. J. Phillipson. IBP Handbook no. 18.

SCHEFFER, U.B. 1958.
Seals, sea-lions and walruses. A review of the Pinnipeds. Stanford University, Press.

SIEGFRIED, W.R. 1981.
The roles of birds in ecological processes effecting the functioning of the terrestrial ecosystem at sub-Antarctic Marion

Island. Colloque sur les Ecosystemes sub-Antarctiques. C.N.F.R.A. Biologie 51: 493-497.

SIEGFRIED, W.R., WILLIAMS, A.J., BURGER, A.E. & BERRUTI, A. 1978.
Mineral and energy contributions of eggs of selected species of sea-birds to the Marion Island terrestrial ecosystem. S. Afr. J. Antarct. Res. 8: 79-87.

SLATER, F.M. & AGNEW, A.D.Q. 1977.
Observations on a peat bog's ability to withstand increasing public pressure. Biol. Conserv. 11: 21-27.

SKINNER, J.D. & VAN AARDE, R.J. 1983.
Observations on the trend of the breeding population of southern elephant seals Mirounga leonina at Marion Island. J. Appl. Ecol.20:707-712.

SMITH, V.R. 1976.
The effect of burrowing species of Procellariidae on the nutrient status of inland tussock grasslands on Marion Island. Jl. S. Afr. Bot. 42: 265-272.

SMITH, V.R. 1977.The chemical composition of Marion Island soils,plants and vegetation.S.Afr.J.Antarct.Res.7:28-39.

SMITH, V.R. 1978.
Animal-plant-soil nutrient relationships on Marion Island (sub-Antarctic). Oecologica 32: 239-253.

SMITH, V.R. 1979.
The influence of sea-bird manuring on the phosphorous status of Marion Island (sub-Antarctic) soils. Oecologica 41: 123-126.

SOBEY,D.G. 1975. The relationships between herring gulls and the vegetation of their nesting and roosting sites.Ph.D thesis, University of Aberdeen, Scotland.

SOKAL, R.R., & ROHLF, F.J. 1981.
Biometry. The principles and practice of statistics in biological research. W.H. Freeman, San Francisco.

SORENSON, J.H. 1950.
Elephant seals of Campbell Island, Mirounga leoninas. Linn. Cape Exped. Surv. Bull. 6: 1-31.

TRAVE, J. 1977.
Les Oribates (Acariens) des Archipels de Kerguelen et Crozet:Essai Biogeographique C.N.F.R.A. Biologie 41:61-72.

VAN AARDE, R.J. 1980.
Fluctuations in the population of southern elephant seals, Mirounga leonina, at Kerguelen Island. S. Afr. J. Zool. 15: 99-106.

VAZ-FERREIRA, R., & PALERM, E. 1961.
Efectos de los cambios meterologicas sobre agrupociones terrestres du pinnipedioa Rev. Fac. Hum. y Ciene (Montevideo). 19: 281-293.

VAN ZINDEREN BAKKER, E.M. (Sr), WINTERBOTTOM, J.M., & DYER, R.A. 1971.
Marion and Prince Edward Islands, report on the South African biological and geological expedition 1965-1966. A.A. Balkema, Cape Town.

WALLWORK, J.A. 1963.
Phylogenetic relationships and geographical distribution of some Oribatei (Acari) from Antarctica. Proc. XVI Int. Congr. Zool. Washington D.C., August. 20-27.

WALLWORK, J.A. 1970.
Acarina: Cryptostigmata of Heard and Kerguelen. Pacific Insects. 23: 179-182.

WEIL, R.R., & KROANTJE, W. 1979.
Effects of manuring on the arthropod community in an arable soil. Soil biol. Biochem. 11: 669-679.

WILLIAMS, A.J. & BERRUTI, A. 1978.
Mineral and energy contributions of feathers moulted by penguins, gulls and cormorants to the Marion Island terrestrial ecosystem. S. Afr. J. Antarct. Res. 8: 70-73.

WILLIAMS, A.J., BURGER, A.E. & BERRUTI, A. 1978.
Mineral and energy contributions of carcasses of selected species of sea-birds to the Marion Island terrestrial ecosystem. S. Afr. J. Antarct. Res. 8: 52-58.

APPENDIX 1

ASSESSMENTS OF INDIVIDUAL MOULTING SITES

All the seal affected sites on Marion Island were assessed in terms of: the exact location, size of the area used (which represents maximum area used); general slope of the area, biotic overlap and vegetation types; the extent of seal use and topographical limits restricting the seals. Vegetation assessments were based on Gremmen's (1981) size community-complexes and 27 plant associations.

No distinction was made between P. annua and A. stolinifera and these are treated as P. annua throughout.

SITE: Boulder Beach Location: 46° 52,7's; 37° 51, 7'E AREA: 11613,91 (m^2) NO. OF SEAL IMPACTED AREAS: 6 TOPOGRAPHICAL LIMITS: None SLOPE TO SEA: 21 °

VEGETATION: The vegetation of the Boulder Beach site has been described (Chapter 3). The major associations are: the Callitricha antarcticae-Poetum annuae and the Poa cookii-Cotuletum plumosae type.

BIOTIC OVERLAP: None.

SITE: Trypot Beach North LOCATION: 46°53,1'S; 37°52,1'E AREA: 1455,23 (m^2) NO. OF SEAL IMPACTED AREAS: 2 TOPOGRAPHICAL LIMITS: 45°; 30° SLOPE TO SEA: 12° VEGETATION: This area is characterised by a typical coastal vegetation type. The vegetation belongs mainly to the Cotulo plumosae-Crassuletum moschatae assoiciation type. Seedlings of P. annua and C.

antarctica occur in the depressions caused by the seals.

BIOTIC OVERLAP: A limited number of fur seals utilise the site.

SITE: Trypot Beach LOCATION: 46° 53,2'S; 37°52,1'E AREA: 5989,57 (m^2) NUMBER OF SEAL IMPACTED AREAS: 5 TOPOGRAPHICAL LIMITS: 30 °;45°; 35° SLOPE TO SEA: 15°

VEGETATION: The vegetation of this site has been described (Chapter 3).

BIOTIC OVERLAP: Fur seals use the area, although only to a limited degree.

SITE Archway Beach LOCATION 46 °54,1'S; 37 °53, 6'E AREA: 7201,38 (m^2) NUMBER OF SEAL IMPACTED AREAS 6 TOPOGRAPHICAL LIMITS 45 °; 35 °; 35 ° SLOPE TO SEA 16 °

VEGETATION: Area consists of the Callitricho antarcticae-Poetum annuae and the Poa cookii-Cotuletum plumosae associations. Acaena ascendens occurs towards the edges of the site, with Montia fontana, Crassula moschata within the area. P. cookii tussock is extensive throughout the area, with seedlings of C. antarctica, P. annua, and M. fontana occurring within the depressions.

BIOTIC OVERLAP: Gentoo penguins (Pygoscelis papua), approximately 13 occur within the site, with King penguins (Aptenodytes patagonicus) on the beach immediately in front of the area. Seals seem to be displaced by the King penguins, either remaining on the beach or moving through the colony over a couple of days.

SITE Archway East LOCATION 46 °54,0'S; 37 °53, 8'E AREA: 8710,69 (m^2) NUMBER OF SEAL IMPACTED AREAS: 2 TOPOGRAPHICAL

LIMITS: 12 °; 55 °; 35 ° SLOPE TO SEA: 10°

VEGETATION: The typical coastal vegetation occurs, namely the Cotulo plumosae-Crassuletum moschatae association. Poa cookii tussock occurs within the site but not with great frequency. Hollows created by the seals are covered with C. moschata, Cotula plumosa and Callitriche antarctica.

BIOTIC OVERLAP: The immediate entrance to the site is used by fur seals (A. tropicalis).

SITE Hansen Point LOCATION 46 ° 54,7'S; 37 ° 53, 5'E AREA: 12252,07 (m^2) NUMBER OF SEAL IMPACTED AREAS: 11 TOPOGRAPHICAL LIMITS: None

VEGETATION: A typical hollow-hummock characteristic with Poa cookii-Cotuletum plumosae association occurs. On the coastal sector (-/+ 30 m) C. plumoa and P. cookii tussock is dominant, while P. annua becomes dominant close to the river and where seal use seems to be greatest. A small unused area occurs west of the site and consists of the typical coastal vegetation with a dense bryophyte layer.

BIOTIC OVERLAP: None.

SITE Bullard West LOCATION 46 °59,5'S; 37 ° 52, 9'E AREA: 11999,54 (m^2) NUMBER OF SEAL IMPACTED AREAS: 5 TOPOGRAPHICAL LIMITS: Slopes 8 °; 10 °; 10 ° SLOPE TO SEA: 20 °

VEGETATION: The area is characterised by an almost pure stand of P. cookii. The vegetation occurring in this area consists mainly of the Leptodontio proliferi - Poetum cookii association. No C.plumosa occurs within the site, with P. annua and C.antarctica growing within the wallows. In the areas little used by the seals, *A. magellanica*, *A. ascendens* and a dense bryophyte layer occur.

BIOTIC OVERLAP: Overlap with King penguins, and the present population of seals seem to use only 38% of the total area.

SITE Killerwhale Cove LOCATION 46 °56,0'S; 37 °52,5'E AREA: 1282,78 (m^2) NUMBER OF SEAL IMPACTED AREAS: 2 TOPOGRAPHICAL LIMITS: cliffs on both sides SLOPE TO SEA: 10 °

VEGETATION: Consists of the Callitricho antarcticae - Poetum annuae association. The area is extremely rocky, *P. annua*, *P. cookii* and low frequency of *C. plumosa* growing on hummocks of the wallows. Seals move away from rock areas and move up the northern slopes and create wallows. Slope consists of *P. annua* and *C. plumosa* and no *M. fontana* growing. *C. antarctica*, *M. fontana* and *R. biternatus* occurring towards the edge of the used areas.

BIOTIC OVERLAP: A limited number of fur seals occur within the area.

SITE Waterfall Cove LOCATION 46 ° 56,5'S; 37 °52,4'E AREA: 10037,96 (m^2) NUMBER OF SEAL IMPACTED AREAS: 16 TOPOGRAPHICAL LIMITS Slopes 15 °; 30 ° SLOPE TO SEA: -

VEGETATION: The vegetation of this site consists mainly of the Poa cookii-Cotuletum plumosae association. In the depressions/hollows, seedlings of *P. annua*, *C. antarctica* occur. *A. magellanica* occurs although plants are scattered and do not occur with any great frequency.

BIOTIC OVERLAP: None.

SITE Kildalkey North LOCATION 46 ° 57,6'S; 37 ° 51, 5'E AREA: 26508,71 (m^2) NUMBER OF SEAL IMPACTED AREAS: 10

TOPOGRAPHICAL LIMITS: Slope 30 °; 30 ° SLOPE TO SEA: 7 °

VEGETATION: an extremely large area consisting (on the coastal edge) of Poa cookii - Cotuletum plumosae association while further inland the vegetation consists mainly of the Callitricha antarcticae - Poetumannua association, with very little _C. plumosa_ occurring. On the extreme northern edge of the site _A. ascendens_ and _A. magellanica_ occur while on the south-western site stands of _B. penna-marina_, _A. magellanica_ and _P. cookii_ occur.

BIOTIC OVERLAP: None.

SITE Kildalkey Beach LOCATION 46 ° 58,1'E ;37°51,1'E AREA: 15563,76 (m^2) NUMBER OF SEAL IMPACTED AREAS: 11 TOPOGRAPHICAL LIMITS: Slope 25 ° SLOPE TO SEA: 12 °

VEGETATION: This site is characterised by _P. cookii_ tussock and _C. plumosa_ growing extensively. Vegetation belongs to the Poa cookii - Cotuletum plumosae association. Stands of _A. magellanica_ occur throughout the site with isolated stands of _P. annua_ growing within the wallows.

BIOTIC OVERLAP: King penguins use the area to reach their breeding areas.

SITE Hooker Cove LOCATION 46 ° 58,3'S; 37 ° 50, 9'E AREA: 2937,10 (m^2) NUMBER OF SEAL IMPACTED AREAS 3 TOPOGRAPHICAL LIMITS: slope 30 °; 45 ° SLOPE TO SEA: 8°

VEGETATION: Vegetation belongs mainly to the Poa cookii - Cotuletum plumosae association. _P. cookii_ tussock occurs throughout the area. Within the wallows seedlings of _C. plumosa_, _A. magellanica and C. antarctica. M. fontana_ and _P. annua_ are not present at this site.

BIOTIC OVERLAP: Fur seals _(A. tropicalis)_ use the higher parts of the area with the elephant seals occupying the easier accessible points.

SITE Watertunnel LOCATION 46 ° 57,9'S; 37 ° 45,1'E AREA: 36297,69 (m^2) NUMBER OF SEAL IMPACTED AREAS: 16 TOPOGRAPHICAL LIMITS 30 °; 28 °; 50 ° SLOPE TO SEA: 8° degrees

VEGETATION: This large moulting site consists mainly of two vegetation community complexes and three associations. The Poa cookii - Cotuletum plumosae association is restricted to the coastal area, while further inland the Callitricho antarcticae - Poetum annuae association becomes more important. On the extreme coast, the Cotulo plumosae - Crassuletum moschata association is prevalent.

BIOTIC OVERLAP: _A. tropicalis_ use the moulting site, although their activities are restricted to the coastal areas.

SITE Watertunnel South LOCATION 46 ° 58,0'S; 37 °45,0'E AREA: 9727,86 (m^2) NUMBER OF SEAL IMPACTED AREAS: 2

TOPOGRAPHICAL LIMITS: 25 °; 35 ° SLOPE TO SEA: 4°

VEGETATION: The two main plant associations of this site are the Callitricho antarcticae - Poetumannuae and Poa cookii - Cotuletum plumosae. Elevated areas (-/+ 2m) within the area have stands of

A. magellanica, B. penna-marina and A. ascedens. Azorella selago plants are scattered throughout the area.

BIOTIC OVERLAP: A. tropicalis and A. gazella use the area.

SITE Goodhope West LOCATION 46 ° 58,1'S; 37 °41,4'E AREA: 866,12 (m^2) NUMBER OF SEAL IMPACTED AREAS: 3 TOPOGRAPHICAL LIMITS: None SLOPE TO SEA: 15 °

VEGETATION: The area possesses the typical heterogeneity in vegetative cover with the major vegetation association being the Callitricho antarcticae - Poetum annuae. Poa cookii tussock occurs throughout the area. C. plumosa occurs in patches along the coastal area.

BIOTIC OVERLAP: None

SITE Kaalkoppie Beach LOCATION 46 ° 54,5'S; 37 °36,0'E AREA: 23884,34 (m^2) NUMBER OF SEAL IMPACTED AREAS: 0 TOPOGRAPHICAL LIMITS: None SLOPE TO SEA: 8 °

VEGETATION: The area consists entirely of the Cutulo plumosae - Crassuletum moschatae association with traces of P. cookii occurring. C. antarctica and R. biternatus occurs in the water-filled depressions.

BIOTIC OVERLAP: Fur seals (A. tropicalis) occur throughout the area.

SITE Mixed Pickle LOCATION 46 ° 52,2'S; 37 ° 38,3'E AREA: 9575,33 (m^2) NUMBER OF SEAL IMPACTED AREAS: 0 TOPOGRAPHICAL LIMITS: Cliff; 12 ° SLOPE TO SEA: 8 °

VEGETATION: This area is characterised by the Crassula moschatae - Azorelletum selaginis association. A. selago and C. plumosa away by the trampling action of the seals. C. antarctica and P. annua occur throughout the site.

BIOTIC OVERLAP: The area is extensively used by A. tropicalis with bulls of A. gazella occurring on the beaches. Elephant seals have to move through the beaches occupied by fur seals to reach their moulting site.

SITE Sealers Beach LOCATION 46 ° 49,5'S; 37 °42,0'E AREA: 17579,51 (m^2) NUMBER OF SEAL IMPACTED AREAS: 1 TOPOGRAPHICAL LIMITS: None SLOPE TO SEA: -

VEGETATION: The area consists of the Montio fontanae - Callitrichetum antarctica association. C. antarctica is eroded away by the action of large numbers of fur seals, with R. biternatus growing on the disturbed areas. Patches of C. plumosa occur and P. annua tussocks grow throughout the area. Occasional small stands of A. selago occur towards the edges of the site. Fur seals maintain and possibly create small water-filled depressions, which become covered with C. antarctica and A. magellanica. Juncus scheuchzeroides occurs within the centre of the area on bare patches created by the fur seals.

BIOTIC OVERLAP: Fur seals (A. tropicalis) utilised the whole site. Elephant seals use a small area on the extreme eastern edge of the site.

SITE Storm Petrel LOCATION 46 ° 49,9'S; 37 ° 45,2'E AREA: 4185,55 (m^2) NUMBER OF SEAL IMPACTED AREAS: 2 TOPOGRAPHICAL LIMITS: 40 °;20 ° SLOPE TO SEA: 12 °

VEGETATION: The Cotulo plumosae - Crassuletum moschatae association is the main vegetation type occurring in this area. M. fontana occurs within the hollows with occasional P. cookii tussock growing on the hummocks. Small patches of P. annua, R. biternatus occur in the area.

BIOTIC OVERLAP: Fur seals occupy and seem to prefer the slopes towards the back of the site, possibly as protection against the wind.

SITE Goney Beach LOCATION 46 ° 50,0'S; 37 ° 46,5'E AREA: 2354,29 (m^2) NUMBER OF SEAL IMPACTED AREAS: 6 TOPOGRAPHICAL LIMITS 36 °; 30 °; 45 ° SLOPE TO SEA: 10 °

VEGETATION: The moulting site is in the salt spray zone and consists of almost entirely C. plumosa and C. moschata. The vegetation association is the Cotulo plumosae - Crassuletum moschatae association. Seedlings of C. plumosa and C. moschata occur in the wallows, with occasional tussocks of P. cookii occurring towards the back of the site (furthest from the seals). No stands of P. annua, R. biternatus or M. fontana occur.

BIOTIC OVERLAP: A. tropicalis occur within and use the area.

SITE Log Beach LOCATION 46 ° 50,2'S; 37 ° 46, 8'E AREA: 8948,93 (m^2) NUMBER OF SEAL IMPACTED AREAS: 7 TOPOGRAPHICAL LIMITS: 30 °; 40 °; 45 ° SLOPE TO SEA: 15 °

VEGETATION: This area is extensively used by elephant seals and consists of the Poa cookii - Cotuletum plumosae association. The site is situated approximately 90m from the sea and the vegetation is dominated by C. plumosa and P. cookii tussock. A. magellanica and C. plumosa occur near the back of the site. Stellaria media occurs within the area in small patches.

BIOTIC OVERLAP: Overlap occurs with King penguins, and where these occur the vegetation is almost completely destroyed, with P. cookii tussock and C. plumosa remaining.

SITE Log Beach South LOCATION 46 °50,3'S; 37 °47,0'E AREA: 4529,97 (m^2) NUMBER OF SEAL IMPACTED AREAS: 1 TOPOGRAPHICAL LIMITS: 15 °; 15 ° SLOPE TO SEA: 17 °

VEGETATION: Area consists of the Cotulo plumosae - Crassuletum moschatae and the Poa cookii - Cotuletum plumosae associations. This small area consists of C. plumosa with C. moschata seedlings occurring within the hollows. A. selago marks the boundary of the site. Occasional stands of P. annua and C. antarctica occur within the site. The area is surrounded by waterlogged bogs of A. magellanica which restrict the movements of the elephant seals.

BIOTIC OVERLAP: None

SITE King Penguin West LOCATION 45 ° 40,3'S; 37 °47,3'E AREA 19627,25 (m^2) NUMBER OF SEAL IMPACTED AREAS: 3 TOPOGRAPHICAL LIMITS: 35 °; 37 ° SLOPE TO SEA: 20° degrees

VEGETATION: The vegetation of this area consists of the Poa cookii - Cotuletum plumosae association. P. cookii tussocks occur throughout the area. The deep depressions consist of P. annua and C. antarctica. Small stands of A. ascendens occur. P. annua, C. antarctica and R. biternatus occur in the hollows.

BIOTIC OVERLAP: Used by King penguins mainly towards the edges of the site with coastal overlap with Rockhopper penguins

(*Eudyptes chrysocome*).

SITE King Penguin LOCATION 46 ° 50,3'S; 37 ° 48,0'E AREA: 10115,94 (m^2) NUMBER OF SEAL IMPACTED AREAS: 5 TOPOGRAPHICAL LIMITS: None SLOPE TO SEA: 5 °

VEGETATION: This area consists of the Poa cookii - Cotuletum plumosae association. Stands of *A. magellanica* occur on the sides of the depressions with *C. antarctica* occurring in the hollows. Stands of *M. fontana* occur in the heavily trampled areas.

BIOTIC OVERLAP: King penguins occur and use the area extensively.

SITE King Penguin East LOCATION 46 ° 50,3'S; 37 °48,1'E AREA: 400,95 (m^2) NUMBER OF SEAL IMPACTED AREAS: 1

TOPOGRAPHICAL LIMITS: 30 ° / Cliff SLOPE TO SEA: 7 °

VEGETATION: The vegetation of the area consists mainly of the Poa cookii - Cotuletum plumosae association. Limited amount of *P. cookii* tussock.

BIOTIC OVERLAP: None.

SITE Sea-elephant Point LOCATION 46 ° 50,4'S; 37 °48,4'E AREA: 3886,68 (m^2) NUMBER OF SEAL IMPACTED AREAS: 7

TOPOGRAPHICAL LIMITS 40 °; 30 °; 25 ° SLOPE TO SEA: 12 °

VEGETATION: This association is similar to the above with *C. plumosa* and *P. cookii* dominant. *P. annua* and *C. antarctica* grow in the hollows.

BIOTIC OVERLAP: Areas used by Gentoo penguins within the site and Rockhopper penguins on the coastal areas.

SITE Sea-elephant Bay LOCATION 46 ° 50,5'S; 37 °48,3'E AREA: 600,00 (m^2) NUMBER OF SEAL IMPACTED AREAS: 1 TOPOGRAPHICAL LIMITS: 40 ° / Cliff SLOPE TO SEA: 14 °

VEGETATION: This small area consists of the Poa cookii - Cotuletum plumosae vegetation association type. C. antarctica grows in the depressions with Poa cookii tussock on the hummocks.

BIOTIC OVERLAP: None.

SITE Sea-elephant Beach LOCATION 46 ° 51,0'S; 37 °50,2'E AREA: 3749,15 (m^2) NUMBER OF SEAL IMPACTED AREAS: 5

TOPOGRAPHICAL LIMITS: 45 °; 11 °; 25 ° SLOPE TO SEA: 16 °

VEGETATION: The vegetation of this area is characterised by two associations, the Callitricho antarcticae - Poetum annuae and Poa cookii - Cotuletum plumosae. C. antarctica, R. biternatus and P. annua occurs in the depressions caused by the seals, with J. scheuchzeroides growing on the bare patches created by the seals. P. cookii tussock is extensive throughout the area, with small stands of A. ascendens occurring within the site.

BIOTIC OVERLAP: King penguins occur on the eastern side of the site and limited usage of the area by fur seals.

SITE Sealers South LOCATION 46 ° 51,2'S; 37 °50,5'E AREA: 565,86 (m^2) NUMBER OF SEAL IMPACTED AREAS: 2 TOPOGRAPHICAL LIMITS: 40 °; 43 °; 30 ° SLOPE TO SEA: 9 °

VEGETATION: This area occurs within the salt-spray zone, and although it is dominated by C. plumosa, P. cookii tussock occurs throughout. P. annua is scarce, growing in the used wallows. C. antarctica occurs within most of the recently used wallows, together with *Prasiola crispa*. The area immediately accessible to the seals is totally eroded away except for the remaining peat stools.

BIOTIC OVERLAP: Rockhopper penguins use the coastal part of the site.

SITE Ships Cove LOCATION 46 ° 51,3'S; 37 ° 50,5'E AREA: 4907,94 (m^2) NUMBER OF SEAL IMPACTED AREAS: 4 TOPOGRAPHICAL LIMITS: 35 °; 35 °; 30 ° SLOPE TO SEA: 8 °

VEGETATION: The area is characterised by a heterogenous vegetation type, typical of areas extensively used by seals. The main vegetation association type is the Callitricho antarcticae - Poetum annuae type. *P. annua* seedlings grow extensively within all the wallows. The coastal section is dominated by *C. plumosa*, *P. cookii* tussock and stands of *A. magellanica* where no recent seal activity has occurred. The accessible areas find erosion of peat layer with peat stools of *P. cookii* remaining.

BIOTIC OVERLAP: Large numbers of fur seals occupy the site during the moult of the elephant seals.

SITE King Bird Head LOCATION 46 ° 51,8'S; 37 °51,3'E AREA: 7851,10 (m^2) NUMBER OF SEAL IMPACTED AREAS: 4 TOPOGRAPHICAL LIMITS: 25 °; 15 ° SLOPE TO SEA:-

VEGETATION: The main association type of the vegetation of this area belongs to the Callitricho antarcticae - Poetum annuae association type. Coastal areas have deep wallows where the vegetation is dominated by *C. plumosa* and *P. cookii* tussock with small patches of *A. magellanica*. *Unicia dickii* dominates the extreme western edge of the site, with small stands of J. scheuchzeroides and A. ascendens occurring. Seals do not move to the area dominated by A. selago.

BIOTIC OVERLAP: Fur seals also occupy the site.

SITE: Duikers Point LOCATION 46 ° 51,9'S; 37 °51,5'E AREA: 1158,35 (m^2) NUMBER OF SEAL IMPACTED AREAS: 0 TOPOGRAPHICAL LIMITS: 60 °; 40 °; 45 °; 45 ° SLOPE TO SEA: 8° degrees

VEGETATION: This small unused area is characterised by the Montio fontanae-Callitrichetum antarctica association type. Water filled depressions consist of R. biternatus, C. antarctica, M. fontana and A. magellanica, with dry depressions covered by C. plumosa and A. ascendens. A. magellanica occur throughout the area.

BIOTIC OVERLAP: None.

SITE: Rockhopper North LOCATION 46 ° 52,1'S; 37 °51,5'E AREA: 1169,87 (m^2) NUMBER OF SEAL IMPACTED AREAS: 0 TOPOGRAPHICAL LIMITS: 60 °; 50 °; 38 ° SLOPE TO SEA: 17 °

VEGETATION: This abandoned area consists of the Cotulo plumosae - Crassuletum moschatae association type. Small stands of P. cookii occur with P. annua seedlings growing in the hollows. Water filled wallows consist of R. biternatus, C. antarctica and P. annua.

BIOTIC OVERLAP: Gentoo and Rockhopper penguins move through the site to and from the sea and their nesting sites.

SITE Rockhopper Beach LOCATION 46 ° 52,2'S; 37 °51,4'E AREA: 1360,88 (m^2) NUMBER OF SEAL IMPACTED AREAS: 2 TOPOGRAPHICAL LIMITS 42 °; 35 °; 35 ° SLOPE TO SEA: 35°
degrees.

VEGETATION: The Callitricho antarcticae - Poetum annuae association is dominant within this area. _M. fontana_ occurs within the disturbed and recently vacated wallows, with seedlings of _P. annua_ and traces of _C. plumosa_ occurring. In the moist wallows the algae _P. crispa_ occurs. No _S. apetala_ occurs within the site, and _A. magellanica_ occurs in small patches throughout.

BIOTIC OVERLAP: None

SITE Rockhopper South LOCATION 46 ° 52,5'S; 37 °51,5'E AREA: 1332,28 (m^2) NUMBER OF SEAL IMPACTED AREAS: 1 TOPOGRAPHICAL LIMITS: 14 ° SLOPE TO SEA: 12 °

VEGETATION: This small area along a drainage line consists of one major vegetation association type, the Callitricho antarcticae - Poetum annuae type. Wallows are formed on a slope, with growth of _P. annua_, _C. antarctica_ and _S. apetela_ seedlings growing within the used wallows. Small patches of _C. plumosa_ and _J. scheuchzeroides_ occur.

BIOTIC OVERLAP: Fur seals occupy the beach area to the site.

APPENDIX 2

METHODS OF CHEMICAL ANALYSES

The following procedures for the determination of all the mineral elements were used :-

Soil samples : The soil samples were air dried and N, P, K, Ca, Mg, Na, Cl, ash and exchangeable P, K, Ca, Mg and Na content were determined. NH_4-N and NO_3--N were determined on frozen soil samples. Total values were expressed as a percentage of air dried soil, exchangeable values expressed as parts per million (ppm). pH values were determined on a sub-sample of fresh soil samples using a pH meter (DDs ph 800).

Plant Samples : Plant samples collected were oven-dried at 80°C and the total values determined namely: total N, P, K, Ca, Mg, Na, Cl, ash and expressed as a percentage of the dried sample.

Hair Samples : Air dried hair samples were analysed for total values of N, P, Ca, Mg, Na, and expressed as a percentage of the dried sample.

Urine Samples : Determinations were carried out on frozen urine samples and NH_4 and NO_3, total N, P, K, Ca, Mg, Na, Cl determined and expressed as milligrams per litre (mg/1).

Faecal Samples : Faecal samples were oven dried at 80°C and the following determinations were carried out: NH_4-N, NO_3--N; total N, P, K, Ca, Mg, Na, Cl (percentages), NH_4 and No_3 were determined on dry and frozen samples.

Whole Seals : Seals (complete) were homogenised and freeze dried. Fat-free samples were used for Total N, P, K, Ca, Mg, Na and Cl determinations, expressed as a percentage of dried mass.

Frozen samples : Extractions for NH_4 and NO_3.Frozen samples were processed in Pretoria. 250 ml of 0,1N K_2SO_4 plus 250 mg phenol were added to the sample, and allowed to thaw. The sample was thoroughly mixed and left for 1-2 h before the material was extracted. The residue was weighed and the determinations for nitrates and ammonia in the liquid determined. A final adjustment of the calculated values as to correct for the varying amounts of water present and the results were expressed in terms of the dry material.

ANALYSIS OF TOTAL ELEMENTS

(SOILS, PLANTS, HAIR, URINE, FAECES, WHOLE SEALS)

INDIVIDUAL PARAMETERS:

Total N - Total N in the sample was determined using the Kjeldahl method following the procedure given in Bremmer (1965).

Total P - The total P of the samples were extracted by digestion of these with $HClO_4$ and the fusion of Na_2 ,CO_3 and P was determined calorimetrically (Pratt 1965a).

Total K & Na - The organic and inorganic fractions of the soil were decomposed using Hf and $HClO_4$. K and Na were determined by flame-photometry (Pratt 1965b).

Total Mg & Ca - Total Mg and Ca were determined according to the methods of the FSSA (1980).

ANALYSIS OF AVAILABLE ELEMENTS

(SOILS, URINE, FAECES)

Available P - Available P was extracted with the Bray 1 solution and follows the procedure given by the FSSA (1980) and the method of Bray and Kurtz (1945).

Available K,Ca, Mg & Na - The available forms of these mineral elements were determined using the methods of the FSSA (1980).

Inorganic N (NH_4 & NO_3) - Inorganic nitrogen was determined using the MgO - Devarda alloy steam distillation method (Bremmer 1965).

Chlorides - The Cl^- in the samples was determined using the methods of the FSSA (1980).

Ash - The ash contents of the soil were determined by placing 1 gram of the sample in a furnace at 800 °C for one hour, allowed to cool and the ash remaining weighed.

PHYSICAL AND GEOGRAPHICAL MEASUREMENTS

The following methods for the measurements taken at each sampling location were used:

UTILISATION INDEX - The utilisation index was calculated by summing the maximum number of seals for each day that they occurred in an area, divided by the total number of observation days (97 days).

$$U.I. = \frac{\Sigma \text{ Number of seals}}{\text{Observation days}}$$

SLOPE - Slope was determined using an inclinometer and measured to the nearest degree.

HEIGHT ABOVE SEA LEVEL - Measurements were determined using a general purpose level. Measurements represent the height above the mean high and low water sea levels.

PERCENTAGE MOISTURE - Moisture content of the soils was determined from sub-samples of the freshly collected soil cores. Samples were oven dried at 80 ° C until a constant weight and expressed as a percentage of the oven dried soil.

BULK DENSITY - Bulk density of the soil samples were determined by expressing the oven dried weight of the cores as a ratio of the volume of the cylinder. Bulk density was expressed as grams of oven dry soil cm^3.

PENETROMETER - Measurement of soil penetrometer resistance was carried out using an impact penetrometer based on that described in Malcolm (1964) and Liddle (1973). The dynamic impact penetrometer used in the present study consisted of a central rod of approximately three metres which passes through a hammer (2,2 kg). In action the hammer is lifted to its maximum height and drops 1,8 metres and allowed to fall on the anvil. The force produced drives the point into the ground and the distance penetrated was recorded. The mean of four replicates was taken and the results expressed as the log number of impacts to reach 15 centimetres.

SOIL DEPTH - The depth a steel rod 100 cm long (2 cm diameter) could be pushed by hand into the soil, the value recorded being the mean of four replicates.

pH - Sub-samples of the freshly collected soil cores were taken and thoroughly mixed (end over end)in a 1:5 ratio of distilled water for 30 minutes, and the reading taken after 30 minutes with a pH meter (ADS 800).

TEMPERATURE - Temperature measurements were made with kane-may temperature meter and a chisel probe.

AIR DRYING - Three soil cores of fresh soil were spread out on a drying rack at room temperature (24-25 ° C) for 8 days.

The average difference of duplicate soil samples analysed (in percentage) was:

SOIL SAMPLES - Available P (0,5%); K (12,8%); Ca (3,2%); Mg (3,1%) and Na (8,9%) Total P (6,1%); N (3,5%); K

(6,6%); Ca (3,8%); Mg (1,7%); Na (4,6%), Cl (0,0)

PLANT & HAIR
SAMPLES - Total N (2,1%); P (7,2%); K (5,6%); Ca (14,2%), Mg (8,4%) and Na (12,1%).

APPENDIX 3a. Total number of seals (5 day intervals) hauled out at the Boulder Beach Site.

November 1980 - February 1981

	Nov 12	Nov 26	Dec 1	Dec 6	Dec 13	Dec 18	Dec 23	Dec 28	Jan 2	Jan 7	Jan 12	Jan 17	Jan 22	Jan 27	Feb 1	Feb 6	Feb 11	Feb 16	Feb 21	Feb 26
*Juveniles	12	20	18	18	6	14	16	3	9	0	0	0	0	0	0	0	0	0	1	1
Sub-adults	6	6	17	20	23	26	28	21	21	16	17	3	2	6	2	1	1	1	0	2
Adult cows	0	0	0	0	0	0	4	21	22	22	27	26	26	27	17	11	8	3	2	0
Adult bulls	0	0	1	1	0	0	0	0	0	0	0	0	0	0	2	3	4	6	5	7
Total	18	26	36	39	29	40	48	45	52	38	44	29	28	33	21	15	13	10	8	10

*Juveniles include pups of the year

APPENDIX 3b. Total number of seals (5 day intervals) hauled out at the Trypot Beach Site.

November 1980 - February 1981

	Nov 22	Nov 26	Dec 1	Dec 6	Dec 13	Dec 18	Dec 23	Dec 28	Jan 2	Jan 7	Jan 12	Jan 17	Jan 22	Jan 27	Feb 1	Feb 6	Feb 11	Feb 16	Feb 21	Feb 26
Juveniles	28	50	55	40	30	25	9	10	3	0	2	0	0	0	0	0	0	0	0	2
Sub-adults	2	12	13	17	21	23	38	26	19	11	16	9	3	1	2	0	1	1	5	3
Adult cows	0	0	0	0	0	0	4	4	22	31	39	45	19	39	35	23	16	5	2	0
Adult bulls	1	0	0	0	0	0	0	0	1	0	0	0	1	1	1	3	3	3	6	6
Total	31	62	68	57	51	48	51	40	45	42	57	54	23	41	38	26	20	9	13	11

APPENDIX 4a. SOIL ANALYSIS, PHYSICAL AND GEOGRAPHICAL MEASUREMENTS - Boulder Beach site wallows.

Site	U.I.	Distance to sea (meters)	Aspect	Slope	% Moisture	Temperature (°C)	L.P.I.	B/D	pH	Soil Depth	P - available (ppm)	K - available (ppm)	Ca - available (ppm)	Mg - available (ppm)	Na - available (ppm)	N - TOTAL %	P - TOTAL %	K - TOTAL %	Ca - TOTAL %	Mg - TOTAL %	Na - TOTAL %	Chlorides %	ASH %	NH_4 - %	No_3 - %
1	0,11	97,4	0	0	327,748	13,5	0,20	0,22	6,83	3,5	206	597	598	980	234	3,06	0,23	0,15	0,15	0,16	0,10	0,03	34,3	48,9	6,1
2	0,02	96,0	0	0	781,481	4,8	0,36	0,12	5,66	6,7	379	223	548	484	56	2,57	0,28	0,15	0,22	0,11	0,10	0,02	40,0	4,3	12,9
3	0	103,2	340	5	409,902	6,5	0,33	0,23	5,23	3,2	435	174	332	358	22	1,47	0,19	0,13	0,29	0,71	0,10	0,01	66,4	19,9	8,0
4	0	108,0	350	5	406,493	7,0	-0,18	0,12	5,04	15,7	625	101	558	436	25	1,96	0,29	0,13	0,27	0,17	0,11	0,01	54,8	39,3	39,4
5	0	104,0	0	0	399,520	5,5	-0,28	0,24	5,41	0	281	467	383	362	141	2,68	0,24	0,13	0,12	0,07	0,08	0,02	40,7	21,1	7,1
6	0	105,2	0	0	515,478	8,5	0,00	0,18	6,57	13,0	319	148	495	480	42	2,50	0,19	0,13	0,20	0,13	0,10	0,02	50,3	8,4	2,0
7	0,10	102,6	45	9	549,571	8,5	0,38	0,15	4,97	21,5	188	168	787	797	77	3,52	0,20	0,12	0,17	0,16	0,09	0,02	29,3	554,6	4,8
8	0,02	98,0	60	14	660,751	9,0	0,15	0,15	4,87	20,0	135	326	784	890	157	3,61	0,26	0,15	0,16	0,12	0,09	0,01	22,9	13,6	6,8
9	0,12	108,7	247	2	414,260	23,0	0,05	0,17	7,66	12,5	176	330	780	867	187	3,54	0,23	0,15	0,15	0,13	0,09	0,02	26,0	1228,9	3,3
10	0	98,6	75	10	725,490	11,5	-0,02	0,14	6,70	14,5	154	1300	853	864	187	3,79	0,21	0,14	0,17	0,10	0,08	0,02	22,7	10,3	6,6
11	0,33	96,5	0	0	347,362	15,5	0,40	0,21	8,42	4,3	356	496	299	344	134	2,63	0,27	0,17	0,15	0,21	0,11	0,04	42,4	495,7	2,6
12	0,10	85,2	0	0	470,472	9,5	0,41	0,17	5,31	3,8	173	254	572	644	149	3,02	0,21	0,15	0,13	0,10	0,10	0,03	28,9	127,8	23,2
13	0,02	106,8	0	0	618,908	8,5	0,63	0,15	4,84	5,2	191	1310	403	454	270	2,76	0,24	0,12	0,13	0,09	0,10	0,02	31,9	22,1	11,1
14	0,11	110,0	0	0	560,099	12,0	0,51	0,15	4,63	7,7	199	1124	551	520	245	3,26	0,24	0,14	0,18	0,12	0,10	0,02	31,1	537,6	5,9
15	0,02	104,4	0	0	679,941	15,0	-0,14	0,11	6,65	17,7	86	255	710	518	142	3.71	0.16	0.11	0,13	0,06	0,08	0,02	19,9	6,2	10,4
16	0,01	99,4	015	2	549,571	10,5	-0,09	0,15	5,26	18,2	2250	409	1150	375	147	3,16	0,52	0,13	0,75	0,07	0,08	0,01	25,9	31,0	8,9
17	0,07	88,0	345	10	347,362	14,3	0,00	0,22	5,73	8,8	386	218	823	805	218	3,40	0,27	0,16	0,31	0,14	0,09	0,02	-	76,1	9,0
18	0,11	92,7	360	0	462,184	10,0	0,40	0,22	8,80	11,5	218	235	147	172	72	3,75	0,24	0,17	0,08	0,04	0,09	0,04	26,7	1519,3	5,8
19	0,04	92,5	315	7	582,137	10,5	0,02	0,16	7,53	13,2	341	511	957	893	208	3,14	0,25	0,15	0,25	0,16	0,12	0,02	21,7	220,1	2,6
20	0,02	81,6	0	0	723,634	13,0	0,00	0,10	5,50	5,3	83	1453	744	828	476	3,43	0,18	0,15	0,19	0,11	0,08	0,03	17,7	7,3	7,2
21	0	88,0	27	12	610,835	12,5	-0,52	0,11	5,78	35,0	49	419	798	888	259	3,66	0,18	0,13	0,18	0,11	0,08	0,04	9,3	14,2	9,7
22	0	87,9	210	7	534,839	12,5	0,11	0,13	6,76	8,3	221	261	1123	1131	197	3,95	0,27	0,16	0,25	0,15	0,11	0,01	16,1	64,4	4,6
23	0,06	134,7	113	17	532,107	9,0	-0,25	0,14	5,61	32,5	158	196	1233	932	466	3,97	0,28	0,15	0,29	0,13	0,08	0,02	12,7	24,0	17,2
24	0,07	146,3	214	10	396,334	9,0	0,22	0,16	5,36	16,8	203	493	504	464	466	4,13	0,29	0,14	0,12	0,08	0,07	0,02	15,9	103,1	8,6
25	0,06	140,0	350	2	446,304	7,0	0,49	0,17	6,65	8,5	199	401	679	615	171	4,03	0,33	0,16	0,17	0,09	0,11	0,02	15,2	173,6	19,3
26	0,03	146,0	0	0	437,724	6,5	0,00	0,19	5,75	0	150	307	675	663	95	4,27	0,24	0,14	0,32	0,11	0,09	0,02	16,4	54,8	36,5
27	0	153,8	347	2	877,982	12,3	0,00	0,10	5,40	0	47	1115	315	420	537	3,59	0,11	0,14	0,08	0,06	0,09	0,06	7,5	37,2	30,9
28	0,42	116,6	0	0	443,408	11,5	0,00	0,10	6,59	29,0	188	276	983	1206	319	4,32	0,14	0,18	0,24	0,17	0,14	0,03	1,5	209,4	13,0
29	0,01	119,1	175	2	387,793	13,0	0,06	0,22	6,09	9,0	386	408	808	878	402	3,02	0,28	0,16	0,26	0,26	0,11	0,01	37,0	53,0	12,9
30	0,04	120,8	0	0	538,303	11,0	0,00	0,13	6,06	18,8	65	1454	709	1079	819	2,99	0,14	0,16	0,13	0,13	0,09	0,03	4,2	10,5	0,8
31	0,66	128,9	143	15	446,957	14,5	0,26	0,19	7,30	11,8	195	573	1160	1094	178	3,77	0,17	0,15	0,30	0,23	0,10	0,02	27,8	111,9	0
32	0	136,5	105	3	934,894	12,0	0,00	0,08	5,27	33,3	35	846	708	730	400	3,98	0,14	0,13	0,16	0,10	0,07	0,02	9,1	6,8	0,2
33	2,78	153,8	347	2	753,699	13,0	-0,17	0,10	6,81	20,0	115	694	568	602	281	3,94	0,14	0,21	0,13	0,09	0,15	0,16	11,2	827,8	0

APPENDIX 4b. SOIL ANALYSIS, PHYSICAL AND GEOGRAPHICAL MEASUREMENTS - Boulder Beach site permanent quadrat - December 1980.

Site	U.I.	Distance to sea (meters)	Aspect	Slope	% Moisture	Temperature (°C)	LPI	B/D	pH	Soil Depth (cm)	N - TOTAL	P - TOTAL	ASH - %	K - TOTAL	Ca - TOTAL	Mg - TOTAL	Na - TOTAL	Chlorides	NH_4^+ - available	NO_3^- - available	P - available	K - available	Ca - available	Mg - available	Na - available
1	0,02	154,2	24	4	1193,90	4,0	-0,378	0,072	5,04	100	2,86	0,14	4,6	0,16	0,11	0,13	0,19	0,06	51	0,52	45	1535	677	1098	552
2	0,02	150,2	70	8	1136,34	4,5	-0,396	0,082	4,68	100	3,15	0,17	5,7	0,13	0,16	0,12	0,19	0,05	30	1,98	43	504	638	1006	558
3	0,02	146,2	80	15	1118,94	4,5	-0,293	0,066	5,00	89,3	3,09	0,16	6,5	0,14	0,11	0,10	0,08	0,03	42	0,85	41	370	544	861	342
4	0,02	142,2	46	13	970,54	5,0	-0,297	0,078	4,70	74,5	3,21	0,17	6,6	0,15	0,11	0,10	0,08	0,04	88	0	44	572	544	879	373
5	0,16	138,2	37	14	912,43	4,5	-0,208	0,098	5,18	80,8	3,33	0,18	6,6	0,15	0,10	0,10	0,08	0,04	87	0	47	774	543	896	403
6	0,16	134,2	115	32	1045,74	5,0	-0,226	0,118	5,36	68,3	3,31	0,16	6,9	0,14	0,12	0,09	0,08	0,03	124	1,02	40	448	594	798	380
7	0,16	130,2	205	15	727,26	5,5	-0,130	0,137	5,33	21,3	3,53	0,19	11,1	0,14	0,17	0,11	0,08	0,02	92	0,27	50	681	717	865	286
8	0,16	126,2	0	0	461,52	5,0	0,034	0,128	4,87	25,3	3,43	0,17	16,5	0,15	0,14	0,07	0,06	0,01	176	0,51	57	467	479	482	218
9	0,31	122,2	335	2	604,43	4,5	0,061	0,114	7,03	18,8	3,67	0,16	13,5	0,13	0,16	0,07	0,08	0,03	68	0,41	82	347	771	766	304
10	0,31	118,2	58	10	784,66	5,0	-0,031	0,087	5,13	29,5	3,91	0,17	14,3	0,16	0,13	0,08	0,08	0,04	118	0,52	44	600	534	565	263
11	0,31	114,2	334	15	1067,46	5,0	-0,049	0,101	5,20	62,8	3,64	0,18	9,5	0,15	0,11	0,01	0,11	0,06	146	0,47	41	627	500	757	589
12	0,31	110,2	70	20	858,22	6,0	-0,371	0,094	5,10	100,0	3,38	0,21	9,2	0,16	0,09	0,08	0,09	0,04	79	0	61	1071	593	695	462
13	0,25	106,2	85	1	714,44	4,5	-0,071	0,103	5,29	64,8	3,26	0,16	13,6	0,15	0,10	0,06	0,08	0,03	36	0	40	415	437	523	277
14	0,25	102,2	0	0	957,06	6,0	-0,256	0,094	5,26	27,0	3,10	0,22	12,9	0,15	0,13	0,11	0,09	0,03	92	0	101	2195	747	958	312
15	0,25	98,2	0	0	704,08	6,0	-0,272	0,162	5,28	23,5	2,88	0,31	-	0,23	0,09	0,11	0,16	0,15	189	0	184	2510	467	832	249
16	0,25	94,2	51	10	538,97	5,5	-0,000	0,152	4,57	51,3	3,31	0,21	26,6	0,14	0,12	0,06	0,08	0,02	15	0,41	139	294	296	334	249
17	0,66	90,2	0	0	453,72	5,5	0,056	0,133	5,63	10,3	2,55	0,26	41,5	0,14	0,23	0,25	0,11	0,02	22	3,85	281	657	616	705	293
18	0,66	86,2	267	12	155,11	5,5	0,102	0,164	5,78	7,8	3,10	0,33	40,2	0,14	0,13	0,15	0,10	0,02	29	0,83	251	279	253	310	49
19	0,66	82,2	50	8	617,57	5,5	0,07	0,155	5,53	36,0	3,70	0,13	19,6	0,13	0,18	0,08	0,09	0,03	39	0	62	393	743	656	426
20	0,66	78,2	45	1	375,60	6,0	0,144	0,200	5,17	13,8	2,56	0,21	44,0	0,14	0,18	0,10	0,10	0,01	35	0	281	206	398	427	152
21	0,39	74,2	350	15	468,88	5,5	0,064	0,209	5,47	14,0	2,71	0,29	40,7	0,14	0,18	0,11	0,10	0,01	19	1,07	378	222	509	547	187
22	0,39	70,2	310	10	352,88	7,0	0,198	0,177	5,50	15,3	3,01	0,21	27,6	0,14	0,17	0,10	0,09	0,02	22	68	120	293	690	661	252
23	0,39	66,2	60	30	723,00	6,5	-0,141	0,164	5,60	29,0	2,64	0,22	31,3	0,14	0,20	0,10	0,10	0,02	90	135	229	303	652	579	224

APPENDIX 4c. SOIL ANALYSIS - Boulder Beach site permanent quadrat - February 1981.

Site	N - TOTAL	P - TOTAL	ASH %	K - TOTAL	Ca - TOTAL	Mg - TOTAL	Na - TOTAL	Chlorides	NH_4^+ - available	NO_3^- - available	P - available	K - available	Ca - available	Mg - available	Na -available
1	2,90	0,13	4,0	0,16	0,12	0,12	0,11	0,03	32	0,41	51	1105	680	1052	475
2	2,92	0,11	6,0	0,14	0,10	0,10	0,08	0,03	74	0	45	471	535	855	466
3	3,10	0,16	5,6	0,15	0,11	0,12	0,09	0,03	98	0,44	53	679	616	1018	364
4	3,32	0,13	4,5	0,13	0,12	0,11	0,08	0,03	25	0	45	515	681	997	336
5	3,06	0,14	5,8	0,13	0,11	0,10	0,08	0,03	30	0	39	410	631	902	319
6	3,36	0,13	6,2	0,15	0,13	0,10	0,08	0,02	70	0,83	38	362	550	751	278
7	3,26	0,31	15,5	0,13	0,14	0,09	0,08	0,02	112	0,74	38	461	552	626	241
8	3,62	0,23	16,2	0,12	0,14	0,07	0,07	0,02	75	0,16	206	288	559	500	172
9	3,90	0,17	5,3	0,14	0,17	0,10	0,08	0,02	1405	3,00	86	499	751	790	292
10	3,32	0,36	22,2	0,11	0,18	0,10	0,07	0,01	70	0,45	398	189	534	669	114
11	3,71	0,15	6,9	0,15	0,08	0,09	0,10	0,06	95	1,14	65	1400	478	752	569
12	3,49	0,17	6,8	0,15	0,07	0,07	0,09	0,03	115	0,82	55	837	441	615	356
13	3,35	0,15	12,6	0,14	0,09	0,06	0,09	0,04	115	0,91	61	770	472	590	350
14	2,87	0,20	31,0	0,13	0,19	0,09	0,09	0,02	118	1,42	255	311	605	513	157
15	3,27	0,19	21,2	0,11	0,13	0,07	0,08	0,02	123	0	120	198	569	532	253
16	3,37	0,19	24,2	0,14	0,13	0,07	0,08	0,01	70	0,49	124	196	542	467	136
17	2,26	0,36	2,6	0,13	0,20	0,14	0,10	0,01	159	1,85	625	159	388	587	111
18	2,81	0,39	39,4	0,14	0,13	0,09	0,09	0,02	118	0,41	398	336	302	358	84
19	3,07	0,21	50,1	0,13	0,24	0,08	0,08	0,01	217	0,86	255	133	892	447	101
20	2,79	0,21	37,0	0,13	0,11	0,07	0,09	0,02	87	0	248	268	317	329	111
21	2,80	0,27	35,7	0,13	0,15	0,10	0,10	0,02	79	0	240	335	319	418	181
22	3,08	0,22	29,0	0,12	0,19	0,10	0,09	0,02	71	0,19	158	261	784	659	318
23	3,09	0,19	25,7	0,13	0,21	0,09	0,10	0,03	315	3,29	169	190	702	620	257

APPENDIX 4d. SOIL ANALYSIS - Trypot Beach site permanent quadrat - December 1980.

Site	U.I.	Distance to sea	Aspect	Slope	% Moisture	Temperature	LPI	B/D	Ph	Soil Depth	N - TOTAL	P - TOTAL	ASH	K- TOTAL	Ca - TOTAL	Mg - TOTAL	Na - TOTAL	Chlorides	NH_4^+ - available	NO_3^- - available	P - available	K - available	Ca - available	Mg - available	Na - available
1	0	40,6	200	25	778,76	7,0	-0,047	0,101	4,69	38,3	3,80	0,19	8,2	0,14	0,47	0,06	0,07	0,04	327	2,27	225	1163	2441	382	660
2	0	41,0	200	25	851,84	8,0	-0,204	0,105	4,94	27,3	3,44	0,20	14,9	0,14	0,29	0,09	0,08	0,06	251	8,23	191	535	1655	679	235
3	0,73	35,0	0	0	353,30	12,0	0,348	0,192	6,57	3,8	3,09	0,35	34,3	0,11	0,37	0,09	0,09	0,03	563	0	844	648	1528	267	113
4	0,73	32,9	180	21	587,89	8,5	0,079	0,146	7,74	9,6	3,20	0,35	37,8	0,16	0,75	0,13	0,09	0,06	1307	3,60	1062	818	3320	536	231
5	0,73	30,8	180	5	265,35	9,5	0,192	0,168	4,75	6,8	2,57	0,52	41,9	0,15	0,40	0,08	0,08	0,03	155	0	1000	282	1590	195	23
6	0,53	29,4	0	0	220,04	8,5	0,139	0,200	6,45	10,1	2,04	0,48	47,1	0,18	0,62	0,15	0,10	0,05	250	2,00	1125	752	2218	495	117
7	0,53	28,0	0	0	549,68	9,5	0,066	0,093	5,76	11,5	3,54	0,31	20,1	0,15	0,30	0,14	0,10	0,04	146	17,30	338	536	1209	806	232
8	0,28	27,0	0	0	412,05	10,0	0,212	0,185	6,18	7,4	2,73	0,52	38,6	0,15	0,73	0,16	0,09	0,04	185	4,40	875	467	2785	649	82
10	0,10	30,1	0	0	457,15	7,0	-0,169	0,125	6,30	21,6	3,01	0,40	28,7	0,14	0,64	0,14	0,07	0,03	328	5,30	656	221	2938	795	71
12	1,11	34,3	0	0	553,35	8,5	-0,064	0,124	5,89	16,5	2,53	0,24	39,9	0,15	0,24	0,13	0,11	0,05	41	0,10	270	498	830	663	325
13	1,11	36,4	0	0	619,97	7,0	-0,052	0,163	5,97	11,4	2,60	0,15	35,7	0,15	0,31	0,14	0,11	0,05	15	0,10	176	430	1231	885	178
14	1,11	38,5	0	0	566,28	9,0	0,117	0,122	5,67	11,6	2,14	0,21	47,1	0,18	0,30	0,15	0,11	0,04	30	12,1	263	470	949	774	85
15	1,11	42,7	0	0	516,93	7,0	-0,035	0,143	5,56	16,3	2,54	0,49	27,1	0,24	0,33	0,11	0,11	0,08	61	3,8	1350	1168	1463	620	256

APPENDIX 5a. INTERVARIABLE CORRELATION MATRIXES - Boulder Beach permanent quadrant. January 1982.

SIGNIFICANCE AT: * 5%
** 1%
*** 0,1%

	Seal utilization	Distance to sea	Aspect	Height above sea level	Slope	% Moisture	Temperature	Penetrometer	Bulk density	pH	Soil depth	Total - N	Total - P	% Ash	Total - K	Total - Ca	Total - Mg	Total - Na	Chlorides	NH_4	NO_3	Available - P	Available - K	Available - Ca	Available - Mg	Available - Na
Seal utilization																										
Distance to sea	-0,82 ***																									
Aspect	0,18	-0,22																								
Height above sea level	-0,74 ***	0,91 ***	0,12																							
Slope	-0,15	0,02	-0,22	0,14																						
% Moisture	-0,75 ***	0,75 ***	-0,27	0,72 ***	0,27																					
Temperature	0,20	-0,21	-0,06	-0,19	0,04	-0,14																				
Penetrometer	0,74 ***	-0,68 ***	0,45 *	-0,58 **	-0,23	-0,85 ***	0,21																			
Bulk density	0,68 ***	-0,84 ***	0,32	-0,72 ***	-0,0	-0,80 ***	0,03	0,70 ***																		
pH	0,45	-0,31	0,53 **	-0,29	-0,06	-0,37	-0,04 *	0,44	0,27																	
Soil depth	-0,68 ***	0,71 ***	-0,29 **	0,68 ***	0,28	0,81 ***	-0,31	-0,79 ***	-0,74 ***	-0,51 *																
Total - N	-0,22	0,37	0,17	0,24	0,07	0,22	0,29	-0,0	-0,42 *	0,05	0,17															
Total - P	0,46	-0,57 *	0,19	-0,62 **	-0,06	-0,57 **	0,06	0,24	0,59 **	0,16	-0,54 **	-0,52 **														
% Ash	0,82 ***	-0,84 ***	0,19	-0,73 ***	-0,14	-0,84 ***	0,12	0,74 ***	0,86 ***	0,27	-0,75 ***	-0,59 **	0,76 ***													
Total - K	-0,18	0,03	-0,32	-0,14	-0,23	0,12	0,17	-0,34	-0,03	-0,18	0,01	-0,11	0,36	-0,33												
Total - Ca	0,57 *	-0,51 *	0,15	-0,29	-0,05	-0,48 *	0,07	0,54 **	0,54 **	0,37	-0,60 **	-0,37	0,15	0,67 **	-0,51 *											
Total - Mg	0,30	-0,10	-0,21	-0,06	-0,21	-0,25	-0,07	0,02	0,12	0,20	-0,26	-0,59 **	0,44 *	0,42	-0,04	0,50 *										
Total - Na	-0,17	0,20	-0,14	0,27	-0,21	0,34	-0,18	-0,44 *	-0,11	-0,17	0,31	-0,38	0,13	-0,10	0,33	-0,02	0,29									
Chlorides	-0,28	0,22	-0,21	0,09	-0,18	0,37	0,01	-0,48 *	-0,20	-0,11	0,23	0,02	0,18	-0,72 **	0,87 ***	-0,50 *	-0,07	0,58 **								
NH_4	-0,31	0,26	-0,19	0,12	0,07	0,27	0,18	-0,27	-0,2	-0,09	-0,01	0,33	-0,04	-0,47 *	0,61 **	-0,40	-0,36	-0,06	0,53 *							
NO_3	0,21	-0,09	-0,02	0,01	0,04	-0,10	-0,03	0,10	0,06	0,11	-0,14	-0,43 *	0,24	0,37	-0,28	0,61 *	0,71 ***	0,26	-0,20	-0,30						
Available - P	0,67 ***	-0,74 ***	0,16	-0,63 *	-0,08	-0,67 **	0,02	0,49 *	0,79 ***	0,26	-0,65 **	-0,73 ***	0,80 ***	0,95 ***	0,01	0,56 *	0,50 *	0,08	-0,17	-0,33	0,39					
Available - K	-0,25	0,17	-0,41 *	-0,05	-0,33	0,35	-0,0	-0,54 *	-0,25	-0,12	0,10	-0,11	0,22	-0,41	0,77 ***	-0,41	0,12	0,44 *	0,73 ***	0,47 *	-0,23	-0,12				
Available - Ca	-0,18	0,18	0,03	0,24	0,04	0,37	-0,03	-0,23	-0,26	0,35	0,07	-0,15	-0,45 *	-0,38	-0,20	0,33	0,13	-0,11	-0,01	0,03	0,10	-0,33	0,21			
Available - Mg	-0,36	0,33	-0,14	0,35	0,07	0,27	-0,11	-0,32	-0,32	-0,27	0,25	0,12	-0,17	-0,28	0,04	-0,19	0,02	-0,07	0,09	0,09	-0,15	-0,22	0,02	0,05		
Available - Na	-0,33	0,45	-0,05	0,44 *	0,09	0,69 **	-0,20	-0,47 **	-0,51 *	-0,14	0,64 **	0,28	-0,51 *	-0,60 **	-0,03	-0,21	-0,22	0,46 **	0,29	0,09	0,07	-0,54 **	0,22	0,43	-0,28	
Bare %	0,34	0,30	0,14	-0,13	0,04	-0,60	-0,44	0,18	-0,43	0,76 *	-0,44	0,15	0,45	0,27	-0,23	-0,08	0,52	-0,14	-0,21	-0,27	0,32	0,17	-0,20	-0,52	-0,55	-0,47

APPENDIX 5b. INTERVARIABLE CORRELATION MATRIXES – Trypot Beach permanent quadrant. January 1981.

SIGNIFICANCE AT: * 5% ; ** 1% ; *** 0,1%

	Seal Utilization	Distance to sea	Aspect	Height above sea level	Slope	% Moisture	Temperature	Penetrometer	Bulk density	pH	Soil depth	Total - N	Total - P	% Ash	Total - K	Total - Ca	Total - Mg	Total - Na	Chlorides	NH_4	NO_3	Available - P	Available - K	Available - Ca	Available - Mg	Available - Na	Bare %
Distance to sea	0,16																										
Aspect	-0,45	0,29																									
Height above sea level	-0,57*	0,61*	0,58*																								
Slope	-0,54	0,42	0,91***	0,75**																							
% Moisture	-0,24	0,64*	0,43	0,66**	0,67**																						
Temperature	0,09	-0,42	-0,17	-0,11	-0,28	-0,49																					
Penetrometer	0,25	-0,41	-0,20	-0,30	-0,36	-0,68**	0,85***																				
Bulk density	0,24	-0,37	-0,29	-0,38	-0,42	-0,77**	0,44	0,68**																			
pH	0,21	-0,41	-0,33	-0,48	-0,20	-0,31	0,24	0,29	0,41																		
Soil depth	-0,56*	0,54	0,46	0,72**	0,64*	0,73**	-0,66**	-0,74**	-0,69**	-0,53																	
Total - N	-0,63*	0,13	0,53	0,63*	0,66**	0,60*	-0,04	-0,27	-0,56*	-0,16	0,54																
Total - P	-0,05	-0,51	-0,16	-0,46	-0,37	-0,78**	0,28	0,46	0,58*	0,19	-0,47	-0,34															
% Ash	0,61	-0,41	-0,74 -0 43	-0,74**	-0,60*	-0,70**	0,35	0,53	0,66**	0,50	-0,78**	-0,87***	0,37														
Total - K	0,45	0,31	-0,22	-0,31	-0,22	-0,08	-0,43	-0,14	0,01	-0,03	-0,04	-0,50	0,32	0,19													
Total - Ca	-0,43	-0,52	0,12	-0,22	0,14	-0,32	0,01	0,21	0,40	0,57*	-0,12	0,02	0,52	0,20	-0,06												
Total - Mg	0,28	-0,53	-0,69**	-0,71**	-0,59*	-0,29	0,02	0,07	0,21	0,56*	-0,48	-0,52	0,15	0,57*	0,24	0,29											
Total - Na	0,86***	0,11	-0,62*	-0,49	-0,56*	-0,12	0,05	0,14	0,15	0,21	-0,50	-0,61*	-0,12	0,49	0,53	-0,43	0,53										
Chlorides	0,29	0,53	0,07	0,09	0,23	0,36	-0,48	-0,04	-0,12	0,09	0,16	-0,10	-0,02	-0,13	0,72**	-0,12	0,04	0,45									
NH_4	-0,06	-0,05	0,46	0,09	0,52	0,08	0,21	0,27	0,18	0,64**	-0,17	0,34	0,00	0,02	-0,20	0,49	-0,13	-0,20	0,15								
NO_3	-0,16	-0,09	-0,12	0,01	-0,01	0,30	0,04	-0,14	-0,60*	-0,10	0,07	0,25	-0,19	-0,26	0,12	-0,18	0,32	0,11	-0,01	-0,18							
Available - P	0,14	-0,24	-0,08	-0,39	-0,22	-0,67**	0,19	0,45	0,63*	0,39	-0,47	-0,34	0,88***	0,37	0,46	0,52	0,06	0,01	0,25	0,30	-0,32						
Available - K	0,00	0,55*	0,22	0,41	0,39	0,27	-0,26	-0,03	-0,09	-0,03	0,38	0,24	-0,02	-0,40	0,46	0,04	-0,34	0,07	0,59*	0,31	-0,12	0,28					
Available - Ca	-0,60	-0,33	0,33	0,03	0,39	-0,07	-0,14	-0,01	0,18	0,45	0,14	0,29	0,38	-0,10	-0,13	0,94***	0,06	-0,63*	-0,06	0,55*	-0,17	0,41	0,14				
Available - Mg	0,13	-0,00	-0,47	-0,24	-0,25	0,40	-0,44	-0,56*	-0,41	0,14	0,10	-0,09	-0,40	-0,05	0,21	-0,15	0,68**	0,41	0,25	-0,34	0,52	-0,46	-0,27	-0,17			
Available - Na	-0,24	0,51	0,40	0,61*	0,60*	0,66**	-0,43	-0,40	-0,55*	-0,32	0,77**	0,58*	-0,50	-0,70**	-0,01	-0,17	-0,50	-0,17	0,27	0,12	-0,06	-0,37	0,70**	0,03	-0,08		
Bare %	0,17	-0,10	-0,61*	-0,23	-0,54	-0,24	0,36	0,28	0,23	0,24	-0,29*	-0,31	0,11	0,35	-0,11	0,06	0,36	0,13	-0,34	-0,27	-0,01	0,01	-0,32	-0,06	0,17	-0,40	
Total Plant Species	-0,12	0,49	0,22	0,41	0,30	0,51	-0,21	-0,21	-0,31	-0,43	0,28	0,29	-0,04	-0,52	0,41	-0,22	-0,21	0,06	0,53	-0,12	0,36	-0,03	0,41	-0,10	0,18	0,26	0,26

APPENDIX 5c. INTERVARIABLE CORRELATION MATRIXES - Boulder [illegible]h Wallows. December 1980.

SIGNIFICANCE AT: * 5% ; ** 1% ; *** 0,1%

Utilization Index																										
Distance to sea (m)	0,39*																									
Aspect	0,24	0,27																								
Slope	-0,03	0,04	0,22																							
% Moisture	0,14	0,18	-0,08	-0,01																						
Temperature	0,19	-0,08	0,07	0,01	-0,03																					
Log penetrometer impacts	-0,11	-0,08	0,00	-0,25	-0,16	-0,14																				
Bulk density	-0,18	-0,20	0,10	-0,05	-0,77***	-0,08	0,30																			
pH	0,24	-0,10	0,24	-0,12	-0,25	0,47**	0,04	0,26																		
Soil depth (cm)	0,14	0,13	-0,07	0,46**	0,28	0,12	-0,46**	-0,54***	-0,06																	
Total - N	0,34*	0,41*	0,01	0,27	0,23	0,28	-0,16	-0,36*	0,18	0,4*																
Total - P	0,21	-0,20	0,03	0,08	-0,36*	-0,21	0,12	0,30	-0,09	-0,11	0,11															
Ash	-0,12	-0,31	-0,06	-0,23	-0,35*	-0,31	0,30	0,46**	-0,12	-0,39*	-0,71***	0,18														
Total - K	0,54***	0,18	0,32	-0,08	-0,12	0,24	0,04	0,02	0,49**	0,01	0,25	-0,02	-0,27													
Total - Ca	0,40**	-0,10	-0,05	0,16	-0,17	-0,09	-0,20	0,07	-0,17	0,10	0,12	0,43**	-0,19	0,23												
Total - Mg	-0,10	-0,10	0,22	0,12	-0,32	-0,09	0,18	0,37*	-0,05	-0,16	-0,55***	-0,19	0,39**	0,10	0,19											
Total - Na	0,25	0,10	0,27	-0,24	-0,16	0,03	0,15	-0,04	0,32	-0,08	-0,03	-0,17	-0,27	0,60***	0,43**	0,34*										
CL	0,08	0,38*	0,25	-0,16	0,31	0,19	-0,18	-0,27	0,23	0,09	-0,07	-0,20	-0,26	0,46**	0,23	0,29*	0,88***									
NH_4	0,50***	0,00	0,31	-0,17	-0,09	0,07	0,31	0,17	0,48**	0,01	0,32	0,20	-0,02	0,42**	0,07	-0,19	-0,07	-0,02								
NO_3	-0,18	0,15	0,18	-0,14	-0,14	0,32	-0,09	-0,05	0,05	-0,12	0,03	0,06	0,05	-0,15	-0,12	-0,13	-0,09	-0,04	-0,15							
Available - P	0,17	-0,19	-0,02	-0,08	-0,17	-0,12	-0,07	0,14	-0,12	-0,02	-0,08	0,79***	0,18	-0,06	0,59***	-0,03	-0,05	-0,09	0,08	-0,03						
Available - K	0,26	0,13	-0,21	-0,20	0,46**	0,17	0,09	-0,33	-0,16	-0,12	0,13	-0,14	-0,28	0,11	-0,08	-0,21	0,08	0,20	0,01	-0,18	-0,15					
Available - Ca	0,43**	-0,03	-0,12	0,55***	0,02	0,23	-0,36*	-0,28	-0,03	0,48**	0,24	0,16	-0,37*	0,33*	0,90***	0,14	0,56***	0,32*	0,09	-0,11	0,22	0,00				
Available - Mg	-0,03	-0,04	-0,16	0,40*	-0,03	0,35*	-0,24	-0,24	0,08	0,37*	0,09	-0,37*	-0,43**	0,39**	0,26	0,33*	0,64***	0,57***	-0,31	-0,05	-0,29	0,02	0,47***			
Available - Na	0,51***	0,39*	-0,06	0,03	0,26	0,23	-0,22	-0,37*	-0,16	0,24**	0,42**	0,02	-0,52***	0,31*	0,29*	-0,18	0,33*	0,16	0,18	-0,15	0,01	0,49***	0,39**	0,09		
Bare %	0,49**	0,18	0,21	0,01	-0,38*	0,40*	0,04	0,25	0,63***	0,06	0,24	0,12	-0,11	0,63***	0,09	-0,06	0,44**	0,36*	0,33*	0,11	0,08	-0,25	0,16	0,14	-0,07	
Total Plant Species	-0,40*	0,00	-0,22	-0,09	0,54***	-0,09	-0,35*	-0,46	-0,36*	0,13	-0,43**	-0,29	-0,15	-0,53***	-0,06	-0,17	-0,44**	-0,15	-0,33	0,01	-0,17	0,39*	-0,06	-0,07	0,30	-0,68***