A Geographical Study of Machair

Vegetation in the Uists

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PREFACE

It takes about 30 minutes to drive from the centre of Glasgow to the airport on the city's outskirts. A similar flying time will convey one from there to Benbecula airport in the Outer Hebrides. If, as is common, cloud cover is unbroken during this journey, the last view of the ground after take-off, the shipyards and factories of Clydebank surrounded by clusters of tower blocks of flats, presents an extreme contrast with the first glimpses of the Outer Hebrides. As the aeroplane banks and descends below the cloud, there appears a landscape fragmented by water, untidily dotted with cottages and flanked to the west by long, wide sandy beaches of a fine silvery colour. Just before touchdown, the aeroplane skims low over the sea, and passes a few feet above a line of steep high dunes, crested by a superb dense stand of marram grass. This is a good introduction to the machair landscape.

It is a landscape which is unspectacular, and in inclement weather can be quite inhospitable, wide open on the west coasts of the Outer Isles to the full force of Atlantic storms. But in summer on a fine day, the variety and colour of the vegetation make it one of the finest parts of Scotland. In contrast with most parts of the Highlands, its interest and beauty are enhanced by closer inspection. The absence of the grand sweep of mountain and sky, and its treelessness is at first disappointing, but the striking vegetation patterns, the extensive flora and the intricacy of tiny landforms more than compensate for its lack of grandeur. The influence of man through livestock and cultivation can be seen in all parts of the machair, but beyond this there is little apparent human interference. This is one of the last remnants of peasant agriculture in Britain, a curious mixture of the ancient;

tiny plots sometimes unfenced together with extensive open common grazings, and of the modern; tractors and telephone lines. The machair landscape is a product of a unique combination of physical and human factors and for this reason the word 'machair' cannot be given any precise meaning in the sense in which it is used in the Hebrides. It is a Gaelic term for a particular landscape, with both natural and man-made elements, but by scientific analysis its distinctive and important features can be isolated and explained. This latter was the aim of the research project.

The author was fortunate enough to be able to spend a total of more than four months in the field in the Uists, during which time many local people gave aid and advice. Throughout the course of research considerable assistance was given to the author, in correspondence and discussion. Listed in the acknowledgments are the main contributors to whom the author owes a particular debt, but many others who have given help must be omitted through lack of space. In particular, special mention must be made ot two people. Professor R. Miller, Head of the Department of Geography, the University of Glasgow, has given constant advice and encouragement to the author. Dr. Joy Tivy, Reader in the Department of Geography at the University of Glasgow, who supervised this project has given invaluable help, and the necessary critical assessment throughout the period of research. Without this assistance so freely given, the results would be of little value. Any merit that this work has is due mainly to her, its shortcomings are the sole responsibility of the author.

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Appendices 1-5, Maps 1-12, Figures 1-18 and Tables 1-8 are bound separately in Volume 2, pp. 241-340.

A Note on Presentation

In presenting a geographical thesis there are certain problems, difficult to resolve, which require that the format chosen to be of a particular kind. In this case the thesis contains a large number of maps and other figures which must be consulted several times during the reading of the text. For this reason these are best bound separately so that they may be most easily used. Similarly to avoid confusion between those maps, tables, figures and illustrations which are in the above category and those which are not, all such material is bound separately in Volume 2.

A further problem is that of location. In covering a large, unfamiliar and rather unwieldy area, as in this thesis, the problems to both author and reader are acute. If a system of grid references (either O.S. or other) is employed the text may be excessively broken up, so that this method has not been employed here. Instead, locations in the text are given general geographical contexts (e.g. southern North Uist) and are supplemented by township names (e.g. Ormaclett, Central South Uist). A copy of map 10 which shows these principal locations is in the end papers of this volume as well as Volume 2, and to supplement this a half-inch scale topographic map of Uist and Barra, published by Bartholemews can be found in the end-pocket of this volume. The aim has been to allow fluency in the text without detracting from clarity.

During the course of this study, much advice and practical help was freely given, and the author is indebted to all who assisted him, both in Glasgow and in the Uists. This list below is only of the principals.

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Dr. J. Tivy, Department of Geography, University of Glasgow.

CHAPTER 1

INTRODUCTION

A research programme such as the one undertaken in this study evolves rather than materialises in a single moment of time. During the course of research, changes in methods and in concepts must result, and in fact this experience may well form to the researcher, the most valuable part of the study. Nonetheless, if meaningful results are to be achieved, very early on the problems which are to form the basis of research must be identified and defined with sufficient precision to allow the researcher at all times to know what are the aims of the study.

This study developed in two stages but both have common aims which were determined at the onset of each stage. During the first twelve months of research the aim was to produce an analytical description and map of the vegetation of Grogarry Machair in South Uist. The location of this study area is shown in map 1. This area forms a part of the Loch Druidibeg National Nature Reserve, and it was hoped that this study would be of value in developing future management plans for the reserve. On completion of this work, it was decided to describe and analyse the vegetation of all of the machairs in the Uists. This latter area, as is shown in map 2, is much larger in size than Grogarry Machair, comprising the machairs on the islands of North Uist, Benbecula, South Uist and several islets off the western coasts which together form a recognisable spatial unit. In spite of the fact that this area was about 100 times the total area of Grogarry Machair the same general aims were maintained. The objects of the Uists study were to produce a series of vegetation maps and to give analytical descriptions of machair vegetation, using methods appropriate to the scale of study which were comparable to and partly based on the earlier Grogarry survey. The reasons for these objectives can be appreciated by examining the nature of the problem in greater detail.

Firstly, it was decided to obtain accurate descriptions of all recognisable, real (i.e. 'concrete') plant communities, using cover-abundance data. This would yield data comparable with other general studies such as those in 'The Vegetation of Scotland' (Ed. Burnett, 1964). Furthermore cover-abundance data provides a wide range of information, on which to base analysis. Secondly, it was decided to produce a series of vegetation maps covering all of the research areas. These maps though as accurate and detailed as possible were produced by simple techniques and thus are sketch maps rather than maps based on detailed field survey or photogrammetry. It was felt that sketch maps would allow large areas to be tackled within a reasonable period of time, and whilst greater accuracy in surveying would enhance the cartographic information of these maps, sketch maps are well suited to general description and analysis of vegetation. Finally the maps and cover-abundance data were to form the basis of a general interpretation, together with more detailed analysis of the Grogarry area. The aim of this interpretation is to explain the occurrence of the delimited plant communities, to evaluate machair vegetation processes and status, and to produce a simple explanatory theory of machair development.

Although the aims of research can be defined, these aims remain very general. This has been a deliberate choice from the beginning. A general approach is best suited to the size of the areas under consideration, the type of data collected and to the geographical perspective. The aims of research, together with general and particular methods of vegetation study are discussed in detail in chapters 4 and 5.

The physical and human environments of the study areas are considered in depth in chapters 2 and 3. These show that the choice of these areas was not accidental. Clearly the study location for the Grogarry Machair project was fixed by the limits of machair in the Nature Reserve and the reasons for the study. However, had a free choice of any similarly sized machair area in the Hebrides been available, Grogarry Machair would have been very high on a list of suitable sites. This is a consequence of the variety of its vegetation, and of the range of human and physical environmental factorsoperating within its boundaries. The decision to extend the study area for the second survey to the whole of the Uists was almost inevitable. The three islands of North Uist, Benbecula and South Uist, provide a wide range of machair landscapes, and yet form a relatively homogeneous geographical unit separated from Boreray, Bernery and Harris to the north, and Eriskay and Barra to the south by deep water channels. In spite of the apparent fragmentation of the machair study area around the west and north coasts of North Uist, only on one occasion was it necessary to cross a stretch of about 100 metres of open water by small boat.

Machair vegetation is highly attractive for such general investigations as carried out in this research project, since it is as suitable an area for the development of general descriptive and analytical techniques for vegetation at the chosen scales of work, as any in the British Isles. Machair vegetation is relatively homogeneous physiognomically, has considerable but not extreme human influences acting on it, and is the product of a distinctive physical environment. The presence of a National Nature Reserve is an added commendation, and this is one of the few coastal areas in the United Kingdom which has not been profoundly affected by recreational pressures. In Britain this is the most serious threat to sand-dune vegetation and yet is probably the least understood factor of the coastal environment. Thus, study of machair, an extensive and relatively well-maintained coastal dune and sand plain area, is a worth-while objective.

Remarkably little has been written about machair in spite of its importance in scientific terms and as a human resource in the Hebrides. Over a period of more than ten years, research into the physical and human environment of the Uists has been carried out by members of the Geography Department of the University of Glasgow. This study is a continuation of that work, and research has been considerably facilitated by the store of data and expertise which has accumulated. Much of this material is not readily available so that this project was greatly enhanced by the help and co-operation so freely offered. These are further strong reasons for basing research into development of general descriptive and analytical techniques, on machair vegetation in the Uists.

Field work was an important part of this study. For the Grogarry Machair survey this was carried out in October 1967, January, February and May 1968, a total of six weeks being spent in South Uist. Whilst the time of data collection was not ideal, work in the winter months was essential as there was a definite time limit on this study. In some respects research in the winter period was valuable, in that it yielded data on the machair habitat when environmental conditions are very different from those in the summer. Subsequent evaluation indicated that the results obtained in winter were valid, and compatible with the other data collected for this survey. Certain land-use data were collected in September 1968, a suitable period for such work since at this time, before the harvest in the Hebrides, maximum information and clearest patterns can be discerned. Mapping and sampling of vegetation for the general survey of the Uists occupied some eights weeks in June, July and August of 1969. This is the optimum period for such field work, since identification is facilitated by flowering, the largest numbers of species, including most of the annuals, are represented in samples and interruptions by bad weather are minimal. In 1970 and in 1971, there were further brief visits to the Uists, and in all about eighteen weeks were spent in the field.

Besides field work, documentary and literary sources were consulted and yielded much valuable information. Much has been written on the development of techniques pertinent to the approach used in the two surveys. More specific material dealing with machair is much less common and often fields quite peripheral to vegetation study were consulted. Archaeological and biological sources were most valuable in this respect. In the interpretation of machair vegetation several studies of sand-dune and coastal vegetation were helpful. These included studies of machair elsewhere in the Hebrides and several other investigations in Britain and North America. Very considerable amounts of profitable information were obtained during the course of discussions and correspondence with colleagues, other researchers and local people. The principals who contributed invaluable help are detailed in the acknowledgments.

The content of this thesis is divided into five parts. The first section comprising chapters 2 and 3 is an account of the environment of machair vegetation, drawing both on field observations and documentary sources. Following this, the second part, consisting of chapters 4 and 5, contains a general account of the development of methods of description and analysis of vegetation applicable to this study. Developing on this theme the specific methods used in both the Grogarry and in the Uists surveys are considered in detail. The third component of the thesis, chapters 6 and 7, present the detailed description of the vegetation of Grogarry Machair, and of all of the machairs in the Uists respectively. These two chapters are accompanied and supplemented by the maps and statistical analyses of appendices 1, 2, 3 and 4. The fourth section is made up of the analysis and explanations of machair vegetation based on the detailed descriptions. Chapter 8 investigates the ecological relationships observed in the field, and the following chapter comments on machair vegetation status and suggests a hypothetical development scheme. The general character of interpretation is based on the aims of the research programme and the nature of the available data. The fifth and final component of the thesis, chapter 10, presents a conclusion in which a summary of the more important findings is given, and in which an evaluation of the project is made. This includes assessment of the nature and sources of error, the value of the surveys and an indication of further problems raised during the research, either specifically related to machair in the Uists or more generally with respect to geographical approaches to vegetation analysis.

CHAPTER 2

THE ENVIRONMENT OF MACHAIR VEGETATION - THE PHYSICAL HABITAT

In the Hebridean islands of North Uist, Benbecula and South Uist (known collectively as the Uists), machair forms an almost continuous, low sandy plain fringing the Atlantic coasts. Remarkably little is known about this distinctive landscape although it provides the richest agricultural land to be found in the Hebrides, and constitutes one of their most valuable natural resources.

Machair is a Gaelic term which is difficult to define precisely. The Hebridean crofter referring to machair means the area between the Atlantic shore and the acidic moors to the east; this low western plain is used intensively for both cropping and grazing. In this context therefore, it is a term with a purely local currency referring to a landscape in a particular location. However this definition does not take account of the implications which the word has acquired. Machair occurs widely in the islands and less commonly on the mainlands coasts of north-western Scotland, but is best developed along the western coasts of the Outer Hebrides. It is a remarkable natural phenomenon. In terms of geological age, nature of constituent materials and resultant landforms, it presents an extreme contrast with the other parts of the Outer Isles. To the west, machair is composed of calcium carbonate rich, post-glacial sands which form a complex of dunes, low hills and plains. Aelian processes of the past few thousand years, and presently continuing, have largely shaped current landform patterns. To the east lie low, mamillated hills of glacially gouged, Archæan gneisses. The contrast in landforms are reflected in, and heightened by vegetation. The herb-rich, machair grassland is characterised by diversity of flora, and a well defined response of plant communities to variations in local conditions. The peaty moorland on the acidic rocks to the east, is characterised by the poverty of its flora and a continous range of variation in composition of vegetation.

Analagous to machair are several other Gaelic terms used to describe landscapes in the Hebrides. Dubhthalamh or 'Black Land' is used to describe the low marshy areas immediately east of the machair, on which croft houses and their attendant 'in bye' fields are normally located. The hill and mountain areas further east, occurring throughout the Uists, but broken by long sea lochs which in a few places extend westwards from the Minch almost to the 'Black Land', are known locally as Gearraidh (so called 'skinned hands' because of their extensive peat cuttings), and Monadh ('Mountains') respectively (Jaatinen, 1958, p. 93). The contrasts with machair become more extreme further from the west coast.

In scientific terms machair has three definite characteristics. Firstly it is located on extensive, low coastal plains adjacent to the Atlantic shore; secondly these plains are composed of sand which has a very high calcium carbonate content, and is worked into a variety of landforms; and thirdly machair vegetation is a herb-rich calcareous grassland intensively used by man.

However, machair is best described as a landscape, because it is a composite of several interrelated facets. For the purpose of analysis, these can be broken down into two main groups, the physical and the human. The physical habitat of machair comprises, the local climate, geomorphology, hydrology and pedology. It must be emphasised that these elements are closely interrelated in an environmental complex, and that the subsequent treatment under these headings is for convenience and clarity.

In many vegetation studies, particularly those concerned with the British Isles, the effects of man are regarded as a special or extraneous factor causing an unnatural disturbance in otherwise natural vegetation. This view is difficult to support, since there is no part of Britain in which vegetation development and current status has not been, to a greater or lesser extent influenced by man. In the case of machair, man's effect has been profound, and is probably more responsible for present vegetation patterns than any other single factor. Again it is difficult to separate man's influence from the complex of factors forming the physical habitat. Each have mutual effects on the other and in terms of the whole landscape as it presently exists, man is an integral factor. However tracing the influence of man is of such a complex nature, that it seems best to accord this a separate chapter.

Climate

Situated at the extreme western edge of the north European continental shelf, the Outer Hebrides experience an exceptionally oceanic climatic regime. This climate is characterised by a very low annual temperature range, a moderately large total precipitation, relatively low amounts of sunshine and excessive windiness. Unless otherwise indicated, the climatic data are abstracted from observations made at Ballivanich Airport, Benbecula, ($57^{\circ}28'$N, $7^{\circ}22'$ W; grid reference NF 785555). This location is ideal for the purpose of this study since it is near the mid-point of the 73 km. north-south machair strip, and is actually located on the extensive, low, level machair plain[1]. The climatic information given here can thus be taken as being reasonably representative of that of the whole machair area of the Uists.

1. The instrument height was 5.62 m.

The annual range of temperature is extremely small for the latitude. The average mean temperatures for January and July in the period 1901-1930 were 5.3°C (41.5°F) and 12.8°C (55.5°F) respectively[1]. Figure 1 shows the monthly maximum and minimum temperatures. Strong winds tend to depress sensible temperatures but frosts are relatively uncommon and snow, whilst occurring at some time every winter (occasionally in substantial amounts which may cause some disruption to human activities inland) rarely lasts more than two or three days on the machair areas. The relatively mild winters, the average minimum January temperatures[2] being 2.6°C (37.0°F), are favourable to biological activity, and annual plant species may be recorded in any month of the year. Most livestock are out-wintered, though supplementary feedstuffs are normally essential.

Rainfall is high enough to ensure that in the water-budget of the Uists, supply normally exceeds demands, through the year. Figure 2 shows the mean monthly rainfall for the period 1949-61. The annual total of 131 cms. (51.7 inches) is not excessively high, but only during the month of May does the average precipitation value fall below 5 cms. (2 inches). There are twin maxima in October and December, both months having a value of 16.2 cms. (6.4 inches). Figure 3 shows monthly precipitation plotted against evapo-transpiration for 1962-4 at Stilligary, South Uist (grid reference 770387) about 1.6 km. from the intensively studied Grogarry Machair survey area. In three years deficits occurred only three times, once each in February, March and April. Very large surpluses were commonly recorded during autumn (September-November). At a regional level, therefore, vegetation has more than adequate water supplied throughout the year.

1. For the period 1931-60 figures were January 4.5°C (40.0°F) and July 13.6°C (58.2°F), means of maximum and minimum temperatures.
2. Minimum night temperature (21-9 hours) 1945-60.

However this regional pattern is very considerably modified in detail by local hydrology, itself a function of the water-balance, together with geomorphology and soil characteristics.

Insolation plays an important part in the process of evapo-transpiration since bright sunshine increases water loss, viz. Potential Transpiration, Ministry of Agriculture, Fisheries and Food, 1967; p. 3-4. The amount of insolation which occurs in the Uists, is relatively low. The average length of recorded sunshine per day in January is just over 1 hour (13% of the total possible) and in July 5 hours (28% of the total possible) and thus water balance is minimally affected. Shortage of light is unlikely to have a direct effect on the vegetation of the machair, since few areas experience continuous deep shade. However low insolation plays an important role in the general environment of north-west Scotland.

The most distinctive feature of the climate of the Uists is wind and this is a climatic factor which does have profound direct effects on the vegetation cover. Still days are so rare as to be remarkable, and after a few days the visitor is quite accustomed to a constant 6.7 m./sec. (15 m.p.h.) wind. At 10 m. above the ground, an average wind speed at Ballivanich is 8.1 m./sec. Strong winds and gales are commonplace throughout the year and every winter many gusts exceeding 26.8 m./sec. and reaching 35.7 m./sec. (80 m.p.h.) or even 44.6 m./sec. (100 m.p.h.), are recorded. Such winds have very great potential energy resources, which could readily be used to move large quantities of the sand of which machair is composed, if other factors are favourable. Though wind energy is generally lower in the summer months, more sand movement occurs then, since much of the machair surface is dry and thus sand particles can easily be transported. Every year thousands of tons of machair sand are moved by wind.

Direction of wind is therefore an important consideration. Table 1 shows wind resultant directions, and it can be seen that the resultant of all winds lies in the sector between south and south-west. Strong winds are concentrated in the sector 150°-290° (with nodes at 150°-190°, and 260°-290°) in the summer, and in the winter in the sector 140°-290°. These strong winds are of the greatest relative significance in sand movement, and again the concentration of directions between south-east and west is important. The role of sand movements in the development of distinctive vegetation patterns is very considerable.

The direct effect of wind on the vegetation of the machair is difficult to assess. Its treeless character can no doubt in part be attributed to the strength of the dominantly westerly winds, but the situation is complicated by anthropogenic and biotic factors. Man's activities would seem to be the single most important factor in shaping present machair physiography. Wind does have one direct effect on machair vegetation which is probably significant. High winds tend to increase plant transpiration rates, and in some local areas of the machair, water deficits in the rooting zone may be serious during the summer months, in spite of the apparently favourable regional precipitation/evapo-transpiration balance. The reasons for this water deficit are related to low soil water capacity and local hydrology, and are discussed more fully in the subsequent sections dealing with soils and hydrology of the machir. Wind, therefore, may induce physiological drought conditions and exacerbate physical drought in the freely drained and very exposed dune areas. The competitiveness of Ammophila arenaria, which has xerophytic characteristics is undoubtedly assured by this factor, although its abundance is initially due to other factors, such as its preference for a habitat in which moderate sand blowing is currently active.

Geomorphology

One of the most distinctive features of machair landscapes is the close reciprocal relationships between geomorphology and vegetation composition. This is evident both in terms of the present patterns and also in developmental processes. In this section three aspects of the geomorphology of the Uists are examined. These are the nature of the machair sands, the geomorphological origin, and the characteristic morphological patterns of machair. No attempt is made to describe the detailed regional patterns of the machairs of the three islands. The detailed work of Dr. W. Ritchie (Ritchie 1966a, 1970) contains a wealth of geomorphological information, and this section is largely based on these studies.

The constituent material of machair is a silver-grey sand, fine in texture, and with a very high calcium carbonate ($CaCO_3$) constituent. Table 2 indicates in quantitative terms the nature of this distinctive sand. The calcium carbonate fraction rarely falls below 20% and occasionally exceeds 80% of the total by weight. One consequence is that pH values, even at the surface, where the lime-rich sand has the highest content of acidic humic material, rarely fall below 6.0, and deeper down at 1 m. below the surface, may exceed 9.0, a phenomenally high value in the British Isles. It is hardly surprising, therefore, that the vegetation of the area is distinctive. Detailed examination of the sand has shown it to be composed of two quite different types of material. The calcium carbonate fraction is almost exclusively organic in origin, being derived from the comminuted shells of vast numbers of marine molluscs, as yet specifically unidentified, which existed on the shallow sea-bed to the west of the Uists, in late-glacial times. The remaining fraction, mainly siliceous in composition, is derived from the considerable amount of morainic detritus dumped to the west of the Uists during the quaternary glaciations. The absence of any sizable west-flowing rivers, precludes the possibility of an appreciable sand supply from that source.

Initially the constituent materials were moved to the west coast of the Uists, by onshore wind and wave action. Three conditions were essential for the formation of machair. Firstly a shallow, gently shelving, western sea-bed was necessary to allow the growth of vast number of shell fish and to make possible the transport of subsequently derived sands without hinderance. Offshore investigations have revealed a gently sloping, rock-platform extending for several kilometres west of the Uists. Secondly, prevalent winds and wave action had to act in such a way as to move the sands in the direction of the islands. These are the present circumstances, and there is no evidence to suggest that there has been any radical change in these conditions since the time of machair formation. Thirdly, the coastlines of the Uists were low and unhindered by barriers such as cliffs. The subsequent physiographic evolution of machair has been controlled to a large extent by the particular nature of the receptive surface.

Investigations into the physiographic evolution of the machair have indicated that the major period of formation was between approximately 5,700 year B.P. (Before

Present) and 2,000 B.P. The available evidence suggests that there was a net submergence of the area in Post-glacial times, and that the rate and amount of this submergence was considerable before approximately 5,700 years B.P. $\pm$ 170, but that thereafter the amount of vertical change has been relatively small; the above figure is derived from the radio-carbon (C_{14}) dating of organic deposits immediately below the sand surface. This, and a considerable weight of further evidence, indicates that submergence of the coasts was pronounced up to this date (Ritchie, 1966b, p. 81-2). This correlates well with broader studies of sea-level change (Ritchie, 1966b, p.86; 1966a, p. 217). Archaeological records show that there was a sand or machair surface along the west coast of the Uists, before or during Romano-British times. This evidence was provided by the excavation of the Kilpheder sites of South Uist, by Lethbridge (Lethbridge, 1952). Although the wheelhouse[1] structures of these sites have been covered by sand-blowing, they are set on an older sand-surface. The available artifacts indicate that the economy of the wheelhouse people was both of a collecting and agricultural nature, and as the 'blackland' would be unfavourable for crop-production, it seems probable that machair land sustained these agricultural activities. This evidence is for the approximate period 100-200 A.D. Hence, the major period of machair formation has been bracketed between approximately 5,700 years B.P. and 2,000 B.P.

Within these dates the Sub-boreal climatic period occurs, the general nature of which was suited to machair genesis. The climate, drier than at present, was

1. wheelhouse: name given to dwelling of the Iron Age B period, due to their distinctive plan

favourable to the heaping of great masses of wind-blown sand on to the exposed coastlines, on top of the earlier Post-glacial raised beach, and the hardened organic layers of the previous, more humid Atlantic bioclimatic period. Being outside the zero isobase, raised beaches are absent from the Uists, but organic layers buried beneath machair sand have been observed and dated, as shown above. Following the Sub-boreal period, the wetter Sub-Atlantic period would lead to more stable sand conditions; thus by 2,000 years B.P. a relatively stable sand surface was in existence in the Uists.

The detail of evolution of machair has been studied by Evans (1971). Examination of a machair site at Northton in South Harris, about 8 km. north of North Uist, shows changes in ecological conditions in response to geomorphological evolution, as revealed by sand stratigraphy and faunal spectra of land snails. Table 3 summarises the main conclusions of this work, and approximate dates are supplied, in the first two cases by C_{14} assay (Simpson 1966, p. 139), and in the latter two cases by general archaeological correlation. This detailed work does not wholly agree with the conclusions of Ritchie, in that the initiation of machair formation was rather earlier (c. 350 years), but this may be explained either by acceptible error in dating (total of one standard deviation each for both dates is 310 years), or by local variations in development history, or by subsequent marine incursion and erosion. In other repects, the sequence described in table 3 shows very considerable similarities to the sequence described at Borve, Benbecula, the site at which a date of 5700 years B.P. was obtained by C_{14} analysis. The terms forest and woodland are misleading, and the pollen records confirm that the "forest" described by Evans (1971, p. 59) is likely to have been open, scrubby, pine and birch woodland. It is unlikely that the exact sequence of developments analysed at Northton are applicable to the whole of the Uists, but the general mode is certain to have been very similar.

The exact mode of machair formation remains unknown, but on the available evidence two possible theories of evolution can be put forward. In both cases the process must have been rapid, as is indicated by the preserved organic horizons, beneath the sand, Fairbridge (1961) describes an ideal transgressive sequence in non-reef areas, where the sea advancing over a low coastline, with rising seal level, sweeps a great build-up of sand in front of it. A short negative oscillation will expose this great accumulation to wind action and littoral dune building. An alternative sequence is suggested by Johnson (1919). Sand and shingle are built into a bar sub-parallel to, and at some distance from the original shore-line. This bar retreats landwards before onshore wave and wind forces, crosses the lagoon-marsh formed in the initial stage, and in so doing buries the marsh facies beneath the sand. At a later stage in the process these organic deposits outcrop on the seaward side of the bar and are rapidly removed by wave action, except in areas where they have special protection. The bar or bars are replaced by sand dunes during the ultimate stage of development, and these dunes extend over and obscure the original coastline. The extent of these dunes varies with the supply of sand available.

The present day geomorphological patterns in the machairs of the Uists are a result of sub-aerial and marine processes operating over the last 2000 years. The result is a relatively stable and mature surface. Map 3 shows the geomorphology in the Grogarry Machair area. A gently shelving, sandy beach is backed by a well-developed shingle and cobble bank. Behind this lies a continuous line of consolidated dunes, to a greater or lesser extent vegetation covered. Intermittently these dunes are broken by 'corridor' blow-outs, which are in various stages of erosion, recolonisation and stabilisation by vegetation. Beyond the dunes lie the machair plain, low and practically level over most of the area, but in the centre and in the north, zones of sand hills complicate the pattern. Between the dune belt and the machair plain are pronounced dune slacks, in which during the months of November to March or April, so called 'winter lochs' form, attaining a considerable size, up to 45 m. across and several hundred metres in length, at their maximum extent. The Lon Mor is such a semi-permanent water-body, expanding greatly in the winter, but contracting to a tiny muddy pool or even completely drying up for a few weeks during the summer months. This is due to a major drainage cut, which flows through it, and provides a limited water supply when the water-table has fallen. To the east the machair is separated from the 'black land' by a continuous line of lochs and marshes. Over parts of the machair plain, sand hills of various forms and sand cuestas rise above the level surface, some remnants of earlier surfaces, others products of more recent accretion.

Throughout the machairs of the Uists, a great variety of small-scale landforms are found. Those occurring at Grogarry Machair are representative of most of the types which might be found on any of the machairs. This area, has a rather larger suite of landform facets than most machairs which tend to be both simpler in structure and small in extent. In addition to those found at Grogarry Machair, four should be noted. First, composite zones are found in several locations, especially in North Uist. Here machair plain and sand hill types up to $\frac{1}{2}$ hectare in extent, but frequently much smaller, occur in such close juxta-position as to form a landform mosaic, which can only be sub-divided at the most detailed level of study. Secondly 'high-machair' areas are found in locations where the sand surface attains considerable height, due to its piling up on ridges in the normally very low, planated, sub-surface, gneiss platform (Ritchie 1966a, 1970). At Balranald in western North Uist such a sand surface exceeds 20 m. above sea level. Thirdly true salt marsh areas are very rare due to the vast amount of sand on the west coast, the exposure of the coastlines, the absence of west-flowing rivers of any size to carry fine particles to the coast, and the amount of sand movement occurring in the zone close to the shore. However, at Loch Paible, in North Uist a type of salt marsh does occur. Its origin is due to the relatively recent breaching of the western bank of this small loch by the sea. The tide ebbs and flows rapidly through a narrow gap in the coastal dunes, producing in this sheltered lagoon suitable conditions for littoral deposition of fine particles. Finally, non-machair areas not covered by blown-sand which at several points on the west coast of the Uists break the continuity of the broad sandy beaches, should not be overlooked. These normally occur when the underlying basement rocks rise above sea-level in east to west, or south-east to north-west ridges running out to sea. Their role in the regional geomorphological evolution of the machairs of the Uists is a most important one, and they further constitute a distinctive part of the biological environment of the west coast, in terms of both flora and fauna. The Rhuda

Ardvule at the mid-point of the South Uist coast, and the Ben Scolpaig headland at the north-western extremity of North Uist are major examples of such features.

Hydrology

Hydrology is of fundamental importance in understanding machair landscapes. "In many respects, the water-table is the most important control of machair evolution, and with both depositional and erosional forces level or gently sloping landforms are produced. In the first instance, sand deposition on a wet reception area produces flat spreads, or gentle fans, and at the other extreme, the water-table is the base level of wind excavation and ... "flat or gently sloping surfaces are ultimately produced". (Ritchie, 1967, p. 171). The water-table is high; even in summer when it is at a minimum level, it is very near the surface in the lowest areas. At Drimore in the extreme north of the Grogarry Machair area, measurements have shown that the water-table lies about 1m. below the surface of the low, level machair plain, in the summer months.

The seasonal fluctuation of the water-table is a second important factor in the hydrology of the machair. The average rise in the water-table between winter and summer is approximately 1 m. This gives seasonal variations in ecological habitats, at the same spatial location, which range from total inundation to drought. The rise in water-table causes the formation of winter lochs in the dune slacks during November to April. These seasonal water bodies may exceed 1 m. in depth, and many other low-lying areas have pools of water a few centimetres deep lying on their surface. Yet in early summer (May and June) the dune slacks are quite dry, and rabbit burrows can be seen in use along their margins. The annual variation in conditions is explained partly by increased precipitation and partly by reduced evapo-transpiration in winter, over the extensive catchment area which drains through the machair.

Much of the drainage of the Uists is channelled through the machair water-table. The absence of west-flowing rivers (the only major natural drainage tract on the west coast of the Uists is the Howmore River in central South Uist), and the relative ease with which water can pass through the pervious sands are due to this movement through the machair. However, the reason for development of this type of drainage lies in the mode of origin and age of machair as a geomorphological feature. Its continued landwards movement and its youth have resulted in an absence of surface streams.

Machair drainage patterns are changing, and this can be attributed to two causes. Firstly, slow positive change in sea-level, due to eustacy, has resulted in the sea encroaching on, and breaching narrow sand-dune barriers, and reaching the fresh water lochs fringing the eastern edge of the machair. Along the south-western coast of North Uist, the islands of Kirkibost and Baleshare are remnants of this process. The sea has breached the dune barrier to form three, narrow, deep channels through which the tide ebbs and flows, to the extensive flats of Oitir Mhor, Traigh Eachkamish and Traigh Leathann. Present sea water tainting of Loch Bee in the extreme north of South Uist, is an earlier stage in this process. Besides long term geomorphological changes, this has a more immediate effect on vegetation, particularly that fringing the areas invaded by the sea; the salt marsh around Loch Paible, North Uist, is an example. This rise in sea level is also responsible for a diminution in the natural east to west drainage processes through the sub-surface machair water-table. This, left alone, would lead to an increasingly wet plant habitat. However, the second cause of change operates in the opposite direction. To counteract the lowering in efficiency of drainage, surface channels have been cut in many places to improve drainage from the areas east of the machair to the sea, for sporting purposes. Little has been done to change the drainage of the machair itself, though in a few places, such as West Geirinsh Machair in northern South Uist, tile drains have been used to improve a particularly low, wet area. Nonetheless, the direct removal of water from the eastern lochs, by drainage cuts, has lowered the level of these lochs and kept the machair water-table at a lower level than would otherwise be possible. This has tended to make ecological conditions relatively constant, and thus act against major seral vegetational changes.

Pedology

The soils of the machair reflect in fine detail the variations in habitat resulting from the interaction of the many facets of the environmental complex. The major components of the physical habitat, climate, geomorphology and soils combine with the vegetation composition to produce distinctive soil patterns. Machair soils have certain distinctive characteristics which can be analysed at two levels, the regional and the local.

Machair soils, like other aspects of the machair landscape, have particular features which clearly distinguish them from other soil types which occur in north-western Scotland. In terms of constituent materials their make-up is most distinctive, considering both physical and chemical composition. The mean size of 19 median particle diameters from samples taken at Dremisdale, about 2 km. is south of the Grogarry Machair area was 0.38 mm., and the range of median diameters was 0.26–0.38 mm. (neglecting two values from samples taken below 30 cms. depth in profiles). Clearly, the constituent particles of machair soils fall largely within the sand fraction (Buckman and Brady, 1965, p. 40). The highly calcareous nature of the parent material has already been noted. In general terms, throughout the Uists, machairs vary in composition from 89% $CaCO_3$ in the machair of Oronsay Island just off the north coast of North Uist, to 31% $CaCO_3$ in the dunes of Askernish in southern South Uist (Ritchie, 1966a, 1970). Most values fall in the range 40–70% and no regional pattern of variation can be discerned (see again Table 2).

The high lime content of these soils is matched by a deficiency in organic material. The organic content is "generally less than 10% and frequently as low as 2%". (Moisley, Caird and Tivy, 1956, p. 1). There are several other deficiencies in machair soils which occur ubiquitously in the Uists. Nitrates, phosphates and potassium are all in short supply as would be expected in dune soils with a low organic content (Roberts, Kerr and Seaton, 1959). The deficiencies in the trace elements copper and manganese, are serious enough to make treatment essential if agricultural yields are not to be adversely effected (Ibid. p. 225). Local variations in these conditions occur within the machair lands of the Uists, and thus very detailed studies are necessary to make quantitative assessments. The North of Scotland College of Agriculture advisors at Ballivanich, Benbecula, have done much work in this field and have been responsible for a considerable improvement in the knowledge of, and consequently in the use of machair soils.

At a local level, as has been stated, there is a considerable variation in machair soil conditions; these variations are most significant in terms of the vegetation composition and patterns that occur on machair in the Uists. Table 4 and Figure 4 give details of these variations. The pattern of variation is such that the soil analyses shown in Table 4 could be described as a machair catena. The principle factors which are responsible for differences in soils at this scale of study are local geomorphology and hydrology. These two factors are intimately related and the resulting soil and vegetation patterns are to a considerable extent manifestations of this interaction. The higher areas, well above the water-table, are most susceptible to aeolian erosion and deposition, producing a skeletal soil almost devoid of organic matter. Such a soil has an exceptionally low water-retention capacity, remains very open to continued deflation and sand accretion, and hence provides a habitat suitable to the pasammophillous grasses and other species ecologically tolerant of such unstable conditions. Such soils are likely to remain at least potentially unstable, and will be poorly developed until the physical environment becomes less dynamic. Vegetation does make a major contribution towards this end, and over time the increased organic build-up resulting from a prolonged period of vegetation cover reduces the soil's susceptibility to major change.

In the low-lying areas, occurring in the level machair plains and dune slacks, soil conditions are quite different. The water-table is close to, or at, the surface for most of the year and thus erosion is almost non-existent. Sand accretion is slow except on the margins of these areas, as the distance over which sand has to travel from the source areas, is considerable. The circumstances of these soils are thus much more stable than in the elevated areas. The typical profile exhibits several major differences. There is a well developed A horizon in which the organic matter content is normally more than 10% and may exceed 30%, if there has been no recent human interference (by cultivation). In the latter circumstances the organic content usually falls below 10%, and only builds up to these higher levels over a period of a decade or more. This layer is usually 10 cms. or more in depth, and dark brown or black in colour. The pH of this horizon is generally within the range 4.5-6.0, considerably lower than in the surface horizons of the soils of the drier areas. Mottling may well occur in the lower parts of the profile, indicating the poor drainage of these soils. There are variations between the soils of the drier and wetter areas which exhibit a continuous range in the components described above. At the landwards (eastern) edge of the machair, the soils become peaty, highly acidic (pH below 4.5), more poorly drained, having a smaller proportion of the sand fraction, and having a lower exchangeable base capacity. Soil conditions reflect the change in parent material and there is normally a fairly abrupt transition between these soil types and the machair soils on the calcareous sands to the west.

Two major soil-forming factors which operate throughout Scotland are drainage and land utilisation. Both are important in the development of the machair soils of the Uists. The roles of drainage and sub-surface hydrology in producing different soil-forming conditions have already been noted. The importance of land-use in the machair landscape as a whole is discussed in the subsequent chapter. However, it should be noted at this juncture, that agricultural land-use has a considerable modifying influence in the process of soil development. Grazing has a limited direct influence on soil-forming processes, though animal manure may be a significant contribution to a soil with a low inherent organic content. The indirect influences through modification of vegetation pattern are of greater importance: these are assessed more fully in the following chapter. Cultivation fundamentally modifies soil profiles. More important than the removal of minerals and water, is the breakdown and dispersal of the surface organic layer. This, particularly in the higher and drier areas where the organic crust may be only one or two centimeteres thick, can lead to greatly accelerated deflation; clearly this is a cyclic sequence and great care in land management policies is necessary if serious long-term damage to the soil is not to be caused.

The four major components of the physical environment, though investigated and analysed as separate entities are parts of a most distinctive machair ecosystem. Its potential in terms of land utilisation is much greater than any other corresponding area in Highland Scotland. For this reason the resulting landscape is as much a product of human activities as it is due to its unique 'natural' physical environment. In the following chapter, man's role in the evolution of machair is examined. In spite of its open aspect, the machair clearly bears the signs of human use, and it seems most probable that it always has done so to a greater or lesser extent (see Chapter 3). The relationship between the landscape and man is, or certainly has been, symbiotic; the distinctive physical attributes discussed above have enabled men to live in an otherwise harsh and barren area. At the same time, the machair ecosystem is readily disturbed and man's contribution too frequently has been a negative one.

CHAPTER 3

THE ENVIRONMENT OF MACHAIR VEGETATION - THE HUMAN FACTOR

The role of man in shaping present vegetation patterns in Scotland has been profound. Directly and indirectly, intentionally or accidentally, human activities have shaped developmental processes both at a regional and local level. Anthropogenic influences are most obvious in the relatively densely peopled lowland areas where townscape and farmland occupy virtually all space, and vegetation and land, in which natural processes played evolutionary roles, is limited to very limited areas set aside for recreational purposes, or exempt from intensive land-use due to unsuitability of the terrain, drainage or location. Even in these latter areas a superficial examination will reveal how severely natural processes have been modified by man, through clearing, planting, grazing by domestic animals or pollution (in the widest sense). In Highland Scotland human influence on vegetation is less obvious, but nonetheless is profound and a serious consideration of this factor is vital to any understanding of present day patterns. This is particularly the case for the machairs of the Uists.

The machair lands of the Uists have been used more intensively by man than almost any other coastal sand dune and sand plain area in Britain. The earliest settlers in the Uists arriving not later than 2,000 years ago, settled on the western coastal areas (Lethbridge, 1952). As has already been shown (viz. p.16) this immediately followed the major period of the physiographic development of the machair. Man's influence, therefore, on machair vegetation must have been more or less continuous from its inception, since the west coast has remained the focus of human activities from that time to present day. The population distribution at the census of 1961 shows this pattern in Map 4, in the case of South Uist. This present day pattern is similar to that which has occurred in the Uists during man's occupancy. Thus, the human factor is as important in the long-term historical development of machair vegetation as any of the physical components of the environment.

In tracing the historical evolution of land use, for 2,000 years, there must be considerable breaks in the continuity of the story. Paucity of accurate data, lack of investigations, but above all the impermanence of the record makes this unavoidable. However, certain major periods can be discerned, each with distinctive cultural elements which, blended with the pre-existing society, produced a distinctive way of life which held sway for a considerable interval until some new outside influence intervened. Each of these components, despite different anthropological characteristics relied on agriculture as the mainstay of their economy. Thus the machair land, the best agricultural area in the Uists, was continuously under distinctive and intensive forms of land-use. Two factors, therefore, are most important in the history of land-use of machair; firstly, the continuity of land-use: secondly, the evolution of land-use practices. The earliest known occupants of the machair lands, the Iron-age wheel-house people, had settled on the west coast of the Uists by early Romano-British times (2,000 B.P.). There are a sufficiently large number of dwelling-sites of this type to indicate that "There was a relatively high density of settlement" (Ritchie, 1967, p. 172) although it is likely that these buildings were not in continuous use, and the population to some extent were migratory pastoralists. Investigation of one of these sites at Kilpheder on the west coast of southern South Uist (Lethbridge 1952) revealed artifacts and other evidence which pointed to a dual economy of sea food collection and agriculture. The coasts were the chief area of collection, principally of shell-fish, and the machair must have been the centre of agricultural activities. The inhabitants of the wheel-houses kept pigs, sheep and shorthorn cattle and grew grain, probably barley (Ibid. p. 182). The land to the east of the machair would be quite unsuited to these pursuits as they were as infertile as they are today, and most probably were covered with an open birch forest.

During the ninth century, the Uists came under the aegis of the Vikings. These warrior-traders have left little physcial evidence on the ground of their period of rule and their contribution to the island's history. Their main legacy has been in place names, and many of the names to be seen on the present-day map are undeniably Scandinavian in origin, e.g. very many of the hills in the Uists have the Norse ending "-val". The chief contribution which the Vikings made to the embryonic Hebridean Society was in organisation. For nearly four centuries the Western Isles were firmly under the control of the Norsemen, who used the islands as permanent bases for their expeditions to Western Europe. Conquest, and then settlement of the Hebrides resulted in the reorganisation of the remnants of the indigenous peasantry into a well-developed Viking tribal system. Intermarriage and permanent settling in the island produced a specifically Hebridean culture. By treaty and contact, this Viking outpost gradually became assimilated into the Picto-Celtic tribal frings of the emerging feudal Scottish kingdom, so that during the early middle ages a dynastic tribal system, that of the clans, was the basic form of organisation in the Western Isles (Mitchison, 1970, p. 3-11).

In terms of agricultural land use, this system had many distinctive features, some of which have continued virtually unchanged, for many hundreds of years. Organisation of the survivors of the original inhabitants, combined with Norse settlement and natural increase made for considerable growth in total population by the early middle ages. This partly necessitated, and was partly a result of, an increase in the efficiency of land-use. Settlements became permanent, some enclosure of land near these settlements resulted, and stock-rearing was intensified; this latter completing the destruction of the remnants of the natural open birch forest on the eastern moors and hills which was begun by the Vikings. Although there is very limited evidence to offer support, it seems most likely that the machair areas were the focus of agricultural activity. Grazing for the stock was probably the principle land-use, though it is likely that the new organisation allowed the use of simple ploughs on the light machair soils for the first time. Elsewhere the ancient foot-plough or 'cascrom' would be the instrument of tillage. The increased numbers of population would certainly mean that the machair areas were under fairly intensive land use from the early Viking period onwards.

In the period between the end of direct Norse tutelage (nominally 1265, but in social terms rather earlier) and the reorganisations which followed 1745, the utilisation of machair land followed the following pattern. The whole of islands were held by feudal chieftains, whose authority was nominally granted by the king or a regional baronial magnate. In practice the local clan chief was an absolute potentate, and could command total loyalty from his tribal clan. His land was administered by gentlemen tenants, 'tacksmen', who paid tribute to the clan chieftain by supplying a certain number of men for military service; the fierce and unremitting inter-tribal warfare which continued for many centuries guaranteed the existence of this system. The tacksmen in turn sub-let their parcels of land to the peasant members of the clan, in return for their military allegiance and contributions of agricultural produce. The peasants lived in small clusters or 'clachans' and worked their shares of land, to a large extent in common. The hill land now largely cleared of the open birch forest provided grazing for their livestock (principally the short-horn cattle which were the island's main source of revenue). In-by land was located close to their huts, on the 'blackland' and some cropping was carried out here. The machair land was used as an outfield area. Each clansman had a share in the machair land, which was cultivated in strips on the run-rig system. Normally, grain crops, such as barley or oats, were grown for three successive years on the machair outfield. This provided food for human consumption, and was used for winter fodder. The three years' cultivation were followed by manuring and fallowing for one year or more, in which natural recolonisation would occur. (Jartinen, 1957, pp. 26-7; Collier, 1953, pp. 41-42). The inherent relative natural fertility of the machair land led to a concentration of cultivation on these areas. Together with population pressure, which remained at a fluctuating, but generally high level after the Viking stabilisation up to the nineteenth century, this resulted in an over-intensive use of the machair land. Early documentary evidence on the nature of machair in the Uists stresses the antithesis of potential fertility and productivity against the ravages of erosion and sand movements which occurred as a result of over-exploitation (Clanranald Papers; Statistical Account of Scotland, 1792, Vols. 10 and 13; Macfarlane Geographical Collections, 1907).

The final era in the history of land-use of the machairs started in 1745. The failure of the second Jacobite rebellion, saw the breakdown of the feudal clan system. The chieftain was reduced to the level of a landlord, and his rights to personal military service abolished. Land was worked in return for money rents. Some chiefs were deprived of their lands, others sold out and many tacksmen and clansmen left the Highlands rather than work under a new and alien system, but this did little to alleviate the acute pressure on the land or the concomitant grinding poverty of the peasantry over the next one hundred years. Land tenure was organised into crofting townships in which the middle men 'tacksmen' were eliminated and cash rents paid to the landowner. Hill land was used for grazing, each crofter having a 'souming' or entitlement to graze a certain number of beasts. The blackland adjacent to the crofthouse was commonly used for cultivation of potatoes, in 'lazy beds', deep rig and furrow plots which both improved the naturally poor drainage and gave a better soil bed. Machair sand was often used as a fertiliser on the peaty soils. The intensive use of the outfield machair land continued, but little was done to improve its condition and yield, by more advanced agricultural practises. Animal manure and seaweed were used in small quantities to improve the fertilityof the lime-rich soils, but primitive cultivation, an archaic land tenure system in which a crofter's machair land was divided into a number of unfenced tiny strips (held temporarily in most cases until the periodic reallocation), and virulent weed infestation kept productivity low.

The Uists did not escape the effects of the Highland Clearances. The change in status which the chieftains underwent after the Forty-Five, resulted in a new consciousness of their position as landlords. An increasing demand for money, necessary for the Highland nobility to adopt the way of life of the upper classes in eighteeenth and nineteenth century Britain, resulted in a much more capitalistic land-use policy. Often the result was the removal, by inducement or by compulsion, of crofters, occupying marginal hill land. Subsistence agriculture was replaced by sheeping farming on a large scale, run from a central farmstead employing a handful of shephers to manage thousands of acres. The money returns from the hill sheep were many times greater than the croft rents they replaced. The inherent potential of machair land made this type of land-use uneconomic but some reorganisation did occur, to produce mixed stock rearing farms. Such can be seen at Milton, Ormaclett and Drimore in South Uist, Nunton in Benbecula, and Balmartin in North Uist (subsequently most of these farms were broken up and reallocated amongst crofters). In spite of emigrations, pressure on the land scarcely diminished. The machair, in particular, was intensively cultivated, since it had to provide most of the food for the crofters. The kelp boom of the first two decades of the nineteenth century stifled emigration, and advances in scientific knowledge which had percolated to the north-western fringes of Britain, helped to increase life-span in an area where, thanks to warfare, famine and disease life had been cheap. But by the standards of the rest of the contemporary community (regarded nowadays as wholly inadequate) the lot of the Hebridean crofter was a harsh one. Illiterate, destitute, disenfranchised and disease ridden he was at the mercy of man and nature, neither inclined to be for long favourably disposed in the Western Isles (Collier, 1953, Ch. 4, pp. 38-51).

At the beginning of the modern era, the position of the crofter was indeed tenuous. The potato blight which struck the Hebrides in the period 1845-51 was as devastating in its effects as the better known Irish disaster, though emigration rather than death was the main consequence. But from this time several social changes took place, which in the following hundred years slowly changed the nature of crofting and its traditional land-use. Several factors were responsible for this change in the land utilisation of the crofting areas, and these were most marked in the Uists. Firstly, an awareness by the rest of the community of the precarious state of the crofters, brought interest, inquiry and eventually as a result of these, action. The impoverishment of the crofters of the islands was in no small measure due to the system under which they lived; an unhappy marriage of a medieval system and a Hanovarian political solution, it was an anachronism at the beginning of the nineteenth century. The Napier Commission Report (1884) spelt out clearly where the problems lay and suggested legislative action. Over the next eighty years repeated measures were taken with mixed success. "In 1953, most of the changes from which so much was hoped have come to pass, but they have not brought with them improvements on the scale anticipated". (Collier, 1953, p. 3).

Secondly, social advances affecting the whole nation brought considerable improvements to the islands. The Education Act (Scotland) 1872 and the welfare measures of the Liberal administration of 1906 improved the lot of the young and old. Increasing involvement by government departments in the crofting problem, provided both capital and expertise. Adoption, by the crofting community in the Uists, of the facilities of an 'urban' way of life, with sanitation, modern, dry and comfortable housing, motor and air transport has made the islands less remote, and life less arduous for the inhabitants. The change in crofting from subsistence agriculture to modern scientific cash farming is now nearly completed.

As a result of the metamorphosis in crofting life of the last century, there has been more change in land use in the Uists during the past 100 years than in the preceding 2,000, and the machair, the islands' prime agricultural resource has experienced the greatest changes. Map 7 shows generalised land use on machair in the Uists in 1968. The drift from the crofting areas to the south has relieved pressure on the land. At first archaic and unwealdy inheritance laws hindered croft amalgamation, but in the last decade sub-letting of unworked land has become legal. This has enabled active crofters to increase the size of their holdings to a level where economic returns can be obtained. The viability of these enlarged crofts is such that it allows expenditure on agricultural improvements, and these have been made attractive by government loans and subsidies. Substantial tracts of the machair have now been apportioned amongst the members of some townships, instead of being held in common, and the individual plots are fenced to farm small fields. Extracts from detailed land-use maps compiled in 1955 and 1968 show this pattern of change clearly. Maps 5 and 6 show the township of Sollas in North Uist, in 1955 and 1968 respectively. Between these dates the extensive machair outfield of this township was apportioned, and the result is that the cultivated area had more than doubled by the latter date, and fenced fields have surplanted the open plots, which are shown on the earlier map. In other places in the Uists the older pattern still persists and the machair remains in common ownership. No regional pattern of crofting rehabilitation can be detected, since apportionment depends on initiative from a particular township's inhabitants. Often the townships which have apportioned their machairs are those with the best agricultural potential and relatively few crofters. These, being largely active agriculturalists have most to gain by improvement. On the other hand, in the overcrowded townships farming is less likely to be the main source of income and legal complexities may deter the inhabitants from the difficult process of land arbitration and apportionment.

The use of artificial fertilisers on the machair is commonplace; high phosphate types are employed, a typical N - P - K balance being 15/40/15. The adoption of synthetics has been largely at the expense of application of the traditional organic fertilisers, such as sea-weed and animal manure. Thus, whilst the supply of available bases in machair soils has been increased by the use of modern dressings, the level of organic matter in the soil is liable to fall with cultivation; as discussed in the preceding chapter, the available quantities are limited, so that any diminution would produce serious repercussions. Fortunately there are signs that this need not be the case. Reseeding of the machair was practically unheard of ten years ago. Recent action by the Crofting Commission has made undersowing compulsory for qualification for full crop subsidies. There is already clear evidence that this procedure will not only stem loss of organic matter from machair soils, and thus prevent erosion and sandblowing, but actually improve the fertility and inherent productivity of the machair. The basis of machair seed mixtures are white and red clovers and various type of ryegrass (Trifolium repens, T. pratense and Lolium spp.) The occurrence of the latter two species in abundance in samples from a part of the machair is strong evidence that such an area has been reseeded or undersown at some time previous. This process is certain to play a most important role in the future development of machair vegetation, though at the present time it has not been carried out for sufficiently long to have made a major impact. Its adoption is to be commended.

The problems in cropping the machair in the Uists have been enunciated by Kerr (1954), and Roberts, Kerr and Seaton (1959). The available acreage is restricted by areas subject to poor drainage or sandblowing; little can be done to change this without expenditure which would not be justified in terms of returns from increased production. Soil deficiences have already been noted. The trace element manganese deficiency which occurs on machairs in the Uists, gives rise to the serious 'grey speck' condition in white oats (Roberts, Kerr and Seaton, 1959). The organic matter deficiency is most serious and as has been noted, applications of organic fertilisers have not increased, in recent years. The smallness of the units discourages the use of machinery. With the relatively poor techniques employed, and the system of land tenure and utilisation virulent weed infestation of cultivated machairs, by such species as Sinapis arvensis, Senecio spp., Bellis perennis, Potentilla anserina and several grass species, remains an inevitable consequence. Many solutions have been put forward: these include, increasing the size of units and of individual fields, increasing use of soil treatments specifically to combat mineral and humus deficiencies, the use of specially bred crops such as the Welsh oat S.171 (Avena strigosa x A. brevis), the use of weed-killers such as 2,4-D (though with recent reappraisal of the potency of these agents and their effect on the environment, this may be questionable), fencing machair plots and the use of wind-breaks, use of general purpose seed mixtures based on the clovers, wider use of certain early bred varieties such as S.24 perennial rye grass (Lolium perenne), and continued increased availability of capital in the forms of grants, loans and subsidies aimed at supporting agricultural improvements (Kerr, 1954; Roberts, Kerr and Seaton, 1959). There has been mixed success in the attempts to adopt these measures, since the problems are both chronic and acute and the natural reticence and conservatism of the crofter towards innovation is a considerable barrier to progress.

Pastoral agriculture is an important element in the anthropogenic environment of the machair. The purpose of most of the present-day machair cultivation is to provide animal feedstuffs, and very little of the uncultivated portion of the machair is not grazed to some extent by domestic animals. Patterns of grazing, both temporal and spatial, are difficult to isolate, due to the complexity of the agricultural system, so that assessment of the role of domestic grazing is difficult to quantify or even describe in adequate qualitive terms. The best machair grazings are used for cattle, and most beasts of townships which have machair will spend sometime on this area. Much grazing is also done on the improved, reseeded areas in the 'black-land', and together with the complexities of machair land tenure, this makes it impossible to give grazing densities with any accuracy. A township in Benbecula, with about 50 hectares (120 acres) of machair partly held in common, and partly allotted, in 1968 supported about 100 cattle, though a significant part of the year, especially the summer, is spent on the improved 'black-land' grazings. A clear pointer to the importance of machair land is the much higher cattle densities which occur in all townships which have machair, as compared to those which do not, throughout the Uists.

Cattle rearing is the most important aspect of the agricultural crofting economy in the Uists; and in the more progressive areas, has increased in scale and efficiency, to such a level, that the larger crofts are really small farms. It can be a profitable business. It has been calculated that the return from cattle rearing in the Uists is equivalent to the sale price for each beast sold, per year (Caird, 1968, personal communication). Recently, two-year-olds have been fetching between £60-£100 each depending on quality and demand.

In the light of this profitability, which has stimulated cattle rearing, machair grazing presents problems. Overgrazing has in the past been common, and resulted in many occurrences of serious sand blowing. Trampling of vegetation in the sand hills and dunes can cause scars which rapidly develop into major blow-outs. For these reasons, careful grazing control is to be advocated. Machair enclosure is essential, and some form of block grazing system highly desirable (Roberts, Kerr and Seaton, 1959). Machair grazing should be primarily reserved for winter use. This would both limit erosion damage, and allow use of 'black-land' grazings when they are able to give their best yields. Finally all areas subject to sand-blowing (which could well be delimited by the occurrence of <u>Ammophila arenaria</u> with a cover-abundance value of 4 or over on the Domin Scale) should at no time be grazed.

The grazing of sheep on the machairs of the Uists is a very haphazard process. In general, scant attention is paid to sheep-rearing in the Uists, and the animals are of such poor quality generally, as to warrant little expenditure or effort on the activity. On the machair, grazing densities, are considerably higher than anywhere else on the islands. Sheep are normally left free to wander over the poorer machair grazings and virtually no attempt is made to exercise proper control. Often the areas, subjected to the intense grazing which sheep carry out, are those which are most vulnerable to erosion. Sheep are a major cause of sand-blowing problems in the machairs of the Uists, and strenuous efforts should be made to eliminate, or effectively control their grazing habits.

The effects of grazing animals on the machair are difficult to assess. The only fully satisfactory evidence which could be put forward, would have to be based on comparative studies of grazed and ungrazed machair in the Uists, over a period of at least several years. No such work has been done, and the observations on Tiree machair (Boyd, 1960, Vose, Powell and Spence 1956) are based on a short period, and are confined to a small, relatively isolated island where there are no rabbits. Nonetheless, the observations of Boyd that in ungrazed machair ...."from inspection it is clear that Festuca rubra becomes dominant and the other species which are normally dispersed throughout the grazed swards occur only at isolated centres in the deep rank Festucetum."....(Boyd, 1960, p. 36), correlated in principle at least with observations made by the author. The assertion that the ...."Tiree machair is a Festucetum rubrae which develops as a biotic plagioclimax...." (Vose, Powell and Spence, 1956, p.108) undoubtedly applies to the Uist machairs, but it is difficult to find any support for the claim that ...."the climax vegetation, if grazing ceased, would be Calluna or Molinia heath." (Vose, Powell, and Spence, 1956, p. 108); certainly in the machairs of the Uists there is no evidence to suggest this.

The whole question of the status of machair vegetation is discussed in depth in subsequent chapters. It should be made clear at this point, however, that grazing has to a considerable extent been responsible for the creation of present day machair vegetation patterns. Grazing pressure by domestic and wild animals is and has been intense for many centuries. Consequently, the 'natural' development of machair vegetation has been arrested, and the resulting biotically maintained plagioclimax is only a mature stage of development in terms of continued intense grazing.

Three characteristics of the vegetation of machairs in the Uists may be ascribed to grazing. Firstly, the grassland physiognomy is a consequence of the high grazing pressure, since grasses are best physiologically equipped to tolerate the exacting conditions of this ecological niche. Secondly, the hazards of overgrazing, accelerated erosion and deflation, are common in the machair landscape, and thus the vegetation reflects this element of the habitat in a mosaic of several stages. The dynamic ecology of machair vegetation is made very complex by such factors as grazing. Thirdly, the extensive dominance by certain grasses and sedges, notably Festuca rubra, and Carex flacca, which would apparently develop over much of the lower, more stable machair areas, is curtailed, and the abundance of certain herbaceous species such as Bellis perennis and Senecio jacobaea more tolerant of an unstable environment and less subject to grazing, is an inevitable consequence of long continued, grazing.

It is very difficult to compare the effect of grazing by domesticated cattle and sheep play, with that by wild animals. The rabbit (Oryctolagus cuniculus) exists in incredibly high densities on the machair, the conditions of which provide an ideal habitat. Presently the extensive warrens amongst the dunes and sand hills abound with rabbits, though locally myxomatosis is evidently epidemic. This disease, according to local reports, virtually eliminated the whole population in the early 1960s and though a complete recovery has taken place since then the disease remains endemic with sporadic epidemic outbursts decimating the population in specific areas at recurrent intervals of four to five years. The disease has been important in controlling the numbers of rabbits and was introduced by man for this purpose. Other attempts at limitation by man, mainly by shooting or gassing, have had practically no effect on overall numbers. The other main control has been through predation. The locally reported increase in numbers of buzzards (Buteo buteo) in the Uists in the past two or three decades, is due to a plentiful supply of food, and this bird, the most common of large raptors in the Uists, is the only natural predator which can have any effect on the rabbits' numbers. Yet, recently in periods when rabbits have been scarce, it has shown a remarkable ability to maintain population size (Yapp, 1970, p. 181). It seems likely that the numbers of rabbits on the machair are so large (the total must be numbered in tens of thousands) that their total biomass and thus their intake of food are many times greater than the combined total of all other herbivorous animals. Comparisons with machair vegetation on Tiree where there are no rabbits (Vose, Powell and Spence, 1956) are made in detail subsequently, though again it is difficult to isolate effects which are due solely to rabbits. The studies of Ranwell (1959, 1960) at Newborough Warren in Angelsey are helpful in this field and are considered more fully in Chapter 8. Man was responsible for the introduction of rabbits to Scotland, and local reports indicate that the rabbit was absent from the Uists up to the mid-eighteenth century. This agrees with the period of establishment of the animal in analogous areas (Darling and Boyd, 1969, p. 87).

The only other animal which may have a measurable effect on machair vegetation, owes its continued survival, at least in part, to man. Geese, particularly the grey lag goose (Anser anser) Britain's only native breeding goose, graze on the machair. Though its numbers are limited, there being some 400-500 birds dispersed throughout the Uists, it may have an important effect for three reasons. Firstly, it is concentrated in relatively large groups on the lochs which form their breeding territories. Thus, on and around Loch Druidiberg some 50-100 birds are found. The nature reserve situated here is primarily a sanctuary for these rather rare birds. Secondly, these birds have very specific grazing locations, and at times concentrate all their feeding activity within about 100 metres of the edges of the machair-fringing lochs. No evidence is available for support, but it seems to be possible that effects of geese are significant within this zone, particularly as their diet is centred on a few preferential species. Thirdly, their food intake is large, and as a very approximate measure the amount of grazing by three geese is equivalent to that of one cow (Newton, 1968 personal communication).

The above section, illustrates the extent that man has influenced the whole machair environment in the past. In the last two decades man has utilised machair, in two further ways, which are having a considerable effect on the environment, and particularly its vegetation. The establishment in 1949 of the Nature Conservancy, was a landmark in British ecological history, and machair land in the Uists fell under the aegis of this body in 1956 when the Loch Driudibeg National Nature Reserve was created. Almost 25% of this 500 hectare (1200 acre) reserve is machair, incorporating parts of the township of Stilligary, and the large estate-owned Drimore farm, in northern South Uist. The Laird's residence, Grogarry Lodge, lies to the east of the machair land in the reseve, and consequently this 120 hectare(½ sq. mile) machair is referred to in this thesis as Grogarry Machair. An analysis of, and commentary on, the vegetation of this area forms a substantial part of this thesis, and is dealt with in Chapters 8 and 9. Although the main function of this nature reserve is to provide a sanctuary and breeding area for grey lag geese, much study has been focused on the machair. Besides the author's own study (Dickinson, 1968), work on geomorphology, entomology and fresh water biology has been carried out in the machair area.

The normal land-use of the machair is continued in the reserve area, though there is close cooperation between the crofting community, the management of the South Uist estates and the Nature Conservancy. Besides serving as a study centre this reserve provides an excellent example of environmental conservation in which all parties concerned, are trying to work in harmony. The whole of South Uist immediately north of the Nature Reserve is under the control of the Ministry of Defence. Situated on West Geirinish Machair is the range-head of the Royal Artillery (Hebrides) rocket range. This establishment carried out research and testing of both civilian and military missiles. West Geirinish Machair is very extensive, about $1\frac{1}{2}$ km. wide, and provides an excellent location for the launching of missiles. These operations require several hectares of low, level land, but these make very little direct impact on the machair landscape, beyond the 'hardware' of the launch sites and attendant facilities. The larger scale effects are due to the control of the machairs, shores, and coastal waters of northern South Uist, necessary when firing is being carried out. Expansion of both the physical facilities, and of the intensity of the activities of the rocket-range, going on at present, will increase the effects on the machair landscape. It is to be hoped that the authorities cooperate in conservation in this expansion period, and do not allow undue disturbance of the landscape; up to the present the army have made considerable efforts to negotiate with the crofting community, and other parties interested in the machair.

Conservation and military zoning are two contemporary examples of the continued intimate involvement of man, in the machair landscape. Man has had an almost continuous history of involvement in the landscape since the time of stabilisation 2000 years ago. Its effects, direct and indirect, have been profound, and the vegetation of the machair is as much a product of man's activities as of the distinctive ecological niche it occupies. The interrelationships of the human-environmental complex are very difficult to evaluate. Some are easy to identify, many more are not, and all relate to the present structure, composition and status of machair vegetation. Therefore, it must be re-emphasised that man is essentially an integral part of the machair environment, and in terms of the subsequent analysis of machair vegetation, man should be regarded, not as a 'special' factor but as part of the total habitat that has been responsible for the development of this distinctive grassland.

CHAPTER 4

METHODS OF DATA COLLECTION AND ANALYSIS

1. AIMS AND METHODS IN BIOGEOGRAPHICAL STUDIES

The object of this chapter is to relate methods adopted to appropriate trends in vegetation reseach. Particular attention is paid to the broad development of analytical and synthetic methods involving the formulation of generalisations based on sample data.

Fortunately, the specialist worker in this field has several major sources to draw upon which may serve as foundations for an understanding of the contemporary scene and historical development in plant ecology and geography. Early concepts are outlined by Tansley (1947), and a very full commentary together with an extensive bibliography is presented by Whittaker (1962). These two sources give a fairly detailed summary of the development of plant ecology up to 1960. Development of biogeographical research is outlined by Stoddart (1965, 1967) and Simmons (1966), but both tend to be rather specific in approach. Greig-Smith (1964) provides an eloquently stated commentary on techniques in quantitative plant ecology, and an exhaustive bibliography. The latter study has proved invaluable in evaluating methods and in developing techniques for this research project. A general review of trends in vegetation classification and description is provided by Pears (1968a), again offering much useful background material.

Major Trends and Concepts

In the period 1930-50 several leading geographers examined the philosophy and methods of their discipline. Concurrently research in the subject began on an increasing scale, to use more accurate data to delimit, analyse and theorise on spatial patterns (Taylor, 1957; Woolridge and East, 1951; Hartshorne, 1939, 1959).

Biogeography throughout this time remained a rather neglected branch of the subject and specialist work was very limited both in quantity and quality. At the same time plant ecology was undergoing a rapid and important development. During the 1920s and 1930s, the subject had become firmly established as a major branch of biological studies. Research flourished and there was a wealth of published material on a wide range of topics. In the English-speaking countries much attention tended to be focused on the individual species and its relationships with the environment. However, the pioneer work of the Americans Cowles (1899) and Clements (1905) and subsequent theories on succession (Clements, 1916) had, in spite of, or perhaps because of, the criticisms they received, led to a great interest in synecology and particularly its dynamic aspects.

Early pioneers working in Britain produced several valuable studies (Smith, 1898, Moss, 1907, 1913, Tansley, 1911) but circumstances prevented full capitalisation on this base. The elegant work of Smith (1898) is practically the only example of vegetation mapping produced till the 1950s. Tansley's ideas about vegetation followed rather different lines from those in the U.S.A. based on the 'association'[1] a visibly discrete grouping distinguished principally by the dominant species and other species of high abundance. This culminated in the monumental two volume work of Tansley The British Islands and Their Vegetation, (1949). Although open nowadays to criticisms on several technical grounds, particularly the highly subjective methods of data collection and determination of associations, its scope and vigorous style, must ensure its recognition as a major landmark in

[1] See overleaf

the history of ecology in Britain, and responsible to a significant extent for the great strides made in the subsequent two decades. Geographers, too, were influenced by this work (in fact an eminent geographer, H. Darby, had written one section of the book), and an increasing interest in biogeography can be traced from this point.

In France during the 1920s and 30s a sophisticated, hierarchical, classificatory treatment of vegetation had been propounded and put into practice in a number of studies. The individual communities[2] are distinguished on the basis of fidelity, a concept that certain species are more or less 'faithful' to particular communities (Braun-Blanquet, 1951). British ecologists had long been scathing in their criticisms of this sytem, pointing out that, to them it seemed as if the whole scheme was based on the circular argument that communities, defined by groups of faithful species, formed clearly recognisable units. The acceptance of the concept of fidelity presupposes the existence of the community (based on fidelity) and vice versa. Nonetheless apart from Tansley's broad-based survey and a few similar studies, British ecologists were reluctant to put forward any

1 Ecology suffers from a proliferation of confusing terminology to the extent that the same word is used for quite different purposes by different authorities. In this work, in so far as is possible, terms which occur are used in the sense intended by the initial author who is quoted. These terms are denoted by single quotation marks. Other terms used or proposed, are defined in the text.

2 Community is used throughout this section as a non-specific term for any particular 'concrete' or abstract vegetation assemblage.

alternatives to the methods of the so-called Zurich-Montpellier School headed by Braun-Blanquet. In spite of acknowledged defects of these continental phyto-sociologists work and limited usefulness of the results, this school was influential in the scheme used in the series Carte de la Vegetation de France 1/200,000. These maps represented vegetation patterns with a far higher degree of precision than in any previous work, and successfully incorporated information on dynamic process and status, as well as presenting a detailed inventory of present distributions (e.g. Gaussen, 1948). The only major criticism which could be levelled at them, within the context of their system of description and classification, is that they were extremely expensive of time and labour in production.

In the mid-1950s a modification to Braun-Blanquet's scheme was put forward by a British ecologist. M.E.D. Poore proposed that whilst discrete vegetation units could normally be recognised, these could not be placed within a single taxonomic hierarchy, and thus suggested classes which were abstractive and non-hierarchical. These he termed 'noda'. They were to be produced by abstraction from detailed species lists compiled from a number of samples taken at a location where a particular community could clearly be recognised by inspection. With increasing numbers of samples and experience, the subsequent lists which characterise the noda could be refined. This was termed 'successive approximation'. The nodum was recognised on the basis of a combination of attributes of which dominance and sub-dominance were principals, but amongst which constancy and fidelity were also taken into consideration (Poore, 1955a, 1955b, 1955c, 1956). The critical boundary problem was avoided since no attempt was made to recognise the limits of these units spatially, although the samples themselves were accurately located. Poore's constructive criticisms stimulated a reappraisal of ecological studies of vegetation in Britain, and in particular led to the publication of two major works. McVean and Ratcliffe (1962) made a study of the plant communities of the highlands of Scotland "....in a regional account based on a classificatory approach...." (Greig-Smith, 1964, p. 161), although the authors found that: "As work progressed it became increasingly apparent that variation in Highland vegetation is virtually continuous." (McVean and Ratcliffe, 1962, p. 6). By 1964 sufficient work had been carried out to enable a collection of studies drawn from many of the major types of vegetation occurring in Scotland to be published. The methods advocated by Poore form the basis of the studies used in 'The Vegetation of Scotland' (Burnett, (ed.) 1964). Although problems of coverage and of availability of data were noted, it could be stated that: "It is a remarkable testimony to Poore's claim, that his method is primarily one for reconnaissance, that it proved so successful for communities so very different from those on the Breadalbane hills where it was devised." (Burnett, 1964, p.7). In both of these works, altitudinal zonation formed the basic division of the vegetation, and little work was done within a spatial framework.

In the U.S.A. during the 1950s certain other important developments in vegetation description were taking place. In 1951 a study of forest vegetation in Wisconsin utilising and advocating a non-classificatory method of description heralded a new chapter of developments (Curtis and McIntosh, 1951). This method was based on the 'continuum concept' to which this school subscribed, in which variation in vegetation composition was regarded as being continuous, rather than having any clear, well-marked breaks revealing any clearly marked discontinuities between community types. In this continuum study, data were ordered in a single linear dimension (the continuum index a composite index of scores for the attributes of each stand along a transect line). In 1954 Goodall in a study of Australian 'mallee' vegetation, used 'factor-analysis', in which either the attributes (species) of each individual (vegetation stand) or the distribution of each species throughout the stands could be the object of study. In this paper Goodall first employed the term 'ordination' to describe this approach to vegetation study.

The essential differences between classification and ordination are based on the differences in their parent theories, the organismic and the individualistic concepts. In the former, change is believed to be towards similar organismic communities which can be meaningfully aggregated in a classification. Associated with the development of these ideas are Clements, Cowles and Tansley. The latter concept first put forward by Gleason (1926) maintains that vegetation, varies continuously along environmental gradients, and that species forming vegetation vary according to their requirements of individual environmental components. Continuous variation precludes classification and made essential the development of a method in which environmental and vegetational data could be arrayed, and not aggregated in classes

In the mid 1950s three important developments together promoted a considerable advance in the techniques of vegetation description. These were: firstly, reassessment of approaches resulting in non-hierarchical classifications and in non-classificatory descriptions, both normally based on more accurate, quantitative or pseudo-quantitative objective assessments; secondly, the development of electronic computers and mathematical techniques ('hardware' and 'software') which enabled ecologists to base their studies on much large amounts of data, handled by far more rigorous and sophisticated statistical methods than had been possible before; thirdly, advances in all aspects of biology and an increasing awareness of the environment, brought an increasing urgency to ecological studies. However, problems increased with these developments. By 1962, Whittaker could recognise five quite differents schools of ecological thought, which differed not only in approach to problems, but were often at variance in the theory and factual detail of the subject. Proliferation of terminology, usually alas, without any commmon acceptance of meaning for a single word, led to confusion and to barriers between the various schools. Recently a leading ecologist made the following plea: "....we must press forward, doing our utmost to 'sell' ecology, not by any tricky salesmanship, but by intensified research into and teaching of fundamental principles and by bruiting around the applied repercussions of these principles on management and conservation." (Southern, 1970, p.2).

During the 1950s geographers were making considerable advances as a result of an increasing awareness of the necessity to collect accurate, detailed data as a basis for description and theorising. In England between 1930-60 under the aegis of L.D. Stamp and A. Coleman, two complete, national land-use inventories were made. Most of the information collected in these surveys was published, but all too frequently much of the collected data remained in an inaccessible form. Though with more reserve than in the biological sciences, geographers began to adopt the techniques made possible by the advances in data handling, and this above all else made a major impact on the discipline in the 1960s. Chorley and Haggett, pioneers in this field, summarised at length the state of geographical research based on these ideas in 1967. Interest in plant geography increased throughout this period, and a number of important contributions were made. Küchler (1967) gave a detailed account of the techniques which could be employed in vegetation mapping. In his own studies on continental North America he concentrated on the physiognomic rather than floristic attributes of vegetation and on climax or potential, than actual. This approach has most commonly been used by biogeographers in studies of large areas, and has been refined to the extent that such analyses of vegetation are recognised to be of major value in themselves, and are not mere adjuncts to general geographical description.

In 1935 Tansley had proposed the term 'ecosystem' to described a distinctive organisational level composed of a number of biological populations together with their environment "....naturally living together as a sociological unit." (Tansley, 1946, p. 206). This concept provided a 'model' (Stoddart, 1967) which was attractive to geographers, particularly those influenced by the trends of the past decade and was adopted as the basis of many studies. It is a "monistic, structured functional system" (ibid. pp. 524-8) and thus provided a framework which could be used by geographers in their studies of 'biome'[1]-man-environment situations, and the spatial patterns associated with these situations. The machairs of the Uists could be described as an ecosystem and studied within this context.

[1] 'biome' Tansley, 1946, p. 206 ".....whole complex of both plants and animals...."

Recent Related Studies

In both plant ecology and biogeography in recent years, research work has primarily concentrated on improvement and refinement of methodology: this has been to some extent at the expense of the study of actual problems. Since 1956 several studies have appeared, which are related in concept (though different in execution to these studies in the Uists). Pears' studies of vegetation status and history in the Cairngorm Mountains of Scotland. Pears, 1965, 1967, 1968b), showed the present-day altitudinal limits of forest to be related to changes in a number of factors, of which man was deemed to be a most important one: "To determine the natural tree-line in the British Isles is never easy. The long history of human interference, and the paucity of meteorological data make this so." (Pears, 1968b, p. 79). The study was based on evidence drawn from meteorological data, distribution of vegetation types, and study of the historic role of man. Cartographic display supplemented the discussion of spatial patterns. Pears is as explicit in enunciating the methods employed, as in tracing and explaining the developmental patterns he discerned. Taylor in the years 1961-1966 commenced a vegetation survey of Wales at a scale of 1:10560, ".....including every major species of 10% or more estimated cover and quoting an average range of from two to five dominant species per association." (Taylor, 1968, p. 92). The field methods were based on direct visual observation and recording of all "significant" and "characteristic vegetation units" (ibid. p. 92) mappable at the above scale. The concept of this regional survey employing a geographical approach is a commendable one; however, lack of explanation of the techniques used, limit the potential usefulness of the data. As in Pears' work, the emphasis on man's role in shaping current vegetation patterns is considerable, and historical and anthropogenic factors are analysed. The methodology is apparently derived from Poore's concepts, but without detailed explanation it is difficult to see that this is an advance over earlier geographical studies of moorland vegetation, (e.g. Tivy, 1954).

Poore's concepts were developed in a third geographical study - the vegetation of an upland ecosystem (Edgell, 1969), a detailed study of Cader Idris, Merionethshire. The study embodied a vegetation map of 'community-types' of an area of approximately 20 sq. km. (7.7 sq. ml.) of upland terrain (between 200-900 m. (650-3000 ft.) elevation), which was derived from air photographs. "The sampling procedure used was based on that of Poore (1955). The basic sampling unit is a stand, a plant community-site system which usually occupies a reconisable topographic unit." (Edgell, 1969, p. 338). The method of 'successive approximation' (Poore, 1955) was adopted to give lists based on criteria of general physiognomy, dominance, floristic composition and constancy. The term 'sociation' was applied to a community type of more than five lists whilst those with less than five were called 'noda'. The experiences of McVean and Ratcliffe (1962) led the author to delimit intermediary related units known as 'facies'. An 'association-analysis' of the type first used by Williams and Lambert (1959, 1960) was used as a means of accurately correlating the classification with environmental information in the manner suggested by Ivimey-Cook and Proctor (1966). Although it can also provide a check on the efficiency and suitability of the initial classification (Crawford and Wishart, 1968) this was not undertaken in this particular study. Edgell's study is perhaps the most informative spatial study of vegetation yet produced by a geographer.

Methods of Vegetation Description

Ultimately central to the purpose of both plant ecology and biogeography, lies the explanation of the natural phenomena which forms the objects of study. The difference between the two disciplines is in approach and emphasis, rather than in the body of facts which are being studied (see figure 5). Both require accurate descriptive information, specifying as much data as is necessary for the particular study. The complexities of vegetation are such, that description forms a problem of considerable magnitude, and in spite of great research efforts, no solution has yet been found which satisfies data needs for explanatory purposes, in more than a few specific cases. It seems almost certain that no such single solution exists and that a number of alternative schemes can be used to solve problems which have different attributes. In fact different approaches may be used to study one type or area of vegetation with success, depending on the aims of the reseach and the logistics of study.

Description can be based on subjective or by objective data. Subjective means involves a personal statement by the particular worker, on whatever aspect of vegetaion he wishes to study. Clearly error due to inaccurate assessment, difficulty in comparison with other data and problems of standardisation limit the usefulness of such data very appreciably. However, in situations where time limitations or size of study area are major considerations, it may be the only possible solution in spite of its limitations. Whenever possible vegetation data should be obtained by objective means. This involves measurement of the data by accepted parameters, that is scales which have been previously and independently determined and standardised.

Normally collection of such data is much more time consuming than subjective assessments, so that logistics interpose constraints on the amount of data which can be collected. Two devices are used to extend the coverage of such data. Firstly, selected attributes of the vegetation may be measured, to characterise the whole within the objects of the study. The attributes which are most commonly chosen are presence, density per unit area, distance between individuals of the same species, frequency, cover, cover- abundance, and fidelity. These may be accurately measured (quantitative data) or may be placed with a class of prescribed limits, in scale, by means of a subjective assessment (pseudo-quantitative data) (Greig-Smith, 1964, pp. 1-19).

The second device employed is sampling of vegetation. This involves selecting stands of vegetation for measurement or assessment, which will serve as representatives of the total vegetaion. In practice, in all but the most intensive studies of very small areas (or of very limited attributes) sampling is obligatory. Selection of suitable samples may be subjective or objective. The selection of the most appropriate sampling mechanism for a particular purpose is critical, as is the choice of method by which data are to be recorded. Validity of statistical analyses, to a large extent depends on the use of objectively located data (i.e. systematic, random or stratified random data). "Selection of typical sites is clearly inappropriate to a quantitative approach, as their choice is dependent on the observer's preconceived ideas of the character of the vegetation, and data from such samples cannot be considered an unbiased estimate of the vegetation of the area". (Greig-Smith, 1964, p. 21). However, as Poore showed in his studies, subjectively located samples can provide a very valuable source of information for certain purposes, and recently it has been shown that certain data with a relatively high degree of locational subjectivity may be amenable to a particular type of statistical analysis (Crawford and Wishart, 1968). Nonetheless careful consideration of the design of sampling is essential in any study in which it is used; a fuller discussion of this topic is offered by Greig-Smith (1964, pp. 20-53).

Statistical analysis, currently is widely used as a tool to aid rationalisation of vegetation descriptions. Recently, many geographical studies have made wide use of statistical techniques, and in both plant ecology and geography the use of sophisticated data handling devices is becoming more essential, with the increasing quantification of the subjects. The collection of large amounts of numerical data, together with developments in computing, have allowed both subjects to formulate laws, theories or models which can be accurately evaluated. Surveys on the nature and use of such techniques have been carried out by Grieg-Smith (1964) and Kershaw (1964) in plant ecology, and by Chorley and Haggett (1967) and Cole and King (1968) amongst geographers.

In plant ecology two basic approaches to vegetation description can be recognised. These are classification and ordination. Classification of vegetation is often based on the assumption that units broadly corresponding to those analysed, exist in the real situation. It may be used solely as a convenient aid to description, but normally it is held that a classificatory approach is one which also best describes the observed vegetation patterns. Classification may be hierarchical or non-hierarchical.

In the former, units may be grouped into successively larger units through a number of stages, the units of each stage having the same status. The Montpellier school of phyto-sociologists used such a system. In the latter case a non-hierarchical system has a number of classes, but these have no particular status and cannot be readily grouped into larger units. Poore's 'noda' were class units of such a type.

Ordination, a non-classificatory approach to vegetation description has been considerably refined and widely used, since its initiation (Curtis and McIntosh, 1951). Basically it involves the location of an individual or stand in relation to one or more axes each of which supplies information about it. These axes may supply information about the vegetation itself (Bray and Curtis, 1957), or may be measures of certain environmental gradients (Loucks, 1962). Clearly such an approach has more appeal when the vegetation under study is considered to form part of a continuum, in which discontinuities corresponding to discrete units are not readily discernable. Detailed accounts of recent developments in methods of vegetation description are given by Grieg-Smith (1964, pp. 158-209) and Pears (1968a, pp. 165-168).

A great deal has been written about the merits of the two systems, e.g. Webb (1954), Anderson (1965). However, it is becoming clear that each system has particular merits which make its use more suited to either a particular type of vegetation or to a particular study. Nor are the two methods mutually exclusive; classification in some form is normally a necessary prelude to ordination, and ordination may be used as a basis for classification. Although it is pointed out by Greig-Smith (1964, p. 203)...."At the present moment it is not possible to make any firm general recommendations....", it seems most probable that the general trends indicated by him are being substantiated, and the classificatory techniques are being most used in broad, rapid or reconnaissance type surveys, whilst ordinations are frequently successfully applied to detailed intensive studies of rather limited ranges of vegetation. Both methods can be readily related to spatial criteria, and hence are suited to geographical description and analysis of vegetation. The use of quantitative and statistical techniques in both classification and ordination make their assimilation in current geographical methodology most appropriate.

A discussion of the differences in approach, and distinctive subject matter of plant ecology and biogeography is as inappropriate as it is unprofitable. The two subjects have a common field of study, comparable objects and frequently similar methodology. They are essentially complimentary approaches to a single study, each drawing on the main body of the parent subjects. Ecology contributes the specialist botanical knowledge and taxonomic systematics essential for accurate description and interpretation. Geography offers a distinctive spatial approach, and a broad-based experience of the total environment, and in particular the role of man in ecosystems. Geographical method, with its expertise in solving problems on a spatial basis, its human orientated viewpoint and linking position between many disciplines, is appropriate to studies of this sort. Thus, the differing emphasis in approach can make equally valid contributions to the understanding of vegetation.

In this particular study the two surveys were carried out to fulfil the following requirements. Firstly, a spatial description of the vegetation of the two delimited machair areas was required, in which areal representation by means of maps at a suitable scale, and analytical description interpretation based on detailed pseudo-quantitative measures of vegetation were highly desirable. Secondly, the surveys were to provide the maximum amount of information, according to the above criteria, within pre-established limits of study area, time resources and man-power. Thirdly, the two studies were to serve as examples in which methods to achieve the above ends could be developed. Fourthly, the studies were to supply information on a particular type of vegetation, occupying a unique ecological niche and modified in a distinctive fashion by man. In the following section the field methods and data processing techniques which were developed to satisfy these four requirements are described in detail. It should be borne in mind clearly, that the objects of the study shaped these methods, and that whilst recent developments in ecological and geographical research were a critical factor in shaping the structure of the techniques, these developments were subordinate to the purposes of the study, which solely governed its strategy.

CHAPTER 5

METHODS OF DATA COLLECTION AND ANALYSIS

2. FIELD AND ANALYTICAL TECHNIQUES USED IN THE MACHAIR SURVEYS

The field techniques and the analytical methods, which were used in the two surveys of machair vegetation in the Uists, were developed with reference to research work already carried out as indicated in the preceding chapter, but primarily in response to the particular demands of the project. The following is a detailed account of the methods which were developed to meet these requirements.

1. A Detailed Study for a Small Area

The method of field work was determined by three factors each of which posed certain related problems: (1) the time and resources available for the project; (2) the size and nature of the area under study; (3) and the use to which the data was to be put.

The whole project which was carried out between October 1967 and November 1968, was to provide a vegetation survey of the machair part of Loch Druidibeg National Nature Reserve. The bulk of the field work had to be carried out in the winter months when weather could have seriously limited the amount of work done outdoors. Fortunately at no time, however, was the author seriously limited by inclement weather. As about two-thirds of the original data were collected during winter, it was realised that this might give a seasonal bias to the vegetation analysis. However, a further visit in late May, during the growing season, revealed that whilst there were some changes in the relative abundance of species within groups, the limits of, and differences between these were not altered substantially. Nor was the character of these groups substantially altered. Careful observations, checks at later dates, and an examination of the summer flora by Wilson (1967) indicated that the main differences (which would occur in annual plants), were likely to be relatively minor in terms of overall cover measurements, and of the groupings resulting from these.

Although the area under study was relatively small (approximately 130 hectares - 320 acres) time limitations made the use of any form of intensive random sampling impractical. Moreover, as an initial reconnaissance showed that different types of vegetation did not occupy the same sizes of areas, it did not seem likely that any low-frequency, random sampling would provide sufficient data for mapping purposes. A further consequence would be that problems would arise in statistical analysis. Therefore, non-random methods were used, as these provided ample information for the scale of work that could be carried out in the time available. As this survey was of the rapid, reconaissance type, a classificatory approach was considered most appropriate. Non-randomly located data, as has already been indicated, proved most suited to the purpose and viewpoint of the project. Another problem related to the nature of the area was the difficulty of obtaining precise locations. Grogarry Machair is quite flat and relatively free from man-made features such as fences and telegraph poles, which might have facilitated work. However, it was found that with the help of the 1:2,500 map, and the use of air-photographs, points on the ground could be established on the map to within limits of accuracy necessary for the scale of this study, i.e. the location of points could be established within 1 metre, and at the initial drafting scale of 1 : 1,250 (2x that of the final map), this is represented by less than 1 mm which approaches the limit of plotting capability.

From previous research, reconnaissance, and other studies on machair in Scotland, it is clear that a number of well-established ecological gradients run from the Atlantic shore across machair land to the 'black land'. As response by vegetation to these appeared marked, sampling by transects following the line of the ecological gradients was appropriate. The coast at Grogarry Machair runs approximately north to south, and the ecological gradients were taken as extending from west to east more or less constantly. Sampling along transects was by means of quadrats of one metre square. Measurements of cover-abundance were taken using a modified ten-point Domin scale (Evans and Dahl, 1955). There were several reasons for obtaining information in this way. Firstly, the size of quadrat is that most frequently used in surveys of unwooded areas in Britain. Secondly, it gave a reasonably accurate pseudo-quantitive measure of dominance; this quantity relates closely to the overall composition of the vegetation. Thirdly, it could be collected fairly rapidly and required little equipment or special techniques. Fourthly, these measurements have been most frequently used in current British ecological research, and therefore allow data to be presented in a standardised manner which facilitates comparison with that collected by other workers in other areas. Fifthly this minimises sample size and edge effects problems. The one metre side square seemed likely to offer the best compromise, without detailed preliminary, statistical investigation of the vegetation patterns. In view of the limited time available, this was the only practical approach. According to one leading authority...."No guide but experience and trial of different sizes can be offered towards effecting this compromise."

(Greig-Smith, 1964 p34).

The merits of these methods have been effectively demonstrated in the recent works on Scottish vegetation (Burnett (Ed.) 1964; McVean and Ratcliffe, 1962).

The locations of both transects and quadrat samples were established largely by subjective means, based on an extensive initial reconaissance. The whole of the area under study was covered on foot, and wherever the visible appearance of stands of vegetation changed, possible boundary zones were noted. In practice, the results of the reconnaissance were found to conform fairly closely to the Reconnaissance Vegetation map by Wilson (1967), and with few modifications this map was used as the reconnaissance document. At this stage locations for transects were selected; these were placed in order to include not only samples of major types of vegetation but also physiographic variations within the area. Along each transect the number of quadrat samples was also determined by the visually differentiated stands. Where vegetation appeared relatively homogeneous, sampling was at a low intensity (about 1 sample per 20–40 m.) and where an apparent boundary was crossed the frequency with which quadrat samples were taken was correspondingly increased (to approximately 1 sample every 2-5 m.) At first appearance this process would serve merely to substantiate the vegetation patterns derived from the reconnaissance. However, as is shown more fully subsequently, this was not the case. Once the data were obtained, they were analysed by relatively objective means, based on the empirical qualities of the information, and not on preconceived impressions of Machair vegetation. The results substantially confirmed the validity of this approach to data collection. Significant differences in vegetation composition, not readily apparent during a rapid visual inspection, were discovered. This method of field work gave more satisfactory results in terms of the conditions of the project, than an entirely subjective or objective approach.

Having decided what data to collect, the methods of collection, and the way in which this information was to be used, there remained the practical problems of the actual field work. A full coverage of the area was obtained in six transects, and in all, more than 160 quadrat samples were obtained. Transects were laid out using surveyor's ranging rods, a cloth measuring-tape 30 m. long, a prismatic compass, and several steel pegs. The starting point of each transect was wherever vegetation first appeared above high-water mark on the beach. This point was located with care, by taking bearings on to, and measuring to, obvious known points such as paths and drains. When this starting point was established, it was marked clearly on a field copy of the 1 : 2,500 map (Wilson 1967). The transects ran in a straight line due east to the inland edge of the machair. In all but one case, the eastern boundary of the machair vegetation was taken at the western bank of Loch a Mhachair. In the remaining case, a boundary wall on the eastern side of the marsh between the machair and 'black land' provided a suitable terminal point.

On a bearing taken with the prismatic compass, the transects proceeded across the machair in a true easterly direction. It was a simple matter once this bearing was established, to keep a true direction by lining up the ranging rods. If two were along the line of transect at any one time, a third placed in the same line of sight continued the transect in the required direction. Quadrats were taken along each transect at the prescribed intervals. The distance of each sample from the start of the transect was noted on the tape, and this was recorded, together with the vegetation data obtained from that quadrat. Ancillary data on location, nearness to certain features, slope and drainage were also recorded where this was significant. The apparatus used for delimiting the area of one square metre, for quadrat samples, consisted of four metal pegs about nine inches long, held together by a stout cord, and forming a square of side one metre. This device was both accurate in practice, as was revealed by frequent checks with a laboratory metre stick, and convenient to transport. The whole of the equipment used in the field was readily portable and could be used with little difficulty by the author alone.

In obtaining data from the quadrat samples the following procedure was adopted. A careful examination of the area, which the sample occupied, was made, in which all the plant species present were noted. Samples of unknown types were taken for identification; several samples were identified by Dr. H. McAllister, to whom the author is most grateful. Once the species list was complete, the cover value for each species present was noted. This was an estimation, but the Domin scale limited error since it used percentage values which were converted to an index number for a range of percentages. Comparison with values obtained from the same quadrat area, at the same time, by very experienced workers revealed a close similarity. The sampling methods were further supplemented by field sketches, plans and photographs in areas of particular interest. As a secondary effort, several other types of information were recorded in the field. These included some soil samples, chiefly on depth and nature of organic horizons, obtained with a core augur; these were taken as indices of soil stability. Information on flooding, drainage, present cultivation, and patterns of former cultivation was also collected, largely by observation, measurement and interview.

Although the whole of the method of collecting and processing information to produce a map and an analytical description of the vegetation of Grogarry Machair was evolved before the start of field work, the studies of Poore (1955, 1966) and other authorities over the last fifteen years were taken into consideration in deciding methods of analysis and description. In the case of this study the author was primarily concerned with considering the area from a geographical viewpoint. This meant that delimitation of 'concrete' associations or stands, which occupied specific areas on the ground, was considered to be of much greater significance than the identification of established 'abstract' community-types, by 'minimal-area' techniques. (Burnett (Ed.), 1964; p.6).

The actual processing programme was undertaken in three stages. These were: initial reduction and tabulation of data; sorting into groups; and, mapping, description and interpretation. Firstly, the information was transferred from field notebooks to a more clear and convenient form. This was followed by tabulation of the data taken from the quadrat samples. A constant species list was drawn up, including every species encountered in any of the samples. Each quadrat sample was represented by a vertical column with the cover-abundance for each species present being entered in the appropriate column. Blanks were left in the column for species which were absent from a particular sample. To aid the process of sorting, the Domin scale values were grouped into four classes, and each class entered on the table in a different colour. Initially, the quadrat samples were recorded in the order in which they were collected in the field. Subsequently these were rearranged into a conventional list. When all the samples were entered on the table, each vertical column representing an individual quadrat was cut out. Thus prior to sorting, every sample was represented by a long strip of paper on which data were recorded in a standard form. Samples could be sorted visually, and ultimately the table reconstituted, with the samples grouped into comparable units.

Grouping samples was a largely objective operation since the derived units were based on certain empirical attributes of the data, and neither geographical location, nor the reconnaissance of visible stands played significant parts in this process. The process was carried out at two levels. The first stage was to sort the samples according to dominant species. In practice, four major classes were clearly delimited. These were samples with dominants of Festuca rubra, Ammophila arenaria, Moss species and other species. Within each of these four classes, a second sorting process was carried out. There was no single uniform criterion for this operation, rather a variety of standards were applied, dependent upon appropriateness for that particular sub-group. Cover-abundance, presence, and number of species in samples were the measures used. In spite of the apparent weaknesses in this system, in practice it was most satisfactory, since the units produced by this means were based upon real similarities present in a number of samples of the vegetation. If uniform standards had been used, a more satisfactory classificatory scheme would have resulted, but it would have been at the expense of obtaining groups which corresponded to real differences in the vegetation of Grogarry Machair.

Final subdivision gave about 25 separate units. Before these data were transferred to the map, it seemed most unlikely that all these groups would form relatively homogeneous areal units. Nevertheless, the scheme produced satisfactory results from the first, and only minor changes had to be made to give material which was suitable for mapping purposes. There were two reasons for the success of this method. Firstly, the whole of the process was devised with the purpose of obtaining the most accurate picture of the actual patterns of vegetation. Secondly, the type of vegetation which was the subject of this study gave very clearly distinguishable stands. This is a characteristic of vegetation occupying habitats where dynamic processes, seral change and a marked response to micro-habitat have primarily shaped vegetation patterns. In these situations of vegetational instability, ecotones are most frequently very narrow, and distinctive stands are likely to occupy each sector of the habitat. A summary of this information is contained in appendix 3, and which gives simple averages of the samples which constitute the final units. Any average value for a particular species which was below 1.0 was recorded as 1.0., and averages were rounded off to the nearest whole number. Clearly there are many disadvantages in such a scheme; averages are inaccurate, and low values are difficult to compute the table can give no more than an indication of the vegetation characteristics of each unit. The descriptions and analysis in chapters 6 and 8 are based on a detailed consideration of all the material, and not simply on this table.

Transference of the data from the table to a map was carried out in two stages. A schematic diagram at two times mapping scale (i.e. 1 : 1,250) was constructed. On this diagram the limits of the area were shown and transect lines entered accurately. The location of each quadrat sample was plotted, and the sub-group into which it fell indicated by an index letter. On the diagram, quadrat samples in the same sub-group were taken to form a spatial unit. However, in some cases a spatial unit included more than one of the vegetation sub-groups derived from the table; in these cases there was a marked similarity in most respects. At this stage a few adjustments were made to the results of the scheme of classification. This involved transferring some samples to different groups to give coherent areal units. However, for the reasons given above, few changes had to be made from the original draft. Boundaries to vegetation zone were drawn on the diagram. Placing of boundaries, where these fell between transects, was aided by information gathered previously for that purpose on geomorphology, date of last cultivation, flooding, and presence of particular plant species. There was some variation in the width of the ecotone between spatial units. In many cases it was so narrow that the boundary could be termed sharp and indicated with reasonable accuracy by a definite line, but in a few cases it was broader and a more diffuse boundary had to be shown.

When the schematic diagram was complete, the information it contained was transferred to an accurate manuscript map at a scale of 1 : 2,500. During this process attention was paid to the design of the map. Use of shading patterns, lay-out, and lettering sizes were the main considerations, and in this aspect the technical sections of Küchler (1967) proved valuable. Lastly, a final copy of the map was drawn in which the same degree of accuracy of detail was maintained, but a higher carto-graphical standard was applied. A reduction of this map is shown in map 8 and the original is contained in appendix 2. The table summarising description of the vegetation is shown in appendix 3.

2. A General Study for a Large Area

The Grogarry Machair survey was carried out in approximately one year, and was designed to give an analytical description of, and commentary on, the vegetation of approximately 1 sq. km. When this study had been completed it was decided to undertake a second study of machair vegetation in the Uists. In this second project the area (the whole of the machairs of the three main islands) was of a quite different order of scale, but the time allowed for the survey was approximately the same as for the detailed Grogarry survey. Thus the field work in this area of approximately 70 sq. km. was carried out in about eight weeks, compared with the six weeks which the detailed survey took.

There were several reasons for attempting a survey of all machairs in the Uists. Several important questions on the nature of the vegetation had been raised during the Grogarry survey, and it was most unlikely that any sort of answer to these could be given without further studies in other machairs. A geographical inventory of the vegetation of the machairs of South Uist, Benbecula and North Uist was a justifiable end in itself. The area was circumscribed by well-defined boundaries, those of the three main islands, and the offshore islets which were clearly morphological components of the Uist machairs; (i.e. North Uist, Benbecula, South Uist, together with Oronsay, Vallay, Kirkikost, Baleshore, Vorran and Orosay islands). This provided a convenient framework for analysis, and as this was a distinctive geographical unit, in which machair vegetation was virtually continuous along the western and north-western coastlines, yet clearly separated from other similar areas in north-west Scotland, the hypothesis that the region would be ecologically significant seemed sound.

The size and location of the survey even provides a third reason for undertaking the small scale study. The absence of major ecotones, the relationships between vegetation and environment and comparability with other dune and coastal studies indicated that this was a highly suitable study location. The total area under consideration and size of the delimited units were well suited to the study methods developed, and the scale of the survey was convenient to the union of ecological and geographical ideas.

The area under study was approximately 55 Km. from north to south and varied in width from a hundred metres or less to two kilometres or more, but was normally within the range half to one and a half kilometres. This not only necessitated the use of new field methods for data collection, but also gave rise to certain new problems in the execution of the field work. Accessibility to machair areas rarely posed any problem and normally no more than a few kilometres walk was necessary to visit any particular site. However, in the case of the offshore machair islets certain difficulties were encountered. Baleshore island is connected to the mainland of North Uist by a causeway; Gualann Strand is accessible from South Uist by wading across a channel about 100 m. wide and no more than 30 cm. deep at low tide; Vallay Island can be reached by crossing the strand from North Uist, a distance of about 2 km., which is uncovered for about two hours on either side of low tide. Kirkikost Island, however, could only be reached by boat, crossing the channel between Kyles Paible and the north-west tip of the island, a distance of approximately 300 metres.

The main problem in carrying out the field work was distance. From the extreme south to the extreme north of the field area was almost 100 km. by road, and travelling made significant inroads into the available time. A further problem concerned the availability of a suitable base map for field survey. The 1 : 10,560 scale O.S. maps were the only series available at suitable scale for the second study. These were rather dated, having been originally surveyed about 1875 and last fully revised in 1900-1. None the less, within the limits of accuracy of the field mapping, this series proved perfectly adequate for the survey. It is noteworthy that only in the last few years has this part of Britain been resurveyed, and as yet few large scale sheets have been published. None of these problems, however, proved a serious obstacle to the field work programme, but careful planning was necessary to make best use of the available resources.

The field techniques which were developed to undertake this survey differed considerably from those used in the Grogarry Machair survey. However, there were features common to both. The first is that the fundamental purpose was to provide an accurate description based on pseudo-quantitative data, which would form a basis for analysis and explanation of the vegetation patterns. The second is the assumption that the major units recognised in the Grogarry Machair survey could be distinguished in machairs throughout the Uists. These units form discrete groups characterised by distinctive visual appearance and a phyto-sociological composition which is sufficiently homogeneous to be classified. Relationships between these vegetation zones and their physical environment were normally recognisable.

The normal procedure in collection of field data was to survey an area of approximately the same order of size as Grogarry Machair at one time, i.e. an area of 1–4 sq. km. This usually took one or two days. A brief reconaissance of the area was made noting distinctive or unusual features. Following this, the limits of the zones which were recognised were drawn accurately on a field copy of the 6 inch scale map. This was carried out by observation and in conjunction with the detailed geomorphological maps of Ritchie (1966a,1970). Air photographs which under other circumstances would have been invaluable were not used, due to the indifferent quality of the available prints, and the fact that Ritchie's maps were largely based on interpretation of air photographs. The information which would have been abstracted from air photographs was contained in Ritchie's maps and thus these provided a satisfactory and more convenient substitute. Using these methods, points normally could be located to within two or three metres and this was sufficiently accurate for mapping.

Within each delineated zone, sampling was carried out according to the following procedure. Metre square quadrats were delimited by means of a portable frame. Within each quadrat all species present were identified and accorded a cover-abundance value on the modified Domin scale shown in table 5. This scale was devised and adopted for the following reasons. Firstly the incorporation of the lowest three values into one single class (P) meant that work was considerably speeded up. Any plant which was present, but the cover-abundance score of which was less than 4% (as reckoned on a conventional Domin scale) could be placed immediately in a class. This limited the amount of time which had to be spent in making assessments of a small number of an individual species, a task which normally occupied much of the time devoted to sampling. This procedure in no way detracted from the accuracy or thoroughness of the sampling procedure. Secondly, the substitution of one single value for the Domin scale values + to 3 would seem to provide an answer to one of the major problems in the use of the Domin scale. It has been stated that; "When the Domin scale is examined with respect either to cover or frequency alone or to combined cover and frequency estimates, it is found that the relationship is non-linear, particularly in the lower part of the scale. Such a non-linearity would seem to invalidate the direct averaging of Domin values in order to provide estimates from a number of stands." (Bannister, 1966 p665). Furthermore if importance values are used; "Species with a high Domin scale (dominants) will tend to be underestimated (in terms of importance values based on measures of cover and frequency) whilst these species with only low scores will tend to be overemphasised." (ibid. pp. 665-6). In this paper Bannister devised a scheme based on regression of combined cover and frequency values whereby transformed Domin numbers might be obtained. "These transformed values can be used for the calculation of species importance values, or, with back transformation for producing more accurate averages of several Domin numbers, where this is considered desirable." (Bannister, 1966 p667). Using Bannister's regression formula, a single transformed value was calculated to allow average values to be calculated utilising the new lowest class (P). In fact whilst an approximate value was obtained, derived from the regression equation for the upper part of the graph (this value was 28), this approximation was very close to the correct value as the trend of the whole of the new 8 point scale was very close to that of the regression line for the upper 7 values of the 10 point scale. The synoptic descriptions of the vegetation of the zones is based on this method with certain modifications. The data used were not those quoted in Bannister's paper of 1966, but were based on an improved approach advocated by him at a later date (Bannister, 1970 – personal communication). In this, the formula used to calculate all the transformed values was $t = (3.117 + 1.082\,d)^2$, where t = transformed value and d = Domin number. The new transformed values are shown in table 5.

The third reason for using this eight point scale, is that it seemed well suited to a geographical description of vegetation. Dominance and cover of the principal component species would be well represented in the abstracted descriptions. Species with low cover-abundance and frequency values, which might be of ecological significance in terms of their presence in a particular location, could be recognised without detracting from the main features of the system. The aim of this sampling system was to produce a scheme which gave prominence to cover-abundance and frequency without neglecting presence and the overall species list.

Sampling which gave the primary data for both the description and the subsequent analysis of the vegetation was carried out in the following way. Between 3 and 5 samples were taken in each 'block' (the basic area delimited on the maps); the number depended on the approximate size of the block. In a block of area less than approximately 10,000 square metres (0.01 sq. km) 3 quadrats were taken, areas between 10,000 square metres and 100,000 square metres (0.1 sq.km.) were sampled at four points, and if a block exceeded 100,000 square metres in extent five samples were taken. This semi-logarithmic relationship was used to relate the number of samples, to the area of the block, without giving undue prominence to discrete blocks of large absolute size. The location of the samples was made randomly by taking samples at points along a line following the longest axis within the blocks. The points were selected by pacing out a prescribed number of steps, according to a table of random numbers. As far as was possible, each discrete block was sampled, but in a few cases where blocks were very small in extent or made up of a number of small components at a particular location, one group of samples was taken as being representative. Very extensive areas covered by a continuous single block were not uncommon. In some cases blocks ran unbroken from north to south for several kilometres. In these instances a group of samples was taken approximately every kilometre. Whilst certain problems were encountered, this procedure yielded data which was suited to the methods of description and analysis employed in the survey.

Two further considerations relating to field work are worth noting. Firstly a constant species list, an example of which is shown in Figure 6, was used. This facilitated field work and made handling the large number of samples collected much more convenient than by recording in field note books. If very large amounts of data or sophisticated statistical analyses are used, it might be desirable to record data in the field on some medium which can be transferred directly to a computer store. Secondly groups of species-area curves were drawn up from samples taken for that purpose. Contiguous plots, alternately square and rectangular, ranging from $\frac{1}{4}$ square metre to 4 square metres and doubling in size at succeeding levels, were delimited, and the number of species occurring within each noted. These samples are difficult to evaluate (Greig-Smith, 1964 pp153-6) but provided some information on the relative suitability of the sample design. The results are shown in Figure 7, and it can be seen that at the 1 square metre level, normally a turning point is reached.

Analysis of field data was undertaken in three stages. Firstly a series of maps derived from the field maps were drawn up. These are shown in appendix 2. The major problems involved in the production of these maps were of a technical cartographic nature, similar to those mentioned in the preparation of the Grogarry Machair map (see above). Location of boundaries was only exceptionally a problem due to the absence of well-marked ecotones, and to the method of field mapping. Choice of area patterns was more difficult and care was necessary to select black and white patterns which could be distinguished on the final map. These maps, as were all those in this thesis, were drafted on translucent media and subsequently photocopied.

Secondly the data was processed to give a synoptic summary. These tables are shown in appendix 4. This formed the second basis of vegetation analysis and description. As noted above, the field procedure was devised so as to yield data from which meaningful averages could be computed by Bannister's 'transformed values'. This was a simple, if tedious, arithmetical procedure, which could be speeded up in future by the use of simple computing techniques.

Thirdly using both bases, the maps and the statistical description, a geographical analysis of the vegetation of the machairs of the Uists was developed.

This is the substance of chapters 8 and 9. Interpretation was based on the following: (1) location analysis particularly with respect to environmental gradients; (2) relationships between vegetation and geomorphological processes; (3) relationships between vegetation and existing or past land use patterns and practices; (4) other possible relationships, such as those with drainage and soil characteristics; (5) evaluation of dynamic processes within machair vegetation. The description and analysis of the vegetation of machair in the Uists, in the following sections, concentrate on generalised patterns and broad interrelationships, both appropriate to a geographical approach.

CHAPTER 6

THE GROGARRY MACHAIR SURVEY

The precedure described in the previous chapter resulted in the production of a map of the vegetation of Grogarry Machair, in which five major units were distinguished, each of which being sub-divided into a number of sub-units. The detailed map produced is contained in Appendix 2, and the statistical table on which vegetation description is based is found in Appendix 3. Map 8 is a reduced version of the detailed map, produced to conform to a format for inclusion in the text of the thesis. Each unit delimited was given a simple descriptive name, and is designated by an index letter, which corresponds to those used in the Uists survey. The units delimited in this detailed survey are thus comparable directly with those of the large scale study. The absence of units, B, G and J from the Grogarry area is a reflection of the range of vegetation. The results put forward in this chapter are analysed in chapters 8 and 9, together with those of the Uists study. In order to maintain continuity in the text, photographs of machair vegetation with full captions are contained in Appendix 5, separate from this chapter.

Unit A: The Dune Front

This zone is located on the seaward-facing slope of the dunes which back the cobble bank on the Atlantic shore. Three sub-units can be distinguished on the basis of percentage vegetation cover and the relative importance of *Ammophila arenaria* in particular locations. The first sub-unit (A_1)[1] includes areas in which total vegetation cover is less than 50 per cent. *Ammophila arenaria* with a cover of less than 10 per cent is usually the only significant

1 This index refers to the particular sub-unit as shown in the key of the map

species present. Whilst *Rumex crispus, Bellis perennis, Festuca rubra, Sedum acre* and *Honkenya peploides* are present to a very limited extent, they are minor components of the vegetation. Moss species are absent. This sub-unit occupies narrow strips no more than 8 metres wide in the south and extreme north of the unit. It did not occur in the centre.

The second sub-unit (A_2) is also characterized by dominance of *Ammophila arenaria* but differs from A_1 in having a total vegetation cover of more than 50 per cent. Six or more other species are frequently present in samples. These included *Rumex crispus, Plantago lanceolata, P. maritima, Sedum acre, Festuca rubra, Trifolium repens, Bellis perennis* and *Galium verum*. Individual cover values rarely exceed 10 per cent for these associates. Moss species are again virtually absent. In the southern part of Grogarry Machair dunes, this division forms a strip generally less than 6 metres wide immediately behind the first sub-unit. As in the case of the latter, A_2 is discontinuous, being absent from the central part of the area. In the north, however, it is more extensive than A_1, and thus over much of that part of the dune fore-slope forms the first distinguishable unit above the unvegetated cobble bank.

The final sub-unit (A_3) is distinguished by a complete vegetation cover in which *Festuca rubra* is dominant with *Ammophila arenaria* sub-dominant. The combined cover-values of these two species do not fall below 75 per cent in any sample. Samples register up to 10 species, including those found in A_2 with the addition of *Lotus corniculatus* and *Vicia cracca* spp. Mosses are found present, the main representatives being *Rhytidiadelphus squarrosus* and *Hylocomium* *splendens*. This sub-unit is confined in extent to the southern and central parts of the area under study. In the south it is located behind the second sub-unit, in sequence from the sea; in the centre it encroaches directly on the cobble bank until it merges into A_2 which occupies the northern parts of the coastal edge. The width of the strip nowhere exceeds 10 metres.

The establishment of boundaries in this unit does not present severe problems. Only in the centre between A_2 and A_3 is there any appreciable ecotone. Elsewhere, boundaries between the different types of vegetation are sharp.

Unit C: The Dune Back Slope

The back slope of the sea dunes is quite different from the seaward-slope. It is up to 100 metres in width, and extends from the dune-crest to the seasonally flooded dune-slacks. The difference in elevation between these points varies between 3 and 6 metres. The vegetation in this area also contrasts markedly with that nearer the sea. Bare ground is extremely rare, being confined to patches of recent erosion. *Ammophila arenaria*, whilst frequently present, is generally of considerably less importance. Finally, a larger range of species is encountered in this zone.

The Dune Back Slope is composed of four sub-units. In the extreme south is a vegetation complex (C_1), associated with a terrain of low irregular hummocks, standing less than 60 cm above the general surface. Vegetation near the top of these flattened mounds is dominated by *Ammophila arenaria*, with *Festuca rubra* and *Rhytidiadelphus squarrosus* important associates;

the rest of the species, which rarely exceeded 10 per sample, most frequently include Trifolium repens, Rumex crispus, Plantago lanceolata, Bellis perennis, Ranunculus repens, Lotus corniculatus and Galium verum. In the depressions between the hummocks, the moss Rhytidiadelphus squarrosus frequently attains dominance, whilst over the rest of the sub-unit Festuca rubra is the dominant species. In both the latter instances, the list of associated plants is similar to that for the Ammophila arenaria dominated areas. The dominant species rarely exceeds a 50 per cent cover-value, and the remainder of the cover in samples is found to be shared in approximately similar proportions by the associates.

The second sub-unit (C_2) occupies the centre of the unit, and includes that part of the region from which dune slacks are absent. Here terrain is rather higher and more broken than in C_1. Steep-sided, vegetation-covered, most probably recolonised, depressions cut into an elevated surface. Throughout this sub-unit Festuca rubra is dominant, but Ammophila arenaria is normally present, though never achieving cover values as high as those recorded for the fescue (up to 50 per cent). The associated species, the most frequent of which are similar to those found in C_1, are correspondingly reduced in abundance. Mosses, too, have lower cover ratings, but were present in most samples. Again Rhytidiadelphus squarrosus is the most frequently encountered species, but Hylocomium splendens and Acrocladium cuspidatum are also present. In the deep depressions mentioned above, evidence of a wetter habitat can be observed, in the form of stands of

Potentilla anserina and Rhytidiadelphus squarrosus. In one case a particularly dense stand of Urtica dioica can be seen in the bottom of a deep depression. This was the only occasion on which this plant was observed on Grogarry Machair, and its presence is probably due to human interference with the site.

The vegetation of the Dune Back Slope to the north is again quite different from that of the southern units. In the extreme north this unit extends for more than 100 metres between the dune crest and the edge of the seasonally flooded slack; further it includes two distinct vegetation sub-units. The western sub-unit (C_3) lies in a physiographic complex of erosion and stabilization. Extensive blow-outs are abundant and the surface of the Machair can be observed in all stages from totally bare, unstable, sand corridors to wholly stabilized depressions with a complete vegetation cover. Similarly the vegetation is a complex showing at different points different stages in a secondary psammosere. On a fresh sand surface initial recolonization can be effected by a number of agents. Ammophila arenaria though commonest was by no means the exclusive coloniser. Bellis perennis, Plantago lanceolata, Sedum acre and the moss Rhytidiadelphus squarrosus also share this role. Figure 8 shows in detail a good example of this process.

Once a bare sand surface is stabilised Ammophila arenaria attains quite high cover-values, sometimes forming dense stands. These seem to be related to the presence of a sand supply from still unstable parts of a blow-out. With full recolonization Festuca rubra becomes the clear dominant and whilst Ammophila arenaria remains frequently present, its cover value is no higher than the other typical associates. These include Bellis perennis (which occasionally has a cover value of more than 25 per cent), Trifolium repens, Plantago lanceolata, Rumex crispus, Ranunculus repens, Galium verum, Lotus corniculatus and Hieracium spp.; Rhytidiadelphus squarrosus is commonly present but normally of low cover-value.

To the east of this complex, the surface relief becomes much more level and the back slope falls gently to the edge of the Winter-loch site. The vegetation of this sub-unit (C_4) exhibits three marked differences from that to the west. Firstly, there is very little active erosion and thus virtually no complex of seral stages. Secondly, Ammophila arenaria was always present, with cover values up to 33 per cent. Thirdly, certain species indicative of a wetter habitat become prominent. These include Carex spp., Ranunculus ficaria, Sagina martima and most notably Potentilla anserina. In general the rest of the species list is similar to that in C_3, with Festuca cover-values up to 75 per cent. Particularly dense localised stands of Potentilla anserina and Rhytidiadelphus squarrosus occur along the edges of the winter-loch site. Near the southern end of this sub-unit demarcation between it and C_3 is sharp. Further north, however, the boundary becomes increasingly diffuse and at the extreme northern end an ecotone more than 30 metres wide occurs between C_3 and C_4.

Within the whole of the Dune Back Slope boundaries are most frequently diffuse, and only on the western edge does the dune crest give a clear delimiting line. The ecotone between the hummocky complex (C_1) and the central area of broken terrain (C_2) is narrow, but the transition to the northern eroded complex (C_3) is almost imperceptible over at least 60 metres. To the east, the winter-loch sites in the dune slacks provide a clear-cut boundary, but in the central area where a line of low sand hills interrupts the continuity of the slacks, an almost imperceptible change in the type of vegetation occurs over an ecotone of 15 metres.

Unit D: The Elevated Areas East of the Dune Slacks (Sand Hills)

The major part of Grogarry Machair lies east of the dune slacks. This is the area which is commonly cultivated by the Hebridean crofters and which, as a result, is referred to as 'the machair' in local terms. It is bounded to the east by Locha Mhachair, Loch nam Balgan and marsh land. These latter features mark the landward limits of machair as defined for the purposes of this project. However, this very extensive area is by no means uniform in vegetation cover. There are several areas of upstanding relief and on these occur types of vegetation which contrast most strongly with the surrounding level plain. Three different vegetation sub-units can be recognised on these upstanding areas. Each is clearly distinguishable from the Machair Plain by the presence of *Ammophila arenaria*, and other distinctive vegetational traits indicating response to rather different habitats.

The first sub-unit delimited (D_1), consists of a number of sand hills in the southern part of the Grogarry Machair complex. The largest of the areas comprising this sub-unit merges in the west with the broken, high Dune Back Slope (C_2) and forms an area of high ground between the two dune slacks. This large area extends in a south-easterly direction to within 90 metres of Loch a Mhachair. Three smaller areas included within this zone are found immediately to the east of the dune slack occupied by the Lon Mor lochan.

The salient characteristics of this vegetation sub-unit are firstly, the presence of Ammophila arenaria, secondly, a low total number of species present in samples and finally, the important role of mosses, particularly Rhytidiadelphus squarrosus. All of these features contrast markedly with the surrounding Machair Plain. Ammophila arenaria clearly delimits the extent of this sub-unit, as it is entirely absent from the latter area. Its presence seems likely to be associated with the supply of fresh sand, obtained from blow-outs in less stable sand hills. The other characteristics of the vegetation are also related to conditions of relative instability and the whole cover of this sub-unit gives the appearance of being at a less mature stage than the surrounding areas. Festuca rubra is the most common dominant, but both Ammophila arenaria and Rhytidiadelphus squarrosus attain quite high cover-values. The rest of the short species list most commonly includes Ranunculus repens, Rumex crispus, Lotus corniculatus, Carex spp. (Carex panicea is most common, but Carex arenaria was also present), Plantago lanceolata and Trifolium repens. The cover-value of the three principal species together usually exceeds 70 per cent, so that other species have relatively low values.

The second vegetation sub-unit (D_2) in this major unit extends eastwards from the northern winter-loch site. Though quite different in physiographic detail, it exhibits similar contrasts in vegetation as compared with the surrounding Machair plain as does D_1. A sobriquet of 'pimple dunes' has been aptly suggested for this area. It consists of a dense system of low mounds, close enough together on the ground to give the surface a rapidly undulating character. In terms of vegetation this sub-unit has certain notable features. Again the presence of Ammophila arenaria clearly delimits it from the surrounding Machair Plain. The rapid alternation of low hummocks and intervening depressions gives rise to a vegetation mosaic. On the mounds Ammophila arenaria and Rhytidiadelphus squarrosus are dominants each having cover-values generally in excess of 33 per cent. The accompanying species commonly found in samples are Festuca rubra, Carex spp. (chiefly Carex panicea), Trifolium repens and Lotus corniculatus. In the hollows, the stands of Ammophila arenaria and Rhytidiadelphus squarrosus are virtually absent. The dominant species is Carex panicea, which frequently occupies more than 50 per cent of the total cover. Its associates are Festuca rubra, Ranunculus repens, Bellis perennis, Sagina maritima and the mosses Pseudoscleropodium purum and Mnium undulatum. Individual cover-values for these species rarely exceeded 10 per cent. The whole of this sub-unit is clearly delimited by the areal extent of the succession of hummocks and depressions.

The distinctive vegetation of these sub-units is related to the geomorphological processes in the area.. The absence of any large blow-outs and the consequent complete vegetation cover is taken as evidence that the 'pimple dunes' are accretionary features developing on a stable low sand surface (analagous to Unit E), close to the water-table. Sand supply is from the unstable western areas closer to the shore, and must be a slow process. The combination of high cover-values for Ammophila arenaria and mosses, together with similarly high values for Festuca rubra, and an extended species list indicates that the processes must be slow enough to allow a certain measure of vegetational stability and maturity to develop. These aspects are discussed more fully in chapter 8.

The final sub-unit (D_3) in this unit, occurs in the northern sector of Grogarry Machair, within 150 metres of Loch nam Balgan. Here too there is an obvious relationship between geomorphology and vegetation. The sub-unit is associated with a sand-ridge which extends from north to south across the Machair. In the extreme north this ridge exceeds 3 metres in elevation and has the form of a low cuesta with a well-defined, west-facing, steeper 'scarp"-slope. The latter is frequently broken by slumped and eroded blow-outs. The principal distinguishing feature of this vegetation sub-unit is the presence of Ammophila arenaria, a feature, which as before, is related to the active erosion noted. In most of the samples Festuca rubra and Carex spp. are co-dominant with Ammophila arenaria the third most abundant species. Although floristically varied, species other than these (which each occupied about 25 per cent of the areas sampled) seldom attain cover values greater than 4 per cent. The most frequent associates are Achillea millefolium, Trifolium repens

Bellis perennis, Galium verum, Lotus corniculatus, Luzula campestris, Cerastium vulgatum, Sedum acre, Ranunculus repens and Rumex crispus. Mosses are represented by Rhytidiadelphus squarrosus, Hylocomium splendens, amd Hypnum sp., though again with low cover-values.

The northern part of this vegetation sub-unit is co-extensive with the sand ridge and could thus be easily delimited. Towards the south, however, the ridge, decreasing gradually in elevation and width, extends beyond the limits of the area characterized by Ammophila arenaria and active erosion: its vegetation, distinguished by the absence of the latter species, is more like that of the surrounding Machair Plain than that of any of the sub-units in this unit. The abruptness of the transition from the area in which Ammophila arenaria is present to that in which it is absent gives a clearly defined and easily located boundary even where, as in the south, the relationship between the sub-unit D_3 and physiographic features are not concordant.

Unit E: The Machair Plain

Though only forming a part of the vegetation complex on the coastal calcareous sand plain referred to as Grogarry Machair this is the most important area in human terms. This unit has been the most intensively used and modified by man. While the whole of the Machair complex has been grazed, the Machair Plain is the area which has been most extensively cultivated at one time or another. Sampling revealed that the most significant variations in the vegetation of this zone occurred from north to south and were related to the last date of cultivation.

This factor, therefore, provided the most satisfactory basis for the delimitation of sub-units. The resulting boundaries run from east to west, at right angles to the ecological gradients due to physical factors.

Three sub-units can be recognised, each patently related to one another. In the extreme south, a large field which was cultivated a year previously to the survey is a conspicuous feature (E_1). The vegetation of this sub-unit is the initial recolonization stage, after cropping has left a practically bare surface. Unvegetated sand generally occupies 80 to 90 per cent of the area of samples. Species which occur in these samples thus had practically no measurable cover. The principal species present are Avena spp. (a residual from the crop of 1967), Sinapis arvensis, Ranunculus ficaria, R. repens, Cerastium vulgatum, Potentilla anserina, Vicia cracca, Honkenya peploides and Hydrocotyle vulgaris.

In the second sub-unit (E_2) recolonization is complete, but development of vegetation is continuing. Records of this area show that the fence crossing Grogarry Machair, beside the road from Grogarry Lodge, delimits areas which to the south have been cultivated in 1960 and to the north have not been cultivated for at least 40 years. The southern of these two sectors forms the second sub-unit in this major zone. Festuca rubra is exclusively dominant, occupying between 50 and 75 per cent of the cover in samples. The more important associates which make the largest contribution in the remainder of the cover are Carex spp., Poa pratensis and Potentilla anserina. The rest of the species list is completed by Agrostis spp., Ranunculus repens, Bellis perennis, Hydrocotyle vulgaris, Trifolium repens, Succisa pratensis, Vicia cracca sp., Sagina maritima and Cerastium vulgatum. The principal moss is Thuidium sp. again with a low cover-value.

The final sub-unit (E_3) represents a mature stage. This is not climax vegetation in the strict sense, but since grazing by cattle and sheep has occurred continuously since this area was last cultivated, the vegetation can be regarded as a biotically maintained plagioclimax. Dominance is shared by Carex spp. (chiefly Carex panicea), and Festuca rubra. Each normally has a cover-value between 33 and 50 per cent. The rest of the species present, though large in number, are low in abundance; some samples record 20 or more in the metre quadrat.

Occurring in the majority of samples are Bellis perennis, Luzula campestris, Ranunculus repens, R. acris, Galium verum, Sagina maritima, Achillea millefolium, Lotus corniculatus, Poa pratensis, Plantago lanceolata, Leontodon spp., Vicia cracca, Trifolium repens, Pinguicula vulcaris, Cerastium vulgatum, Orchis mascula and Juncus spp. Mosses at present in similar abundance are Rhytidiadelphus squarrosus, Hylocomium splendens and Thuidium sp.

The nature of the principal controlling factor gives very sharp boundaries corresponding to the limits of certain contemporaneously cultivated areas. Only to the east, where the Machair Plain meets the Marsh communities flanking the eastern edges of Grogarry Machair, are boundaries less distinct. Around Loch a Mhachair and Loch nam Balgan, the boundary between this zone and the fringing marshes (unit E) was marked by a small but distinct break of

slope, so that the marsh surface was about 30-50 cm lower.
However, in the extreme north beyond Loch nam Balgan, there is an ecotone up to 30 metres width, between the Machair Plain and the fringing marsh.

Units F and H: The Wet Habitat

The final major type of vegetation in the Grogarry Machair complex, is that associated with poorly drained conditions. It occurs in those areas, subject to periodic inundation during the winter and much of which may be completely submerged for three months or more. On the basis of summer sampling two sub-units were distinguished.

The first sub-unit (F) consists of the dune slacks, in which winter-lochs form during the period November to April. The boundaries of this sub-unit were defined by the maximum extent of the winter lochs. This can be very easily seen when the flooding subsides, a wave deposited line of detritus marks the maximum level of the water bodies. There are two separate dune slacks, divided by the central sand hills. To the south is a semi-permanent water body, known as the Lon Mor. Though much of this slack is exposed in summer, a central marshy area is maintained by an outflow drain from Loch a Mhachair.

The northern slack, though large in extent dries up completely. In winter, both were submerged, and thus sampling was impossible at that time of the year. In spring sampling was still difficult; the vegetation which had been submerged had died, and regrowth, though prolific was obscured by a grey, tangled mass of dead vegetation. Quantitative measurements on the basis of cover-abundance were thus not possible, but observations show that *Festuca rubra* is dominant, often occupying more than 50 per cent of the area under regrowth. *Carex* spp. are sub-dominant with an abundance which did not exceed one-third of the regrowth area. *Potentilla anserina*, with occasional cover-values of 25 per cent or more, occurs in irregular stands around the periphery of the slacks. Other species present, although frequent, have very limited cover-values. These include *Poa pratensis*, *Ranunculus repens*, *R. acris*, *R. flammula*, and *Vicia cracca*. The moss *Rhytidiadelphus squarrosus* forms a diffuse layer at ground level. Though abundant, the moss does not give a dense enough cover to exceed a value of 3 on the Domin Scale. These features are characteristic of the vegetation of the drier part of the Lon Mor slack, and of the northern slack. However in the remnant Lon Mor water-body *Equisetum* spp. are conspicuously abundant. They are also prominent in the surrounding swamp, but here are exceeded in abundance by *Potentilla palustris*. This wetter area represents an ecotone between the area periodically and that permanently flooded, and for this reason has not been treated as a separate sub-unit. Throughout the dune slacks great variation occurs within very short distances and it seems better to regard these as components of the one sub-unit, than to attempt a more detailed sub-division of units, which would have been very difficulty to map with any accuracy, at the scale used.

The same problem was encountered in the second division of the wet habitat. This second sub-unit (H) is located along the fringes of Loch a Mhachair, Loch nam Balgan, and in the marsh which forms the north-eastern boundary of Grogarry Machair. These areas are also subject to flooding for considerable periods in the winter. The vegetation, however, has a much richer flora than that of F and is dominated by different species. This sub-unit is a very varied vegetation-complex. Round the lochs' shores there are dense stands in which Carex spp., Festuca rubra, Phragmites communis and Iris pseudacorus are either dominant or co-dominant in the samples analysed. In places the ground is not completely vegetated and mud sometimes occupies up to 33 per cent of the areas sampled. Other species which are present include Ranunculus ficaria, R. flammula, R. repens, Bellis perennis, Viola spp., and Vicia cracca spp.; their combined cover-values do not exceed 20 per cent. In some areas Rhytidiadelphus squarrosus forms close wefts rising to a little above the mud surface.

In the north, the transitional marsh has rather a different composition. It is a complex of wetter and drier marsh. Samples on the wetter area located in the very lowest parts of the marsh, were very difficult to obtain. No weight-bearing surface was encountered to a depth of 1 metre below the level of the vegetation growing on the swamp. Mosses are dominant with Polytrichum sp. being most abundant, having cover-values to to 75 per cent. Nevertheless, the following species were also abundant: Carex spp., Cerastium vulgatum, Iris pseudacorus, Viola palustris, Cardamine pratensis, Juncus articulatus, Hydrocotyle vulgaris and Stellaria alsine.

In the drier parts towards the edges of the marsh, rather different types of vegetation are encountered. The ground surface is extremely irregular formed of large numbers of small roughly hemi-spherical mounds about 15 centimetres in diameter. Carex panicea is dominant though showing a preference for the depressions between mounds; cover-values of between 50 and 75 per cent were recorded. Festuca rubra and mosses such as Rhytidiadelphus squarrosus, Hylocomium spendens and Barbula fallax have cover-value up to 25 per cent and tend to be more prominent on the mounds. Other species recorded here are Pinguicula vulgaris, Bellis perennis, Viola tricolor, Ranunculus acris, R. repens, Hieracium spp., Anagallis minima, Equisetum spp. and Leontodon spp.

As already noted, around Loch a Mhachair and Loch nam Balgran the extent of this sub-unit is clearly defined by break in slope. This may be an old shore line of the lochs formed at some time in the recent past when water level in the lochs was higher. The morphology of this feature and its constant elevation was strong evidence that this was a former shore line of the loch. This may be due to a fall in the water level of the lochs caused by drainage to the sea to improve fishing (e.g. the drain running through the Lon Mor); this occurred about a century ago. This feature forms a clear boundary to this part of the zone. North-east of the Lochs, however, the boundary is less distinct and an ecotone of at least 15 metres (50 feet) in width characterizes the more gradual transition from the marshy area of F to the Machair Plain.

CHAPTER 7

THE UISTS MACHAIR SURVEY

In this chapter the results of the large scale survey of the machair of the islands of North Uist, Benbecula and South Uist are given, and complemented by the maps and statistical tables of appendices 2 and 4. The aims of this survey, already discussed in detail in the introduction and in chapter 5, where also the methods used in this project are examined (see pp. 75-83), were to produce a series of maps and an explanatory account of the vegetation of machair in the Uists. The 'units' delimited in this survey are comparable in all respects to those of the Grogarry machair survey, although they have been delimited by subjective means. As a basis for accurate description, average value for cover and frequency were calculated for all samples occurring in each unit of the survey. The following abbreviations are used throughout this chapter: F - frequency measured as a percentage; C.C.A. - computed cover average measured on the 8-point scale described in chapter 5. The grid references are not given since precise location of areas mentioned in text is not meaningful, as the township refers to a general and not a specific location. To facilitate this map 9 gives a simple key to the main maps of appendix 2, and map 10 shows the townships mentioned in the text. Again, in order that the text is not excessively broken up, photographs of machair vegetation are presented separately in appendix 5. The photographs in the latter part of this appendix are particularly applicable to this chapter.

The average cover values which were computed from samples gave figures which were lower than might be expected, and certainly lower than those which would have been obtained from a 'typical' sample. This does not mean that these averages are incorrect, as in the case pointed out by Bannister (1966) when crude averages are calculated from samples based on a normal ten-point Domin scale, in which undue weighting of the lower figures result. The problem in this case lies in interpretation. The average of a number of samples does not give a sample which represents an average of conditions in one square metre of the vegetation unit. In practice deviations from the mean or expected value in any sample, a normal circumstance in work of this type and scale, would cause lowering of expected values. e.g. A plant recording 40-50% of total cover in 90% of all samples in a unit, registering values of 7 or 8 on the Domin scale, will give an average cover value computed in the way previously described of 6. Possible error is minimised by using large numbers of randomly located samples, which minimises variation due to pattern within an area. Small numbers of samples might give an unrepresentative picture.

In both this and the Grogarry Machair survey, observation and simple analyses showed that variation within categories was very much less than between categories. This approach is quite valid if it is remembered that a typical sample of a vegetation unit would give a much smaller number of species and higher cover values than in the description of the whole unit. Greig-Smith (1964, pp. 20-93) gives a full discussion of these problems.

Important in the description of the vegetation 'units' are their spatial characteristics, on a local scale, on a regional scale, and, in a general manner, with respect to others. Certain characteristic environmental relationships were noted and in many cases are used in the process of delimiting the extent of units. These have been discussed in so far as these are relevant to the description of the vegetation units. A more detailed analysis and evaluation of ecological relationship is given in the following chapter. Finally in each of the following sections there is a note on the parameters used in classification and on the establishment of specific unit boundaries.

Unit A: Active Dune Front Unit

The principal characteristics of this vegetation unit are the amount of unvegetated ground recorded in samples and the exclusive dominance of *Ammophila arenaria*. Only 5% of the 40 samples has a complete vegetation cover and the C.C.A. of areas of samples unvegetated was 7. This high value means that in any sample there was a high chance that more of the quadrat area would be barren than under vegetation cover. This is one piece of evidence of the instability experienced in this unit. The dominance of *Ammophila arenaria* is another. It has a C.C.A. of 5 and an F value of 80. All other species had C.C.A. values of P and the highest F score for the remaining 28 species is 32.5 for *Atriplex hastata*. Other species with F scores over 20, are *Honkenya peploides* (27.5) and *Rumex crispus* (22.5).

Normally whenever this unit occurs it is adjacent to the shore just above high water mark. It is found in a variety of general locations. Occasionally it is backed by a second line of moribund dunes (unit B) as at Kilpheder, South Uist, but normally is the only true dune front formation. The assemblage of species indicates that this unit experiences both sand and salt water innundations at sporadic intervals and this is confirmed by observation and measurement in the field. The distribution of this type of vegetation is thus related to exposed sites which either have very flat gently shelving beaches from where fresh sand is blown on to these low dunes, as at Howmore, South Uist, or steep beaches which place the limits of vegetation close to relatively deep water. In this case salt spray and periodic innundation are important environmental factors. Much sand is available in these areas, too, although most of this must come from laterally moving supplies blown from areas eroded by wind and wave action. This is described in detail by Ritchie (1966a, 1967, 1970), who states that "local erosion still occurs, as does local deposition; but taken as a whole the low altitude, the level topography and the presence of unbroken landforms suggests that the machair is approaching a stage of close adjustment to the forces of sea and wind." (Ritchie, 1967, p. 173). The character of the coastline is adapted to a very considerable extent by ancient structural elements "on which more recent coastal forms are imposed" and are "important factors in the evolution of the more dynamic sand and shingle coastlines." (Ritchie, 1970, p. 35).

There are four parameters used in classification and establishment of boundaries. Firstly in many samples 50% or more of the area is unvegetated. There is a statistically valid difference between the number of samples without total vegetation cover occurring in this unit and in the following unit (Unit B: Moribund Dune Front). A chi-square test on the null hypothesis that there is no difference between the two groups yields the following answer:

	Samples without complete cover	Samples with complete cover	Total samples
Unit A	36	4	40
Unit B	72	21	93

Applying Yates correction to the above figures a value of 3.67 for the chi-square is derived. For 1 degree of freedom this gives a value of less than 5% for the null hypothesis. Thus, there is a probability of more than 95% that samples with complete vegetation cover will occur in the vegetation unit B, rather than in unit A.

Secondly the presence of typical halophytes such as Atriplex hastata and Honkenya peploides is strongly indicative of this type of unit. Both are listed by Hepburn (1952, p. 93 and p. 100) as being "typical" of foreshore and foredune communities. Thirdly the dominance of Ammophila arenaria together with the relative absence of Festuca rubra distinguishes this from other units, in which both of these species registered relatively high values.

Finally, samples normally but not invariably have few species, typically 3 or 4. The fewness of species in samples together with high values for species present makes variability high amongst samples. Ammophila arenaria for instance though dominant on average is rarely encountered in areas experiencing the most extreme conditions of exposure to salt, close to high-water mark. This variability is reflected in high values for analyses of average numbers of species occurring in samples. This simple comparison of averages alone is not sufficient to make any further subdivision, and is difficult to interpret, but together with other observations indicated that there is a considerable range of variation within this vegetation unit. In this case variance is 4.84 and the coefficient of variability is 68.8%; it is noteworthy that the figures for the second unit (Unit B: Moribund Dune Front) are equally as high being 12.3 and 64.8% respectively. In each case this variability does not detract from the unity of the groups of samples, and at the scale of work no further subdivision is possible. There was little difficulty in delimiting this unit in the field, and ecotones were usually very narrow. However, the spatial homogeneity of the unit is not reflected by ecological processes within the unit. Cyclical patterns on a micro-scale to a considerable extent account for the range in variation found in the analysis of samples. In the delimitation of this unit, therefore, a level of generalisation appropriate to mapping and description at the 1/10,560 scale of survey is essential.

Unit B: Moribund Dune Front

This unit is much more widespread than the previous one, and its description is based on nearly 100 samples. Its most important vegetation characteristics are as follows. Ammophila arenaria is dominant with a C.C.A.

of 6 and an F value of 96, indicating presence in nearly all samples. Festuca rubra is present in over half the samples, F 57, and has a C.C.A. of 4. While unvegetated ground is an important attribute of most samples, more than half of a sample's area is covered with vegetation - unvegetated ground C.C.A. 6, F 77.

This unit is distinguished by an extensive list of associated species, composed mainly of plants relatively tolerant of an unstable habitat. The most important with F scores above 20 and C.C.A. of P are Bellis perennis (F = 22), Galium verum (42), Plantago lanceolata (45), Lotus corniculatus (25) and Trifolium repens (25). These species are amongst those most common in all parts of the machairs of the Uists. A number of other grasses and sedges are present but their contribution to community composition is small.

In the absence of an Active Dune Front unit this type of vegetation is normally found on the western-most extremities of the machair. The terms "active" and "moribund" are not wholly appropriate since there are no such clear distinctions in ecological relationships apparent in this survey. However, normally there are fewer indications of vigorous, active processes in this unit Rather there is evidence of relative, though by no means complete, stability; salt water influences are limited to blown spray, andsand-blowing is a localised feature related to redistributed sand from blow-outs rather than due to incursions of fresh beach sand. This agrees with the measurements and opinion of Ritchie (1966a). There is considerable variation within this unit in terms of species composition in samples, but there are several clear criteria which made delimitation of this unit a straightforward process. Firstly location is clearly important. In the absence of an Active Dune Front vegetation unit, the Moribund Dune Front type of vegetation usually occurs at the seaward edge of the machair. Absence of dune front is comparatively rare. The combination of relatively high values for Ammophila arenaria, Festuca rubra and unvegetated ground are characteristic of this unit. Normally bryophytes are quite uncommon (as compared with other units inland, in which Ammophila arenaria is important). This concurs with the findings of Gimingham et al. (1948). There is a much larger species list than was found for the Active Dune Front. Samples contained 5 or 6 species and while it has been shown by Grieg-Smith (1964) that the number of species in samples is not a reliable test for similarity or differences between samples, the following point can be taken into consideration. The range of the true mean (based on the samples available) can be calculated from the standard error of the mean. In the cases of units A, B and C that is Active Dune Front, Moribund Dune Front and Dune Back Slope vegetation types, the ranges of the true means of the number of species in samples with 95.5% confidence limits are 2.5-3.9, 4.7-6.1 and 9.2-10.6 respectively. Whilst these figures can not be used in locating any single sample this can be taken as circumstantial rather than definitive evidence of difference between these units. Normally in the field recognition and delimitation of this unit poses no serious problem, and in most instances there is a clear boundary between unit B and those to the east in which the total vegetation cover of samples is usually 100%.

Unit C: Dune Back Slope

The principal distinguishing characteristic of this unit is the dominance of Ammophila arenaria which is present in every one of the 48 samples on which the description of this unit is based. A figure of 6 for the C.C.A. is calculated for this species and the F value is 100. Sub-dominant to this grass are Festuca rubra and Galium verum. The former has a C.C.A. 5 and F 83 whilst the latter has values of 4 and 79. A total of 50 species are recorded of which 12 have F values over 20. Each of the following species have C.C.A. of P and are listed in descending order of F as follows: Plantago lanceolata 79, Trifolium repens 54, Senecio jacobaea 46, Ranunculus bulbosus 44, Lotus corniculatus 42, Ranunculus acris 40, Rhytidiadelphus squarrosus 40, Bellis perennis 38, Achillea millefolium 27, Trifolium pratense 25, Crepis capillaris 21 and Daucus carota 21.
When compared with units A and B there is a higher average number of species for samples, the expected value being in the range 9.2-10.6 (p = 95.5%). This and examination of the statistical summary of species illustrates the marked differences between dune front and dune back units.

In general this vegetation unit occupies a distinct spatial location. It occurs on the eastwards and landwards facing slope of the dunes fringing the Uists. The unit is invariably accompanied by Dune Front types, though the opposite is not always the case. In the instance of Active Dune Front vegetation (Unit A) on a number of occasions there is no corresponding dune back slope type of vegetation. As would be expected this unit, the

Dune Back Slope, is widely distrubuted throughout the Uists. However, there has been a tendency to be most fully developed when located immediately inland of Dune Front units which have an exposed location along the central parts of bays. Where the western edge of the vegetation lies to the landwards of a reef or shingle bank dune back slope vegetation is much more uncommon.

Characteristically this vegetation occupies a transitional ecological habitat between the unstable conditions of the dune front, where open communities with much unvegetated ground result, and the quite stable conditions associated with the machair plain (Unit E) with its closed, relatively mature vegetation cover. The dominance of Ammophila arenaria indicates that conditions are not stable, though dominance by this plant is not necessarily characteristic of the most unstable conditions, particularly where maritime influences are pronounced (Hepburn, 1952, pp. 97-104). The leeward aspect generally enjoyed by this unit is significant in protecting the vegetation from the influence of salt water, yet providing a trap for blown sand. Sand blowing is partly from the beach, though Ritchie (1966a, 1970, personal communication) shows by measurement that only relatively small amounts have this origin. The major component of the sand is derived from blow-outs in or through the dune front. That described in the previous chapter and shown in figure 8 can be taken as being representative of this type of feature. These vary in size from a slightly overdeepened, wind excavated, rabbit burrow to a vast sand gorge measuring over 40 metres along its longest axis (W.S.W. - E.N.E.) about 15 metres wide and nearly 15 metres deep at Hougarry, North Uist.

Several thousand cubic metres of sand must have been displaced from this blow out.

This aspect of the vegetation is balanced by the occurrence, with relatively high F and C.C.A. values, of species associated with a more stable environment, such as Festuca rubra, Galium verum and Trifolium repens. Whilst not being completely vulnerable to unstable conditions these species could not attain such high values in this unit unless there is a fair measure of stability.

Partly as a result of the combination of these stable and unstable habitats, and partly as a result of variations in regional conditions which influence species' assemblages there is a relatively high degree of variability in this unit. As in the case of the dune front vegetation units this high variability is related to the 'openness' of the communities. The different ecological conditions occurring within the unit produced different vegetation responses, and these in turn are reflected in sampling. The variance of the average number of species occurring in samples is 5.76 and the coefficient of variability 41.3%. Such tests are poor measures in themselves, but together with the other evidence presented above give a clearer picture of variability in this area.

In spite of this, there is normally little difficulty in recognising dune back slope vegetation as a unit. To the seaward side are more open communities with high proportions of bare ground, and salt-spray tolerant species are often present. To the east as more stable conditions prevail, Ammophila arenaria disappears quickly and is replaced by machair plain vegetation (unit E) dominated by Festuca rubra. Where sand hills (unit D) merge with back slope vegetation there is normally a marked increase in the moss species amongst the principal components of the vegetation. The variability likewise does not mean that there are no parameters for classification. The variety of response of vegetation to habitat is one largely of degree rather than of kind, and the major unifying element in this unit is again process. Without working at the scale of the Grogarry Machair classification scheme there is no other division which would give as realistic and cogent results.

Unit D: Sand Hills

This unit is the most widespread encountered in this survey of the machairs of the Uists. It is distinctive in terms of appearance, in terms of species composition and abundance and in terms of vegetation contrasts with surrounding areas. It is dominated by Festuca rubra, present in nearly all of the 109 samples, F 92, C.C.A. 6. Sub-dominant are Ammophila arenaria and Galium verum both with C.C.A. values of 4 and F being 89 and 82 respectively. One difference between this unit and the preceding one (Dune Back Slope) is thus in the relative importance of the three principal species. A second difference is the large number of species which record F values of 20 or more (all with scores of P for C.C.A.). These are, in descending order, Plantago lanceolata 83, Rhytidiadelphus squarrosus 69, Lotus corniculatus 65, Bellis perennis 64, Trifolium repens 62, Senecio jacobaea 55, Ranunculus acris 47, Poa pratensis 40, Acrocladium cuspidatum 39, Achillea milliefolium 34, Carex arenaria 30, Ranunculus bulbosus 30, R. repens 27, Carex flacca 22, Prunella vulgaris 21, Luzula campestris 20 and Euphrasia officinalis 20; unvegetated ground occurs in 28% of the samples. This extensive species list is partly due to the larger number of species which typically occurred in samples in this unit, and partly due to the large number of samples which tend to give prominence to more of the subordinate species. In spite of this and a total of 72 species recorded the variance of the average number of species in samples is 5.76 and the coefficient of variability only 18%. This indicates that, according to this criterion, there is a higher degree of homogeneity in the samples of this group than amongst the preceding three vegetations. The extensive species list with F values of 20 or more is a more definitive measure of this factor.

Although this unit occupies a distinctive habitat, its location is variable in terms of distance from the sea, sometimes little more than 20 metres from high water mark, whilst at others near the eastern limits of the most extensive machairs well over 1 kilometre from the shore. However, it is always situated on ground elevated above the Machair Plain Surface (unit E). This level is approximately concordant with the maximum level of the winter water table. In extent too, this unit shows variation, some parts of the unit being only a few square metres in extent, whilst other examples of this vegetation type stretch in unbroken, sinuous tracts to form areas more than one square kilometre in extent.

The location of this type of vegetation seems clearly related to the occurrence of large quantities of sand. Where machair is relatively narrow and shallow, however, it is rather uncommon. But where huge masses of sand have piled up to form the great machair tracts of the Uists, this type of vegetation is most common. Therefore this unit attains fullest development in central South Uist between Daliburgh and Stoneybridge, at the northern extremity of South Uist from Grogarry to the huge machair known as Lochdar and along the broken, hooked arc extending from Ballivanich Benbecula, through the An Tom promontory, along the offshore islets of Baleshare and Kirkibost to the huge sand hills piled on the underlying rock ridges at Knockintorran, Balranald and Huna of the western-most apex of North Uist.

The existence of these sand hills is intimately related to their vegetation cover. This relationship is critical to the whole problem of origin of machair vegetation as it presently exists and is discussed more fully in the subsequent chapter. However Sand Hill vegetation, whatever the form or geomorphological genesis of the sand hills themselves occupies a distinctive habitat in which drought rather then flooding is a problem, in which conditions are not wholly stable, in which sand blowing once initiated has a marked influence on the vegetation and where, in consequence, a distinctive species assemblage is found. These three criteria form the basis for delimitation of this unit. In the field, there is rarely any problem encountered in recognising and delimiting this unit. Where it abuts on to another type of vegetation to the west in which <u>Ammophila arenaria</u> is dominant (e.g. units B or C), this unit can be recognised by its dominant species Festuca rubra, with Ammophila arenaria tending to occupy the subordinate, sub-dominant role. Other important parameters are the greater numbers of species present, which is reflected in the larger number of species in samples and the presence of these more characteristic of this unit such as Carex arenaria and Peltigera rufescens. Mosses are a significant component of the vegetation and this is the only unit in which they achieve any prominence in association with Ammophila arenaria. Where the Sand Hill vegetation meets Machair Plain vegetation, the limits of extent of Ammophila arenaria together with increasing values for Carex flacca and C. panicea, and particularly high values for Poa pratensis show that this is the boundary of the latter vegetation type. As is the case throughout the survey extensive ecotones are not found and the change from one unit type to another is normally accomplished within a few metres, close to the point where the maximum winter water table rises to within a few centimetres of the surface.

Unit E: Machair Plain

Although the habitat which would support Machair Plain vegetation is the most extensive in the Uists the Machair Plain vegetation occupies an area similar to that of the previous unit (Sand Hill vegetation). The reason for this discrepancy lies in man's use of the machair. As is explained in chapter 3 machair has formed the prime agricultural resources of this part of the Hebrides for the last two thousand years. The relatively high, inherent biological productivity of the machair when compared with the acidic moorlands covering most of the islands, ensures that most of the cultivation and high intensity grazing is concentrated here. A considerable part of land which wouldhave ssupported this type of vegetation is under cultivation at the time of the survey, and thus cannot be included in the vegetation description and analysis. Further reference to map 7 shows these patterns in general in the Uists and indicates the extent of cultivation of all machair at the time of survey. Changes in patterns of cultivation, particularly consolidation of holdings, are important factors in the analysis of machair plain vegetation, since all but the smallest fraction of land cultivated would, if allowed, probably revert to Machair Plain vegetation. Thus virtually all land shown as cultivated on these maps occupies the same type of habitat as did Machair Plain vegetation and the Machair Plain vegetation is profoundly influenced by man through the agencies of former cultivation, current grazing, fertilizing or seeding. This factor is critical to any analysis of machair vegetation and isdiscussed more fully in chapter 8.

The vegetation unit is dominated by two grasses: Festuca rubra the dominant species has a C.C.A. of 6 and an F value of 91; Poa pratensis follows closely with C.C.A. of 5 and F of 88. Most samples contain more Gramineae spp. than these two, and a total of 16 are recorded as occurring in this unit. Ammophila arenaria was virtually absent (C.C.A. p, F 6) and this provides a distinguishing factor between this unit and others. In all a further 21 species, each with C.C.A. values of P record F values above 20. These are Trifolium repens 83, Plantago lanceolata 77, Bellis perennis 69, Rhytidiadelphus squarrosus 63, Lotus corniculatus 58, Trifolium pratense 53, Ranunculus acris 48, Achillea millefolium 42, Galium verum 42, Ranunculus bulbosus 41, Senecio jacobaea 41, Euphrasia officinalis 36, Potentilla anserina 34, Acrocladium cuspidatum 34, Agrostis tenuis 32, Prunella vulgaris 31, Carex flacca 29, Stellaria graminea 27, Vicia cracca 25, Centaurium littorale 24 and Agrostis canina 22. The average number of species recorded per sample is high, 14.8, but the coefficient of variability is relatively low at 23%. This together with the large total number of species recorded, some 95 in all, add further distinctiveness to that provided by the quantitative characteristics of the principal species.

The principal characteristic of the sites that this vegetation unit occupies is flatness. Normally these areas are within one metre of the level of the winter-water table. Again the status of the vegetation with respect to current and past geomorphological processes is a most important aspect of the overall plant ecology of the Machair Plain and is discussed more fully in chapter 8. The existence of large uncultivated blocks of Machair Plain vegetation is related to the mode of man's occupancy and use of the land, but in general these are found where machair size is greatest and where pressure on the land is not high. Normally these two factors are related. In South Uist extensive blocks are found near Daliburgh, between Bornish and Stoneybridge, and in the north on the lochdar machair. Benbecula has a high pressure on its machairs, and only at Ballivanich airport are there significant areas of this type of vegetation. In North Uist pressure on the more accessible machair areas confines really extensive machair plain blocks to Baleshare and Kirkibost islands and to Balranald and Huna on the western coast.

Six major environmental relationships can be recognised as stemming from this symbiosis between man and nature, and resulting in machair plain vegetation. Firstly there is a distinctive assemblage of species with Festuca rubra and Poa pratensis dominant, widespread and abundant throughout units previously described and Ammophila arenaria absent from this unit. Secondly the number of species encountered in the machair plain is high. These two factors are related, at least in part, to the relatively stable nature, and absence of blown sand in this low-lying, often wet area. Thirdly there is a delicate balance between weeds and cultigens dependent on man's activities (e.g. Trifolium spp. and Senecio jacobaea) and the 'native' species of the machair (e.g. Carex flacca and Euphrasia officinalis). The nature and expression of this balance is dependent on the size, type and time of man's agricultural activities.

Three other factors are noted here although fuller evaluation of these is carried out in the subsequent chapter. The hydrology of the machair plain relates both to the ecological and to the geomorphological characteristics of the sites occupied by this vegetation unit. The build up of organic material in the soil is both influenced by and to some extent controls machair plain vegetation development, and man's use of similar sites. Finally man's agricultural practices are of fundamental importance in making any assessment of this type of vegetation. Such practices as cropping, grazing, draining and fertilising are major influences on the vegetation of this area.

The physical parameters associated with this unit, the assemblage of grasses, weeds and cultigens, together with the absence of species associated with more unstable or extreme habitats give this unit a sound basis in the scheme of classification. Normally therefore delimitation of boundaries presents no problem, and in most cases these are sharp. Only where very gentle slopes led to gradual changes in ecological conditions between Machair Plain Vegetation and fringe vegetation (unit H) are there any appreciable ecotones.

Unit F: Dune Slacks

The experience of the Grogarry Machair survey might lead to the assumption that Dune Slack vegetation is widespread throughout the Uists, and that major dune slacks are a common part of the machair landscape. This is not the case and those studied in the earlier survey are part of one of only four systems of dune slacks found in the Uists. These are located in Ormaclett in central South Uist, from Grogarry to West Geirnish, South Uist, at Eachkamish on Baleshore island and in Machair Robach in the extreme north of North Uist.

Dune Slack vegetation has co-dominance shared by four species. These are Carex flacca C.C.A. 4, F 100; Poa pratensis C.C.A. 4, F 73; Potentilla anserina C.C.A. 4, F 64; and Festuca rubra C.C.A. 4, F 55. Normally samples are dominated by one or two species, rarely by all four. In spite of variable dominance, this unit is extremely homogeneous in terms of the coefficient of variability of number of species occurring in samples, which is 12.7%. This is substantiated by examination of the species list which contained many with high F values. Breakdown of this unit into further vegetation classes is thus neither possible nor desirable, taking into consideration the scale of work, the problems of mapping, the extent of this unit and the range of internal variation which is compatible with this scheme. Because of the fewness of the samples from this unit, presence in only 3 samples gives species an F value in excess of 20. For this reason 50 is taken as a more meaningful critical value for important subordinate species. Besdies the following 8 species which have C.C.A. values of P and F values in excess of 50, there are a further 13 species with F between 50 and 20. The principal subordinate species with F values in excess of 50 are, in descending order: Agrostis canina 91, Hydrocotyle vulgaris 73, Lotus corniculatus 64, Rhytidiadelphus squarrosus 64, Carex arenaria 55, Anagallis minima 55, Bellis perennis 55, and Prunella vulgaris 55. The average number of species recorded in the samples is 15.6, but a total of only 41 species are recorded. This is partly due to the fewness of the samples, only 11 being taken, and in part due to the relative homogeneity of the samples. This latter aspect can be seen most clearly in the relatively high F values recorded for the species. More than half the species recorded are present in one third or more of the samples.

This vegetation unit is found amongst dune and sand hill areas, that is adjacent to vegetation units A, B, C and D. It only occurred where there are extensive areas of machair in which underlying geological conditions and prevailing geomorphological patterns allowed the development of dune systems in which slacks can form. Formation is related to the nature of the gently westwards shelving gneissic platform below the sand, allowing the surface to lie below the level of the winter water table. A further factor is the presence of relatively stable conditions on the seaward side of the vegetation unit. Dune Slack vegetation is rarely found within 50 metres of high water mark. Dune front activity is seldom important and dune slacks are generally surrounded by vegetation units which are relatively stable. It is notable that dune slack vegetation is found in extensive machair areas, rather remote from townships and used for grazing rather than cultivation. This indicates that this type of vegetation is located in the more mature and less man-modified areas.

Flooding is a prerequisite for the formation of this unit, and a very clear difference between this type of vegetation and that of surrounding areas occurs at the limits of seasonal flooding. In terms of vegetation this unit is distinctive on two counts. Firstly there is dominance by species which are generally suited to stable, mature and wet conditions. Weeds and cultigens play very minor roles in overall composition. Secondly in direct contrast to much of the vegetation of adjacent areas, particularly those to the west, Ammophila arenaria is never present. The fact that this type of vegetation is found mainly in South Uist is a reflection of that island's suitable conditions for formation of dune slacks on its low extensive machairs.

Delimitation of this unit based on the parameters described above poses no problems. It is readily recognisable in the field and this unit can be detected on air photographs. Boundaries are sharp, being related to flooding, and normally occurred within two or three metres, often marked by a line of water transported detritus at the limits of the winter flood. The unit is quite distinctive both in terms of overall species composition and in terms of the dominant species combination.

Unit G: Sea Machair

This vegetation unit, confined to two small areas, is the least widespread of all the areas delimited in this survey. It is an important vegetation unit, not only because of its location, extent and species composition (all of which made delimitation within this particular scheme obligatory), but also because of its ecology. Sea machair is the name given to this unit since in terms of its vegetation composition it lies somewhere between machair and salt marsh. It is extremely homogeneous. The coefficient of variability of number of species per sample is only 16.3% and of the total of 8 species recorded, all occurred in at least one third of the nine samples. Furthermore several of these species, though not those with the highest F and C.C.A. values are confined solely or almost solely to this vegetation unit. Four species formed the principal components. Festuca rubra, almost certainly one of the varieties occurring in salt marshes, such as F. rubra subsp. rubra var. glaucescens (vide Hubbard, 1968, p. 139), is present in all the samples and has the high C.C.A. value of 7. Also with F values of 100, and with C.C.A. 5 are Armeria maritima and Plantago maritima. Spergularia media has a C.C.A. of 4 and F 56. The four subordinate species have identical averages with C.C.A. P and F 33; these are Honkenya peploides, Salicornia sp., Spergularia marina and Nostoc sp.

The surface of this vegetation has a very characteristic appearance, the low, russet-tinged, glaucous vegetation being broken into hundreds of individual, low, flat tussocks, each separated from the the other by tiny channels, which partly fill with salt water around high tide. The soil in which the plants of this unit grows is also distinctive. Besides experiencing a twice daily flushing with salt water, it is composed to a large extent of silt and smaller fractions, although examination through a 10x lens reveals considerable numbers of machair sand grains.

Sea Machair vegetation occurs at Gualann strand between South Uist and Benbecula and around Loch Paible on the west coast of North Uist. These two locations are broadly similar. Each borders tidal salt water, yet both enjoy almost absolute protection from wave action. The physiographic evolution of the machair and absence of major westwards flowing rivers in the Uists makes such conditions very uncommon. Both sites are on the eastern side of recently breached dune fronts, and it is evident from observation and analysis that the habitats of these sites will become more unstable, and Sea Machair vegetation will thus become more vulnerable to erosion. As sea level becomes higher (as is shown to be the current well established trend in chapter 2) the exposure of the site and the action of the sea will become increasingly severe. Already erosion at both sides of Gualann is evident, though at Loch Paible conditions are presently less severe. In the latter location man has a significant role in the formation of this distinctive habitat. The sea breach which allows the tide to ebb and flow through the Loch, was accidentally formed when wave action enlarged and eventually overwhelmed a cut made between the then fresh water machair fringing loch and the sea for drainage purposes in 1793 (Ritchie, 1970). At present, conditions seem quite stable and are ideal for the development of sea machair vegetation around the margins of the sheltered tidal loch.

Both of these locations give the ecological conditions which are essential for the development of Sea Machair vegetation. These are tidal flooding by salt water and protection from wave action, even where the surface of the vegetation is only a few centimetres above high water mark. This, and the highly characteristic assemblage of species gives a clear basis for delimitation. Consequently there are no problems in field mapping, although there are ecotones extending over 20 - 40 metres, where with gently increasing elevation the most halophytic plants (e.g. Salicornia sp., Spergularia marina) are gradually replaced by plants more characteristic of a 'normal' machair environment (e.g. Trifolium spp., Carex spp.). The maximum extent of these typical salt marsh species is taken as the limits of the unit. At Gualann no such problem exists and the sea machair gives way within one or two metres to the Ammophila arenaria dominated strands which occupy the higher western parts of the strand.

Unit H: Wet Fringes

The limits of machair used in this survey are those demarcated by Ritchie (1966a,1970) indicating the extent of surface wind blown sand in the Uists. Experience at Grogarry Machair showed that there is a clear relationship between vegetation and the area covered by sand. This relationship is apparent in the field. Normally field delimitation of machair areas is made by observation of vegetational change aided by information on the extent of sand blowing. Frequently the boundary occurs around a loch, marsh or drainageditch occupying the physiographic depression between the machair and the peaty black land, to the east. In these marshy areas a distinctive type of vegetation occurs. This is termed wet fringe vegetation. Elsewhere, where no such feature is encountered, there is a fairly rapid transition between true machair vegetation types associated with surface deposits of blown sand, and black land vegetation types which though often enriched by pockets of the calcareous sand are sited on acidic peaty soils and dominated by sedges (Cyperaceae), grasses such as Nardus stricta, Molinia caerulea and Deschampsia flexuosa, by rushes (Juncaceae) and by Calluna vulgaris and other Ericaceae. Presence of these species in any appreciable numbers marks the units of machair vegetation. With Wet Fringe machair vegetation there is little problem in demarcation, and where there is a junction between this unit and non-machair types the presence of the characteristic acidophilous species clearly formed the boundary, which is normally less than 10 metres in width.

Samples taken from this unit have a high degree of variability. This is only partly shown by the moderately high coefficient of variability of average number of species present in samples, 38.6% a figure which does not reveal a range of 4 to 31 species in individual samples. This variability is much more clearly and accurately denoted by the absence of any single truly dominant species. No species attains a C.C.A. of 4 or over although two, Carex nigra and Caltha palustris approach this figure. This variability is related to vegetation patterns within the unit caused by response to factors of the micro-habitat. Small changes in ecological conditions are sufficient to cause corresponding variations in vegetation response in this unit. This response together with the absence of man as a major factor, except through the agency of cattle grazing, indicates that there is a considerable degree of maturity in the vegetation of this unit.

The principal components of the vegetation all have C.C.A. values of P. They are listed in descending order of F value: Caltha palustris 67, Hydrocotyle vulgaris 61, Hylocomium splendens 55, Carex nigra 48, Poa pratensis 45, Phragmites communis 42, Stellaria alsine 42, Potentilla anserina 39, Carex flacca 36, Acrocladium cuspidatum 36, Carex panicea 33, and Trifolium repens 33. There are a further 9 species with F values between 33 and 20. Many species which thrive in more acidic and wetter conditions are present in small numbers, e.g. Eriophorium spp., Eleocharis palustris. In a few samples unvegetated ground is recorded. This is either ground which has been 'puddled' by cattle or in which recent flooding has caused silting of some areas. Very often the surface of these areas is broken into tiny mounds or tussocks, a detailed examination of which reveals micro-scale variations in plant response to slightly different ecological conditions. This development seems to have been in part due to differential growth requirements and responses, and to the sand and mud trapping ability of different plants, a process analagous, at a much lesser scale, to dune building. This is in part due to a mechanical breakdown of the surface by heavy grazing animals (and possibly in some areas by grazing)[1] and by wave action around the lochs. This surface provides a characteristic of the vegetation of this unit which facilitates identification and delimitation in the field.

The soil found in areas supporting fringe vegetation is different from that found elsewhere in machair. Flooding and waterlogging by fresh water is largely responsible for this. A typical sample taken from the fringe zone around Loch a Mhachair, Grogarry, reveals a profile in which the uppermost 7 cm is composed mainly of organic material which under waterlogged anaerobic conditions, is slowly changing into a black gelatinous peat. There is evidence of some sand in this layer probably brought in by wind blowing, and around the margins of the lochs sand can clearly be seen as the dominant bottom material in the shallows by the shore. This is confirmed by samples obtained from Loch a Mhachair (Wilson, personal communcation). The pH of this surface horizon is 6.9. This value probably represents a balance between greater acidity of the organic component and the mildly alkaline sand and water soil components. In the nearby loch the pH of the water is 7.3. About 7 cm depth there is a fairly sharp undulating boundary and the organic-rich layer is underlain by yellow-grey sand which has little or nor organic content and a pH of 7.1. These soil conditions are in part due to the parent sand, in part due to its waterlogged nature and in part due to the vegetation response

[1] This question is discussed more fully in the following chapter.

which produce the build up of organic material. A complex cycle of ecological factors and responses is thus an important element of the vegetation of these areas.

In spite of the variability encountered in this unit, there are clear parameters which can be used in its identification delimitation and analysis. It occupies a distinct habitat in a specific location. Although there is variable dominance many of the principal species which form significant parts of the vegetation cover are either confined to this unit, or enjoy much greater prominence than in other areas. Variation within the unit is related to micro-scale response and does not alter the viability of the unit within work of this scale. As has been stated neither field delimitation nor recognition poses serious problems, although care has to be taken in boundary placement. Obtaining samples in this wet environment is more troublesome when elsewhere in the machair, though serious difficulties are not encountered.

Unit J: Non-Machair Areas

The twelve samples which made up this unit are not chosen as a control group or delimited to form a special area for purposes of comparability. These samples are taken from four small areas on which there is little or no blown sand, which are parts of the main islands of the Uists and yet occur to the west of the machair. The main locations at which this unit is found were at Orosay Island, South Boisdale, South Uist, the Rudha Ardvule peninsula in the central part of the southern island, the Rudh'Ard-mhicheil peninsula about 4 km to the north of the extreme western tip of the Uists, Aird an Runair, North Uist. The circumstances which led to the geomorphological evolution of these areas occur when the underlying gneissic basement formed a ridge (due to structural or lithological causes) which give rise to a promentary extending out to sea. This, either at one time was buried by sand, or more probably such sand which might have been deposited had been subsequently removed. The vegetation of these areas is growing in a soil which may have a measurable shell sand fraction, but more commonly is a very thin organic and mineral soil, overlying the basement rocks. In fact, although the vegetation shows certain responses to this habitat, the unit is in many respects similar to Machair Plain vegetation (unit E).

Intermediate values are derived for the variability of average numbers of species occurring in samples; variance is 13 and the coefficient of variability is 27.3%. The average number of species which occurred in the 12 samples is 13.1, rather less than in the machair plain unit. Two species are dominant. These are Poa pratensis with a C.C.A. value of 5 and an F value of 92, and Festuca rubra with corresponding values of 5 and 83. Plantago lanceolata has a C.C.A. value of 4 and F 67, and is thus subdominant. The major subsidiary components with C.C.A.scores of P are in descending order: of F. Value: Bellis perennis 67, Ranunculus acris 67, Trifolium repens 58, Carex flacca 50, Rhytidiadelphus squarrosus 50, Agrostis canina 25, Carex nigra 25, C. Panicea 25, Luzula campestris 25, Achillea millefolium 25, Euphrasia officinalis 25, Hieracium spp. 25, Potentilla anserina 25, Ranunculus bulbosus 25, and Vicia cracca 25. The overall species list is rather short comprising only 56 species, but this can, at least in part, be explained by the fewness of the samples, only one tenth of those used to formulate the averages for Machair Plain vegetation. One or two species are clearly related to ecological conditions in this unit and are not found in Machair Plain vegetation, e.g. Armeria maritima and Triglochin maritima.

On a first consideration, two ecological factors might seem likely to be important. However, a detailed examination showed that these, proximity to the sea and subjection to salt spray action, and absence of machair sand, are of secondary importance. Many species which, if not exclusively confined to machair areas are characteristic of these (e.g. Trifolium repens and Carex flacca), are important constituents of the vegetation of this unit. Most of the areas from which samples for this unit were taken, contain some shell sand. This is probably enough to provide sufficient $CaCO_3$ for the calicoles, and shortage of lime is unlikely to be a limiting factor in these areas. The most important ecological factors are firstly proximity to true machair areas and their pool of species, and secondly relative stability. All of these areas are uncultivated, and have been so for many years. There is little human interference beyond the grazing of animals introduced by man. The vegetation of this unit thus may provide a useful indicator in evaluation of machair status and process in machair vegetation. The scientific importance of these areas, both in terms of their plant ecology (though few rare species are found, the community is unique within this area), and in terms of their resident animal populations, is very high. Delimitation of these areas presents no problems and, though falling outside machair areas, clearly formed an integral part of the whole study.

CHAPTER 8

ECOLOGICAL RELATIONSHIPS IN MACHAIR VEGETATION

The greater part of the study of ecological relationship is based on empirical observations either carried out at the time of vegetation sampling or drawn from studies by other workers. As with the basic vegetation surveys complex statistical methods are not used to any extent. This is due to the inapplicability of such methods to the aims of these surveys and analyses based on the surveys.

It is clear in both the Grogarry survey and in the Uists survey that there are a number of ecological factors which can be separated from the environmental complex as having profound effects on machair vegetation. However it soon became evident as work proceeded that variation in, and plant response to, these factors is not constant in time or space. The scale of the Grogarry, and even more so of the Uists survey means that analysis of ecological relationships has to be based on simple descriptive explanation. Nonetheless the evaluation of such broad relationships, and formulation of simple theories using these as a basis, is a worthwhile objective in terms of the objects of the study. Taking these factors into consideration four major factors can be isolated from the environmental complex for systematic study. These were:

1. Geomorphological processes and morphology
2. Soils and soil stability
3. Machair hydrology
4. Cultivation, grazing and other human influences

Field observations and analysis of the vegetation data indicate that these are the most important ecological factors influencing vegetation development, though not necessarily in that order. It should be emphasised that whilst these factors are to some extent discussed in isolation they exist as part of the environmental complex of the machair ecosystem. A whole web of complex multi-directional interrelationships between all of the ecological factors and the vegetation exists, and only a few aspects of this system are discussed here.

1. Land Forms and Geomorphological Processes

Three types of machair land form, each with its own distinctive vegetation assemblages, provide suitable examples for examination of processes associated with the evolution of machair land forms, and machair vegetation. The three components are the dune system, the sand hills, and the machair plain. Each represents a complex of interactions which in detail are unique to the particular area and habitat, but in general terms can be related to broad genetic and developmental processes.

Dune vegetation is distinguished from other machair types on the basis of three major criteria. There are: dominance by species tolerant of an unstable and exposed site, giving a distinctive species' assemblage and composition; secondly, to a greater or lesser extent incomplete vegetation cover; thirdly, location within an area where certain types of process are dominant (although within that area there are complex vegetational responses to variations in the operation of these geomorphological processes). Geomorphological processes are a major unifying factor in the vegetation units, and within the units variation is in response to changes in degree rather than type of process activity. The processes involved are extremely complex in operation and it is not possible to delimit vegetation units associated with simple erosional and accretionary forms, even at the scale of the Grogarry study. In the case of this more detailed survey, it is possible to delimit vegetation sub-units, using objective methods, which relate quite closely to areas where there is approximate balance between accretionary and erosional factors in dune processes. In the large scale survey no such detail is possible and only two categories can be effectively delimited. These approximate to areas in which geomorphological processes are very vigorous, and had a dominant ecological role, and areas in which such processes have a relatively less important role: units A and B respectively.

The scale of study is of importance since, as with vegetation, geomorphological patterns which are described vary according to scale of study. The following examples illustrate some facets of these processes by reference to localities in some detail. At the mouth of Howmore river in central South Uist, some of the best examples of active dune vegetation are found. These dunes are rather similar in general morphology, construction and vegetation composition to those described as "Early yellow dunes" by Salisbury (1952, p. 212), "Foredunes" by Hepburn (1952, p. 99) or "Embryonic dunes" by Gimingham et al. (1947, p.86). Not more than 1 metre in height and west of all other vegetated areas the vegetation of these dunes is dominated by salt tolerant species such as Atriplex hastata and Calkile maritima, intermixed with considerable dense tussocked stands of Ammophila arenaria. The dune line extends for several hundred metres on either side of the river mouth, though in few places does it exceed 5 metres in width. It is situated at the eastern edge of a broad, low, almost level sandy beach for the most part above ordinary high water mark, only being covered at the highest spring tides or in winter storms. This gives rise to an ideal habitat for this type of vegetation. Sand blowing readily occurs over the dry sand surface, and salt spray and water influences combine to produce conditions in which new dune building can occur. It remains to be seen whether further developments will take place in these dunes. This seems unlikely from observation of the delicate balance in conditions, and a summer's dune building activities will be removed overnight during the winter storms. This area represents a habitat in which for the greater part of the year accretionary processes are dominant, but in which there are cyclical patterns due to sporadic harsh conditions breaking down the low developing dunes. Figure 9 summarizes this situation.

Such active process are much less evident at Grogarry and the protective cobble bank which backs the beach prevents, either severe erosion by the sea, or any appreciable sand supply reaching the narrow Ammophila arenaria dominated dune front. Figure 10 shows a profile of the typical dune front in this location, illustrating the characteristic moribund dune front type. What activity there is, occurs around blow-outs of the type shown in Figure 8. Here on a micro-scale is a complex of sand blowing and stabilisation. Clods of dune turf, undercut by wind erosion of underlying sand unbound by roots or organic material, fall into wind excavated depressions, and in some cases provide stock for recolonisation of the protected, damper floors of the blow-outs. At the ends of the longer axes of such blow-outs are sand spillways normally conforming within a few degrees to the vector of the prevailing strong winds. Here recolonisation by such species as Ammophila arenaria, Carex arenaria, Plantago lanceolata and others, shows this process to be quite different from primary colonisation as at Howmore.

The high moribund dunes at Ballivanich, Benbecula, have a vegetation composed almost solely of dense stands of Ammophila arenaria. Less than half of the dune front on average has any vegetation cover, and dune front faces are very steep. All these contribute to a situation in which erosional processes are dominant. In the narrow strait between the tip of Benbecula and the southern end of Baleshore island, which leads to a broad shallow channel, the North Ford, separating North Uist and Benbecula, there is a rapid and vigorous tidal ebb and flow. This results, as a consequence of intense scouring, in the formation of a deep-water channel between the two dune areas in the west. This channel is probably very recent in origin (i.e. within the last five hundred years) and this in part accounts for the erosion in this area. This factor of instability is heightened by the slowly rising sea levels around the shores of the Uists (see chapter 2). The strong scouring flow through the channel constantly undercuts the dunes and rapidly transports the sand away from the locality. The resulting dunes, up to 10 metre in height as at Eachkamish, Baleshore, have facing angles normally in excess of 45°. Such dunes even where covered by Ammophila arenaria are extremely unstable, and are very rapidly eroded by wind as well as undercut by waves. The constant undercutting and transport keeps the dune face steep, and wind erosion adds to slope and vegetation attrition. It is noteworthy that areas to the south-west, and south-east of the Ballivanich dunes show accretionary processes, no doubt based on a sand supply which in part is that removed from the nearby high dunes.

These examples illustrate aspects of the complex cycling of sand associated with the dune areas of the west coasts of the Uists. Fresh sand supply of marine origin is now limited (Ritchie, 1966a), so that erosion and accretion are naturally complementary, giving rise to complicated dune front patterns. Certain plant species play particularly important roles in vegetation processes in the dunes. Ammophila areanaria is outstanding in this respect, and its role in dune-building and stabilisation is discussed at length by Salisbury (1952, pp. 211-9), Hepburn (1952, pp. 100-3) and Chapman (1964, pp. 140-57). More detailed specific observations are provided by studies based on Braunton Burrows, Devon, (Willis et al., 1959a, 1959b), Newborough Warren, Anglesey (Ranwell, 1959, 1960a, 1960b), and Luskentyre, Harris (Gimingham et al., 1948). The latter study, concerned with machair vegetation about 20 km north of North Uist, indicates that the main role of Ammophila arenaria was in dune stabilisation rather than dune building, and in the north Devon surveys A. arenaria is credited with sand trapping and dune forming roles. As is shown by the above case studies the role of A. arenaria in dunes in the Uists is more similar to that specified in the

Harris study, though there are occasions when it may have a pioneer role. The single dune line of the Uists represents a zone of cyclical processes, and in very few places can active accretion be distinguished. The active growth resulting in sub-parallel lines of dunes and slacks, observed at Braunton did not occur anywhere in the Uists, due to the balance between erosion and deposition. Where accretion is taking place, it is in an environment with very strong salt water influences, so that halophytic species are the principal species present, rather than A. arenaria. The great stands of the latter species found in zone C (dune back slope) throughout the Uists, indicates that the principal role of the plant, as shown by its greatest abundance is in a stabilising role in such areas, on which vegetation cover is well developed beyond an initial pioneer stage.

Gemmell et al. (1953) in a continuation of the south Harris study made a number of observations on the tussock forming habit of A. arenaria. Tussocks were found in a number of locations in the Uists, but by no means in all areas of Ammophiletum. It is difficult to establish any reason for the resultant sporadic spatial patterns, but it seems most likely to be associated with the rate and nature of sand supply, and interaction with other dune species. Spectacular examples of tussocks formed by A. areanaria are found on the crests of dunes in a few locations such as at Dremisdale, in central South Uist. Here several lines of domed sand tussocks 20-40 cm in diameter and 20 cm or more in height, formed a regularly spaced pattern. Between the individuals in the ranks there is a distance of 3-5 metres, and the ranks themselves form straight lines along the coast for distances of 30-50 metres. Examination of one of these tussocks revealed a solid sand core, with no buried organic horizons, cobble or pebble core or evidence of any human disturbance. One possibility is that these mounds are built up by crofters for drying piles of seaweed to be used as fertilizer, or that these mounds develop around such piles. There is no evidence for this in the form of seaweed remains or even organic enrichment, and the exposure of the site would make building of mounds for long term use unlikely to succeed. Rock cairns or wooden posts are much more likely to be used for this purpose. It seems more possible that these are naturally formed tussocks, regularly spaced due to rhizomatous propagation of the plant.

In areas exposed to sea water and salt spray the role of halophytic species such as Agropyron junciforme, Atriplex hastata, Calkile maritima and Honkenya peploides is similar to that described by Hepburn (1952, p. 100). However rarely can any sort of fore dune community develop fully because excessive exposure to wind and sea. water, with periodic destruction by storm and flood tides keeps this type of vegetation at an early stage of development. In view of this and the rising sea levels around the Uists formation of more than one line of dunes at the west coast is most unlikely. Gimingham et al. (1948, p. 95) note that in Harris mosses play a minor role in the vegetation of dunes above high water mark, whilst Birse and Gimingham working on coastal dunes at St. Cyrus, Kincadineshire on the east coast of Scotland state that moss species with "a short turf growth form", (Birse and Gimingham, 1955, p. 530) such as Tortula ruraliformis are primary dune colonizers of some importance. Such species though present have very minor roles in the coastal dunes around the Uists (units A and B). There is no clear explanation for this regional variation, but most probably exposure in the harsher environment of the west coast, particularly salt water exposure may inhibit bryophyte growth near the shoreline, and thus account for the different patterns. Once the more stable and sheltered dune back slope conditions are encountered, mosses and lichens become more prominent, but in Uist they never play more than a subsidiary role in the vegetation of the dune areas. Species which are noted in these areas include Tortula ruraliformis, Hylocomium splendens, Rhytidiadelphus squarrosus and Peltigera spp., the former three noted by Birse et al. (1957, p. 286) as being common components of dunes in the north-east of Scotland. Beyond the dunes, in the eastern vegetation units bryophytes play an important role particularly in the sand hills (unit D) and machair plain (unit E).

In the case of sand hill vegetation units cyclical processes of erosion, accretion and stabilisation are again important. As the terrain of this unit is well above the water table, instability of the sand surface is always an actual or potential factor. Examination of blow-outs frequently reveal horizons running through the sand, below and sub-parallel to the surface. A representative of this type of feature is shown in Figure 11, which is an example from the Grogarry survey in sub-unit D_3 about 70 metres north of the path bisecting the study area. The buried organically enriched horizons represent former vegetation covered surfaces which attained relative stability for a period, until overwhelmed by wind blown sand deposits. This sand has now been removed in the blow out exhuming and truncating these relict layers. In contrast sub-unit D_2 (pimple dunes) of the Grogarry survey are accretionary features. This is indicated by their morphology, by the absence of buried horizons in blow out sections, and by the nature of the vegetation. It is dominated by Ammophila arenaria, bryophytes and a number of other species. This indicates that sand hills are depositional features which have developed upon and at a later date than the surrounding lower surface itself a depositional feature.

Throughout the sand hill vegetation Unit D various stages in the complex physiographic and ecological processes involved in the general eastwards movement of the sand can be recognised. The sequence at Grogarry shows such stages. These processes are by no means complete, and sand hills which may be primarily erosional or depositional features are evidence of the continuation of this movement. In the Uists' survey it is not possible to subdivide the sand hill vegetation (unit D), since cyclical processes involved are at many different stages, often in close juxtaposition to one another. A major unifying factor is the role of Ammophila arenaria. Once again this seems to be associated with a moderate rate of active sand accretion, and only occasionally takes a major role in colonizing bare sand in and around blow outs. This habitat is mainly occupied by mosses such as Camptothecium lutescens and Rhytidiadelphus squarrosus and vascular plants such as Carex arenaria or Plantago lanceolata This concurs closely with the types of plants found to colonise such bare surfaces by Gimingham et al. (1948) and Birse and Gimingham (1955).

The problem of machair status is considered more fully in the following chapter, but the machair plain considered as a geomorphological, ecological and vegetational unit has certain important ecological relationships, and thus is briefly considered at this juncture. Uncultivated machair plain is relatively stable both in terms of geomorphological and vegetation processes. There is little evidence of sand blowing and Ammophila arenaria is rarely present. Ritchie (1966a, pp. 102-4) advances a very strong case that machair plain can be a depositional feature only if sand had been deposited on to a water surface, or a waterlogged surface, since wind blown deposits cannot produce level land forms. Machair plain is generally with approximately 1 metre of the water table, and often much less, so that deflation is very limited. The absence of vigorous process is partly a result of and partly a cause of the vegetation dominated by grasses such as Festuca rubra and Poa pratensis, and various sedges these latter with the exception of Carex arenaria only attaining prominence in relatively stable conditions. The large extent of machair plain vegetation and its inland location means that except in very limited areas around unit margins, there was little freshly deposited wind blown sand from any other less stable areas. In the lea of the prevailing wind east of sand hill areas, limited spread of Ammophila arenaria on to machair plain is evidence that depositional features can form. Cultivation likewise quickly upsets the stability of machair plain, resulting in erosion and redeposition and consequent vegetation change. Dune slacks can be regarded as a more extreme case of machair plain both in terms of geomorphology and vegetation, and whilst apparently stable, their location amongst sand hills or or close to dune fronts, means that this is not the case and stability is only a temporary phase. Dune slacks, particularly when flooded, form highly effective reception areas for sand transported from blow outs in the surrounding unstable areas. Dune slacks, as is suggested by their relative scarcity in the Uists, represent in terms of machair ecosystems, quite extreme conditions which are likely to be impermanent.

These examples illustrate the nature of the relationship between vegetation patterns and their development, and geomorphological processes. These major ecological interrelationships are largely manifest in complex cyclical situations which tend to produce correspondingly complex vegetation patterns. The aggregation of these patterns into the units of the surveys does involve generalisation, but generalisation which approximates to the type of division termed noda by Poore (1955b). Man's agricultural practices further complicate these patterns by adding another factor to the system of processes controlling pattern development. The case studies and general observations indicate the value of detailed geomorphological studies such as those of Ritchie (1966a,1970), and their availability in the study area makes analysis possible at a detailed level.

2. Soils in Machair Areas

As would be expected, throughout machair land, relationships between soils and vegetation are two way, and both components are considerably influenced by many other elements of the environment. Processes are further complicated by the substantial role that man plays in machair areas, which tends to act directly and profoundly on machair soils and vegetation. Detailed studies and measurements of certain soil characteristics were carried out as an adjunct to the Grogarry Machair survey, so that much of the following data is drawn from that area. As has already been noted the Grogarry Machair area contains a wide range of vegetation types and ecological factors that soil studies based on this area can be considered representative of the Uists as a whole. Other important data were kindly contributed by the North of Scotland Agricultural College, and data were also drawn from the literature.

Table 4 shows the type and location of a number of soil samples collected at Dremisdale (immediately south of Grogarry) by Ritchie (1966a) and supplemented by data obtained during the Grogarry Machair survey. Much of the data are purposely drawn from samples located in the uppermost 15-30 cm of the soil in which much of the root activity of annuals is concentrated (Salisbury, 1952, p. 197) and in which the principal activities of grasses and sedges occur (Salisbury, 1952, p. 190). A number of samples taken from greater depth indicate the nature of conditions which might be experienced by the biennial and perennial components, which have much greater rooting depths (Salisbury, 1952, p. 200). Thus the upper parts of soil horizons in machair with their high relative organic enrichment have considerable significance in terms of influence on vegetation.

The depth and relative content of soil organic matter at Grogarry Machair is shown in Figure 12, and this is related to vegetation units and to the principal geomorphological features. A core augur was used to obtain over 20 samples along a transect line, and this proved to be a convenient and satisfactory method of examining samples to a minimum depth of 40 cm. Depth and colour, which are taken to be an approximate index of relative organic content, was measured for the organically enriched surface zones in each sample. In a number of cases pH values were measured using a portable meter. The data obtained reveal that there is a strong spatial relationship between organic matter content of soil, vegetation, stability of surface, and height of surface above the water table, all four elements forming a complex web of interrelationships. Man's influence on this network is direct, and cultivation tends to act against build-up of organic matter, by its mechanical breakdown, by dissipation of that matter already present, by removal by crops and by a limited contribution as a result of cropping. Little green fertilising or manuring is now carried out, and this is tending to exacerbate the deficiency. Samples from long uncultivated and recently cultivated machair plain show the difference in organic matter content clearly.

The contribution of organic matter to machair soil is high. In spite of high $CaCO_3$ content, exchangeable bases are relatively deficient, and the low potassium and phosphorus levels are now widely counteracted by extensive use of 12-15-60, N-P-K artificial fertilizer (Roberts, Kerr and Seaton, 1959). Organic matter is the major contributor of exchangeable bases, and neither the shell sand component nor the siliceous glacially derived sands have any store of exchangeable bases. Furthermore, the very sandy texture of the soil means that the organic rich surface layers have a much higher water holding capacity than the zone below.

Water deficit is a problem to the plant, though this rarely occurs in climatic terms in the moist Hebrides. The water table may be far below the surface in some ares (e.g. sand hills, Unit D) and very little water is available to vegetation in the zone up to 1 metre below the surface. Together the nutrient and water-holding capacities of the organic layer immediately below the surface explain why most rooting activity is confined to the uppermost 30 cm of machair soil. In freshly cut sections of blow-outs, this pattern could clearly be seen.

Organic matter also makes an important contribution to soil stability, combining with a closed vegetation cover to protect the surface from erosion by deflation, by binding together the individual sand particles to form aggregates too large to be wind transported. In the absence of organic material, machair soils are practically structureless, and thus are both susceptible to erosion and difficult to till. At Grogarry the soils of sub-unit E_1 are in this condition, and sand blowing is clearly impeding the growth of the undersown grass crop. Other important factors influencing soil stability are vegetation type and height above water table. There is a reciprocal relationship between vegetation and soil stability. Ammophila arenaria is a significant indicator of unstable conditions, though many other dune species and weeds, found in the machairs of the Uists flourish in disturbed conditions. A major cause of disturbance is man, and the results are prolific stands of weeds such as Senecio jacobaea, S. vulgaris, Stellaria graminea, S. media, Sonchus asper and Bellis perennis, all abundant and frequent components of recently cultivated machair plain as in the Grogarry Survey at sub-unit E_2.

In the Uists survey the relatively high values for these species in unit E is the result of high concentrations in recently cultivated areas, where soil disturbance is most pronounced, whilst in areas long free from unstable conditions, such species are quite uncommon. When a closed, relatively stable vegetation cover is established organic matter in the surface layer builds up quite rapidly, and soil stability increases, in itself promoting development of even more stable vegetation conditions. The patterns observed at Grogarry in sub-unit E_3 illustrate this clearly, particularly when vegetation composition is compared with that of units E_1 and E_2. Soil samples reveal a far greater build up in organic matter as indicated by depth and colour in sub-unit E_3 than in E_1 or E_2. In the former the average depth of organic enriched material is nearly 35 cm, whilst in the latter, where a clear layer could be found it is usually much lighter in colour and less than 5 cm deep. The difference in time of cultivation between E_2 and E_3 is in excess of 40 years. Once stable conditions are established organic build up is rapid, but in most areas there is such a delicate balance between factors influencing soil stability and vegetation cover that natural circumstances can produce rapid changes, and under the influence of man the results can be disasterous.

It has already been noted that machair soils are deficient in the macronutrients nitrogen, phosphorous and potassium. Besides these, trace elements boron and zinc are deficient, though this can be corrected by soil dressing (Roberts, Kerr and Seaton, 1959). Most of such mineral content as is found in machair soils is located in the colloidal humus complex of the organic horizons. Careful husbandry is essential, if serious depletion of this resource by cultivation is to be avoided. The use of artificial fertilisers to raise nutrient status, under the advice of the North of Scotland College of Agriculture is commendable, but the dying away of the practice of using seaweed as a green manure is to be most strongly deprecated. As a consequence of this, most machair soils in the Uists which are currently or have been recently cultivated, are showing serious deficiencies in organic matter content. The results are depletion of nutrients, lowering of water holding capacity and increased vulnerability to wind erosion. A change in the policy of the Crofting Commission and Department of Agriculture and Fisheries for Scotland towards payment for use of artificial fertilizers and traditional manure might help to redress the balance.

Similar processes can be observed in areas under 'natural' vegetation. The largest floras and high presence values for the most nutrient demanding species such as Carex panicea, are confined to low, stable machair plain areas, where freedom from disturbance by man and absence of 'natural' erosive or depositional processes have allowed a relatively thick organic layer to build up. Gimingham et al. (1948) showed that leaching had caused a decrease in Ca CO_3 content along a transect from the coast to inland areas in Harris. Ritchie (1966a, 1970) states that within a margin of about 5% of total content, sand comprising different parts of one machair have a comparable source, so that this $CaCO_3$ gradient generally runs in the opposite direction to that of base status due to soil organic content. As is shown in table 2, in most Uist machairs $CaCO_3$ values doe not fall below 30%, and thus lime shortage is unlikely to be a limiting factor, for a long time in the future. Continual sand supply from the west, which occurs in most areas, though frequently on a very limited scale, helps to make up leaching losses. However, more significantly leaching removes the other soluble mineral salts, which are in very short supply, and thus tends to depress exchangeable base capacity in machair soils. It is extremely likely that base deficiency is a limiting factor, in the ecological sense in at least some areas in the Uists.

The pH values which are encountered in machair soils are normally above 6.0, most frequently in the range 7.0 - 9.0 and occasionally even higher, even when measured in the organically rich zone within 30 cm of the surface. The vegetation response is of the type described by Salisbury (1952, pp. 286-7) containing several species listed as being "Plants commonly associated with calcareous soils", such as Carex flacca, Euphrasia officinalis and Helictotrichon spp., all significantly present particularly in the machair plain (unit E). In view of the critical roles of base status and soil organic content described above, pH in machair soils can be considered as being symptomatic of the whole machair regime, rather than a causal factor in terms of vegetation response. This is indicated by the virtual absence of obligate calcicoles from the species found. The ecological controls expressed by other components of the machair environmental complex are sufficiently strong as to make the high soil pH values a factor of lesser importance than might have been suspected.

Similarly only amongst the active dunes closest to high water mark can the influence of salt (principally NaCl) be detected, in the vegetation response. Randall (1969, personal communication) indicates that measurements detect appreciable quantities of salt in the atmosphere 200 metres or more from the coast on the Monach Islands about 6 kilometres south-west of the westernmost point of North Uist. The closeness of this station and the similarity of the observation sites indicates that comparable results could be obtained in the Uists. However, careful examination of the vegetation of Grogarry Machair reveals that there is no appreciable response in terms of overall vegetation composition, except in some localities along the dune front. Here, and throughout the Uists (unit A - active dune front and unit G - sea machair) the evidence of NaCl influence is clearly shown by the abundant presence of such species as *Cakile maritima*. *Agropyron junceiforme*, *Plantago maritima*, *Armeria maritima* and *Salicornia* sp. However beyond these rather limited areas salt water influence on vegetation appears to be very marginal, though exceptional winter gales may have some effect in units B (moribund dune front), C (dune back slope) and F (dune slack) in some areas. As with pH under other circumstances the role of salt might be much greater, but it seems most likely that this ecological factor occupies a relatively subordinate role compared with factors such as soil stability and nutrient status, in most machair areas.

3. The Water Table

As is normally the case in sand dune areas, the water table in the machair is a major ecological factor. Two elements of machair hydrology are of particular importance, firstly location of the water table below the surface, and secondly seasonal fluctuations in the height of the water table. Willis et al. (1959) and Ranwell (1960a, 1960b) show that in the complex dune areas to which their studies relate, incursion by saline water into the water table is an important ecological factor. Studies in machair areas around the Hebrides have not come to such conclusions; vide Gimingham et al. (1948), McLeod (1947) and Vose et al. (1956) and the vegetation studies in the Uists, and the studies of Ritchie (1966a, 1970), show that except in the case of foreshore vegetation (parts of unit A), this is not a factor of any measurable importance. This can largely be explained by the fact that much of the westwards-flowing drainage of the Uists, moves through the machair water table, rather than in surface streams. The downhill gradient of the water table towards the seashore is evidence of this, as has already been discussed in chapter 2.

The depth of the water table below the machair surface is of considerable importance. Not only does this relate to the water supply available to the plants at the surface, and consequently influences surface ecological conditions, but it relates very closely to the incidence of sand-blowing and thus to soil and vegetation stability. A dry sand surface is easily eroded by wind through the mechanisms of saltation and deflation whilst a wet sand surface, actively resists such processes, and provides a suitable receptive surface for transported sand grains. This in part explains the relationships which exist between vegetation type, height above water table, and soil stability. Hypsometric analysis of vegetation units reveals that there is a close correlation between certain types of vegetation and elevation, the latter closely related to depth of water table. At Grogarry the accurate, photogrammetrically-compiled, topographic map compiled by Wilson (1967) facilitates this analysis shown in map 11. Relatively low-lying ground is invariably the location in which 'wet' types of vegetation (e.g. sub-units F, H, in the Grogarry Machair survey)and all major depressions are occupied by such vegetation. Conversely sand hill vegetation (unit D) can almost be delimited by contour lines, though as shown in chapter 6 this is not invariably the case.

Height above the water table also influences the rate and nature of organic matter build-up. On low ground, with water-logged conditions, a fairly rapid build-up of a peaty humus results, in an anaerobic environment whilst in those areas which are well above maximum water table elevation, organic matter accumulations are rapidly broken down by the rich soil flora and fauna, which exist in such dry, sandy soils (Boyd, 1956, 1960). Leaching and mineralisation are further affected by water movements, and it is no coincidence that the most acidic conditions are found in uppermost soil horizons in the wetest areas. Acidity is counteracted by deposition of fresh blown shell sand, but this process acts very slowly in the wet areas at the eastern fringes of the machair, which are consequently the most acidic areas (Gimingham et al. 1948). Figure 13 shows these trends at Grogarry.

Seasonal variation in the height of the water-table are also important. Seasonal flooding has a less profund influence on vegetation distribution than might be expected, and whilst distinct community-types can be recognised (e.g. units F and H - dune slacks and fringe areas), the extent of area, where vegetation growth is severely inhibited by winter flooding, is very limited. In the central part of the Lon Mor the southern component of the Grogarry dune slacks, there is an area of muddy ground eliptical in shape and of approximately 200 square metres in extent with an incomplete vegetation cover dominated by Equisetum spp. and Angelica sylvestris. This type of vegetation is found nowhere else in the Uists. Elsewhere seasonally flooded areas have a vegetation cover with species tolerant of wet conditions, such as Hydrocotyle vulgaris, Carex panicea, Caltha palustris and Stellaria alsine, prominent components.

At Drimore, in the northern part of the Grogarry Machair survey area the difference between summer and winter water table levels is approximately 2 metres, in the latter season being almost at the surface (Ritchie 1966a, p.102). These conditions are typical of those found in machair plain areas (unit E) throughout the Uists. Thus, whilst machair plain surfaces can experience flooding, and certainly will experience waterlogging for a period from December to April, at the height of the growing season in June and July the water table level will be below the rooting level of many plants, and cetainly below the zone of principal root activity. With limited soil supplies being available only in the organically enriched zone, dry weather can have serious consequences for plant growth. In the 'natural' state machair plain areas tend to become dominated by grasses and sedges which form a strong closed community and develop an organically rich surface soil horizon. However, cultivation disrupts these processes, and reduces available water supply. The consequences are drought damage to crops, prolific weed growth in the disturbed habitat, and in some cases sand blowing. If an area is not cultivated the seasonal fluctuation in water table height has much less profound effects, and vegetation is better able to tolerate periods with limited precipitation in the better soil conditions. Machair plain vegetation is in a state of dynamic equilibrium with respect to water table location, soil stability and organic build up, and sand blowing, unless seriously disturbed by man. Amongst the dune slacks (unit F) and fringe areas (unit H) both totally or partially submerged in winter and waterlogged or wet in summer, and in the dunes (units A, B, C) and sand hills (unit D) in which the water table rarely approaches within 1 metre of the surface, seasonal variations are much less important than the average location of the water table. The average position of the water table strongly influences geomorphological processes, and thus these more extreme cases are less influenced by seasonal variations.

Again it can be seen that machair hydrology is an important ecological factor, but one which is very difficult to separate from other such factors. The complexity of interaction between environmental components and vegetation is such as to make such separation rather artificial.

4. <u>Man as an Ecological Factor</u> - cultivation, grazing and other man-made influences.

In ecological studies the assignment of relative importance values to different factors is at best a very difficult and rather unrewarding task. Most frequently the interaction of the components of the environmental complex makes such evaluation impossible. However in the case of machair vegetation, studies indicate that one factor stands out as being of prime importance. This is the anthropogenic factor. As has been related in chapter 3, the history of man's association with machair vegetation has been long. Over machair plain areas, agricultural activities are clearly the most important factors influencing vegetation, whilst over the remainder of machair areas grazing and other human controlled activities have a prominent role. However, man's activities and their consequences cannot be singled out as a group distinct and separate from other 'natural' ecological factors and their consequences. Man's influence is not confined to vegetation in machair areas, e.g. cultivation and grazing considerably effect geomorphological and soil-forming processes. Evidence on the nature and extent of man's influences on machair vegetation was gathered during the two surveys and together with literary studies are the basis for the following discussion.

The influence of man on machair vegetation is most significant in the machair plain areas. As has already been stated in chapter 7, more than half of the area occupied by a geomorphological landscape which would be expected to support machair plain vegetation (unit E) under 'natural' conditions, is under cultivation. Furthermore, cultivation is very largely confined to such areas, avoiding locations where other vegetation types are found. The reasons for this are clear. Topographically, machair plain is the only extensive level area on the relatively fertile west coast of the Uists and its low elevation, stable natural vegetation and balanced geomorphological processes combine to give an environment most suited to agricultural activities. These areas combine relative soil stability, a fairly high soil organic matter content, relatively large blocks of useable land and adequate drainage. However throughout most of the rest of the machair, and particularly the machair plain (unit E) man's impact on vegetation is hardly less profound through the agency of grazing. Grazing activities influence to a greater or lesser extent, all types of machair vegetation. Though concentrated on the machair plain which has a high feeding potential, the influence on other areas is as great or greater since even moderate grazing pressure can sufficiently disturb the currently somewhat precarious ecological balances, to produce very marked vegetation responses.

Cultivation focuses on the production of grain crops and leys, both of which are used almost exclusively for fodder. In the case of agricultural grasses, cultivation is somewhat of a misnomer, and rather scanty undersowing of grass seed mixtures as a preliminary adjunct to natural regeneration is a better description of the practice in most areas. The principal grain crops in descending order of importance are oats, oats based mixtures, barley and rye, with about 60% of land under grain crops devoted to oats. Only in the last two decades have modern oat varieties been introduced. A similar story can be told for rye and barley, in the latter case yields increasing enormously by adoption of modern six-eared varieties. As has been show in chapter 3, crofting agriculture in the Outer Hebrides is directly descended from peasant cultivation, and until very recently has shown clear signs of its origins. Fencing, rotations and consolidation of working units together with better plant stock have tended to break down barriers to improved efficiency. Kerr (1954) summarises the agricultural problems of machair land and suggests possible solutions. "A high lime and low humus content, wind erosion, a heavy weed burden, and susceptibility to drought damage are the main characteristics of machair land. Our knowledge of how to tackle these difficulties is small but some improvement will be gained from a rotation which includes a sown lea, use of seaweed and generous dressings of nitrogenous fertilizers backed by superphosphates. Building up fertility might be worthwhile in some cases and selective weedkillers could control many of the annual weeds." (Kerr, 1954, p. 160). Nearly twenty years later these remarks are still apposite.

Many problems in the use of machair land remain. These are due to lack of knowledge, though the major factor is actually getting beneficial changes accepted and carried out by the crofters. Township improvement schemes involving consolidation of working blocks and reapportionments (that is redividing of the croft land of a township to provide homogeneous units of land for each crofter, rather than a collection of strips either permanently held or lotted), have helped the more active and progressive townships, but have failed in more resistant communities. The use of artificial fertilizers is now sufficiently widespread to alleviate problems due to mineral deficiencies throughout cultivated machair land, but at the expense of the use of seaweed as an organic fertilizer. The absence of widely used, natural fertilizers has led to depletion of soil organic material, with the serious consequences already outlined. In progressive townships, a typical rotation in a consolidated block of machair is three years under grain, with the third year's crop being undersown by an approved grass and clover mixture, followed by 3 to 5 years under grazings. Fertilizers are used sparingly during the first 3 years, but not to any extent in the second period. In some extensive machair areas the entire township block is divided in two holdings of equal size which are cultivated and fallowed for grazing alternately at 3 or 4 year intervals. This occurs at Ormaclett and Dremisdale in South Uist. In more traditional areas, strips permanently or temporarily held result in variable rotations, but in general practices are much less efficient particularly in the temporarily held plots.

The type of agricultural practice has a very marked influence on the 'natural' vegetation of machair. Where old-fashioned exhaustive cropping methods prevail, the consequences to the environment can be very serious with erosion, sand-blowing and destruction of vegetation being the result. Such havoc if not irreparable, may take scores of years to heal. At best, agriculture if maintained at an intensity which does not seriously upset the precarious dynamic balance operating in machair ecostystems, can maintain relative stability in machair plain areas. All variations exist between these two extremes, and there is a great and continuing need for conservative farming in the machair lands of the Uists[1].

The principal ecological effects on vegetation of man's cultivation of machair can be placed in either directly acting or indirectly acting categories. There are two direct effects. Firstly, the aftermath of cultivation is the predominance of certain types of plants, particularly herbacious annuals, at the expense of sedges and grasses, when a machair area is recolonised by natural vegetation. This case is most clearly examplified at Grogarry Machair, where the vegetation differences between sub-units E_2 and E_3 are almost as marked as those between sub-units E_1 and E_2 (see chapter 6). In this case different dates of last cultivation of the sub-units E_1, E_2 and E_3 gives each of these components of this machair plain area, a different species assemblage and different dominance and abundance values. The dates of last cultivation of sub-units E_1, E_2 and E_3 were one year (1967), eight years (1960) and at least 40 years prior to the date of the field survey, respectively. The species-rich machair plain (sub-unit E_3) has dominance by

[1]Further consideration of past and present agricultural patterns has already been given in chapter 3.

Carex spp. amd *Festuca rubra,* whilst in the species poor sub-unit (E_2) *Festuca rubra* alone is dominant. Where cultivation occurred one year prior to the survey, the most abundant species in an incomplete, sparse and limited vegetation cover is *Sinapis arvensis.* Two trends in vegetation composition of machair plain can be isolated from the Grogarry data. Firstly, as the period of time since last cultivation increases the cover values of species requiring a stable habitat, such as *Carex flacca* and *Agrostis canina* also increases (cf. Ranwell, 1960b), as does the total number of species involved in the vegetation of such areas. Secondly, the more recently an area has been cultivated the greater the role played by weeds of cultivation. The principal species which fall into this group, found in the machair plains of the Uists forming significant components in the vegetation of relatively recently cultivated machair plain areas are *Sinapsis arvensis, Sonchus asper, Senecio* spp, and *Stellaria* spp.

The second direct effect of man's cultivation of machair has been modification of subsequent 'natural' vegetation development, by the addition of man-introduced species. Introduction may be either due to undersowing or seeding of machair areas, or due to proliferation of weeds of cultivation and to relicts of former crops. In the first case the principal component of undersown seed mixtures is normally perennial ryegrass, *Lolium perenne* (Roberts et al.,1959, p. 226) though hybrid varieties are now in widespread use. Studies show that the claim that "perennial ryegrass ..... dominates open machair swards" (ibid, p. 226) is not borne out by the results of the Uists study though this species can attain locally high cover values. This occurs in areas where cultivation and reseeding have occurred in the past two or three years. *Avena* sp., as in the case of the Grogarry survey in sub-unit E_1, or some other grain relict, often forms an important constituent of machair plain areas in early recolonisation stages, and has a detrimental effect on grassland re-establishment (ibid, p. 225). The other important constituent in locally used seed mixtures is cocksfoot, *Dactylis glomerata*, which often replaces *Lolium perenne* in the subsequent stages of colonisation. After four or more years, natural processes result in a sward on machair plain areas dominated by *Festuca rubra*, *Poa pratensis* and *Trifolium* spp., and the sown species are relegated to minor roles. If allowed to develop without substantial interference, after eight or more years *Carex* spp. start to play a significant part in vegetation composition. All these stages can be observed in various locations throughout the Uists and local inquiry will correlate the observed patterns with cultivation practices. Weed infestation by such species as *Sinapsis arvensis*, *Senecio* spp., *Chrysanthemum segetum* and *Sonchus asper*, is a serious problem at all times, and where agricultural techniques are poor, rotations ineffective and cropping over-demanding, may result in a weed dominated machair plain, which may take many years to be replaced by a grass and sedge dominated type.

Indirect influences of cultivation are widespread through interference with soil organic matter build-up, through sand blowing, by removal of protective vegetation cover, and lowering of nutrient status due to the heavy demands placed on soil by cropping. The results are not easy either to delimit or to analyse. An indication of the direction of change in these factors that is produced by cultivation can be obtained from the preceding sections dealing with these topics. As has already been indicated, the delicate balances, which are necessary to achieve any sort of stability in machair vegetation are readily disturbed. Cultivation acts in a variety of ways to cause disturbance of this balanced system, and shows clearly the principle of the holoceonotic environment applied to the machair ecosystem in which man must be regarded as a major part of the environmental complex.

However, man's activities are not confined to cultivation. Grazing, as has been noted, is widespread throughout the machair and is not confined to machair plain vegetation units. The effects of grazing by domesticated animals on machair are profound and almost ubiquitous throughout the Uists. Grazing helps to maintain dominance by grass species, plants well adapted to withstand grazing pressure, due to the resiliant growth forms of these plants. The question of machair vegetation status is discussed more fully in the following chapter, but it is clear that grazing is a major factor preventing development of vegetation dominated by relatively slow growing shrub species such as _Ulex europaeus_, _Calluna vulgaris_ or _Salix_ spp. It is not certain that removal of grazing would result in dominance amongst mature and stable areas (e.g. machair plain types) by one or more of these species, but the statement that "....machair is a _Festucetum rubrae_ which develops as a biotic plagioclimax on calcareous shell sand." (Vose et al., 1955, p. 108) is an accurate and succint designation for machair vegetation in the Uists.

It is suggested that "....species which are apparently on the increase serally show increase following the absence of grazing, and others apparently decreasing serally show decrease." (Ranwell, 1960b, p. 392). Seral change in this study relates to increasing stability and maturity of vegetation cover, and there appears to be considerable comparability with the Grogarry and Uists surveys, although grazing referred to in Ranwell's Anglesey study was by rabbits. Comparison between areas which are grazed by domesticated animals at different rates (based on approximate stocking densities for different townships) indicates that the same trends are applicable. Ranwell (ibid, p. 392) cites Carex flacca as a species which increases with removal of grazing and Agrostis tenuis as a species which decreases. Samples taken in different areas in the Uists survey reveal that similar trends for these two and other species which belong to serally increasing or decreasing groups, can be discerned as is shown in table 7. The contrasts can best be seen in the south part of South Uist from Smerclett to Kildonan which have high grazing pressures, in comparison with central South Uist, from Bornish to Ormaclett where stocking densities per unit area of machair are lower. In the former area machair plain samples have an average number of species of 11.3, whilst in the latter area the corresponding figure is 15.6. Figure 14 shows that the ranges of the true means of the number of species in samples are discrete at the 90% level, and that this increase in the total number of species can be taken as further evidence of th difference between the two areas. These differences are closely matched by stocking densities of livestock in the two areas, which partly related to dense settlement and limited machair area, are high in the south, whereas in the northern area, smaller township populations and extensive machairs make for much lower rates.

Grazing is also an important element influencing vegetation development in areas to the west of the Machair Plain. Sheep, in particular, have a pronounced influence in this area and their intense grazing habits seriously disturbs the ecological balance in machair vegetation units A -D. This factor, together with grazing by rabbits, as is discussed below, is the principal cause of sand blowing in sand hill vegetation (unit D), and a major factor amongst the dunes (units A, B and C). Clear evidence of this can be seen in cases where overgrazing has damaged vegetation to such an extent that sand blowing results, and such cases are common. Amongst these areas and rabbit warrens, which are numerous in the sand hill and dune back slope units (units D and C respectively) vegetation has a characteristic appearance. It is cropped short and even Ammophila arenaria rarely rises more than a few centimetres above the surface. Sand blowing is evident and surface sand from blow-outs is always in danger of swamping the severly inhibited vegetation. Such areas are in a precarious state. Overall, grazing probably shapes current vegetation patterns more than any other single ecological factor, except in areas where regular cultivation takes place.

Certain other ecological factors are worthy of mention. Machair wildlife at the macroscopic level is almost as man-modified as the vegetation, although this is to be expected in this sort of highly modified ecosystem. In terms of numbers and effects on vegetation the principal species is the rabbit, Oryctolagus cuniculus. After their mediaeval introduction to Scotland (Boyd and Darling, 1964, p. 87) they probably reached the Uists in the mid-seventeenth century and very quickly became well-established residents. The principal controls limiting population size are food supply, almost exclusively provided by machair vegetation, disease and predation. The effects on machair vegetation of rabbit grazing have already been mentioned. Evidence from eastern Scotland shows that the total biomass of rabbits per unit area in an upland pastoral farm, can exceed that of domestic animals (Fenton, 1937). Casual observation on numbers of rabbits in certain localities indicate that this must be true for parts of the Uists' machairs. There is a two way interaction between rabbits and vegetation. With overgrazing caused by excessive population pressure, the food value of the vegetation, in terms of both quality and quantity, falls as more palatable species are eaten out. This will result in a fall in the population level to balance food supply, but whether any sort of dynamic equilibrium can be established depends on the ability of vegetation to cope with the increasingly unstable conditions.

In the absence of the fox (Vulpes vulpes) the only predator of any consequence to rabbits in the Uists is the buzzard (Bubo bubo). In an effort to restore the ecological balance so upset by the introduction of rabbits and their consequent increase in numbers, the deadly virus disease myxomatosis was introduced by man to the Uists in 1960. The extra-ordinarily high fatality of this infectious disease almost eliminated the rabbit population. However, immunity was relatively soon developed and now numbers have reached pre-1960 levels in many areas. Crofters maintain that the disease is endemic and re-occurs every four or five years in rabbit populations. Certainly in a number of areas the effects of myxomatosis on present populations are only too painfully apparent. Studies in Anglesey (Ranwell, 1959, 1960a, 1960b) have shown the impact of rabbits on sand dune vegetation, and whilst these have already been noted with respect to domestic grazing in the Uists, the general conslusions are even more valid for rabbit populations on the machair.

The only other animal which may have a significant effect on machair vegetation is the Grey Lag Goose (Anser anser). Newton (personal communication) indicates that particularly in the breeding (May - June) and moulting (September) seasons these birds rarely graze more than 100 metres from the shores of the machair fringing lochs on which they chiefly nest. Thus a high grazing pressure is found in some machair wet fringe areas (unit 1) and may be responsible for some change in these areas. A careful study of one such location, around the western shores of Loch nam Balgan in the Grogarry survey area (sub-unit 1_2), did not reveal any significant discernable variation when compared with other fringe areas believed less heavily grazed.

Man is responsible for other changes in machair vegetation besides those due to agriculture, but as yet these are of lesser significance. Direct human pressure on machair is increasing as the Uists become a more popular and accessible tourist centre. Increase in tourist traffic has increased greatly in the past few years as is indicated all over the islands by the development of new facilities and accommodation to cater for the demand. Sand dune areas suffer mechanical disturbance and attrition, and vegetation damage or destruction is widespread and serious whenever man at his leisure makes extensive use of these areas. As yet, there is no such problem in the Uists, and in most areas vegetation could withstand greatly increased numbers of visitors. Present scarcity of accommodation provides a check on numbers, far below any danger level. Thus as yet effects in the Uists are slight, but in popular areas such as Balranald Machair, where there is an important bird sanctuary of the Royal Society for the Protection of Birds, and beautiful and sheltered beaches, there may soon be a serious problem. The creation of township caravan sites, as in the coastal site of Creagorry township in Benbecula, poses a very serious threat to machair, which offers good potential sites, since they have easy access, are attractive, are quite well drained naturally and are extensive enough to cater for a number of caravans per site without extensive preparatory work. Machair can ill-withstand damage by vehicles and constant repair will be essential to prevent sand-blowing problems.

Pollution, too, may become a very serious problem in the machair as machair ecosystems, vulnerable and highly specialised can cope only very poorly with large amounts of human debris and waste. Already many machair areas are scarred by the rotting hulks of motor vehicles, oil drums, piles of domestic refuse and an assortment of agricultural rubbish, the bulk of these pollutants being contributed by the indigenous population. The Hebridean crofter, already ill-disposed to interference may well cavil at regulations designed to combat abuse of the environment he has long taken for granted. It is to be hoped that international agreement will help prevent marine pollution from causing irreparable harm to the beaches of the west coast, upon which each tide presently casts a rich and varied harvest of more or less noxious human detritus.

Another potentially serious problem is posed by the extensive use of machair land by the Ministry of Defence. Sited in the Uists for strategic and geographical reasons, the Royal Artillery Regiment headquarters in Benbecula, and the missile testing range-head at West Geirnish in South Uist, have become fairly well accepted components of the human community in the Uists. Effects on vegetation are presently not serious and in some instances are actually beneficial. Strict controls on cultivation and grazing over the greater part of Iochdar and West Geirnish Machairs, have resulted in an increase in soil and vegetation stability. This can be seen from the vegetation samples drawn from this area, which show the machair plain to be particularly species rich, the average number present in samples being 18.1, compared with 14.8 for all machair plain samples. The lush, rather poorly drained, machair plain is dominated by grasses and sedges. Access to this area is only regulated at firing periods, a very limited total time, so that the area has not been sterilized in human terms. In a few locations more serious problems are the erection of various structures on or near machair land, with consequent disturbance and destruction of vegetation. This is limited at present, but careful liaison with military authorities is necessary to minimise disturbance, and to conserve and protect important ecological sites such as the Rudha Ardvule in central South Uist.

Throughout this study, the delicate balances resulting from processes operating in the machair ecosystem, are shown clearly in the complex vegetation patterns and their ecology. These are easily disturbed by man, and are in a constant state of change as a result of the operation of 'natural' processes. Almost every change in ecological components including man, must be regarded as trigger factors in ecological terms. The machair illustrates clearly the principle of the holoceonotic environment and thus makes the unravelling of 'natural' ecological and human influences on vegetation difficult. This close, complex and complementary interrelationship between the environment including man and machair vegetation are further reflected in status of machair vegetation considered in the following section.

CHAPTER 9

THE STATUS OF MACHAIR VEGETATION

The objects of this chapter are to analyse the processes operating on machair vegetation and to evaluate the status of the vegetation zones delimited in the surveys. These two objectives are related since the nature of processes operating on machair vegetation in a particular location over a certain period of time determines its status. Status, therefore, may be defined as the relative position, with respect to development, of the vegetation units. Thus location is an abstraction and though time and space are of fundamental importance in evaluating status, processes may be so complex that abolute parameters cannot be used. In the absence of isotope dating or detailed palynological studies an absolute time scale cannot be delimited, and the nature and complexity of the processes operating in machair vegetation mean that interpretation of status on the basis of spatial location is very difficult. The information available for this study is suited best to a broad examination of these topics and the results are pointers to future problems rather than definitive statements. This is in keeping with the aims of the Uists survey which is concerned with analytical spatial description rather than detailed ecological evaluation.

The sources of data for this chapter, are firstly the field data on the vegetation and its environment gathered during the two studies, and secondly available literary sources dealing with either specifically machair vegetation or, more generally, sand dune systems. The ecological factors examined in the preceding chapter, and the vegetation analyses detailed in chapters 6 and 7 form the basis for the first part of this chapter, a detailed study of processes. This is followed by an examination of relevant general theories of sand dune vegetation evolution, in which differences between these expected situations and the observed patterns are particularly noted. Specific studies of machair vegetation, and their relationships to the Grogarry and Uists' surveys are evaluated. Finally, a generalised developmental scheme, showing both processes and status of the delimited units is proposed and described.

Machair vegetation processes can be divided into two major classes according to their dominant role in development. In basic ecological theory, succession, that sequence of stages of development is divided into primary and secondary types according to the relationship between the vegetation sequence and the circumstances of its initiation (Odum, 1971, p. 78). Commonly changes have been divided into two classes, one, autogenic change, stemming from modification of the habitat by vegetation itself, the other, allogenic change, a result of external variations in environmental conditions (Kershaw, 1964, p. 41). However, criticisms of this division (ibid, p. 41), and experience in the Uists, which suggests that it is neither meaningful nor readily applicable, have led to a division of processes into those which are dominantly involved in primary succession and those which are dominantly involved in secondary succession, and are termed primary and secondary processes respectively. The reasons for this division are firstly that it is meaningful in terms of the time scale of development in machair vegetation in the Uists, secondly it affords a possible means whereby processes causing major directional and minor cyclical changes can be distinguished, thirdly evaluation of the balance between these two classes of processes can be related to nature of, and location of, vegetation zones and fourthly the scheme is quite readily applicable to machair vegetation.

The first group, primary processes, is composed of five major types. These are deposition, erosion, stabilisation, eastwards movement and surface lowering, each of which is a component of long term development in machair. The first two whilst being separate processes, can best be discussed in the context of these surveys and with the available data, together. In detailed quantitative analysis Ritchie indicates that relatively little fresh was being supplied to the machair from the extensive beaches to the west of the dunes. "Judging from present conditions it would appear that the quantity of empty shells on the west coast beaches is insufficient to provide sufficient calcareous material to the dunes and machair to replace the lime lost by leaching, let alone explain the enormous build-up which must have occurred at some time in the past." (Ritchie, 1966a, pp. 167-8). This is based on experimental analysis which showed that conditions suitable for sand movement only occurred on seven days out of a total of fifty-six, 12.5% of the possible. In this period rather less than 2 kilograms of sand were collected in a sand-box, 73 cm high by 23 cm wide, not an insignificant amount, but much less than would be expected in a period of eight weeks if accretion was to be a major factor (ibid, pp. 163-4).

Yet both physiographic morphology and vegetation indicate that an appreciable sand supply is being received by certain areas in the machair. On the basis of these observations, reception is by no means uniform, but in some localised areas, such as the sea facing dunes at the mouth of the Howmore river in South Uist, the dune front of the northern part of the An Tom peninsula, Benbecula, or in suitably sheltered parts of Machair Leathann on the north coast of North Uist, sand supply is sufficient to produce active accretional dune forms, characterised by vigorous stands of Ammophila areanaria, or by communities dominated by such species as Honkenya peploides, Atriplex hostata and Agropyron junciforme, species normally regarded as being associated with the formation of a new dune front (Salisbury, 1952, p. 212). The solution to this dilemma, as suggested by Ritchie (1966a, p. 161) is that most of the fresh sand which is responsible for these active accretionary forms and processes has been translocated from another part of machair, and is thus to a considerable extent, reworked material Ritchie (ibid) showed that nearly all machair sand has been transported by wind, and together with the absence of large scale present-day supply indicates that most present sand movements involve translocation of beach or more frequently machair sand, rather than fresh deposition of sand of recent marine origin.

Thus, at the level of inquiry the primary processes of erosion and deposition are difficult to separate, both forming part of a cyclical regime. In fact it is clear that in general theoretical terms of vegetation process the consequences of erosion and deposition are useful and meaningful divisions, but such distinctions have limited meaning in geomorphological terms. The primary vegetation processes termed deposition and erosion show seven characteristic features. These are (1) location immediately adjacent to or at most within 50 metres of high water mark; (2) incomplete vegetation cover of the sand surface, which is in a relatively mobile condition; (3) presence of one or more moderately halophytic plant species such as Honkenya peploides; (4) presence of psammophytic plant species, particularly Ammophila arenaria: the presence of this plant, under normal circumstances in at least moderate abundance, cannot be considered diagnostic of these processes, but such processes are most unlikely to occur in areas in which this species does not occur; (5) ecological factors in a delicate balance, so that direction of process (i.e. from erosion to deposition or vice-versa) can easily be changed; (6) almost complete absence of non-vascular plants, except for limited presence of lichens of the Peltigera genus; (7) representation of all stages of development of vegetation under these processes, with no common readily discernible spatial pattern accounting for these different stages.

The third primary process is that of stabilisation. Vegetation stabilisation reflects changes in ecological conditions, and in the machair lands of the Uists the result is continuous variation along a continuum from initial colonisation of an original sterile sand surface by pioneer species to the ultimate prevailing degree of stabilisation found in a species-rich grass and sedge dominated vegetation cover, at all times closely and completely covering the sand surface. This is in relative terms the most mature type of vegetation, resulting from the environmental and phytosociological stability. Whilst variation along the continuum is uninterrupted in time and space it is not uniform, and real discrete vegetation communities can be recognised. This occurs where ecological conditions result in the development of vegetation cover dominated by a plant species which has a certain role in the stabilisation process. The relationship between Ammophila arenaria and development has been investigated by Gemmell et al. (1953), Marshall (1965), Willis (1965) and Hope-Simpson et al. (1966) amongst others and whilst results are inconclusive, the bulk of evidence indicates that environmental changes are responsible for variations in vigour and abundance of that plant. The recognition of the vegetation units in the two surveys is in part based on the results of the stabilisation process. However there is no simple progression from unit A to unit E, the least and most stabilised vegetation zones in the Uists' survey, either in time or space, and direction of change, extent of change and resulting vegetation patterns all show complex multi-directional variation. The process of stabilisation is associated with five component features: (1) normally, but not invariably, fully stabilised and mature vegetation is located at some distance from the shore, closer to the eastern than the western limits of the machair; (2) invariably vegetation cover is complete: absence of this attribute means that the stabilisation process is incomplete; (3) stable areas are normally chacterised by a richer and more diverse flora than unstable areas; (4) Ammophila arenaria is always absent from completely stable areas; (5) certain species associated with the stabilised conditions, intolerant of disturbed conditions are normally present: these include certain members of the Carex genus

(C. panicea, C. nigra), and certain grasses (Holcus lanatus, Agrostis canina): it is noteworthy that all of these species have relatively wide ecological tolerances but are best suited to moister conditions (Hubbard, 1954, Jermy and Tutin, 1968) and that, as previously discussed, geomorphologically stable areas are close to the water-table.

The fourth and fifth primary processes are again closely related and difficult to distinguish separately. These vegetation processes are associated with major long-term geomorphological activities. The general eastwards movement of the machair and the lowering of its surface (discussed in chapter 2), result in environmental conditions which are more stable for plant growth, are wetter and consequently uninfluenced by sand-blowing. The vegetational reaction is the development of a community type which has the following characteristics: (1) increasing abundance and frequency values for species suited to more acidic conditions, e.g. Iris pseudacorus, Juncus sp.; (2) increasing values for species suited to wet, very wet or even inundated conditions, e.g. Phyragmites communis, Iris pseudacorus, Hydrocotyle vulgaris and Caltha palustris; (3) a location at or close to the eastern physiographic limits of the machair, as defined by the limits of surface wind-blown sand. The vegetation processes responsible for these can be termed acidification and moisturisation.

Secondary vegetation processes are distinguished from primary processes on the basis that such processes operate on vegetation which has developed from a previously vegetated surface. Secondary processes can further be distinguished from analogous primary processes by the different vegetation patterns which result.

Three categories of secondary process can be recognised, although these are closely interrelated. The first component of secondary processes is erosion. This can be distinguished from primary erosion which occurs as part of the cyclical initial colonisation of sand close to the sea. Secondary erosion occurs in areas where the vegetation cover is complete or nearly so, though is not normally at a mature state. Thus in the Uists amongst units B and D are found instances of secondary vegetation erosion. This process results in stripping of vegetation cover, exposure of bare unconsolidated sand, and sand inundation of adjacent vegetated areas, causing death of the individual so affected. Certain common species, found in these susceptible areas, have some ability to tolerate sand inundation; e.g. Bellis perennis has a very limited ability, whilst Plantago lanceolata appears to tolerate more severe incursions. These observations are based on examination of sand spillways of the type shown in figure 8, and distributed throughout the Uists. Ammophila arenaria and various mosses, as discussed in chapters 7 and 8, in part owe their considerable role in the vegetation of unit D to their ability to tolerate considerable inundation by sand (Chapman, 1964, pp. 140-5). Initiation of secondary erosion is often caused by man or some biotic agency such as cattle or rabbits. This results in rapid erosion in potentially unstable areas e.g. close to rabbit warrens the evidence of this form of vegetation process is widespread. Secondary vegetational erosion can be distinguished by three criteria: firstly in terms of location it can occur at any point on the machair, but is uncommon close to the eastern limits of the machair; secondly, it occurs in areas which have a complete or partly complete vegetation cover; thirdly it most commonly occurs in areas which are elevated above water-table level, which are on a steep angle of slope, or both.

The second element of secondary processes is recolonisation. This may occur at any juncture when vegetation succeeds in covering a sand surface sufficiently to inhibit further erosion, to survive burying by relocated sand and ultimately to form a complete cover. The exact point in the erosional sequence at which recolonisation will begin, is dependent on site location with respect to exposure and aspect, height above water-table, and the nature of the surrounding vegetation which normally provides the recolonising stock. Secondary recolonisation, like secondary erosion can be distinguished from the corresponding processes by the following criteria: (1) it can occur on any suitable surface, not necessarily one close to the dune-front but normally one elevated above the water-table: thus the process occurs in units A, B, C and particularly in unit D; (2) normally but not invariably, recolonisation occurs first in the bottom of blow out depressions and around margins where sand is being deposited; (3) Ammophila arenaria, though important, is by no means the sole colonising agent, and Carex arenaria and moss species such as Camptothecium lutescens and Hylocomium splendens can be observed fulfilling this role; this agrees with the findings of Gimingham et al. (1948, p.90); (4) this process results in the formation of discontinuous clustered pattern units during the initial recolonisation period, due to development emanating from localised areas, which are the sites of the parent recolonising stock; often undercut turves which have fallen into a blow-out provide a focal point from which development can proceed; the resulting patchwork of bare sand, colonising species, and gradually encroaching stabilising species such as Festuca rubra, is highly indicative of the process; mathematical testing of pattern distribution types may be in the future a valuable research tool in machair vegetation.

The third type of secondary process is a development of the first two. In this case quite extensive areas (in excess of 1,000 sq. m.) occur in which there is a continuous complex of erosion, deposition and recolonisation, apparently in a state of dynamic equilibrium, with little sand entering or leaving the area. In the Grogarry survey, sub-unit C_3 appears to be of this type, though it is likely that there is some eastwards sand movement. In this case net sand import and export probably balance fairly closely. Along the north west coast of North Uist, around Hosta and Huna, extensive areas are covered with a mosaic of vegetation of machair plain (unit E) and sand-hill (unit D) types. The pattern is irregularly clustered and seems to represent a balance between erosional and depositional processes resulting in an equilibrium situation, with no clear directional developments. In this area, sand supply from around the coast is limited by the headlands of Varlish and Manish enclosing Traigh Verral sands, and to the east the area is circumscribed by the low ridges running inland from these headlands and the backing arc of hills (Carra Chrom, Ben Vanisary and North and South Clettraval), making export of sand from the area equally difficult. This is a clear case of the equilibrium situation and it seems most likely that in several other areas where small scale patterns are found the cyclical processes represent at least a temporary end point to vegetation development. In others such as the pimple dunes of the Grogarry survey (sub-unit D_2) long term directional change can be detected, in this particular case towards Machair Plain vegetation (unit E). Such areas are characterized by considerable extent often occupying several hectares by a rich and diverse flora in part due to their generally recognised unsuitability for cultivation and by vegetation patterns at a scale too small to be mapped in either the Grogarry or Uists surveys, and yet caused by similar factors as were responsible for the units and sub-units distinguished elsewhere.

Map 12 shows the distribution of these types of processes at Grogarry. This map is derived from the Grogarry Machair vegetation map (see appendix 2 and map 8), and from documentation and field observations on soil conditions and geomorphology. It can be seen that most of the area is under the secondary process regime. This is partly a function of the complex geomorphology of the inland part of the area, partly due to the comparative absence of sand blowing at the dune front, and partly due to the scale of man's interference with vegetation particularly in the southern part of the area. Comparison with the vegetation maps shows that process types do not conform to a recognisable pattern. As is discussed more fully below, this indicates that the development of machair in the Uists does not conform to any simple sequence.

Processes in sand-dune areas have been evaluated in many specific cases and a number of general theories have been advanced. Frequently the sand-dune system and psammosere are used to illustrate general ecological principles, though not always in a convincing manner. When machair vegetation is compared with these general theories and hypothetical systems, a number of significant discrepancies between the general and specific cases are apparent. Discussion of these differences is a valuable method of studying the distinctive processes which operate in the Uists. Major processes in dune development are summarised in general terms by Salisbury (1952) and Chapman (1964) and these illustrate the types of sequences normally used to categorise assemblages of dune vegetation according to supposed status. These general theories are not intended to provide definitive explanations of all, or even any, sand-dune systems, but are rather models abstracted from a number of case studies.

It is agreed that certain conditions are essential for dune formation, of which three are most important. These are firstly, a sand supply, secondly, mechanisms to transport this sand, and thirdly, vegetation to consolidate the sand into dunes. In the case of coastal dunes, such as those under consideration, sand invariably has a marine origin, though there is no fixed relationship between the locality and dune sand source. Frequently sand has been transported from another area, or has been produced under different conditions at some time in the past. Such circumstances occur in the Uists and the result is an environment which is partly a product of present-day sand-dune development, and partly a consequence of pre-existing elements in the physical geography of the Uists. Another critical factor related to sand source is the proportion of calcareous material present. This has a considerable influence on dune development particularly when a stable cover has been established, and may result in permanent or very long term changes in the dune succession (Salisbury, 1952, pp. 297-303). Again such conditions exist throughout the Uist machairs, and are at least partly responsible for the vegetation succession found in these areas.

Assuming the availability of a marine process to transport and deposit sand to beaches, wind is the prime agency involved in moving sand to form dunes. The marine and aelian processes operating in the Uists have been described in some detail by Ritchie (1966a, 1970) and have already been discussed in chapter 2. In general, wind moves sand from the beach inland to the developing dune front, by saltation (that is, by jumping of individual grains over a short distance of a few centimetres, which upon impact cause movement of another grain by transmission of kinetic energy, and so on), by rolling, and with fine particles in very strong winds by suspension. The most important of these transport mechanisms is saltation, and this requires a dry sand surface, since grains on the surface of wet or damp sand absorb most of the kinetic energy on impact. Thus an essential for dune formation is an area of dry sand. The existence of such a feature is dependent on a number of factors the most important of which are rate of sand supply to beach, beach gradient, tidal range, and long-term changes in sea-level and climate. Along the west coast of the Uists the sum of these factors produces present conditions which are not generally favourable to large-scale sand transport to the dune front, further confirmation of the empirical evidence cited in the preceding chapter. As was shown in chapter 2, the formation of the extensive sand areas along the west coasts of the Uists over the last five millenia was under different and favourable conditions.

Vegetation is an essential factor in dune formation. Foredune vegetation has largely a hemicryptophyte and therophyte flora in which the principal species belong to the families Cruciferae, Chenopodiaceae and Polygonaceae. Initial colonisation by vegetation takes place along, or immediately above the drift line which marks the limits of high tides and where decaying seaweed detritus provides an organically enriched zone. Seeds of suitable colonist species are carried to this location principally by tidal action, or in some cases by wind. Such colonists have the ability to tolerate high concentrations of chlorides in solution (up to 1.5% permanently or 6% temporarily) and even very occasionally inundation by sea water: this is made possible by the very high osmotic pressures found in the cell sap of these halophytic plants, up to 10 times those recorded in non-halophytic species. With onshore sand movement, this zone will readily trap sand due to a reduction in wind speed caused by the shelter effect of both the colonising plants and the embryonic dune, and dune growth will occur. Such pioneers have some ability to tolerate sand inundation, though this is generally of a lesser magnitude than that of such true dune building species as Ammophila arenaria. As the dune grows in size by sand accretion, the marine influence, particularly on the higher and landward parts, declines and salt tolerant species are swiftly replaced by species tolerant of sand blowing.

However, such conditions cannot occur until an embryonic vegetation cover is established. This embryonic cover has two vital roles; firstly to trap blown sand and increase the size, and in particular the height, of the dune, and secondly to stabilise the sand surface, by lowering wind energy at the interface between the atmosphere and the sand, and thus to prevent deposited sand from being further moved. In the area immediately above high water mark, in the absence of vegetation cover sand import would be balanced by sand export (Chapman, 1964, pp. 132-6).

Steers (1946) proposed a system of dune classification, and this is shown in simple form in figure 15. The units recognised in the Uists' survey can be compared with those indicated by Steers, although these latter are primarily based on dune morphology. Vegetation units A and B are found in the upper part, units B and C in the middle, units C and D in the lower part of the figure. The parabolic forms described by Steers (1946, p. 507) and Briquet (1923) do not occur in the Uists. The discontinuity between these geomorphological forms and the vegetation units of the surveys indicates significant variations between this model situation and the observed patterns in the Uists. A rather more sophisticated approach based on the vegetational characteristics of dunes is advocated by Salisbury (1952, pp. 206-80) and developed by Chapman (1964, pp. 139-155), and is illustrated in figure 16. This classification is primarily based on vegetation processes and recognition of certain characteristic vegetation assemblages associated with stages in development. Again significant differences between those types of vegetation described in the two surveys, and those which are recognised in this system can be detected. As has already been stated, the relationships involved in the ecology of units A and B, (active and moribund dune fronts) are complex, and at the scale of the Uists' survey it is not possible to identify and isolate a consistent direction or balance of ecological components in in machair successions. Even at the detailed scale of the Grogarry survey, such conclusions are tentative. Furthermore, secondary processes often play the major role in shaping the present character of the vegetation. Neither a simple temporal nor a simple spatial system of relationships, as is suggested by the scheme shown in figure 16, exists in the Uists, and in this area relationships are complex and multidirectional. Finally the role of man in shaping machair vegetation is fundamental, and must play a part in any hypothetical system of development.

A system including a number of alternative successions based on different initial conditions and under different basic process regimes has been developed by Olson (1958, p. 152), and is shown in figure 17. This model includes multidirectional relationships, varying development from different initial conditions, and development under two different types of process. Though primarily based on vegetation succession, the model does not ignore geomorphological processes, and provides a satisfactory framework for development of a system applicable to the machairs of the Uists. The detailed studies by Olson (1958) indicate that soil characteristics in general and nutrient status in particular are the critical factors in vegetation development. Man's activities, through the agency of fire is cited as a further important influencing factor. Perhaps the most important consideration in the argument advanced by Olson is that the study illustrates the principles of ecological succession representing, "....a variable approaching a variable rather than a constant." (Olson, 1958, p. 168). The findings of the two surveys in the Uists indicate that these factors are of considerable importance in theoretical explanations of machair vegetation processes and seral development.

Although in the above discussion many differences are noted between the expected or general, and the observed patterns and processes in the Uists, examination of general systems is of considerable value, since the major variations which exist are indicators of important, distinctive elements. On this basis four general conclusions relating to machair vegetation can be advanced:
(1) There are not simple space relationships in the vegetation and changes are both multidirectional and do not necessarily follow any prescribed sequence;
(2) there are no simple time relationships, and existance of a particular vegetation stand cannot be equated with development time, except in a very broad and relative manner, nor need vegetation development reach a certain stage after a specific period of time, although certain relative, general temporal relationships, normally over a short time-base, can be discerned; (3) the human factor and its influence on vegetation development is very important at every stage in development, and no discussion of machair status can overlook or set aside this condition; (4) geomorphological processes, particularly those which are a function of height above water-table play a vital role in vegetation development.

Before putting forward a theory derived from the Uists' observations, it is worthwhile to examine those based on other machair studies, elsewhere in the Hebrides. Vose, Powell and Spence (1956) base their observations on machair vegetation in Tiree, an island about 80 km south-south-west of South Uist. Climatic conditions are broadly comparable, and sand forms quite extensive areas of machair with a high lime content (67%), though the total machair area is much smaller than in the Uists and partly as a result of this, and partly as a consequence of the nature and morphology of the underlying rocks, geomorphological balances appear to be rather different from those observed in the Uists. Apart from grazing pressure which appears to be considerable, the human influence is relatively small because of the relative absence of cultivation at present. Though the species list is limited, floristically the Tiree machair has considerable affinities to those in the Uists. A summary of the vegetation descriptions given in this paper is shown in table 8. Important differences in species composition are apparent; e.g. in the "mobile dunes"[1] the absence of Ammophila arenaria and the high frequency of occurrence of Agropyron junciforme and Trifolium repens; in the "young", "mature", and "older machair" the important role of grasses such as Cynosurus cristatus and Koelaria gracilis; both of these contrast with firstly the patterns observed in the dune units (A, B, C) and Machair Plain unit (E) in the Uists' survey (see chapter 7). However, the main points of variation are in the theories of development. Although

[1] quotation marks are used to indicate descriptive terms used by quoted authors to name various delimited units.

at no point stated as such, the terms employed for characterisation of the various vegetation units (e.g. "young", "mature", "older") suggest a sequential relationship. This impression may be unintentional, but in the absence of further discussion appears to be a tenable conclusion. The statement that "....machair may be regarded as a biotic plagioclimax from which further succession, on cessation of grazing, would culminate on the west coast with either Calluna or Molinia heath." (ibid, p. 105), is not well supported by edaphic data, nor holds substance when applied to machair vegetation in the Uists. In the unlikely event of the removal of all human influences, inherent soil stability and sand-blowing, a geomorphological process which is acting over a sufficiently long time period (several millenia) to be regarded as a constant factor, would compensate for increases in moisture content, acidity and loss of bases by leaching and organic matter build-up. Even in fringe areas (unit H) it is impossible to find any more than very local and inconsistent evidence seawards spread of such acid-loving species as Molinia caerulea or Calluna vulgaris which are common on the 'black land'. Considerable prominence was given in this study of Tiree machair to the role of man in influencing vegetation development.

In a study of Luskentyre Banks in south-western Harris, about 30 km north of North Uist, the findings of Gimingham, Gemmell and Greig-Smith (1948) show considerable floristic similarities with the Uists' surveys. Again species are fewer in number, but this can in part be explained by the limited area of this study (less than 1 sq. km), so that the total number of species is analgous to that recorded in the Grogarry syrvey. Five basic vegetation types, forming components of a seral progression are recognised, described in subjective terms and located on a sketch map; these are "Foreshore Community", "Mobile Dunes", "Fixation" (in two stages) and "Dune Pasture". Process, particularly the role of Ammophila arenaria, as indicated by subjective measurements of cover in the manner of Tansley (1939), is an important consideration in the classification scheme. This study also indicates that processes and consequent spatial patterns are much more complex than in Tiree, and similar to those observed in the Uists. This seems to be in accord with these authors' general ideas on dune vegetation, and thus is an important factor in formulating a general theory for machair vegetation in the Uists. "The succession on the Luskentyre dunes appears to follow a course a to that described on most British dunes, with Ammophila as the principal dune builder, but the succession is much checked and interrupted by the violent winds to which the area is exposed." (Gimingham et al., 1948, p. 94). The status of machair vegetation as a whole is not discussed, but soil studies show that .... "The degree of leaching of carbonate in the successive stages and its differential accumulation at varying depths present a much more complex picture at Luskentyre ...." (ibid, p. 94). This is to a large extent attributed to the very high carbonate values found throughout the original dune sands of which the area is composed.

This study includes a sketch map of the area under consideration, though it is not clear how this was produced, nor what the relationship is between the samples and the areas delimited on the map (ibid, p. 85). The succession which is described by means of the five classes already mentioned, is shown as occupying more or less discrete areas, and though these do not form any regular pattern, there is a broad correlation between the categories and distance from the sea. In this respect, and in the general descriptions accompanying the map, there are considerable similarities between the Uists and Harris (ibid, p. 84-91). In another respect the results of this study of machair in Harris is similar to those of the Grogarry and Uists' surveys. A distinctive secondary sequence of vegetation colonisation of eroded surfaces is recognised. Not only is the identification of such a sequence an important similarity between the two studies, but the characteristics of recolonising vegetation in both locations show considerable similarities. These include the prominent roles play by *Festuca rubra*, *Bellis perennis*, and particularly the relatively important colonising role, in comparison with the primary sequence, of the bryophytes. As discussed in the preceding chapter, the secondary sequence is an extremely important component of the vegetation of the Uists. Although briefly, geomorphological and human activities are discussed (ibid, pp. 82-3) and considerable note is made of soil developmental processes, carbonate leaching and sand-blowing (ibid, pp. 91-4). The role of tussock formation by *Ammophila arenaria* is discussed (ibid, p. 88) and this theme is developed in two further articles based on the Luskentyre Machair (Greig-Smith, Gemmell and Gimingham, 1947 and Gemmell, Greig-Smith and Gimmingham, 1953). In the former paper, analysis of quantitative data leads the authors to conclude that ...."Tussocks are formed only on the older dunes, and are aggregations of aerial shoots rather than true tussocks." (Greig-Smith, Gemmell and Gimingham, 1947, p. 268). Observations on dense stands of Ammophila arenaria on dune back slopes (unit C) and in sub-unit D_2 of the Grogarry survey support this theory.

Three factors are principally responsible for the formulation of a general developmental hypothesis applicable to machair vegetation in the Uists. These are the general theories of dune vegetation development in the British Isles discussed above, the particular machair studies already considered, and above all the observations and analyses of the Grogarry and Uists' surveys. The hypothesis which is put forward is summarised in diagrammatic form in figure 18. The units defined in the two surveys are shown linked according to possible developmental paths, and the whole system is located by two axes, which show relative status. 'Sequences' are delimited along the horizontal axis, and 'phases' along the vertical axis. These terms are defined below. These are non-quantitative parameters and no clear-cut boundaries exist between components, which include one or more machair vegetation units. The sub-units of the Grogarry survey represent finer division which can be equated with more exact statements about the balance of processes within units. No quantitative weighting can be attached to the paths of development, but generally secondary processes are considerably more frequent than primary processes. The evidence for this can be seen in the extensive recolonisation cycles responsible to a considerable extent for the nature of the vegetation in units B, C and D, and previously discussed. In the first two much of the Ammophila arenaria is associated with this process, whilst in the latter unit the same species and a number of bryophytes have this role and contribute to the high values of these species.

In this hypothesis a sequence is a broad division of process according to the starting point of development of the vegetation. Developmental sequences have already been discussed in the context of specific instances. Two developmental sequences are recognised in this system, the primary and secondary sequences. The primary sequence is considered to be that in which development is proceeding from a hitherto uncolonised surface. This does not preclude deviations from this sequence or even cyclical developments, though when this occurs, the sequence becomes either partly or wholly secondary. A secondary sequence is one in which developmental processes act on a surface that is or has been vegetated. Such sequences are not separated from primary ones and paths may cross from one developmental sequence to another. To some extent the breakdown of developmental sequence into primary and secondary classes is artificial cutting across a continuum, but it does provide a framework into which the relative status and associations of the vegetation units can be located. This outweighs the shortcomings of division of the developmental sequence.

Three phases are recognised in the hypothetical scheme. Phases are defined as major stages in vegetation successions which have similar status. Though basically a simple relative description of the status of each component vegetation unit, the three phases correspond to approximate temporal and spatial positions. This system is the most specific statement which can be made on machair vegetation status, on the basis of the available data. The initiating phase includes those units in which vegetation colonizes and develops on sand surfaces to the point where an incomplete vegetation cover in samples is exceptional. These include both dune-front units (A and B). In the sample synopses (appendices 3 and 4) high cover values for colonizing species, and a considerable extent of unvegetated ground are characteristic of the units forming this phase. The dune-back slope unit C is transitional to the second phase, the developing or linking phase. This phase is characterised by vegetation in which cover is normally but not invariably complete, but in which vegetation and environmental conditions are relatively unstable due to continuing development. High cover values for Ammophila arenaria together with lesser but high values for bryophytes and Festuca rubra, and low amount of unvegetated ground are the main features in this phase.

This second phase forms a link between the first and third phase, and irrespective of the actual path of development, whether primary, secondary or composite sequence, succession passes through this phase. The sand-hill unit (unit D) is the principal component of this phase, and whilst the dune-back unit (unit C) and dune slacks (unit F) have affinities with this phase, these are more of the first and third phases respectively in character. Frequently the cyclical vegetation patterns which are typical of machair development circulate about this phase. Except under very abnormal circumstances, no direct path exists between unit C and unit D, and the former is only linked with the developing phase through secondary processes. Similar conditions relate to links between units D and F. Also clearly in the developing phase is sea machair (unit G). Though limited in extent this is of considerable importance in understanding succession, processes and status of machair vegetation. This unit occurs in the developing phase of an important sequence in which environmental circumstances result in eventual complete and final removal of vegetation. There are links between unit G and the sand hill unit (D) so that this path is not exclusive and separate.

The third phase, the culminating phase, is represented by vegetation which has reached a condition of relative stability as a result of the general equilibrium state between the influencing factors. The machair plain (unit E) is the principal component of this phase, though the dune slack unit (F) exhibits many of its characteristics. Although this is termed the culminating phase, this does not mean that once this stage in development has been reached there can be no further developments. Sand blowing or erosion can result in permanent or temporary regression from machair plain vegetation. Machair plain (unit E) has most of the properties associated with vegetation or relatively high stability, including almost complete absence of species indicative of sand blowing, high cover values for species which demand relatively stable environmental conditions, and diverse flora (over 100 species recorded), and associated pedological and geomorphological conditions. Thus the culminating phase is that one in which vegetation development reaches a point of maximum stability relative to the other components in the system, but in agreement with Olson (1958) this is not a constant.

This simple system of phases and sequences in development, although subjective and qualitative, does give a framework for evaluation of machair vegetation status. The location of vegetation units within the two axes allows evaluation of status and developmental processes appropriate to this scale of study. Without much fuller research on these topics it is not possible to make definitive statements about spatial and temporal aspects of succession and status. Each particular area delimited in the maps of the Uists' survey contained in appendix 2, has a unique history, and enjoys unique relationships with its neighbours and many of these would require investigation before any general quantitative theory could be developed. Notwithstanding the above comments the proposed system provides a satisfactory basis for evaluation of status.

As has already been stated the relationships between vegetation units are complex and developmental sequences do not follow any simple direct path to a climax or sub-climax stage. Indeed it is very difficult to put forward any generally applicable model of development. However there are recognisable differences, in terms of process and status between coastal and inland areas. In areas close to the shore where vegetation units A, B, C and D. are located, one suite of processes operates. Here sand-blowing, erosion, recycling and stabilisation are the principal influencing factors, in a strip which is generally between 20 and 200 metres in width immediately above high water mark. Between this area and the landwards limit of machair lies a second area in which another suite of processes can be seen in operation. In this area, which varies in width from 5 m. or less (in a few places it is entirely absent) to more than 2 km, the dominant processes are those tending to produce more stable conditions, including erosion to water-table level, redeposition of sand on machair plain surfaces, organic matter build up and development of those characteristics of vegetation stabilisation already discussed, all resulting in development of more stable, advanced successional stages, which are represented by units D, E and F. The former area is found in the upper part of figure 18, and the latter in the lower part.

Unit D (sand-hill) is found in both areas and as is suggested by its central location in figure 18, this unit forms a bridge between the two areas. This re-emphasises that the two are by no means mutually exclusive, but areas in which dominant groups of processes complex, cyclical, successional patterns between the units found in these areas. To some extent the sand-hill unit (D) represents an end point to the processes of the coastal area, and a starting point to those of the inland area. The sand hills can be regarded as major components in the movement of sand from the coast to the eastern, landwards limit of the machair, and thus form a clear link between the coast and the interior, both in terms of vegetation cover and vegetation process.

Very little information exists on the time scale of processes in the Uists. As discussed in chapter 2 Ritchie (1966a) has shown that geomorphological processes, operating between approximately 5,700 and 2,000 years B.P., gave rise to the vast amounts of sand piled up on the western coasts of the Uists. Development of vegetation during this period and in the last two millenia is in part related to the geomorphological evolution described by Ritchie (1966a, pp. 179-193; 1970, pp. 18-21).

The early development of vegetation, as indicated by the Northton, Harris study (Evans 1971, Simpson 1966) and already discussed in chapter 2 indicates that there have been several major depositional and stabilisation periods, and that at least on two occasions in periods between 5,700 and 2,000 years B.P. stabilisation was so complete as to allow establishment of tree cover. This is also borne out by pollen analyses of a profile at Borve, Benbecula (Ritchie, 1966b, p. 84). However the relevance of these developments to present day processes and machair status is limited, since not only is the influence of man of a totally different order and kind, and there has been a marked climatic deterioration, but also many of the changes which have taken place since the Bronze Age Beaker people's occupancy have been irreversible. These include faunal and floristic changes, changes in hydrology, slowly rising sea level and eastwards sand movement. These changes have been discussed more fully in chapters 2 and 8. As well as the above argument, the sample evidence of the surveys indicates that tree species do not form any part of machair vegetation in the Uists and that this is likely to have been the case for the past 2,000 years. In view of this time scale and the nature of machair vegetation, processes and status can only be analysed by reference to present day patterns and changes occurring in the recent past.

In the areas further from the coast, the time scale of processes is longer and changes less apparent. However, as discussed in chapter 8, the Grogarry survey showed that with appropriate land use data, patterns of development can be detected in machair plain vegetation (unit E). Further investigation at Ormaclett, Dremisdale and Iochdar Machairs in South Uist and at Tigharry in

North Uist, where well established block rotational patterns are in operation reveal similar conditions. Generally in the first three to five years after cultivation, annuals such as Senecio jacobaea, Stellaria media, S. graminea and Plantago lanceolata are dominant being gradually replaced by grasses such as Festuca rubra and Poa pratensis. After 10 years without disturbance sedges begin to play a prominent role. Mosses play a relatively minor part in recolonization and only attain even modest cover values after a grass and sedge community is established. It seems that after 50 years with no further disturbance, a relatively stable and mature machair plain vegetation cover is established and maintained in an equilibrium state by grazing. Even with declining population in the Uists, the pressure on the fertile machair plain is such that this latter stage is reached only in a few areas.

In the future certain changes may occur. Crofting is being slowly replaced by farming, and intensive cropping of machair land is likely to decrease as pastoralism, the only economic form of agriculture in the Hebrides, increases. This is likely to result in extension of mature machair plain and with the grazing control which would come with improved agricultural practices the rest of machair vegetation is likely to come under less severe grazing pressure. This would reduce erosion and sand blowing, though these processes which at least in part are a result of natural factors such as sea level change coastal erosion and eastwards sand movement, will not cease. In certain designated areas conservation policies, particularly cessation of grazing by domestic animals, could allow further development from the machair plain vegetation (unit E) stage. If such protected conditions were established in less acidic wetter areas Salix repens, presently a rare species, may attain greater prominence, whilst in the most acidic landwards areas, Ericaceae and Betula spp. might be present. With reference to machair in Tiree it has been stated that ...."The climax vegetation, if grazing ceased, would be Calluna or Molinia heath." (Vose, Powell and Spence, 1956, p. 108). In the Uists evidence indicates that this would only come about when eastwards sand movements cease, or fall to a low enough level to allow surface pH values to fall appreciably. At present, as shown above, even on the eastern margins of very wide machair plains, sand encroachment at least partly offsets the acidification of soil by leaching and build up of more organic matter. Climax vegetation in its normally accepted meaning is not a meaningful term in an area in which vegetation development and man's activities have been closely interrelated since initiation, and present processes as previously discussed, which are likely to change in scale rather than nature, will continue to shape machair vegetation in the foreseeable future.

In conclusion the four major elements of the above discussion can be summarised as follows:

(1) Two areas of dominant process types result in different vegetation assemblages. These are not mutually exclusive, and Sand Hill vegetation (unit D) is a link between the two. Complex cyclical processes are responsible for the current vegetation patterns in most cases, and in no area is a simple prisere evident. The postulated model shown in figure 18 is a simplified version of the sequence in the Uists based on

the classification, data and analyses of the surveys.

(2) Developmental time scales are very complex and locations of particular vegetation types cannot be correlated with period of development. This is firstly due to the cyclical nature of current processes which are responsible for present day vegetation patterns, and secondly due to the fact that in every unit both long-term and short-term factors are in operation. Very approximate generalisations have already been outlined.

(3) The role of allogenic successional factors, such as sea-level changes and grazing, are at least as important as autogenic factors in the development of machair vegetation in the Uists.

(4) The role of man in the development of machair vegetation is profound, and has been so since initiation of vegetation development. To separate man, even hypothetically, from the sequence is neither meaningful nor productive.

These generalised hypotheses await more precise statement and testing, and whilst the data collected in the two surveys is not suitable for that task, the discussions of chapters 8 and 9 indicate the value of the data and descriptions of chapters 6 and 7.

CHAPTER 10

CONCLUSIONS

From both the methods used and the results of the two constituent surveys, a number of significant points emerge. These form the basis for evaluation of the thesis in both general and particular terms, and the following conclusions can be divided into two broad parts, one of summary and one of evaluation. Firstly a brief resume of the distinctive aspects of the methods used is given and the more important results in the sections dealing with descriptions and analyses of machair vegetation are itemised. Secondly, and based on this, is an assessment of the thesis from three viewpoints. The first is an evaluation of the sources and nature of possible error in the descriptions and analyses. This is followed by consideration of the value of the results of the two surveys. The final aspects considered are the further problems raised by the work, both those relating specifically to machair and its vegetation, and those more generally raised in undertaking vegetation surveys.

1. Summary of the Main Points Raised by the Machair Surveys

As stated earlier, the aims of the two surveys undertaken in this project are to provide maps and analytical descriptions of machair vegetation in the Uists, working at two different scales, but employing comparable methods, and on this basis to offer simple general explanations of the ecological relationships, vegetation processes and status observe. Bearing these aims in mind methods were devised which appeared likely to yield the requisite data, to be workable in the field, and to be broadly compatible with existing descriptive techniques. Because mapping is a fundamental aim, and the study has a geographical prospective location of vegetation in space is vital, and this directs methods towards the use of classification. Although non-classificatory methods such as ordination are by no means precluded in a spatial approach, classification renders mapping much simpler and more comprehensible, particularly in the large scale survey, and seems to be the best way in which to utilise cover-abundance data. As explained in chapter 5 the nature of the vegetation and the aims of the survey, as well as comparability of data all commend the adoption of survey methods based on cover-abundance measures and phyto-sociological classification.

Bearing in mind these points, the design of sample programmes for the two surveys is of considerable importance. For the small scale detailed survey the method, as described on pp. 65-74 , is based on quadrats accurately located in a systematic manner, equally and fairly distantly spaced (30 m. or so apart) when the vegetation appeared homogeneous, and very close (as little as 1 m. apart) when crossing an apparent vegetation boundary. These specifically located samples are aggregated into a system of classification by objective means, and on this basis units capable of being mapped, are readily derived. The second study of the Uists is based on the assumption that vegetation units exist, an assumption based on the results of the first survey at Grogarry Machair. In this case the vegetation units are based on those delimited at Grogarry, and are demarcated by field observation, consultation of geomorphological maps and air photographs. Samples are randomly located within visually delimited units, and the vegetation descriptions are based on aggregation of these. The respective systematic and random sampling used in the two surveys are further adapted to their aims of detection of vegetation within the sample areas in the case of Grogarry Machair, and between sample areas in the Uists' survey.

The simple maps and statistical descriptions derived from these samples form the basis for the analysis of machair vegetation. Explanations are subjective, because the scale of the survey and nature of the problem makes such an approach realistic. Rigorous objective testing of theories, and evaluation of data either by deductive or inductive reasoning, must await more intensive studies of selected sites. In the case of Grogarry Machair the major units are produced by aggregation to form the simplest groups, called sub-units, derived by objective analysis of samples. As such a division is not feasible at the scale of the Uists' survey, the large aggregate, the unit, is the standard vegetation class in the evaluation, and the sub-unit is used to illustrate finer variations. The ecological relationships observed and analysed are discussed in general terms, but much more detailed study of individual aspects is necessary before more definitive statements can be made. The evaluation of machair status follows a similar pattern, but in this case a tentative descriptive model of development is put forward, though its testing is not possible, since it is stated in purely qualitative terms. However it represents a scheme more applicable to machair vegetation than any other existing theory.

The results of the two surveys produce confirmation of the distinctive character of machair vegetation. Analysis of samples give a total of more than 150 species present, and the vegetation units indicate a wide range of variation to be present in the machair. The occurrence of marked discontinuities in the vegetation is a function of characteristic ecological patterns and the chosen approach based on non-hierarchical, phyto-sociological classification is appropriate. On the basis of the descriptions and analyses three factors can be singled out as being of paramount importance in shaping the nature of machair vegetation. These are geomorphological activities, marine influences and most importantly human factors. The processes shaping machair vegetation can be grouped into two major categories, primary and secondary processes which though not readily reflected as homogeneous spatial vegetation units are an important step towards producing a model of development of machair vegetation. The model scheme summarised in figure 18, suggests the ways in which the units delimited in the Uists' survey are interrelated, and indicates the paths of development to, and the status of the various vegetation units. In accordance with the general aims of project the model is purely qualitative, though critical paths are described in detail.

The results of these analyses show that three charactertics are associated with machair vegetation. Firstly, it has an extensive calcicolous flora, the constituent species of which combine to form vegetation patterns readily recognisable in the field and normally dominated by one or more of the following: *Ammophila arenaria*, *Festuca rubra*, members of the *Carex* genus, or certain bryophytes. Secondly, the constituent elements of machair vegetation patterns have characteristic general locations and extent. In terms of extent the five major units of the surveys have sobriquets indicating their normal location.

These are the two dune fore slopes, the dune back slope, the sand hill and the machair plain types, which are not only the largest in extent, but also the most significant in the analyses. Thirdly, machair vegetation has developed as a result of a combination of processes, which can be grouped into primary and secondary types. Developmental processes are peculiar to the machair environment, and are complex both in their nature and in the resultant spatial patterns. Simple sequences do not exist, and cyclical systems in which the component units are interrelated in a complex fashion are much more common than simple seral progression.

2. Evaluation of the Machair Surveys

In making an assessment of the project the above summary must serve only as a guide to the major points, and the following evaluation is based on the whole of the results. It is also important to keep in mind the purpose and objectives of the studies, the scales of the problems and the geographical perspective of the research. As is shown in the concluding sections of this chapter, it is held that these latter factors are critical in developing methods of study, particularly when problems of an applied nature, for example, in land-use management or recreational planning, are the object. There can be little doubt that such work is likely to become increasingly important in the future, and that academic research has a major contribution to make to its development.

The first question to be raised in evaluation of this research project is that of error, the nature and sources of which must be identified and discussed.

Although every effort is made to design a sample programme, in both field work and in analysis in which error and bias are eliminated it is certain that in a project of this scale some error will occur. The increased accuracy afforded by quantitative work limits the degree of error and may preclude the possibility of gross mistake, but in such work the significance of error and variation increases, so that careful evaluation of error is essential in detailed numerical studies. In this work, where descriptive qualitative techniques are in the main used, error and chance variation are more difficult to assess, and the magnitude of these can only be estimated. However, isolation of the most likely areas is possible and useful both in evaluating existing results and in the design and assessment of future work.

The first major potential source of error lies in the identification of plant species. Even an experienced taxonomist may find difficulty with species outside his field of interest. If, as is the case in the machairs of the Uists, ecotypic and genotypic variations are common, the problem is the greater. The study period is critical and as has already been discussed, the programme is most pronounced with annual species. Of the vascular plants, the genus Carex and certain of the Compositae proved difficult to sub-divide and in the Grogarry survey identification of members of the former genus was not taken to species level because of the date of field survey. The extensive flora of the machair (154 species are recorded in the two surveys, and there are indications that as many as 100 more may be found within its limits), and the lack of taxonomic expertise of the author mean that particular attention has to be given to the problem of identification of species, to ensure that accuracy is maintained.

This has been done in the following ways. Firstly, full use was made of available reference works including Clapham, Tutin and Warburg (1962, 1968), Keble Martin (1965), Hubbard (1954), Watson (1955) and Nicholson and Brightman (1966). These proved of great value, and after some time in the field, there were few serious identification problems. Furthermore, the author was fortunate in being able to send doubtful samples for identification to Dr. H. McAllister, a taxonomist experienced in this area, who not only identified the difficult species brought back for examination, but gave much valuable advice on field identification. At various times a number of other individuals helped with identification work, both in Glasgow and in the Uists. In the field, by the second season during which data for the Uists' survey were collected there were no major identification problems, though doubtful cases continued to be taken for detailed examination. In the light of experience careful checking brought to light one or two minor errors and these were corrected either by collection of fresh data or reconsideration of existing information. At present it seems unlikely that in either set of data there are any serious errors attributed to this source.

The second area in which error may arise is in sampling, in which three components can be isolated. The problems of 'edge-effect' already discussed, are dealt with more fully by Kershaw (1964, pp. 30-1) and Greig-Smith (1964, pp. 28-9). To minimise this a square quadrat was used, this shape being the best compromise between minimising 'between sample' variance, keeping the most favourable area to perimeter ratio, and convenience in operation. A personal convention was established and used consistently to clarify dubious cases. As a fairly fine cord quadrat frame was used it was relatively easy to decide whether more or less than 50% of the maximum crown cover of the plant in question was within the perimeter of the frame, and this figure was thus taken as being critical. The second component of sample error lies in the use of subjective estimates of cover-abundance. This is one of the commonest measures used in phyto-sociological and ecological work in Britain and is widely accepted in practice. The problems of using subjective estimates as a basis for objective work have already been discussed in chapters 4 and 5, and by Bannister (1966). The use of the eight point Domin scale in the Uists survey achieves two objectives. Firstly, it provides data which have a fair degree of acceptance and common currency. Secondly, it provides a framework to guide cover estimates using which " ... field workers claim a high degree of accuracy can be obtained with sufficient expertise." (Kershaw, 1964, p. 13). Checks carried out in the field with other workers, by making independent assessments of the same quadrats, revealed few differences; the minor discrepancies noted were in the range of values below 4, and thus use of the eight point scale cut out a sizeable component of the error. In spite of this, it is likely that a small degree of random and systematic error is present in the samples.

A further method used in this study to minimise sample error in the estimates is to use large numbers of samples in the calculation of unit descriptions.

This minimises random error, though it makes little, if any impression on systematic errors. According to Poore (1955, pp. 245-69), cover-abundance descriptions for "noda" should be drawn from a number of sample lists, with commensurate improvement in description accruing from increasing numbers of samples; all sampling is based on a subjectively delimited 'typical stand'. There are significant differences between the approach advocated by Poore and that employed here, and there can be no doubt that the use of large numbers of samples to formulate descriptions is even more important in this case, as average values are abstracted to form the basis of description. In units B, D and E about 100 samples are used, whilst in the remaining major units not less than 30 samples are employed, giving a total of more than 450 samples in the Uists survey. In the Grogarry study about 170 samples have been used to produce the map and analysis. This, though time-consuming, is essential if accurate descriptions of the extensive areas are to be made. It allows also, in the case of the Uists' survey the calculation for comparative purposes of frequency values, and these give further data for analysis. Greig-Smith (1964, p. 38) shows that a minimum of samples are necessary if statistically sound frequency values are to be calculated.

The third possible source of error lies in the location of samples in the two surveys. In contrast to the methods advocated by Poore subjective choice plays little part in delimiting sample sites. This is in order that simple statistical analyses may be based on the sample data. This can only be achieved if samples are located either in a systematic or in a random manner. The advantages and disadvantages of the two systems have already been discussed in chapters 4 and 5 and are considered at length by Greig-Smith (1964) and Kershaw (1964). In the Grogarry survey a form of systematic sampling is the basis of the study. Although changes in pattern occur along transect lines the basic sampling system is regular. Though changes in sampling intensity are conditioned by subjectively delimited changes in vegetation, as denoted by the visual appearance of stands, the location of each sample is basically determined in an objective, systematic manner. The comparability between the Grogarry and Uists surveys, allowing for expected variations, is one pointer to the viability of this approach. More substantial evidence is provided by the ease with which samples can be grouped, since subjectivity is likely to result in increased division rather than homogeneity in an area where dominance is often shared and micro-scale pattern marked.

A second reason for the choice of systematic sampling in the Grogarry Survey, is that the prime objective of this survey is to break down the study area into discrete spatial units. The use of some form of systematic sampling allows more readily the detection of pattern within a group of samples than does random selection. Similarly in the case of the Uists' survey where the object is to provide maximum information between sample groups, random sampling is the more appropriate method. In this latter case there may be some error due to subjective bias in the sample location. Time constraints and the shape of the delimited vegetation units preclude the use of a grid, and thus pacing out of sample locations following random numbers from a central arbitrary point is the method employed. The tendency to undersample peripheral areas is to a considerable extent counteracted by the shape of the units; generally the units have a long axis, which in the case of the Dune Front units (A and B) may be so pronounced that a tract of these units more than a kilometre long never exceeds 20 m in width. In fact, a number of sample random numbers have to be rejected as they lie outside the boundaries of the unit under consideration.

The third major potential source of error lies in the analytical procedures. Few parts of this involve complex numerical work so that these potential sources of error also are few. This does not mean that the explanations are correct since the generality with which they are framed avoids most of the contentious points. Opinions and qualitative hypotheses are not subject to mathematical error which in any way can be assessed, however far from the truth they may be. Nonetheless there are two particular areas in the analysis in which some evaluation of the results can usefully be made, and the fact that these are interrelated is not coincidental. In the production of descriptions of the vegetation units from the modified 8-point Domin scale an effort has been made to give the most meaningful averages possible. Bannister (1966) puts forward an evaluation of the use of Domin scale cover measurements in objective analysis, which serves as a basis for averaging here. This involves transformation of the conventional values of the eight or ten point scales to substitute values with a numerical meaning which allows manipulation of data. Unfortunately in the second stage, transforming back to Domin numbers is a serious problem. As the class intervals in the transformed range are non-linear (this is a function of the basic Domin values), it is impossible to reassign Domin numbers to the averaged transformed values, without specifying the range over which the particular value extends. Use of decimal places in the reconstituted Domin scale is neither meaningful nor advantageous to interpretation. The most satisfactory solution is to use each transformed value as the median of its range and to convert any value falling within that range to the corresponding Domin number. This clearly has disadvantages which detract from the accuracy of the averages and the mixture of mean and median is unsatisfactory. However this seems to be the only feasible approach, without changing the original parameters. This is discussed in general terms later in this chapter, and is one of the more significant problems raised by the research.

The second major problem encountered in the analysis lies in the interpretation of the results. There is a considerable difference in any of the vegetation units between the averaged descriptions and a typical component sample. This is a function of the extent of the units, their floristic diversity and of the number of sample taken, and is particularly applicable to the units furthest from the shore. In the most species rich area (unit E - machair plain) the average number of species present in any sample is 14.1 - 15.5, as expressed by the Standard Error of the sample mean with 95.5% confidence limits. Few samples have more than 20 species recorded present, and yet in the synoptic table in appendix 4 a total of 95 species are listed. This is in part a consequence of the extend of this unit covering about 25% of the total study area (i.e. about 13 sq. km) out of a total of over 50 sq. km). In fact field experience indicates that a detailed floristic inventory might reveal 50 or more additional species. Furthermore the role of the dominant species varies between the sample and the aggregate. In the above case Domin values of 8 and 9 are common yet in the latter the highest value recorded 6, for Festuca rubra. Examination of the frequency value explains the apparent discrepancy, for in the case of this most important species in machair plain vegetation, in 9% of all samples the plant is entirely absent, resulting in a disproportionate lowering of the average value. This in itself is not erroneous, beyond the problem in calculation of averages discussed above, but care must be taken if the data are to be correctly interpreted and properly used. Finally, it is worthwhile to point out at this juncture that neither Poore (1955, 1956) nor Burnett (1964) make clear how the averages used in the method of 'successive approximate' are calculated, nor what decimal places in cover-abundance scales mean. It is not suggested that the approach used in this study gives a definitive answer to these problems, but it does yield data which appear to have a more accurate meaning.

Having discussed sources of error it is now appropriate to evaluate the two surveys both in terms of how far the aims of the projects have been realised, and also in terms of how useful the aims and results are in relation to the two following factors; firstly research requirements and in particular those in the applied fields; and secondly possible changes which might result in increasing the value of this or subsequent similar research work.

The aims of both studies as have been stated previously are to produce maps and analytical descriptions of the vegetation of the chosen study areas. At this level the aims have been realised yet certain underlying issues require rather fuller commentary. Throughout the research programme it has been necessary to maintain a balance in compromise between a need to maximise accurary and detail of data, and the limitations imposed by resources available. Achieving of the most favourable and productive balance possible is the critical problem in the project. Taking these factors into consideration the shortcomings of the methods used and the results obtained can be more objectively evaluated. Many problems in analysis and interpretation might be overcome if a more rigorous quantitative approach was used. However in terms of the aims of the research programme such an approach would be more likely to raise more problems than might be solved. The detailed data required by quantitative work and the sophisticated results do not suit well the aims of the general reconnaissance survey. The additional time required to collect such data, and the inevitable problems in developing processing methods specifically suited to this project, means that either the area under study or the depth of the study would have to be modified if work is to be completed within a realistic time period. Neither of these alternatives are acceptable, and so the methods used with their shortcomings are deemed preferable. Such a problem of approach is likely to be even more important in applied studies. From this rather broader viewpoint too, the aims of the surveys have been accomplished.

As stated in the introduction, the aims of this research project were determined at the outset, and the reasons for the choice have already been discussed in chapter 1. One reason put forward is that a general vegetation survey can be of considerable value in conservation and management. The Grogarry Machair study is specifically tailored to produce information on the machair part of Loch Druidebed National Nature Reserve, and it is hoped that the report produced for the Nature Conservancy (Dickinson, 1968) may be used in management planning. One particular requirement for planning work is accurate spatial description, and presently the best way of fulfilling this objective is by thematic mapping. In the case of land management and conservation, knowledge of the spatial extent of vegetation and landuse is essential if available management resources, normally limited, are to be used most profitably. Mapping has two basic requirements. Firstly, accurate survey of both topographic and planimetric detail and extent of various types of vegetation and/or land use is required. The former may be supplied by appropriate Ordnance Survey topographic maps, but in many cases, particularly at the more detailed scales, a special map may be required. In the Grogarry Machair study this latter is the case, and the base for the vegetation map is derived from a survey commissioned by the Nature Conservancy for management and research purposes. In the case of the Uists' survey, the 1/10,560 scale O.S. topographic map is the only available base, and one which will be considerably improved when the forthcoming revision survey covering all of Highland Scotland is published.

The second mapping requirement is for descriptions which supply information which can be used in management and which is in an accurate and readily comprehensible form. In both surveys the descriptions are given in such a way as to be of value to a wide range of users. The relative simplicity of the systems, absence of complicated and unfamiliar terminology and the use of accepted parameters are all primarily directed towards this end. In the past a number of geographers have advocated the production of national inventories covering a wide range of topics. For example, the late Professor L.D. Stamp and Alice Coleman have been associated with national land use surveys, the first in the 1930s and the second in the past decade. Several prominent continental phyto-sociologists have been working for several decades to produce systems of classification which can be used to produce a unified description of the whole of Europe and possibly the whole of the world. The value of this type of work cannot be over-estimated, but it is not suited to many planning and management requirements, since the scale of this work is often very detailed, and the information produced by a national survey may not be suitable for the solution of the particular problems involved. Increasingly it is necessary to produce specific surveys for individual cases, and the two surveys are oriented towards machair vegetation in the Hebrides, its problems and the other specified needs, rather than to all types of vegetation which might be found in the Highlands of Scotland or even in the Hebrides. From an academic viewpoint, use of a different method to solve each problem may seem unsatisfactory, but when individual problems are considered the benefits of comparability are outweighed by more relevant results. Besides answering the basic problems, the type of general survey, which has similar aims and methods to the two machair studies, raises many questions which may well be the most important part of the exercise, indicating the directions that future research and management policies should take.

3. General Issues

Many problems have been raised during the course of the two surveys, some of which relate directly to machair vegetation whilst others are much broader in basis. Those concerned with machair can be considered under six general headings, and are dealt with at length in the following pages.

The first is related to the evolution of machair. In chapters 8 and 9 the ecological relationships and status of machair vegetation are analysed on the basis of the survey information. These are subjective evaluations and serious study of machair evolution requires a much more detailed approach than is appropriate to the two surveys. Besides academic curiosity there are several other reasons promoting research into the development of machair. The interaction between man, environment and vegetation makes this area one of great interest to the ecologist and geographer. In few parts of Britain is there such an extensive landscape, in which development has been initiated so recently, and in which the record of the sequence of development is so well preserved. Detailed investigation should aim at providing data on which sophisticated succession theories can be based. Great care in the choice of study area would be necessary so that a site is selected where the complexities of interaction of the many variables could be minimised. These problems lie beyond the scope of the present exercise, and the descriptions herein do not provide suitable information for detailed analysis. To obtain a fuller understanding of machair development, quantitative data from a variety of sources, yet concentrated in limited selected sites, is necessary; Grogarry Machair is a promising area for such a future study. Besides detailed investigation of the present day vegetation, study of machair morphology, work on the pollen record and macroscopic remains such as land snail shells, correlation with archaeological artefacts, and where possible radio-carbon dating would all be essential to give enough information to allow a theoretical model of machair development to be tested, or an analogue system to be constructed. Either, or preferably both, should be the next stage to understanding how this distinctive landscape came into being.

The second general type of future problems on machair is related to the first. Processes in machair vegetation have already been shown to be very complex, and the vegetation units described in chapters 6 and 7 are the results of complex interactions. The hypothetical development scheme shown in figure 18 indicates that whilst very general statements on machair vegetation processes can be advanced on the basis of the available data, much more detailed quantitative work is necessary to fully understand this aspect of the vegetation. The one certainty concerning processes which emerges from the discussion of data in chapters 8 and 9 is that processes in the machair are much more complex than is generally suggested by existing explanatory systems of sand dunes. Again it is likely that detailed studies ot a limited number of restricted sites would be more appropriate and rewarding than a broad-based survey.

The third problem is that of grazing of machair vegetation. The explanations put forward in the two preceding chapters indicate that machair vegetation is profoundly influenced by grazing, both by domestic animals (almost exclusively sheep and cattle), and by members of the natural fauna such as rabbits and geese. This subjective explanation is based on comparative observations on the nature of vegetation communities in heavily and lightly grazed areas, and on evaluation of the work of Ranwell (1959, 1960) and Boyd (1960) with respect to machair vegetation in the Uists. Even these tentative conclusions show that grazing is one of the most important ecological facors modifying the development of machair vegetation, but any further evaluation must be based on quantitative data. Such information is difficult to obtain and requires specialised techniques involving both detailed, accurate measurements of vegetation density and yield, and analysis of animal diets.

Fourthly, fuller analysis of the ecological aspects of certain species prominent in machair vegetation is an important field requiring further study. Ammophila arenaria, the principal species in areas where sand blowing is significant is central to a number of problems. The question of pattern and tussock formation in A. arenaria in machair vegetation has already been discussed by Greig-Smith et al. (1947), Gimingham et al. (1948) and Gemmell et al. (1953), and in chapter 8. Quantitative investigation of pattern development would be of great value in analysing the development processes already mentioned. This species also has a major role in dune building and location analysis might be a useful technique in understanding the evolution of dune systems. The species has a complex role in machair vegetation, being a prominent member of both primary and secondary process types. Full investigation on a comparative basis, of pattern, quantity and nature of A. arenaria in the two process type areas is a further important step to understanding the dynamics of machair vegetation.

Sedges (Carex spp.) are amongst the most interesting components of machair vegetation. Six different species are recorded and this suggests that the genus may provide a valuable indicator of finer variations in ecological conditions. Probably the most important and immediate problem posed by the Carex genus in the machairs of the Uists, is the relationships between stability of ecological conditions and abundance of Carex spp. and other members of the Cyperaceae. The preliminary investigations on the machair plain (unit E) at Grogarry Machair show that variations in vegetation composition, which are of economic significance, may be a result of differing response by sedges to varying conditions, and a function of competative ability. In this case the influence of man is an important factor and it may be that the Cyperaceae can provide an information index of certain of man's activities.

Mosses are also good indicators of minor variations in ecological conditions, and there is much to interest the specialist in the machairs of the Uists. However, the most common species Rhytidiadelphus squarrosus is remarkable in that it has a very wide range of tolerance and occurs widely in all units except at the seawards colonising fringes or in the wettest areas along the eastern margins of the machair. The role of this species deserves detailed study, as its contribution to machair vegetation is considerable. One line of inquiry that might be applied to this bryophyte, can certainly be applied to the most common species of all, a vascular plant Festuca rubra. The two subspecies of this common grass which might be expected are F. rubra subsp. arenaria and F. rubra subsp. glaucescens. Identification of these two, which would be difficult and time consuming, is inappropriate to these general surveys, and there are taxonomic problems beyond the skills of all but a specialist. Detailed investigation of the autecology of this important species, however, remains a valuable and important field of study for the future.

The fifth category of problem raised by the machair studies concerns long-term changes in machair soils, particularly those changes in organic matter content and base status which occur in the topmost 30 cm or so. There is a need for detailed comparative studies, using quantitative data on a spatial basis, to evaluate these aspects of machair soils. Of the two reasons for investigating this problem, the value of such work in promoting improvement in agricultural practices needs no further comment, but study of machair soils is also an important source of information on development of the whole landscape, particularly on a relatively short time basis. Laboratory analysis of soil samples and correlation with vegetation and with environmental factors is an important part of the overall understanding of the machair landscape.

The sixth, and final area of future study of machair vegetation lies in evaluation of machair as a biological resource, and this is probably the most important field for future research. Machair vegetation is important as a biological resource in three ways; agriculture, conservation and recreation. As has already been discussed in chapters 2 and 3, the machair lands of the Uists are presently, and have been during the last 2 millenia, the prime agricultural resource of the islands. The archaeological evidence, the density of settlement both now and in the past and the intensity of current activities are all evidence of this. However, machair land cannot be maintained easily and careful practices are necessary to obtain high yields without detrimental effects on the environment. As has been shown in chapters 8 and 9, the machair ecosystem is particularly vulnerable to allogenic change, and man's activities almost invariably lead to deterioration in biological yield and capability. The fragility of the machair ecosystem lies at the heart of all agricultural problems in the Uists, and reorganisation of crofting should be according to acceptable ecological guide lines as well as other considerations. The root of the problem is soil organic matter. If this remains high, potential biological productivity is high due to the high base status, the large soil water retention capacity and the surface stability promoted by organic enrichment of machair sand. As the 'natural' machair succession progresses towards the currently represented optimum condition (machair plain vegetation, unit E), organic matter in the soil increases in response to increasing stability which allows further build up to take place, and in turn sustains vegetation with increasingly mature characteristics. Conversely in the least stable areas, for example, the Sand Hill vegetation (unit D), blow-outs result in the total removal of the surface accumulations of organic material.

Consequently recolonisation takes place on a bare sand surface which generally can only support pioneer species such as Ammophila arenaria or certain bryophytes, and rebuilding of the organic resource takes a long time. Furthermore, the type of organic matter contributed by colonising species is much lower in bases and higher in cellulose, than the species of the maturer machair plain vegetation.

The primary aim of agriculture should be to maintain high productivity without depleting the resource base. The results of the two surveys indicate that this end is most likely to be achieved by using the most stable machair areas for controlled intensive pastoral agriculture. Very strict control, with long periods of complete freedom from grazing, is essential in all areas where Ammophila arenaria is present in any quantity. Cropping is likely to diminish in extent with development of artificial foodstuffs which can be cheaply and easily imported, and with improvement of machair grazings by seeding with specifically bred species, fertilization and scientific management. The main problems in efficiently utilising and conserving the machair lands of the Uists for agriculture are not technical, but are socio-economic. Changes from crofting land-use to pastoral agriculture must result in significant alteration in the disposition of employment and in social organisation. These are problems of extraordinary difficulty and complexity which will not be solved by a second 'Highland Clearance', but will require much more research and case work, to produce acceptable solutions. Continued work into the agricultural potential of the machair is essential, if the best possible solution to the continuing crofting problem is to be achieved.

The relationships between the Grogarry study and the requirements of the Nature Conservancy have already been discussed, but at this juncture one further point must be made. The original reasons for establishment of the Loch Druidibeg National Nature Reserve are conventional, but this Reserve presents a rare opportunity to conduct an experiment in management for conservation in conjunction with the human activities of the west coast of the Uists, crofting, farming and sport. This aim is appropriate to the kind of natural resources which exist in Britain, in which man has to a greater or lesser extent shaped current biological patterns and has had a major role in its evolution. The machair part of the Loch Druidibeg Reserve, Grogarry Machair, is managed by the Nature Conservancy in conjunction with the crofters of the township of Stilligary and the estate farm at Drimore. This means that the characteristic elements of the machair, which are part human and part natural are managed in unison. The experiment seems a success and and relations between all interested parties are harmonious, but much more research into the consequences of this policy and into the attributes and the significance of the components of the machair environment is needed. This is a task which will require the expertise of many besides geographers and ecologists.

Finally, the potential use of machair for recreation is an important question which must receive considerable attention in the future. Tourism is often seen as a panacea for all social and economic ills anywhere in the Highlands and Islands of Scotland, but this is most unlikely to be the case in the Uists. The isolation of these small islands is unlikely to be outweighed by their interest and beauty, so that recreation will be confined to those few holiday-makers content with very limited facilities or seeking special attractions such as fishing or bird-watching. This is not to denigrate the attractions of the islands, which are considerable, but in the face of competition from other areas which have a higher scenic, recreational and social potential, the Uists are unlikely to be able to attract a significant part of the limited available investment capital. As stated in the preface, machair cannot compete as a landscape of outstanding natural beauty, with many other better known parts of the Highlands, and the superb western beaches are subject to the Hebridean summer weather. Thus man's influence through tourism are likely to be much less profound than around most of Scotland's coastline, where it is becoming a very major factor in changing the coastal environment. Machair, as it occurs in the Uists, is such a vulnerable as well as a distinctive ecosystem, that relative freedom from further interference must be welcomed. Nevertheless, careful study will be necessary in the future if the attractions to the visitor of the west coasts are to be fully utilised and yet preserved from degradation. The few caravans already sited on the machair may represent the tip of a sizable iceberg.

Besides these specific problems relating to the machair landscape, the surveys have raised several general problems relating to vegetation study as a whole. Answers have been sought for these, which are appropriate to the aims of the two machair surveys, and in this conclusion mention of the future problems raised during the course of work must be made. As before these can most conveniently be discussed by consideration under a number of general headings.

Firstly, several spatial problems arise out of the attempts to map, describe and analyse machair vegetation at two different scales. Most of these have already been discussed in some detail in chapters 4 to 7, but with specific reference to the methods adopted in this thesis. Mapping and surveying, size and location of units, delimitation of units and demarcation of boundaries are the major difficulties in this project. In solving these problems geography has considerable expertise to offer, and much current research in geography is aimed at developing methods of analysis which combine the geographer's spatial skills with rigorous scientific procedures (vide Harvey, 1969). Yet the discipline must draw heavily on other subjects for experience in particular fields, and in this case the study of machair vegetation owes much to the work of plant ecologists. It seems likely that an interchange of ideas and techniques should lead to advancement and the geographer can hope that the expertise of the ecologist will be complemented by experience in mapping, location analysis or application of one of the techniques developed in other aspects of geographical research. The two surveys undertaken here indicate the role that geography can play and, whilst the purposes of this study are primarily academic, much of this type of work will be in the applied field.

Secondly, the work in the Uists indicates that quantification of data is an important goal in developing spatial descriptions of vegetation. The above discussions indicate that existing techniques are not suited to the scale and objects of the machair projects, either because of lack of precision in definition or because of the absence of a satsifactory spatial framework. There are considerable imperfections in the system developed here, and refinement of the appraoch will continue to be an essential area for research. Quantification not only gives more precise measurements for description, but it also allows the use of statistical techniques, and it is unlikely that there will be any major advances either in the academic search for general theories and models, or the solution of specific problems for management and conservation without use of the methods of the mathematician.

This factor is highlighted in the two surveys by the choice of cover-abundance as the basic form of vegetation data. As already stated, such information provides a good basis for large scale floristic surveys and is well suited to applied work. In coastal areas where species' combinations and quantitative abundance is more important than simple presence or absence, these data have a positive advantage over frequency measurements and the association-analysis family of techniques. Exact numerical measurement is precluded by time limitations, so that estimation appears as the only suitable compromise, but one which is fraught with difficulties. These have already been discussed in chapters 4 and 5, and earlier in this chapter, but two difficulties remain. Firstly, the question of the subjectivity of measurement hampers its use in statistical techniques. Bannister (1966) indicates that these data can, with suitable manipulation, be used for statistical analysis. Ivimey-Cook and Proctor (1966) suggest that association-analysis is a more objective means to the phytosociological end (to which cover-abundance data are almost invariably put), but also indicate the manifest problems of this system (ibid. pp. 188-91). As these authors suggest, much work remains to be done before solutions can be found to these problems. Evaluation of cover-abundance data as used in this research, indicates one possible direction for future study.

Poore (1955, 1956) in his classic study of phyto-sociological methodology evaluates several possible cover-abundance indices, and choses the normal 11-point Domin scale for his 'method of successive approximation'. This scale with the omission of the lowest category is used in the Grogarry survey, but the problem of producing meaningful averages, a problem which recives scant attention by users of Poore's system, leads to the modified 8-point scale being used in the Uists' survey. However, the non-linearity of the scale necessitates the use of a somewhat unsatisfactory statistical compromise, and the problem remains unsolved. Several lines for future research are possible. The requirements for an index of cover-abundance are that it should yield the maximum amount of information (generally implying the largest convenient number of divisions), that it should minimise subjective bias (generally implying broad divisions, the limits of which correspond to commonly used fractions), and that it should correspond to an arithmetic or some other simple mathematical function. The resulting scale will be a compromise, but it is likely to satisfy these requirements more fully than either the 11- or the 8-point Domin scales.

There are three possibilities. Firstly, a simple 8- or 10-point scale of cover-abundance, with equal class intervals can be used. This has the advantage of being simple to use in the field, and likely to yield data at least as accurate as existing scales. Use of devices, such as small clear plastic squares of a fixed proportion of the sample quadrat, to improve accuracy is desirable where the most exact measurements are needed. Statistical computations based on such a scale are readily possible, and commends the use of this type of classification for detailed quantitative studies. The main disadvantage in use of such a scale is that the divisions at the upper end of the scale are more numerous than is necessary and desirable, and similarly the existence of only one class from 0-10 or 0-12.5 per cent is a very coarse measure for the less common species. To the plant ecologist these are serious disadvanatages which limits its usefulness in studies in which species of low cover-abundance are important to the research aims.

Secondly, a scale which conforms to a geometric function can be used. The Hult-Sernander scale predates both the Braun-Blanquet and Domin scales, but has failed to gain any widespread usage in Britain. The scale and its class limits are shown in table 9. Drude (1928) and Du Reitz (1930) advocated rather complex phytosociological systems using this scale, but these were largely rejected in favour of the Braun-Blanquet system. Poore (1955, 1956) also considered this scale and evaluated it in relation to the Braun-Blanquet and Domin scales, favouring the latter in his phytosociological classification. The simple 5-point Hult-Sernander scale has much to commend it. As it corresponds to a geometric mathematical function, it is suitable for statistical handling. The range of the classes is greatest in the high values and least in the low, this being desirable for ecological work. Earlier in this chapter the problem of interpreting averaged

Domin values has been discussed, and in view of this, the very large range of the fifth class, comprising all cover values greater than 50%, is less problematic than may at first seem the case. With the Domin scale few averages in the Uists' survey reach the 50% value (Domin class 6), and although higher average values would result if the Hult-Sernander scale was used, acceptable results would be produced. Greater difficulty would occur in establishing the boundary between classes 1 and 2. Expressed as a percentage the limit is 6.25 and, although if expressed as the vulgar fraction $^{1}/16$, it is easier to estimate, a considerable degree of error would have to be expected. Field trials may show that the Hult-Sernander scale might give an improvement in sampling techniques. For simple descriptive purposes it should be possible to indicate approximate comparisons between this scale and others more commonly used.

The third alternative is to devise a scale conforming to a logarithmic function. Potentially this seems attractive as the nature of the scale indicates that arithmetically equal division of a logarithmic scale into say 8 or 10 classes would produce a system which gives sufficient detail at the lower end of the scale without over-estimation, and two or three wide classes at the upper end of the scale. However when these figures are translated into percentage values for field estimates, class boundaries would be extremely difficult to use in practice. For example, the arithmetic mid-point of a logarithmic scale is approximately 31.6%, and this figure would be the class interval for field estimate. Estimation would be difficult and subject to considerable error, and the corresponding loss of accuracy would seriously detract from the value of such a scale.

The third and final general vegetation problem raised by these studies lies in achieving a balance in the methodological approach between academic aims and the requirements of applied studies. This research project has been influenced by both of these and some of the possibilities for further developments have already been indicated. Particularly in the case of research which is orientated towards answering specific questions, whether for pure research or for management or conservation, achieving a compromise between seeking the most detailed and accurate answer, and getting results which satisfy the particular problems under consideration, is extremely difficult. The experience gained during this work suggests that each problem presents circumstances which require an individual approach. To maximise logistic resources careful design of techniques is essential. For this reason the phytosociological systems of the Montpellier and Scandanavian schools and their subsequent derivatives are unlikely to supply the kind of information necessary for solution of the particular questions which will increasingly be asked in the future. Pressure on resources is certain to accelerate the demands for answers to problems which can serve as a basis for action. For conservation and management purposes, and for very many ecological and geographical questions no single unified system of description, classification and analysis can produce adequate results, since the maintenance of unity in approach detracts from its value to each particular case. This is not to deny the value of such systems of classification, nor even less the allied goal of hypothesis, model and law formulation, but these are secondary considerations when research is aimed at solving a specific problem. Both ecologists and biogeographers are likely to utilise a wide variety of techniques in future work, so that the need for continued methodological research is as great as are the problems which demand answers.

This conclusion is neither an apology or a justification for this thesis. That problems remain unsolved and many new ones have been cast up is reckoned a success, since the broad aims of the two surveys are as much to suggest questions for future evaluation as to provide definitive answers. In the future contributions to solving the kind of problems dealt with in this thesis are likely to come from many sources and the approach of the geographer is complementary to, not in competition with that of the ecologist or other natural scientist. This work is only a beginning and the end is not even on the horizon.

'Qui cupit optatam cursu contingere metam,
Multa tulit fecitque puer, sudavit et alsit'

Horace

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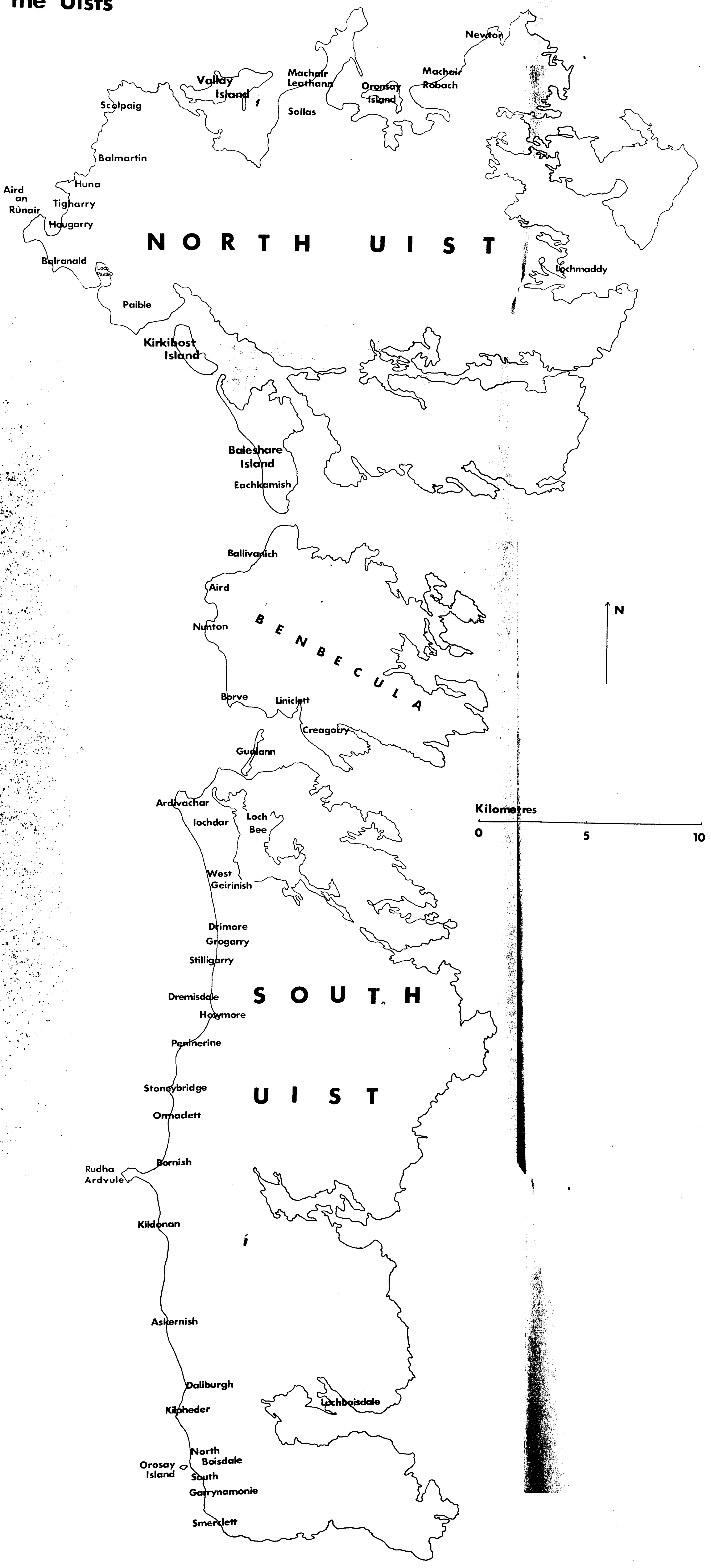
Map 10
Principal locations in the Uists



A Geographical Study of Machair Vegetation in the Uists

Thesis presented for the degree

of Doctor of Philosophy, to the

University of Glasgow,

July 1974

Gordon Dickinson

Volume 2

CONTENTS

Appendices

APPENDIX 1

FLORA OF MACHAIR IN THE UISTS

Based on the Grogarry Machair and

Uists Surveys

Salix repens L.

Equisetum arvense L.

Equisetum palustre L.

Agropyron junciforme (A. & D. Löve) A. & D. Löve

Agrostis canina L.

Agrostis stolonifera L.

Agrostis tenuis Sibth.

Ammophila arenaria (L.) Link

Anthoxanthum odoratum L.

Avena sp. L.

Cynosurus cristatus L.

Dactylis glomerata L.

Elymus arenarius L.

Festuca rubra L.

Festuca ovina L.

Holcus lanatus L.

Hordeum sp. L.

Lolium perenne L.

Nardus stricta L.

Phragmites communis Trin. (P. australis (cav.) Steudel)

Poa annua L.

Poa pratensis L.

Poa trivialis L.

Carex arenaria L.

Carex distans L.

Carex flacca Schreb.

Carex nigra (L.) Reichard

Carex panicea L.

Carex rostrata Stokes

Dactylorchis purpurella (T. & T.A. Steph.) Vermeul. (Dactylorhiza purpirella)

Eleocharis palustris (L.) Roem. and Schult.

Eleocharis uniglumis (Link) Schult.

Endymion non-scriptus (L.) Garcke

Eriophorum angustifolium Honck.

Iris pseudacorus L.

Juncus articulatus L.

Juncus conglomeratus L. (Juncus subuliflorus Drej)

Juncus effusus L.

Luzula campestris (L.) DC

Luzula pilosa (L.) Willd.

Luzula sylvatica (Huds.) Gaud.

Orchis mascula (L.) L.

Achillea millefolium L.

Anagallis minima (L.) E.H.L. Krause

Angelica sylvestris L.

Anthriscus sylvestris (L.) Hoffm.

Anthyllis vulneraria L.

Apium nodiflorum (L.) Lag.

Arenaria serpyllifolia L.

Armeria maritima (Mill.) Willd.

Atriplex hastata L.

Atriplex laciniata L.

Bellis perennis L.

Cakile maritima Scop.

Caltha palustris L.

Campanula rotundifolia L.

Cardamine pratensis L.

Carlina vulgaris L.

Centaurea nigra L.

Centaurium erythraea Rafn.(C. minus Moench)

Cerastium glomeratum Thuill.

Cerastium vulgatum L. (C. fontanum Baumg. ssp. triviale (Link) Jalas)

Chrysanthemum leucanthemum L.

Chrysanthemum segetum L.

Cirsium arvense (L.) Soop.

Cirsium vulgare (Savi) Ten.

Crepis capillaris (L.) Wallr.

Daucus carota L.

Erodium cicutarium (L.) L'Hérit.

Euphrasia officinalis L., _sensu_ _Pato_

Galium aparine L.

Galium odoratum (L.) Soop.

Galium palustre L.

Galium verum L.

Geranium molle L.

Glaux maritima L.

Hieracium sp. L.

Honkenya peploides (L.) Ehrh.

Hydrocotyle vulgaris L.

Hypericum pulchrum L.

Hypochaeris radicata L.

Knautia arvensis (L.) Coult.

Lamium purpureum L.

Leontodon autumnalis L.

Lotus corniculatus L.

Lychnis flos-cuculi L.

Matricaria matricarioides (Less.) Porter

Myosotis arvensis (L.) Hill

Papaver dubium L.

Plantago lanceolata L.

Plantago major L.

Plantago maritima L.

Pinguicula vulgaris L.

Polygala vulgaris L.

Polygonum persicaria L.

Potentilla anserina L.

Potentilla erecta (L.) Räuschel

Potentilla palustris (L.) Scop.

Potentilla reptans L.

Ranunculus acris L.

Ranunculus bulbosus L.

Ranunculus ficaria L.

Ranunculus repens L.

Rumex acetosa L.

Rumex acetosella L.

Rumex crispus L.

Rumex longifolius DC.

Sagina maritima Don

Salicornia sp. L.

Sedum acre L.

Senecio jacobaea L.

Senecio vulgaris L.

Silene maritima With.

Sinapis arvensis L.

Sonchus asper (L.) Hill

Spergula arvensis L.

Spergularia marina (L.) Griseb.

Stellaria alsine Grimm

Stellaria graminea L.

Stellaria media (L.) Vill.

Succisa pratensis Moench

Taraxacum officinale Weber sensu lato

Thalictrum minus L.

Thymus drucei Ronn.

Trifolium medium L.

Trifolium pratense L.

Trifolium repens L.

Tussilago farfara L.

Veronica serpyllifolia L.

Vicia cracca L.

Vicia sepium L.

Viola palustris L.

Viola tricolor L.

Acrocladium cuspidatum (Hedw.) Linb.

Barbula Fallax Hedw.

Bryum sp.

Camptothecium lutescens (Hedw.) Brid.

Hylocomium splendens (Hedw.) B. and S.

Hypnum cupressiforme Hedw.

Mnium undulatum Hedw.

Physcomitrium pyriforme (Hedw.) Brid.

Plagiothecium undulatum (Hedw.) B. and S.

Polytrichum sp.

Pseudoscleropodium purum (Hedw.) Fleisch.

Rhytidiadelphus squarrosus (Hedw.) Warnst.

Rhytidiadelphus triquetrus (Hedw.) Warnst.

Thuidium sp.

Tortula ruraliformis (Besch.) Dix.

Caloplaca sp.

Cladonia sp.

Peltigera rufescens

Peltigera spuria

Nostoc sp.

Reference works used in compiling this flora:

Clapham, Tutin and Warburg (1962, 1968)

Watson (1955)

APPENDIX 2

(1) MAP OF THE VEGETATION OF GROGARRY MACHAIR

(2) MAPS OF THE VEGETATION OF THE MACHAIRS OF THE UISTS

(1) Grogarry Machair

CONTAINED IN END POCKET

(2) Machairs of the Uists

Appendix 2(2) The Uists

KEY TO VEGETATION MAPS

Limits of machair

Diffuse vegetation boundary

Unit A Active dune front

Unit B Moribund dune front

Unit C Dune back slope

Unit D Sand hill

Unit E Machair plain

Unit F Dune slack

Unit G Sea machair

Unit H Wet fringe

Unit J Non-machair area

Cultivated area c c C

N

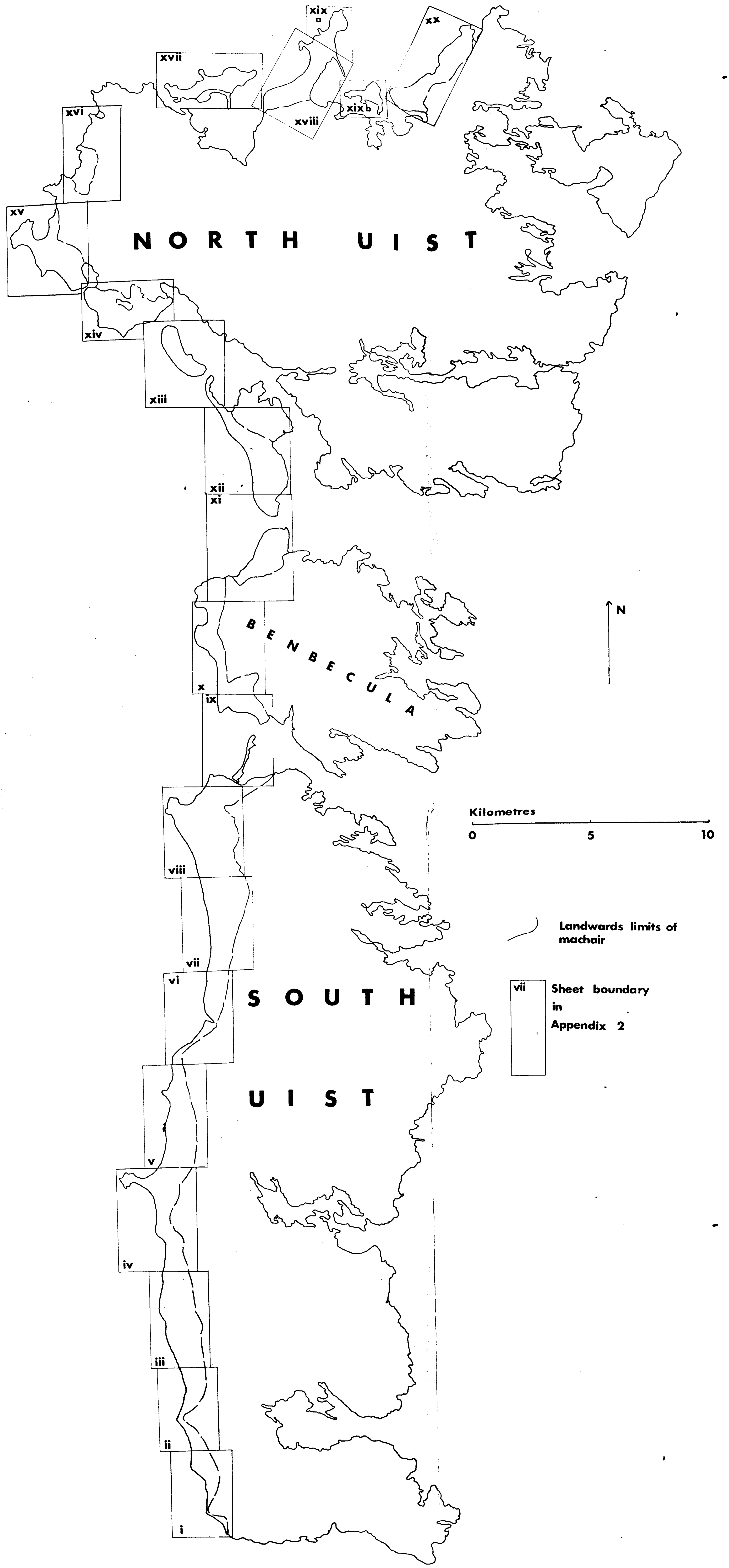
(unless otherwise indicated)

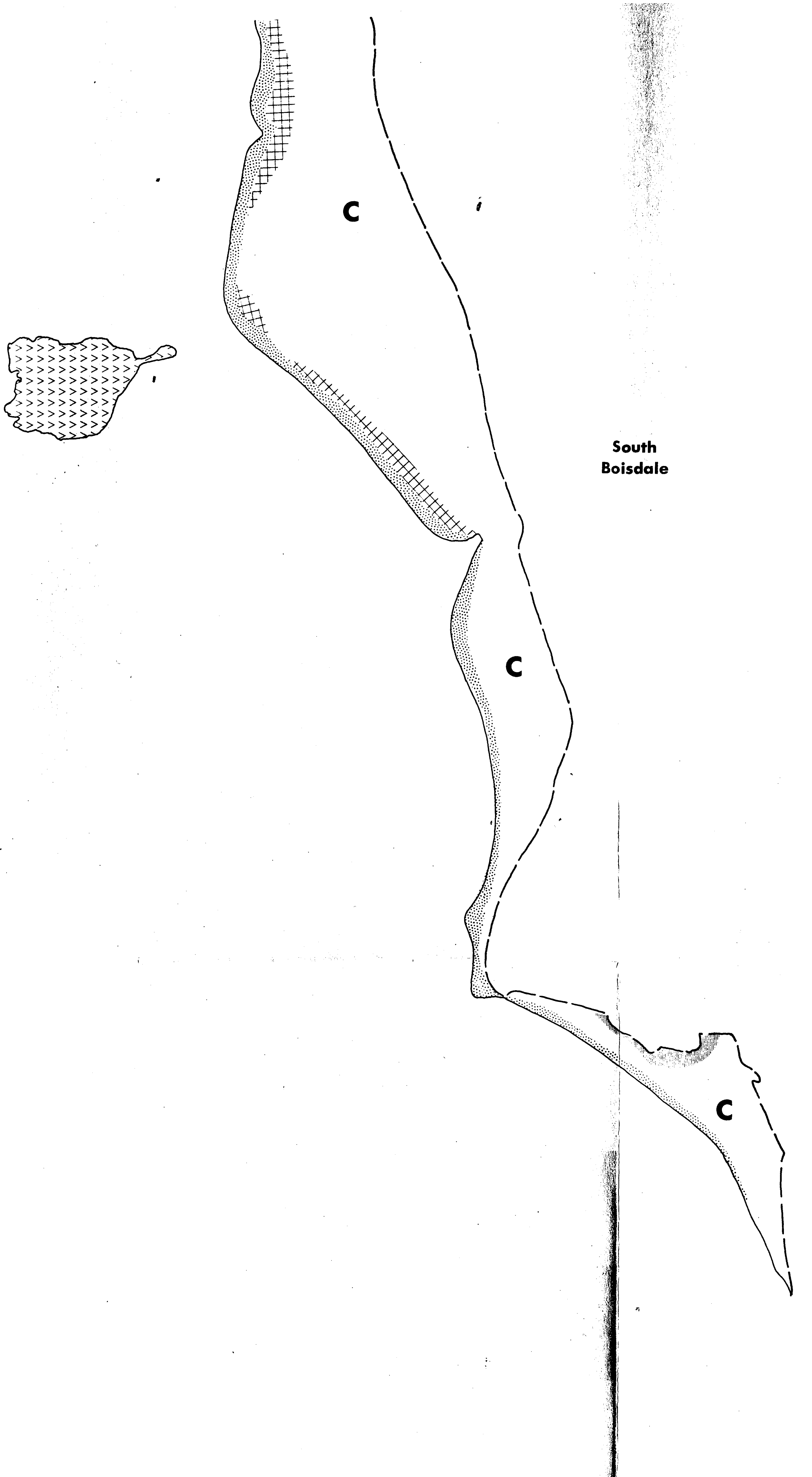
0 0·1 0·2 0·3 0·4 0·5 1

km

SCALE 1 : 10,560

Map 9
Uists' Survey – Key sheet

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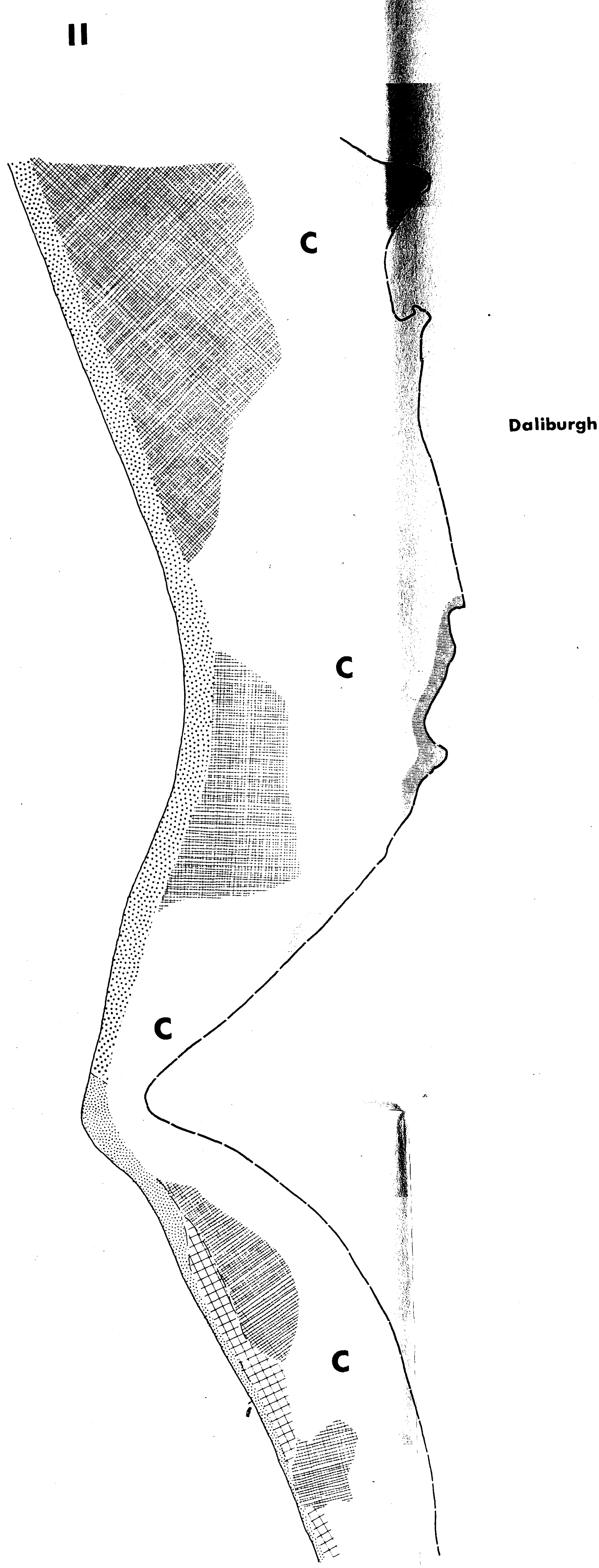
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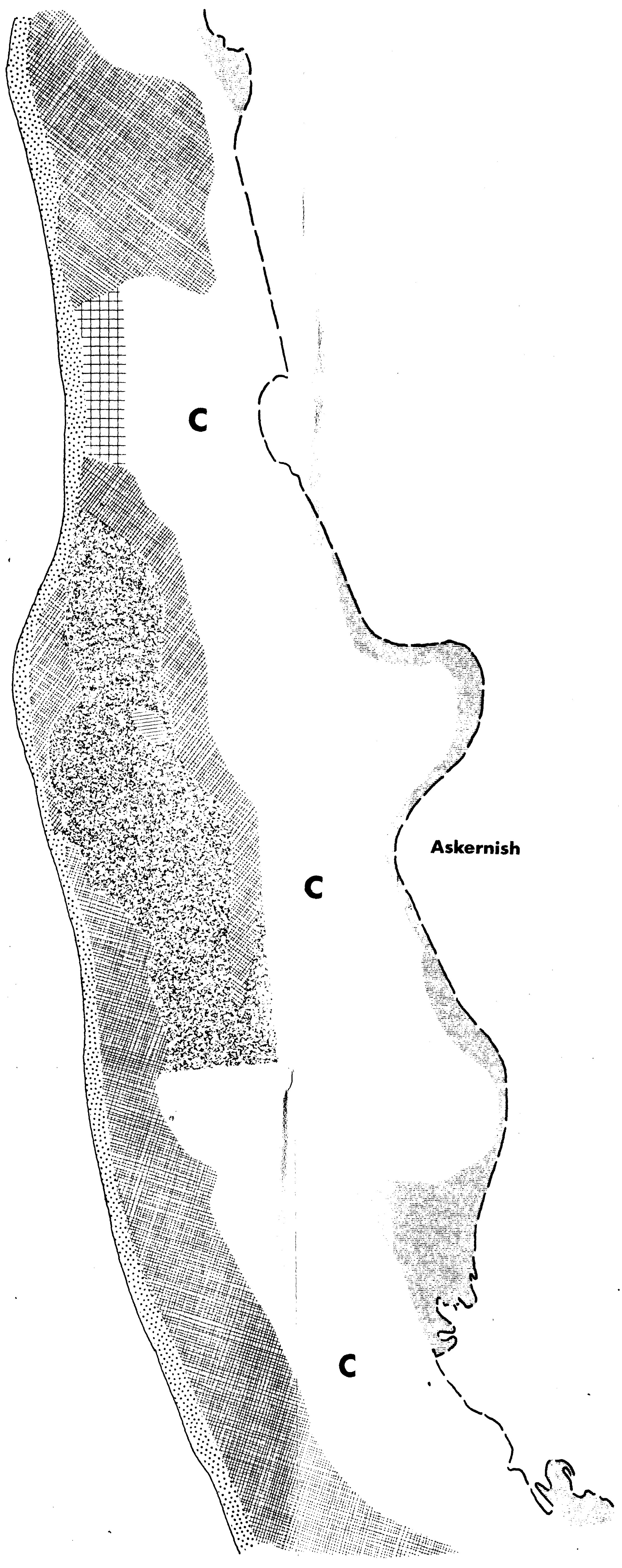

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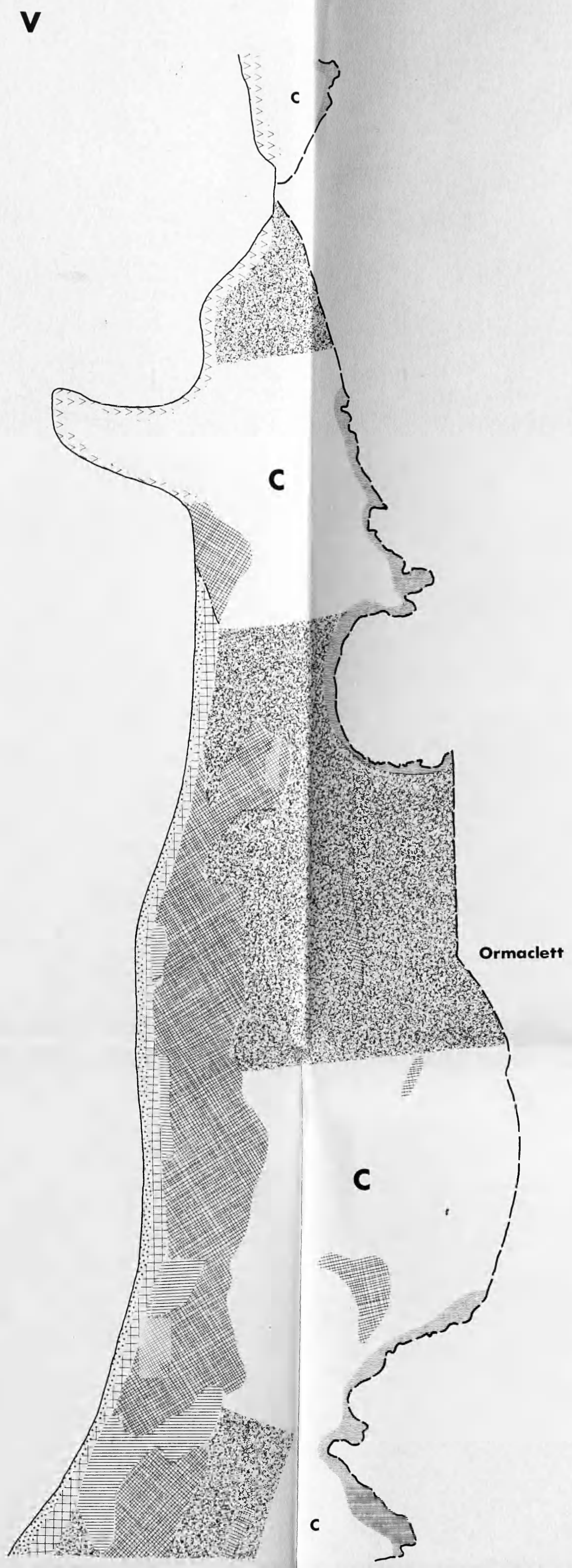
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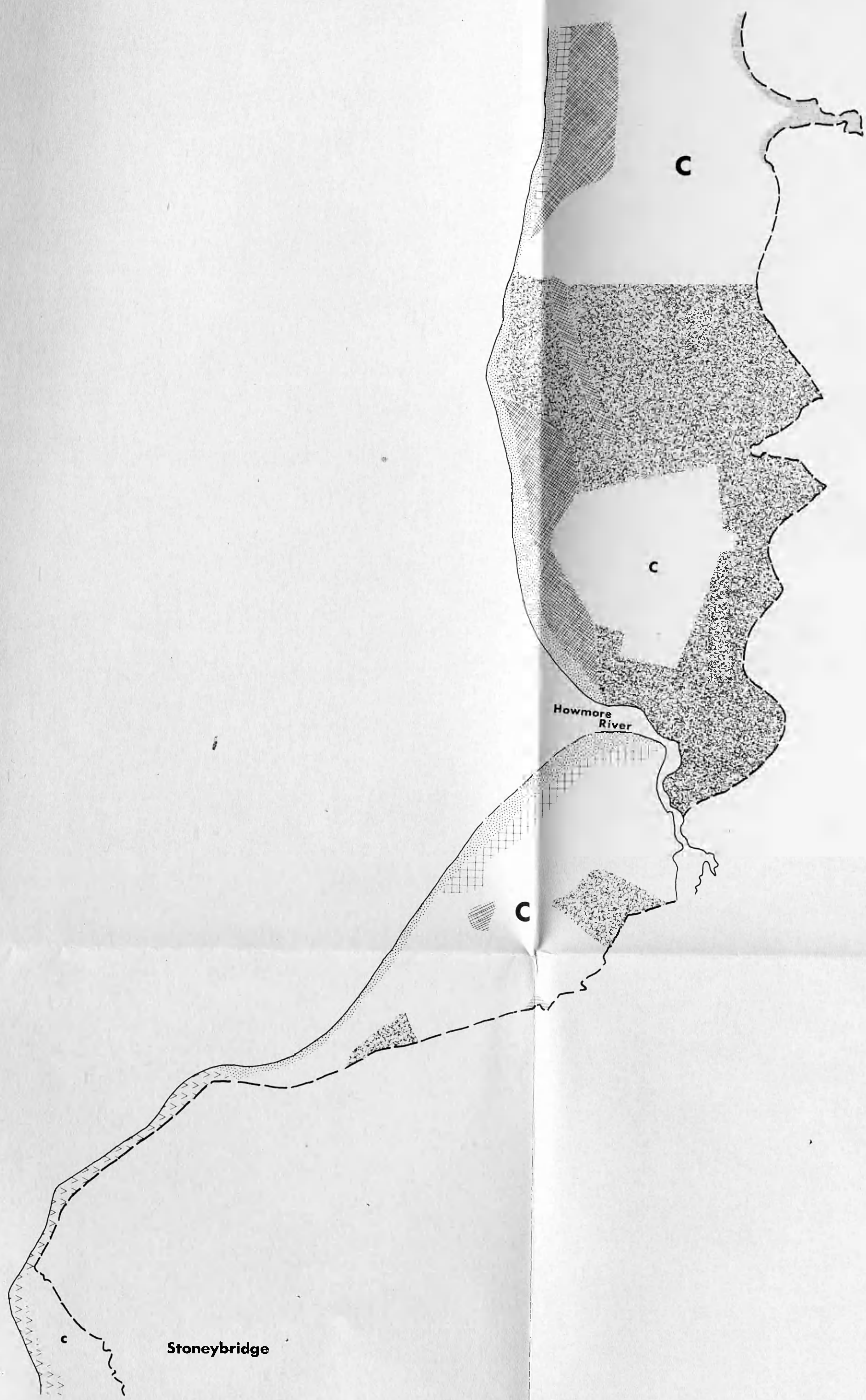

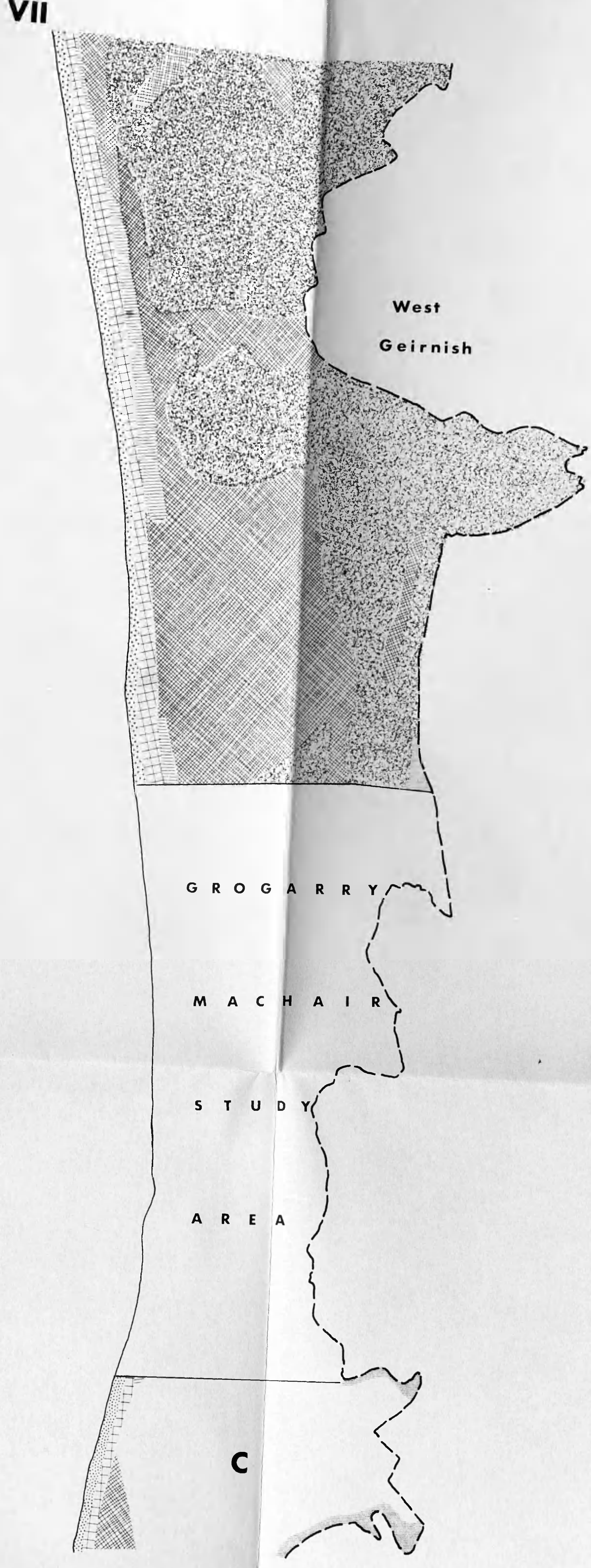
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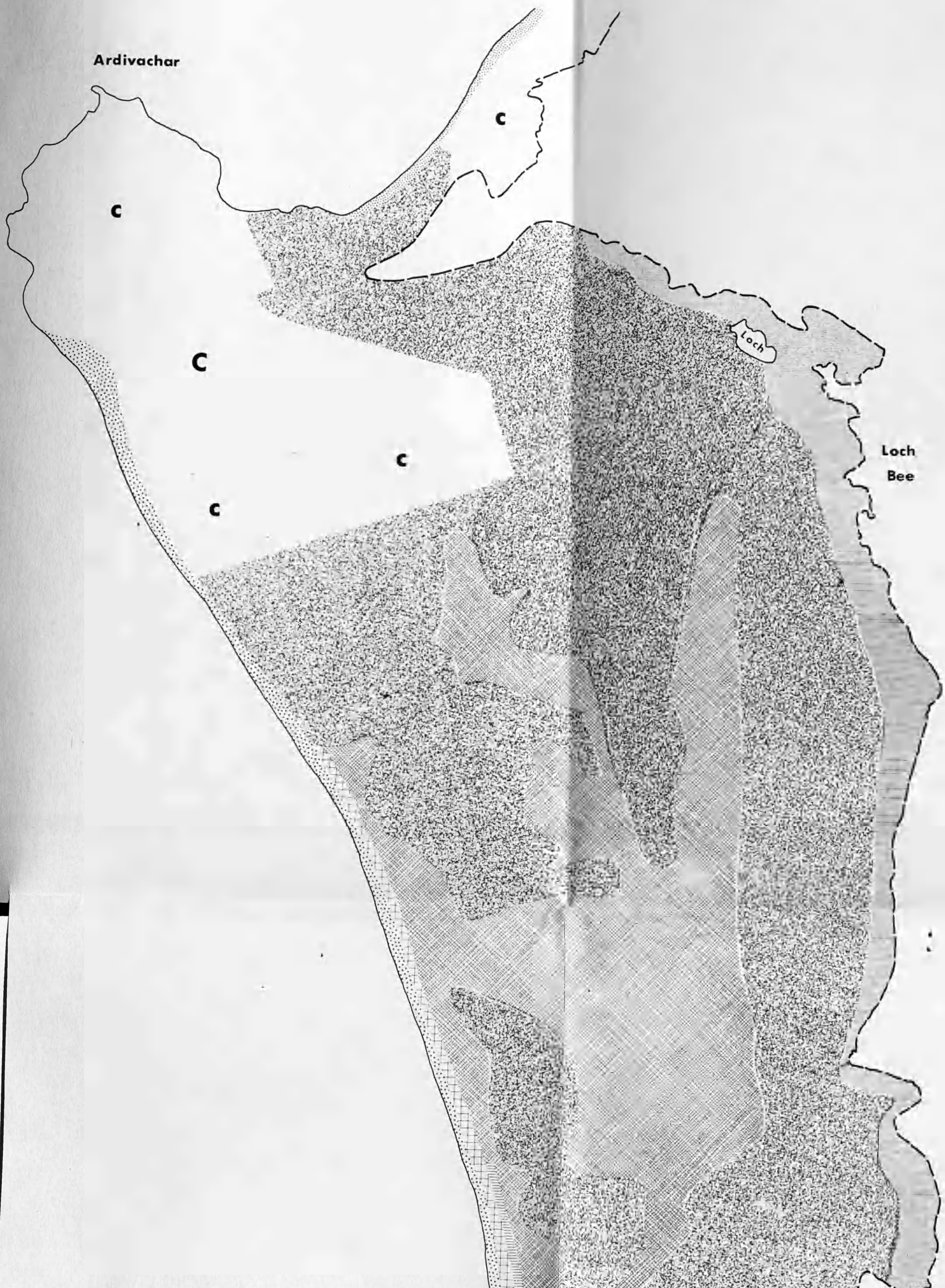

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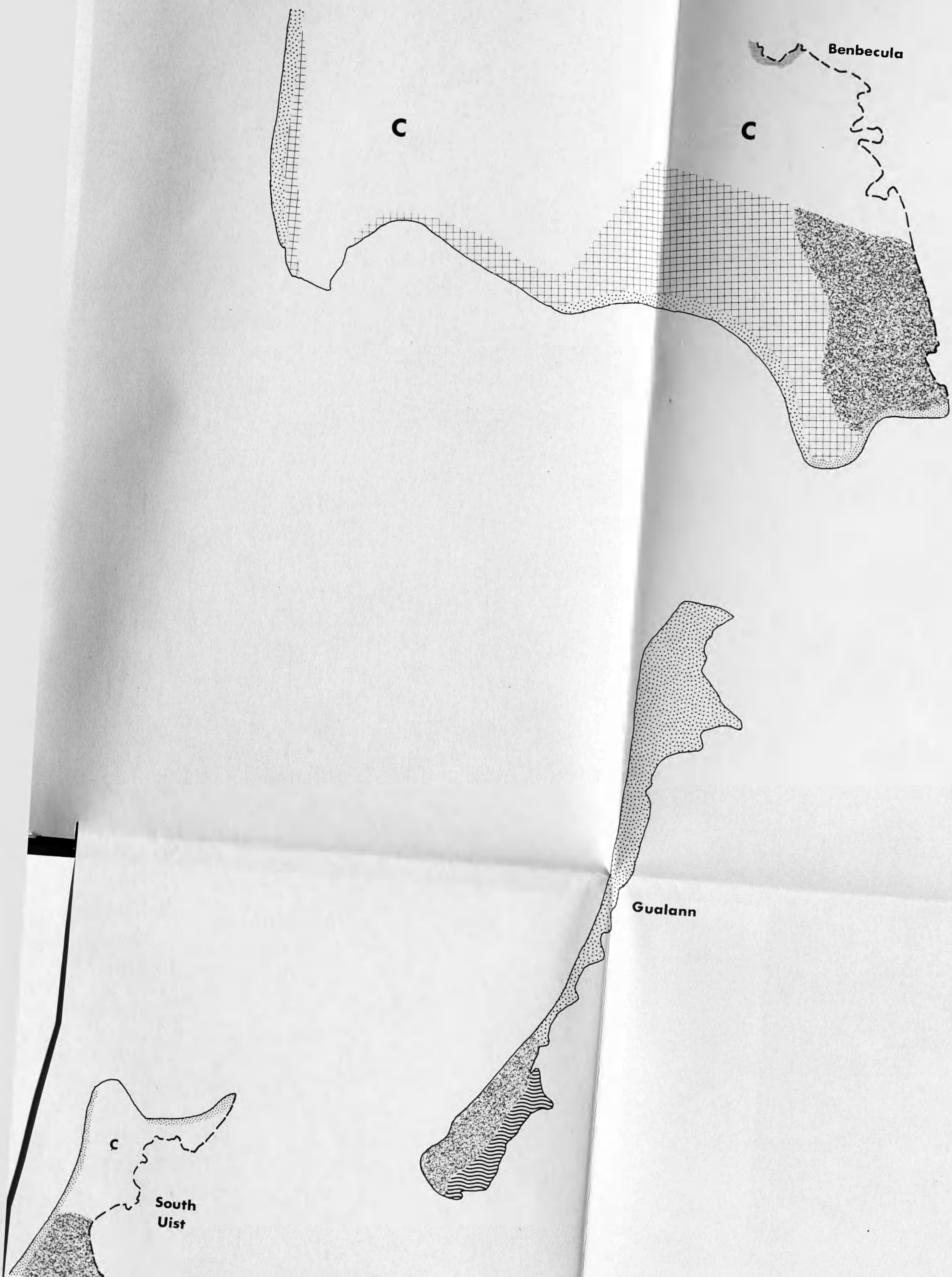

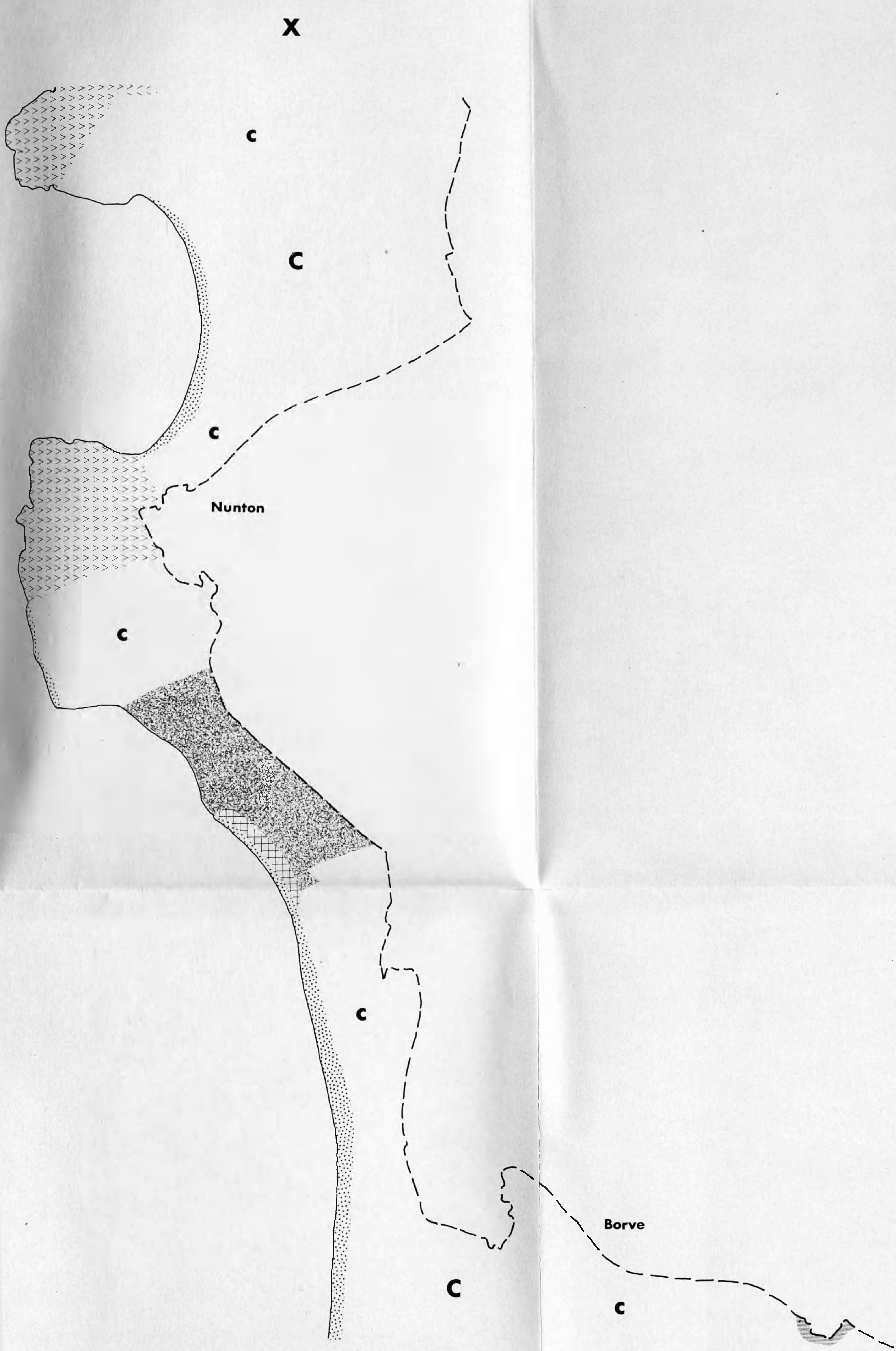

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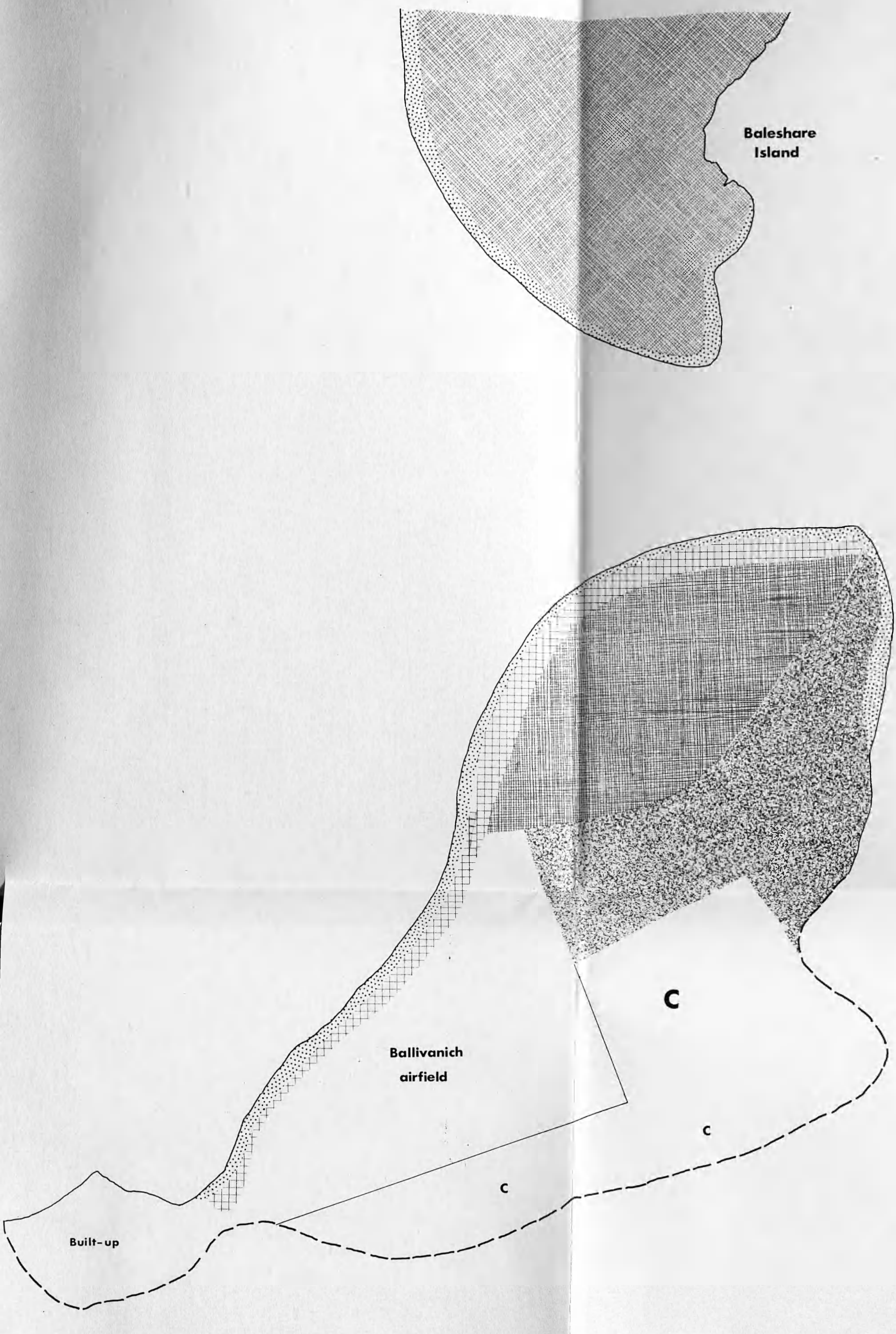

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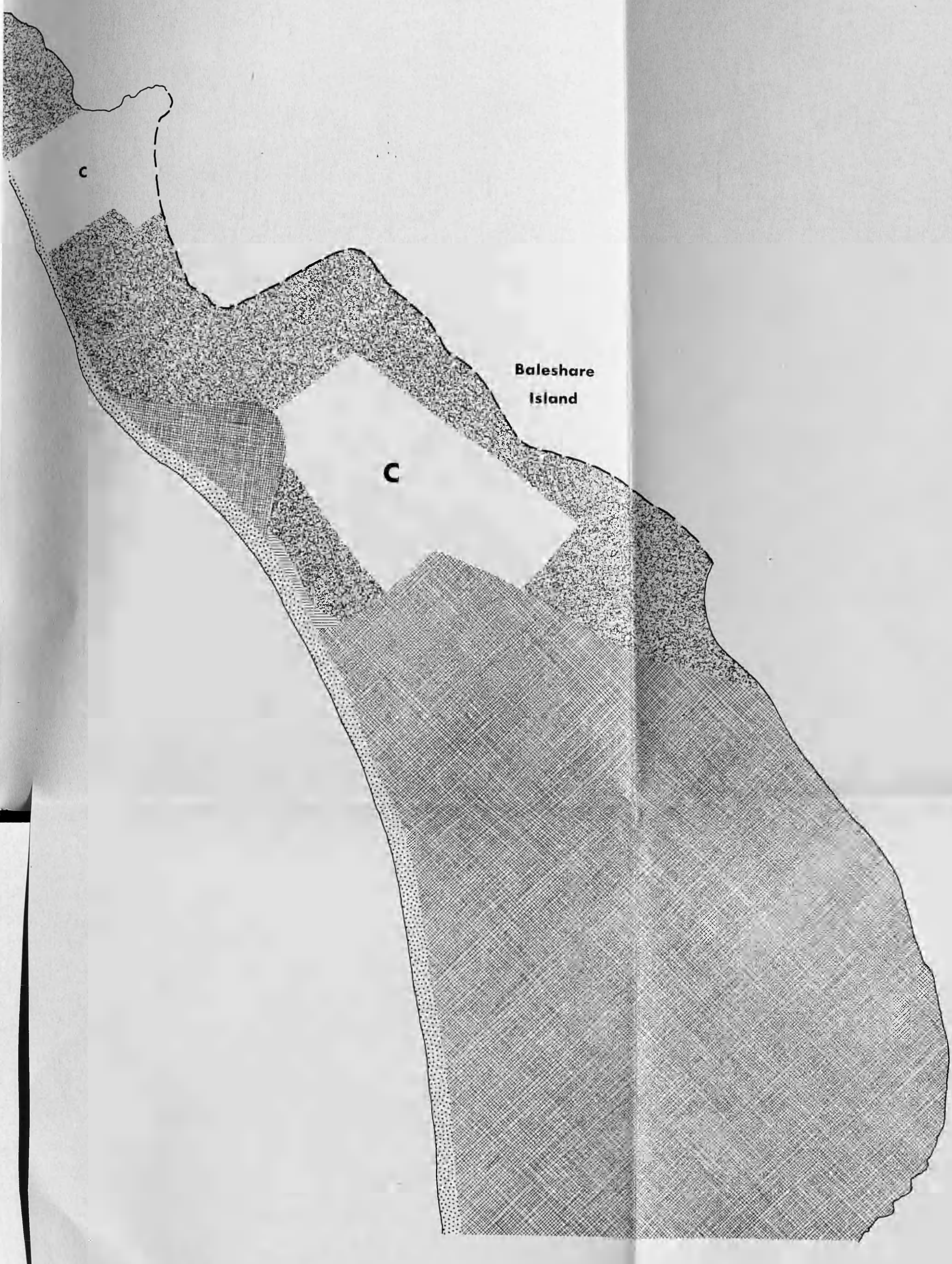

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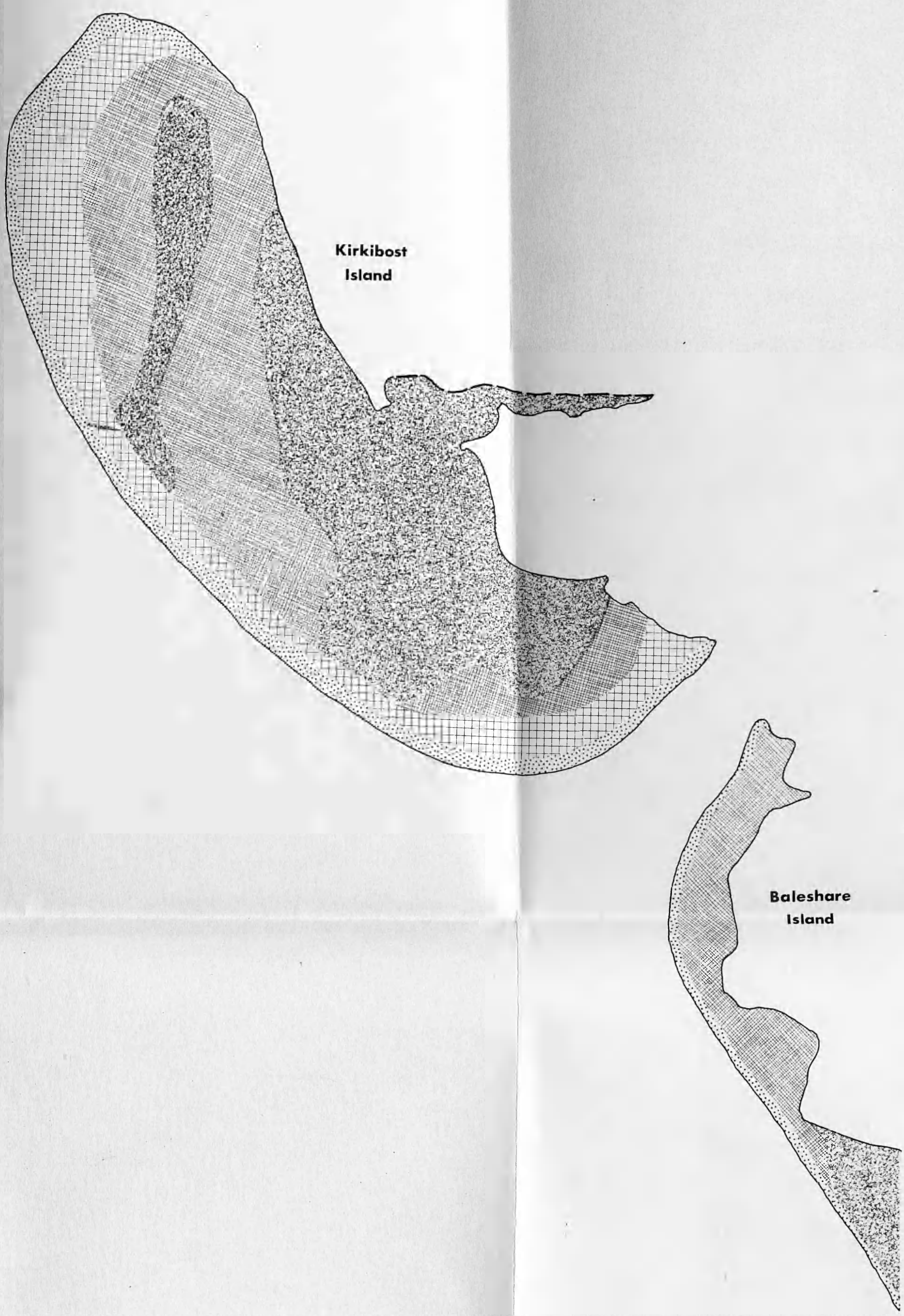

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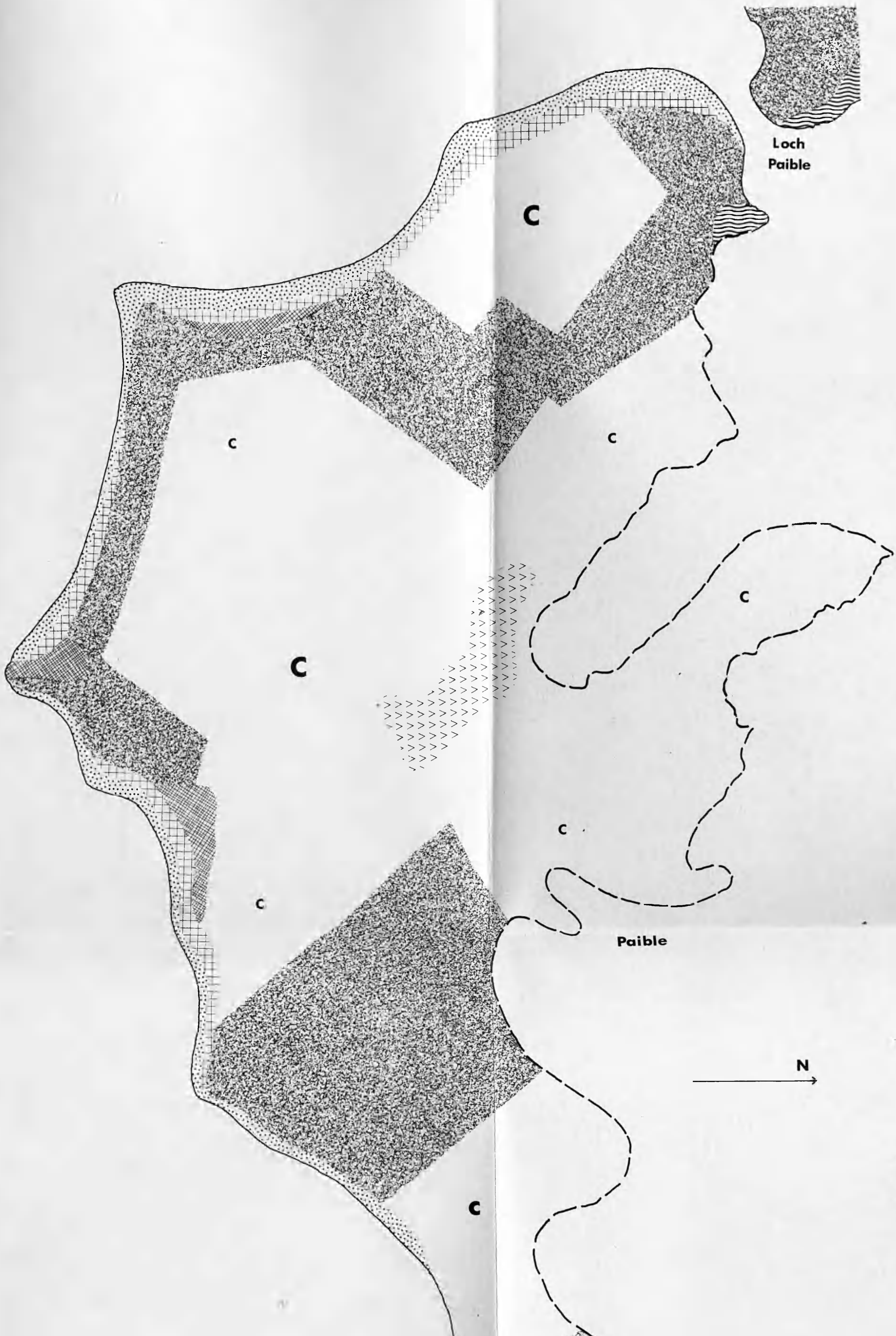

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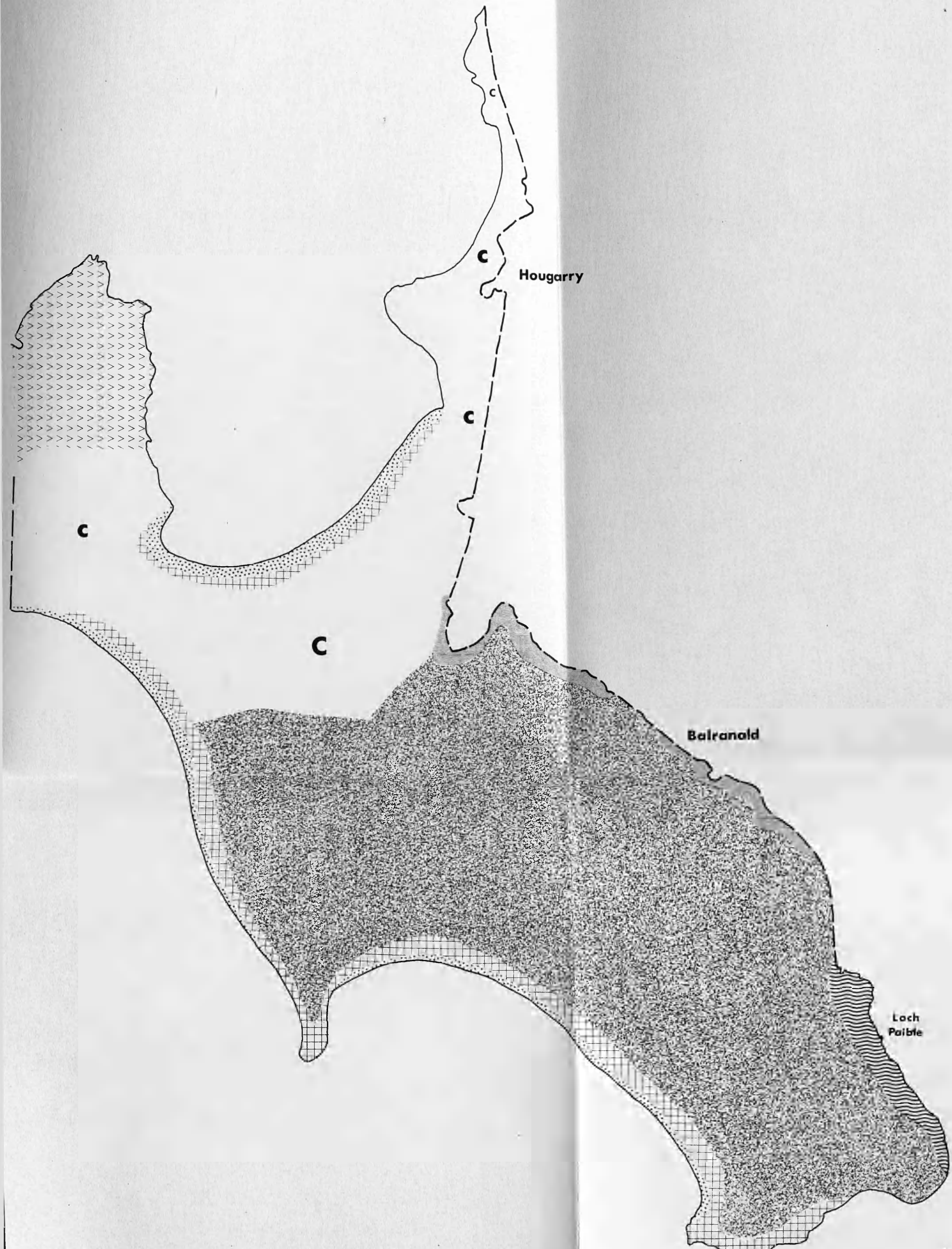

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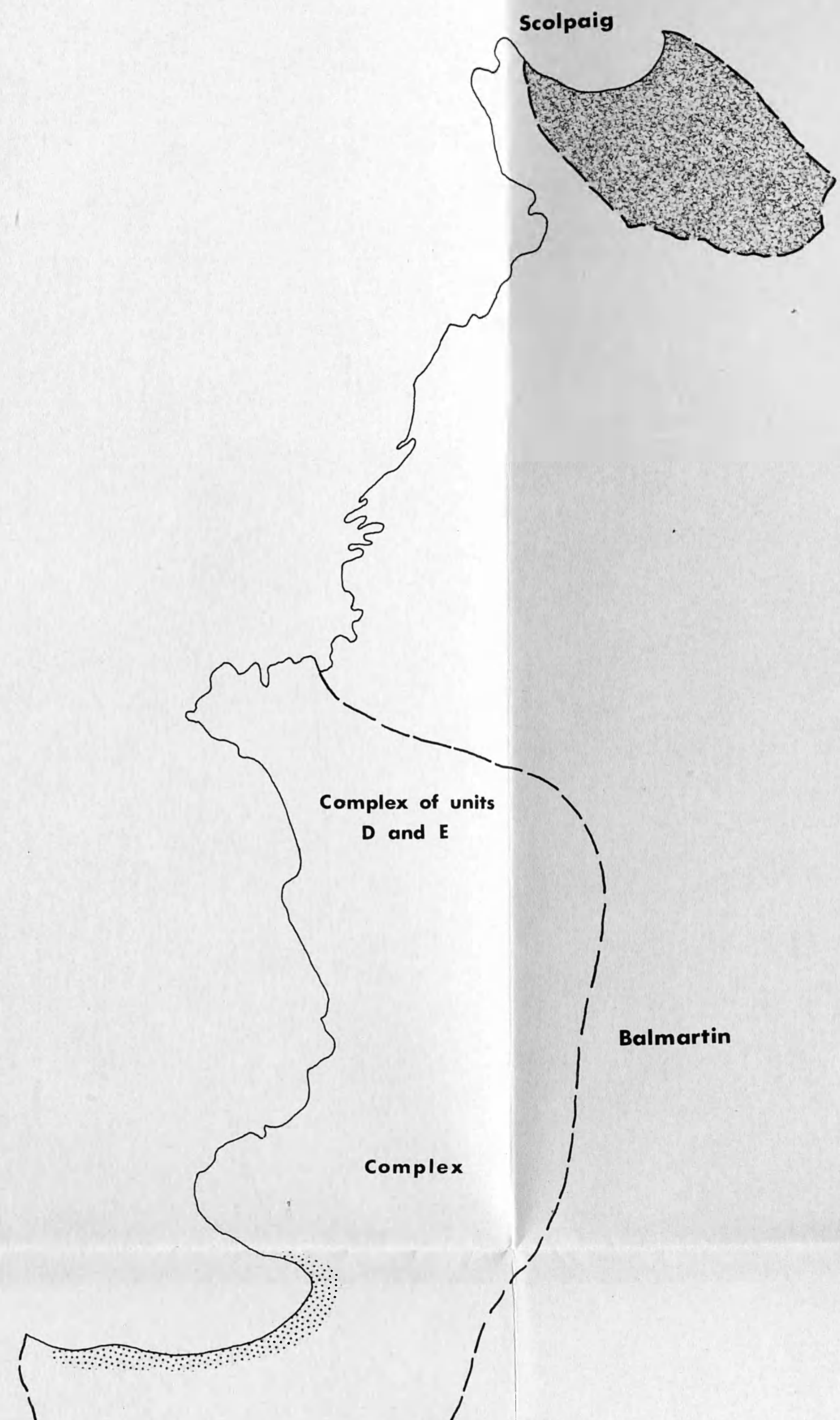
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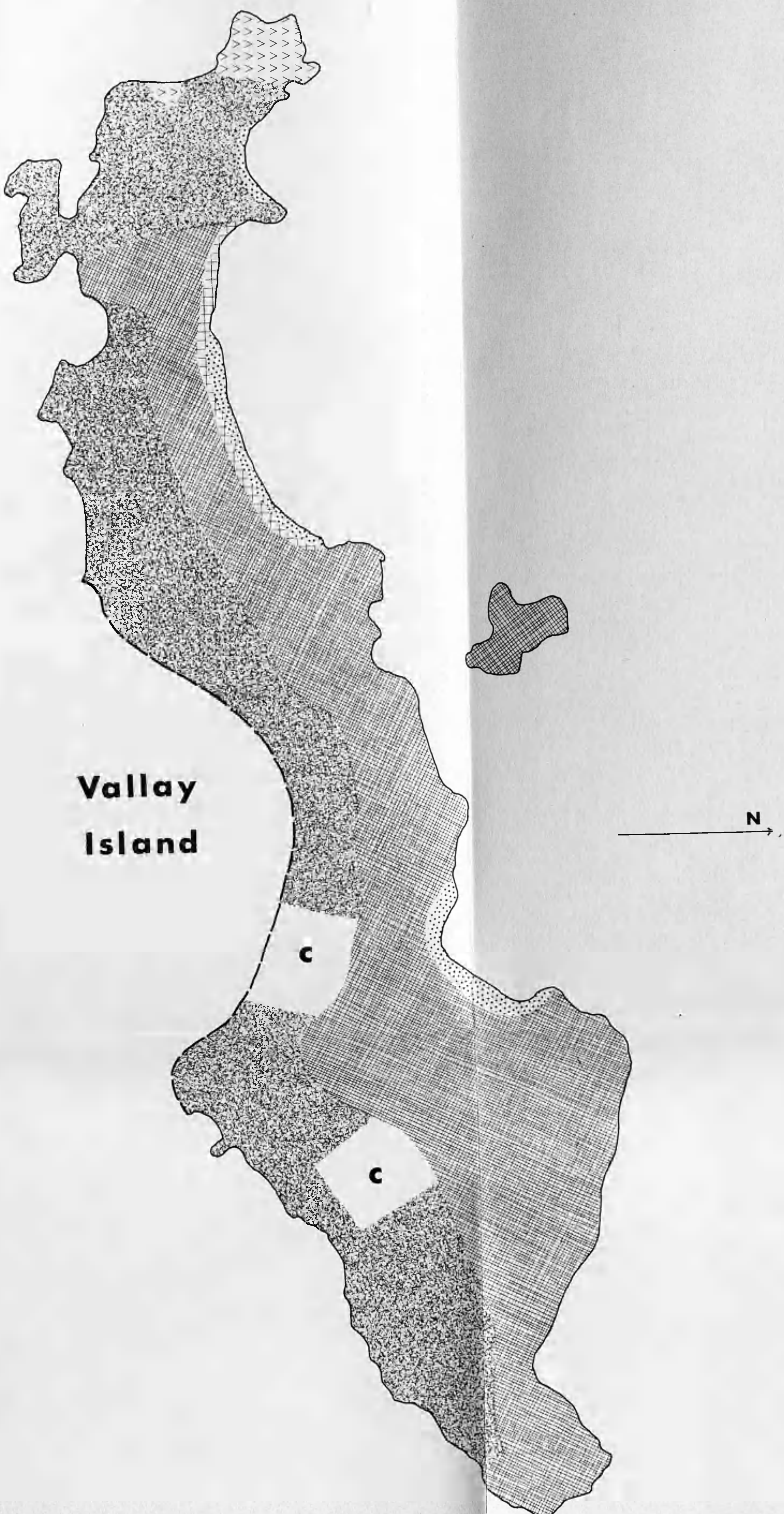

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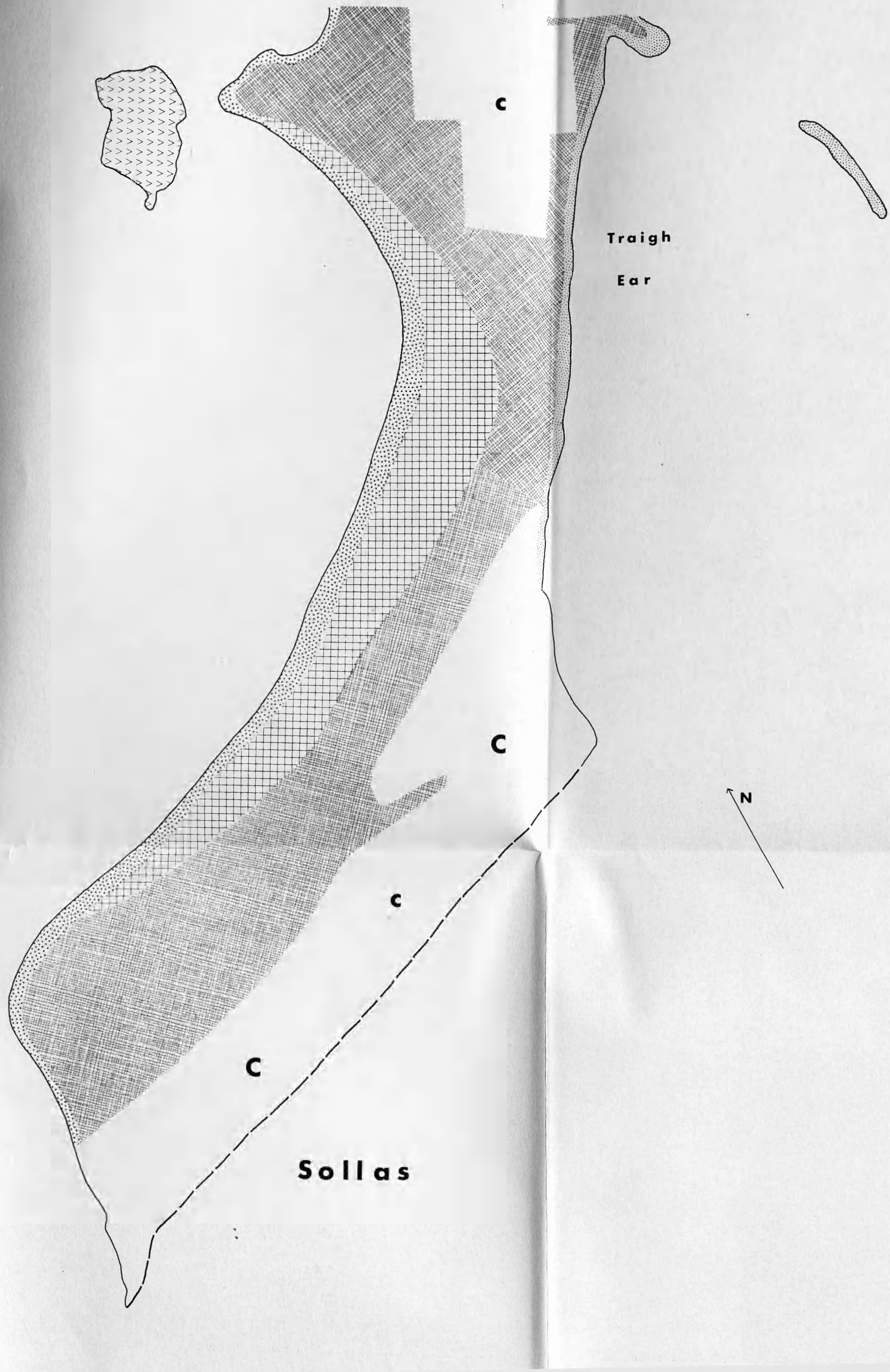

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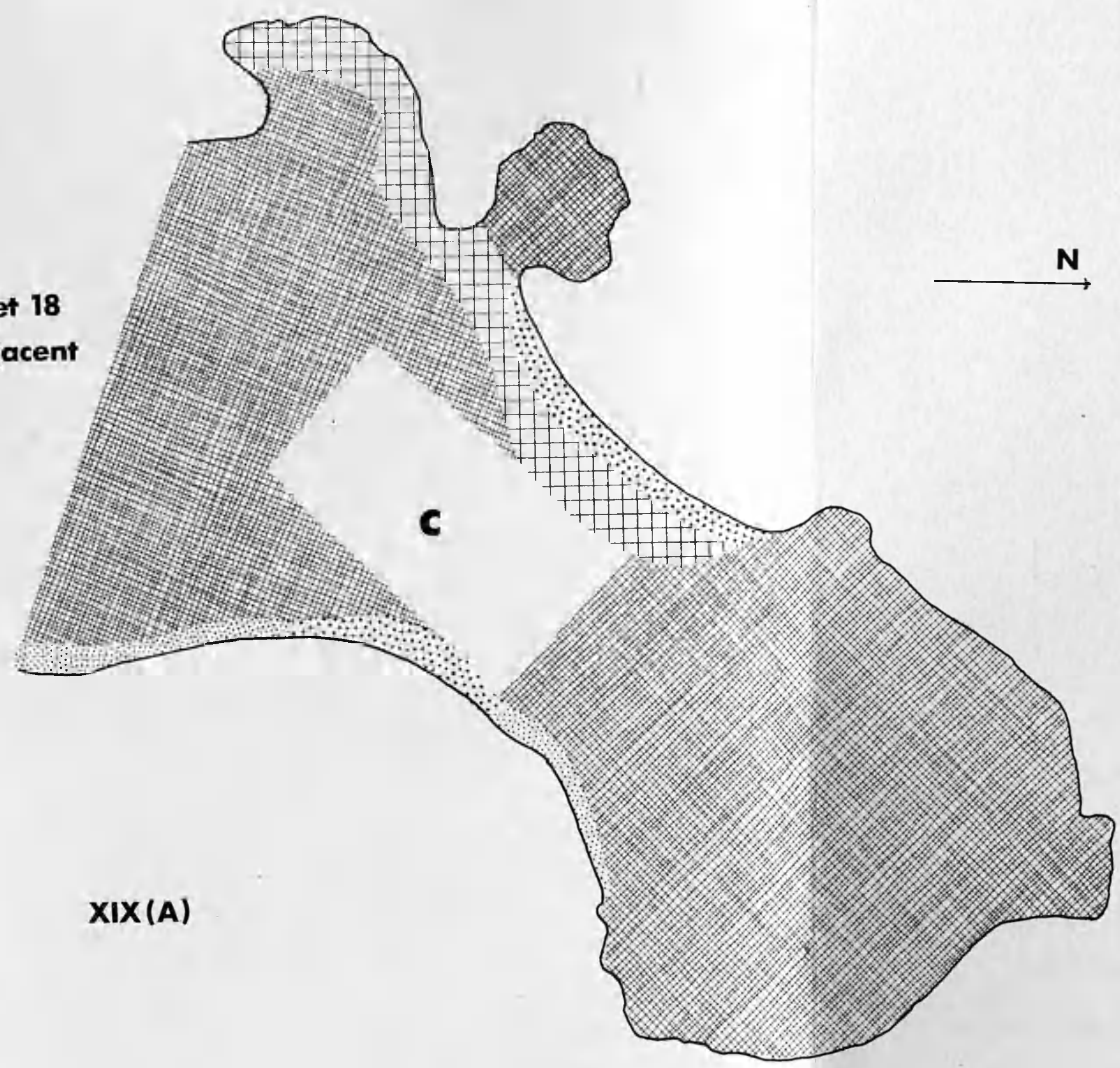

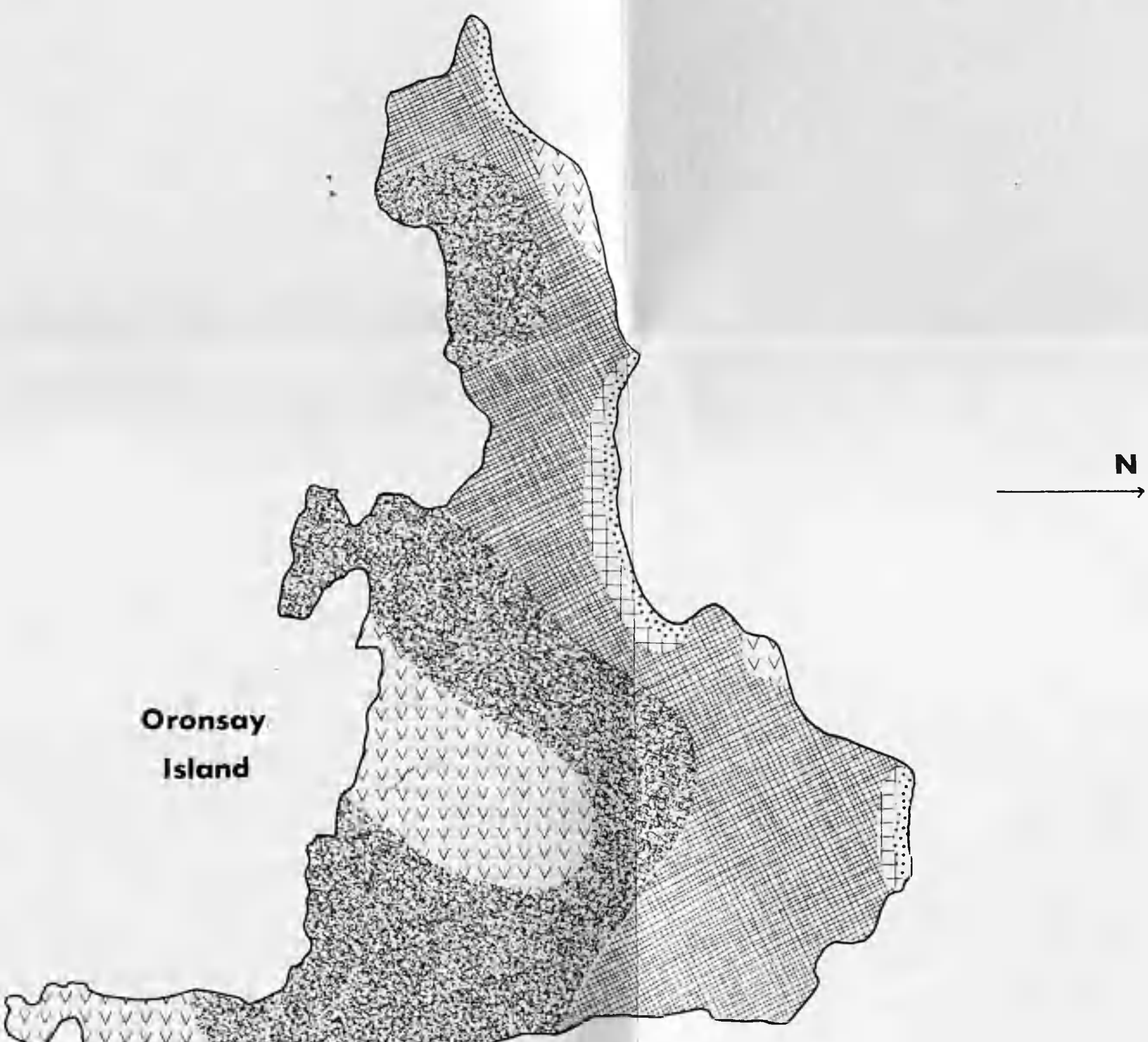

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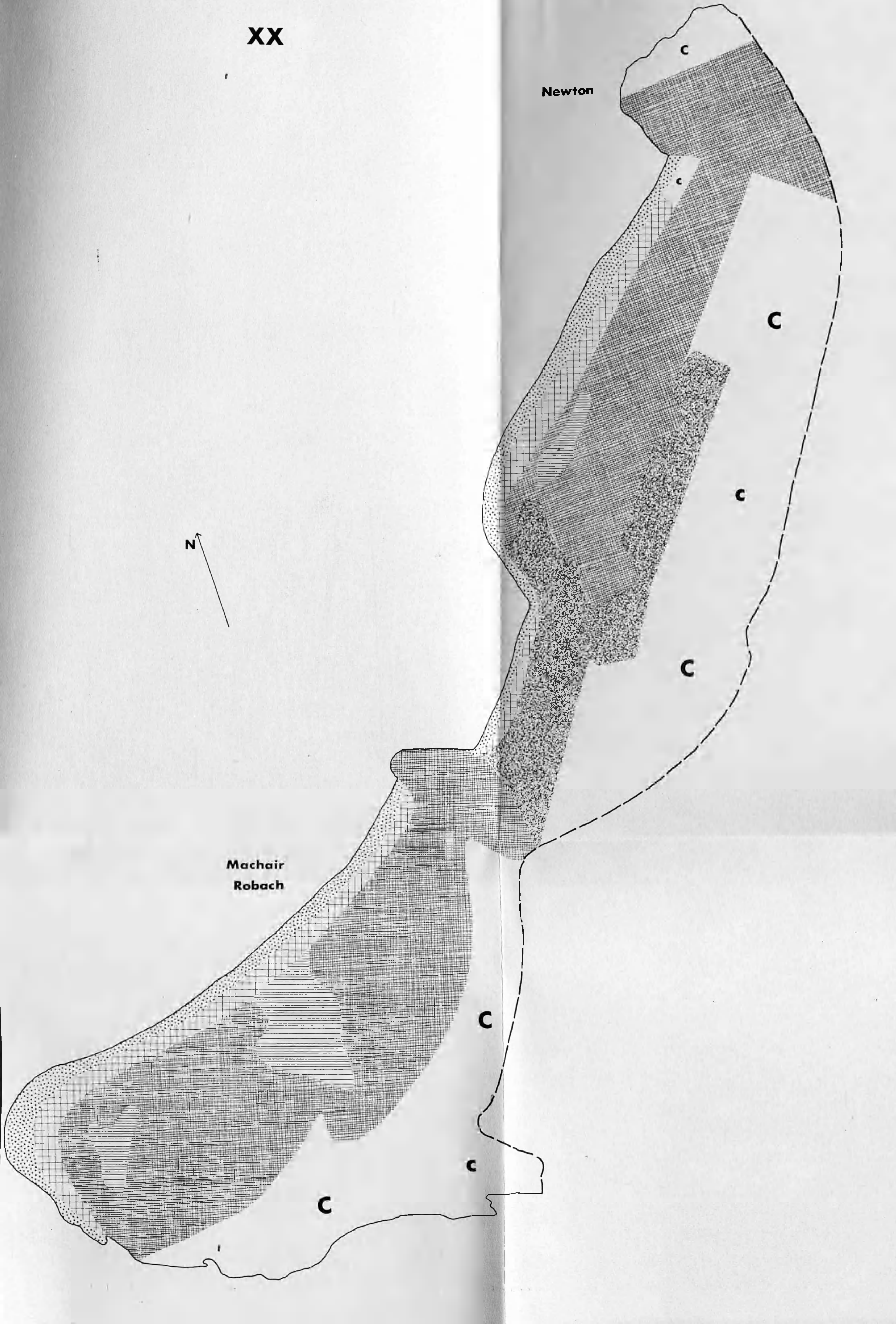


APPENDIX 3

GROGARRY MACHAIR

STATISTICAL SUMMARY OF VEGETATION ANALYSIS

APPENDIX 3

In the following table, aggregate data are given for the delimited vegetation sub-units at Grogarry Machair, South Uist. The spatial patterns formed by these sub-units are shown in the map contained in appendix 2. Percentage frequency is calculated in the normal way, and approximate Domin averages are based on the untransformed values of the appropriate samples. No data are recorded for sub-unit F, as at the time of the survey the area was inundated.

PER CENTAGE FREQUENCY

SPECIES	A1	A2	A3	C1	C2	C3	C4	D1	D2	D3	E1	E2	E3	F	H
Salix repens				14											
Equisetum spp.													3		10
Agrostis spp.				14				7	13	33	100	33	35		40
Ammophila arenaria	100	100	100	72	89	88	100	47	63	67		8	21		
Anthoxanthum odoratum															10
Dactylis glomerata												8	7		
Festuca rubra	33	57	91	100	100	100	100	93	100	100		100	97		90
Holcus lanatus								7	13				14		
Phragmites communis															10
Poa pratensis			9	28		6			13				7		20
Carex spp.				14	33	30	71	40	100	83		33	86		50
Dactylorchis purpurella										17			3		10
Eriophorum sp.				14											
Iris pseudacorus															10
Juncus spp.												8	10		10
Luzula campestris				14					25			8	10		
Orchis mascula													3		10
Achillea millefolium						12	14		25	83	10		10		
Anagallis minima								7							
Anthriscus sylvestris									13	67					10
Anthyllis vulneraria											8				
Bellis perennis		28	55	28	89	100	100	33	75	83		42	86		50
Cardamine pratensis												8	3		10
Carlina vulgaris						6									
Cerastium vulgatum		57	36	57	67	59	57	60	38	67	60	25	41		20
Cirsium sp.						6	14								
Daucus carota				28				13		17		17			
Erodium cicutarium							14				20				20
Euphrasia officinalis		14							13						
Galium verum			9	28	11	24	57	27	50	50		50	14		
Geranium molle						24			38	17			21		
Hieracium spp.				14		24	14			17			3		
Honkenya peploides		28				12					20				
Hydrocotyle vulgaris											10	17	7		
Hypericum pulchrum												8			
Hypochaeris radicata		14				6									10
Knautia arvensis													14		20
Leontodon spp.						6	14						10		10
Lotus corniculatus			9			47	29		63	83			45		
Myosotis arvensis										17			31		
Plantago lanceolata		14	73	86	100	82	100	93	50	100		58	79		20
P. maritima		14	27	14		12							10		10
Pinguicula vulgaris												8	3		10
Polygonum persicaria				14	11	6						8			
Potentilla anserina				42			14	33	13		20	33	24		20
Ranunculus acris						6			25	50	50		31		10
R. ficaria							14				20				20
R. flammula									13				3		10
R. repens				42		18	86	40	38	67		50	55		70
Rumex acetosa		14		28	44										
R. acetosella						6									
R. crispus		28	27	14	56	70	43	47		83		33	14		10
Sagina maritima						18	14		63	33			10		
Sedum acre			18					20		33			10		
Sinapis arvensis						6					90				
Sonchus asper			9												
Stellaria alsine															10
S. media			9							17		8	7		
Succisa pratensis									13						
Trifolium repens	33	28	91	72	44	59	71	60	88	83		83	76		30
Vicia cracca			9	14	11			20	38	17	40	17	31		20
Viola palustris															10
V. tricolor				14									3		10
Acrocladium cuspidatum								13	50			25	14		
Barbula fallax															7
Hylocomium splendens		14	9	14	78	18	14	40		67		33	41		20
Hypnum sp.															14
Mnium undulatum				14	44			20	25				14		
Plagiothecium undulatum			9			6							7		
Pseudoscleropodium purum								7	25				7		10
Polytrichum sp.															20
Rhytidiadelphus squarrosus		14	55	72	100	76	86	67	88	100		58	86		80
Thuidium sp.						12		33				8	17		20
Tortula ruraliformis		42				12		7							
Unvegetated Ground	100	86	55		11	6		7			100				10
Total number of species recorded	3	15	18	26	16	31	21	24	28	27	10	27	48		39

APPROXIMATE DOMIN AVERAGE

SPECIES	A1	A2	A3	C1	C2	C3	C4	D1	D2	D3	E1	E2	E3	F	H
Salix repens				1											
Equisetum spp.													1		1
Agrostis spp.				1				1	1	1	5	1	1		2
Ammophila arenaria	4	6	4	5	4	5	6	3	4	3		1	1		
Anthoxanthum odoratum															1
Dactylis glomerata												1	1		
Festuca rubra	1	3	6	8	7	6	6	6	6	7		8	6		5
Holcus lanatus								1	1				1		
Phragmites communis															1
Poa pratensis			1	2		1			1				1		1
Carex spp.				1	1	1	2	1	5	5		1	5		3
Dactylorchis purpurella										1			1		1
Eriophorum sp.				1											
Iris pseudacorus															1
Juncus spp.												1	1		1
Luzula campestris				1					1			1	1		
Orchis mascula													1		1
Achillea millefolium						1	1		1	2	1		1		
Anagallis minima							1								
Anthriscus sylvestris									1	1					1
Anthyllis vulneraria												1			
Bellis perennis		1	3	1	5	4	4	1	3	3		1	3		2
Cardamine pratensis												1	1		1
Carlina vulgaris						1									
Cerastium vulgatum		2	1	2	2	2	1	2	1	2	1	1	1		1
Cirsium sp.						1	1								
Daucus carota				1				1		1		1			
Erodium cicutarium							1				1				1
Euphrasia officinalis		1							1						
Galium verum			1	1	1	1	2	1	2	1		1	1		
Geranium molle						1			1	1			1		
Hieracium spp.				1		1	1			1			1		
Honkenya peploides		1				1					1				
Hydrocotyle vulgaris											1	1	1		
Hypericum pulchrum												1			
Hypochaeris radicata		1				1									1
Knautia arvensis													1		1
Leontodon spp.						1	1						1		1
Lotus corniculatus			1			1	1		2	2			1		
Myosotis arvensis										1			1		
Plantago lanceolata		1	3	3	3	3	3	3	1	3		2	4		1
P. maritima		1	1	1		1							1		1
Pinguicula vulgaris												1	1		1
Polygonum persicaria				1	1	1						1			
Potentilla anserina				2			1	1	1		1	2	1		1
Ranunculus acris						1			1	1	1		1		1
R. ficaria							1				1				1
R. flammula									1				1		1
R. repens				1		1	2	1	1	2		2	3		2
Rumex acetosa		1		1	1										
R. acetosella						1									
R. crispus		1	1	1	1	3	1	2		1		1	1		1
Sagina maritima						1	1		1	1			1		
Sedum acre			1					1		1			1		
Sinapis arvensis						1					1				
Sonchus asper			1												
Stellaria alsine															1
S. media			1							1		1	1		
Succisa pratensis									1						
Trifolium repens	1	1	4	3	1	2	3	2	3	2		3	3		1
Vicia cracca			1	1	1			1	1	1	1	1	1		1
Viola palustris															1
V. tricolor				1									1		1
Acrocladium cuspidatum								1	1			1	1		
Barbula fallax															1
Hylocomium splendens		1	1	1	2	1	1	1		2		1	1		1
Hypnum sp.															1
Mnium undulatum				1	1			1	1				1		
Plagiothecium undulatum			1			1							1		
Pseudoscleropodium purum								1	1				1		1
Polytrichum sp.															1
Rhytidiadelphus squarrosus		1	2	5	6	3	5	3	4	4		3	4		4
Thuidium sp.						1		1				1	1		2
Tortula ruraliformis		1				1		1							
Unvegetated Ground	9	6	4		1	1		1			8				1

APPENDIX 4

THE UISTS

STATISTICAL SUMMARY OF VEGETATION ANALYSIS

APPENDIX 4

In the following tables, aggregate data are given for the delimited vegetation units in the Uists. The spatial patterns formed by these units are shown in the maps contained in appendix 2. Percentage frequency is calculated in the normal way, and Domin averages are based on the modified 8-point scale and transformation procedure discussed in chapter 5. The values 4-10 correspond to the values which occur in the conventional Domin Scale, whilst the letter P denotes the single class which replaces the 4 lowest classes (see chapter 5 and particularly tables 5 and 6). P+ corresponds to a calculated value of P for which the average transformed value exceeds 28 (the transformed value of P).

UNIT A: ACTIVE DUNE FRONT

40 Samples

Average no. of species: 3.2

Total number of species recorded: 29

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
Agropyron junciforme	7.5	P
Ammophila arenaria	80.0	5
Festuca rubra	10.0	P
F. ovina	12.5	P
Poa pratensis	5.0	P
Carex arenaria	5.0	P
Achillea millefolium	7.5	P
Arenaria serpyllifolia	2.5	P
Atriplex hastata	32.5	P
A. laciniata	2.5	P
Cakile maratima	12.5	P
Cirsium arvense	2.5	P
C. vulgare	5.0	P
Crepis capillaris	2.5	P
Galium verum	2.5	P
Hieracium spp.	5.0	P
Honkenya peploides	27.5	P
Hypochaeris radicata	2.5	P
Plantago lanceolata	12.5	P
Potentilla anserina	17.5	P

SPECIES	FREQUENCY	COMPUTED DOMIN AVERAGE
Ranunculus repens	5.0	P
Rumex crispus	22.5	P
Sedum acre	5.0	P
Senecio jacobaea	10.0	P
Sonchus asper	10.0	P
Trifolium pratense	2.5	P
T. repens	10.0	P
Acrocladium cuspidatum	2.5	P
Hylocomium splendens	2.5	P
Unvegetated ground	95.0	7

UNIT B: MORIBUND DUNE FRONT

93 Samples

Average no. of species: 5.4

Total number of species recorded: 66

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
Agropyron junciforme	1	P
Agrostis canina	1	P
A. stolonifera	1	P
A. tenuis	8	P
Ammophila arenaria	96	6
Festuca rubra	57	4
F. ovina	1	P
Poa pratensis	10	P
Carex arenaria	9	P
C. flacca	1	P
C. panicea	1	P
Luzula campestris	1	P
Achillea millefolium	13	P
Anagallis minima	2	P
Anthyllis vulneraria	2	P
Arenaria serpyllifolia	4	P
Atriplex hastata	11	P
Bellis perennis	22	P
Cakile maritima	5	P
Centaurium littorale	1	P
Cerastium vulgatum	1	P

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
Chrysanthemum segetum	1	P
Cirsium arvense	3	P
C. vulgare	1	P
Daucus carota	14	P
Erodium cicutarium	3	P
Euprasia officinalis	2	P
Galium aparine	1	P
G. verum	42	P
Geranium molle	3	P
Hieracium spp.	4	P
Honkenya peploides	4	P
Hypochaeris radicata	5	P
Lactuca virosa	11	P
Leontodon spp.	4	P
Lotus corniculatus	25	P
Matricaria matricariodes	1	P
Plantago lanceolata	45	P
P. maritima	5	P
Potentilla anserina	4	P
P. palustris	1	P
Primula veris	5	P
Ranunculus acris	12	P

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
R. bulbosus	5	P
R. repens	15	P
Rumex crispus	12	P
Sedum acre	3	P
Senecio jacobaea	17	P
S. vulgaris	10	P
Sonchus asper	6	P
Stellaria graminea	4	P
S. media	1	P
Taraxacum officinale	1	P
Trifolium pratense	4	P
T. repens	25	P
Tussilago farfara	1	P
Veronica serpyllifolia	1	P
Vicia cracca	1	P
V. sepium	5	P
Viola tricolor	1	P
Acrocladium cuspidatum	4	P
Camptothecium lutescens	1	P
Rhytidiadelphus squarrosus	16	P
Tortula ruraliformis	1	P
Peltigera rufescens	1	P
Unvegetated ground	77	6

UNIT C: DUNE BACK SLOPE

48 Samples

Average no. of species: 9.9

Total number of species recorded: 50

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
Agrostis canina	8	P
A. tenuis	17	P
Ammophila arenaria	100	6
Avena spp.	2	P
Festuca rubra	83	5
F. ovina	4	P
Lolium perenne	2	P
Poa pratensis	15	P
P. trivialis	2	P
Carex arenaria	15	P
Luzula campestris	13	P
L. sylvatica	2	P
Achillea millefolium	27	P
Anagallis minima	6	P
Bellis perennis	38	P
Cerastium vulgatum	10	P
Centaurium littorale	13	P
Cirsium arvense	6	P
C. vulgare	2	P
Crepis capillaris	21	P
Daucus carota	21	P
Euphrasia officinalis	15	P

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
Galium verum	79	4
Geranium molle	4	P
Hieracium spp.	13	P
Honkenya peploides	4	P
Lamium purpureum	2	P
Leontodon spp.	6	P
Lotus corniculatus	42	P
Plantago lanceolata	79	P
Polygonum persicaria	2	P
Potentilla anserina	10	P
Ranunculus acris	40	P
R. bulbosus	44	P
R. repens	8	P
Rumex acetosa	2	P
R. crispus	2	P
Senecio jacobaea	46	P
S. vulgaris	10	P
Sonchus asper	4	P
Stellaria graminea	4	P
Taraxacum officinale	17	P
Trifolium pratense	25	P
T. repens	54	P
Veronica serpyllifolia	2	P

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
Vicia cracca	2	P
Viola tricolor	2	P
Acrocladium cuspidatum	13	P
Rhytidiadelphus squarrosus	40	P
Peltigera spuria	2	P
Unvegetated ground	44	P

UNIT D: SAND HILLS

109 Samples

Average no. of species: 13.3

Total number of species recorded: 72

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
Agrostis canina	9	P
A. tenuis	16	P
Ammophila arenaria	89	4
Festuca rubra	92	6
F. ovina	5	P
Helictotrichon pratense	4	P
Holcus lanatus	1	P
Hordeum sp.	7	P
Lolium perenne	2	P
Poa pratensis	40	P
P. trivialis	2	P
Carex arenaria	30	P
C. flacca	22	P
C. nigra	1	P
C. panicea	15	P
C. rostrata	1	P
Eleocharis palustris	1	P
Endymion non-scriptus	2	P
Luzula campestris	20	P
L. sylvatica	1	P
Achillea millefolium	34	P

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
Anagallis minima	14	P
Bellis perennis	64	P
Campanula rotundifolia	2	P
Cardamine pratensis	1	P
Centaurium littorale	7	P
Cerastium vulgatum	9	P
Chrysanthemum leucanthemum	1	P
Cirsium vulgare	1	P
Crepis capillaris	6	P
Daucus carota	6	P
Erodium cicutarium	12	P
Euphrasia officinalis	20	P
Galium verum	82	4
Geranium molle	8	P
Hieracium spp.	6	P
Honkenya peploides	1	P
Hydrocotyle vulgaris	5	P
Hypochaeris radicata	3	P
Lactuca virosa	1	P
Lamium purpureum	6	P
Leontodon spp.	9	P
Lotus corniculatus	65	P +
Myosotis arvensis	4	P

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
Plantago lanceolata	83	P +
P. major	2	P
P. maritima	9	P
Polygola vulgaris	5	P
Potentilla anserina	6	P
Primula veris	2	P
Prunella vulgaris	21	P
Ranunculus acris	47	P
R. bulbosus	30	P
R. repens	27	P
Rumex acetosa	1	P
R. crispus	3	P
Sagina maritima	1	P
Sedum acre	8	P
Senecio jacobaea	55	P
S. vulgaris	6	P
Silene maritima	1	P
Stellaria alsine	1	P
S. graminea	18	P
S. media	5	P
Succisa pratensis	3	P
Taraxacum officinale	3	P
Trifolium pratense	18	P
T. repens	62	P

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
Veronica serpyllifolia	7	P
Vicia cracca	4	P
V. sepium	1	P
Viola tricolor	3	P
Acrocladium cuspidatum	39	P
Camptothecium lutescens	8	P
Hylocomium splendens	6	P
Rhytidiadelphus squarrosus	69	P +
R. triquetrus	3	P
Thuidium sp.	4	P
Tortula ruraliformis	1	P
Cladonia sp.	1	P
Pettigera rufescens	17	P
P. spuria	7	P
Unvegetated ground	28	P

UNIT E: MACHAIR PLAIN

104 Samples

Average no. of species: 14.8

Total number of species recorded: 95

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
Equisetum palustre	3	P
Agrostis canina	22	P
A. stolonifera	4	P
A. tenuis	32	P
Ammophila arenaria	6	P
Avena sp.	13	P
Cynosurus cristatus	11	P
Festuca rubra	91	6
F. ovina	9	P
Helictotrichon pratense	5	P
Holcus lanatus	16	P
Hordeum sp.	10	P
Lolium perenne	13	P
Phragmites communis	3	P
Poa annua	1	P
P. pratensis	88	5
P. trivialis	6	P
Carex arenaria	17	P
C. flacca	29	P
C. nigra	2	P
C. panicea	14	P
C. rostrata	5	P

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
Eleocharis palustris	1	P
Juncus articulatus	2	P
Luzula campestris	16	P
L. pilosa	1	P
L. sylvatica	2	P
Orchis mascula	1	P
Achillea millefolium	42	P
Anagallis minima	14	P
Angelica sylvestris	1	P
Anthyllis vulneraria	2	P
Arenaria serpyllifolia		
Bellis perennis	69	P +
Caltha palustris	1	P
Carlina vulgaris	1	P
Centaurium littorale	24	P
Cerastium glomeratum	2	P
Chrysanthemum leucanthemum	7	P
Cirsium vulgare	1	P
Crepis capillaris	13	P
Daucus carota	10	P
Erodium cicutarium	12	P
Euphrasia officinalis	36	P
Galium palustre	1	P

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
G. verum	42	P
Hieracium spp.	14	P
Honkenya peploides	6	P
Hydrocotyle vulgaris	12	P
Lactuca virosa	1	P
Lamium purpureum	2	P
Leontodon spp.	13	P
Lotus coniculatus	58	P +
Lychris flos-cuculi	1	P
Myosotis arvenisis	12	P
Papaver dubium	1	P
Plantago lanceolata	77	P +
P. major	4	P
P. maritima	11	P
Polygala vulgaris	6	P
Polygonum persicaria	2	P
Potentilla anserina	34	P
P. palustris	1	P
Prunella vulgaris	31	P
Ranunculus acris	48	P
R. bulbosus	41	P
R. repens	17	P
Rumex acetosa	2	P
R. acetosella	2	P

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
Sagina maritima	4	P
Senecio jacobaea	41	P
S. vulgaris	5	P
Sonchus asper	5	P
Stellaria alsine	1	P
S. graminea	27	P
S. media	6	P
Succisa pratensis	2	P
Thalictrum minus	1	P
Trifolium pratense	53	P
T. repens	83	P +
Veronica serpyllifolia	3	P
Vicia cracca	25	P
Viola tricolor	5	P
Acroladium cuspidatum	34	P
Camptothecium lutescens	1	P
Hylocomium splendens	8	P
Hypnum cupressiforme	1	P
Mnium undulatum	1	P
Rhytidiadelphus squarrosus	63	P
Thuidium sp.	6	P
Caloplaca sp.	2	P

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
Peltigera rufescens	2	P
P. spuria	3	P
Nostoc sp.	1	P

UNIT F: DUNE SLACKS

11 Samples

Average no. of species: 15.6

Total number of species recorded: 41

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
Agrostis canina	91	P +
A. tenuis	45	P
Festuca rubra	55	4
Poa pratensis	73	4
P. trivialis	9	P
Carex arenaria	55	P
C. flacca	100	4
C. nigra	18	P
C. panicea	45	P
Luzula campestris	18	P
Orchis mascula	9	P
Anagallis minima	55	P
Bellis perennis	55	P +
Cardamine pratensis	36	P
Centaurium littorale	36	P
Euphrasia officinalis	45	P +
Galium aparine	9	P
G. verum	45	P
Geranium molle	18	P
Hydrocotyle vulgaris	73	P +
Lotus corniculatus	64	P
Myosotis arvensis	18	P
Plantago lanceolata	27	P

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
P. maritima	18	P
Polygonum persicaria	9	P
Potentilla anserina	64	4
Prunella vulgaris	55	P
Ranunculus acris	9	P
R. bulbosus	27	P
R. repens	36	P
Senecio jacobaea	9	P
Stellaria alsine	45	P
Trifolium repens	45	P
Vicia cracca	27	P
Viola tricolor	27	P
Acrocladium cuspidatum	45	P
Camptothecium lutescens	18	P
Hylocomium splendens	9	P
Mnium undulatum	9	P
Rhytidiadelphus squarrosus	64	P +
Peltigera spuria	9	P

UNIT G: SEA MACHAIR

9 Samples

Average no. of species: 4.9

Total number of species recorded: 8

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
Festuca rubra	100	7
Armeria maritima	100	5
Honkenya peploides	33	P
Plantago maritima	100	5
Salicornia sp.	33	P
Spergularia marina	33	P
S. media	56	4
Nostoc sp.	33	P

UNIT H: WET FRINGES

33 Samples

Average no. of species: 12.7

Total number of species recorded: 80

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
Equisetum arvense	3	P
E. palustre	42	P
Agrostis canina	6	P
A. tenuis	12	P
Cynosurus cristatus	3	P
Festuca rubra	27	P
Holcus lanatus	12	P
Nardus stricta	3	P
Phragmites communis	42	P
Poa pratensis	45	P
P. trivialis	9	P
Carex flacca	36	P
C. nigra	48	P +
C. panicea	33	P
C. rostrata	12	P
Dactylorchis purpurella	6	P
Eleocharis palustris	24	P
E. uniglumis	6	P
Eriophorum angustifolium	6	P
E. latifolium	3	P
Iris pseudacorus	27	P
Juncus articulatus	6	P
J. conglomeratus	3	P

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
J. effusus	3	P
Luzula pilosa	6	P
L. sylvatica	3	P
Orchis mascula	3	P
Bellis perennis	12	P
Calluna vulgaris	3	P
Caltha palustris	67	P +
Cardamine pratensis	27	P
Centaurium littorale	15	P
Euphrasia officinalis	9	P
Fumaria officinalis	6	P
Galium odoratum	9	P
G. palustre	9	P
Hieracium spp.	6	P
Hydrocotyle vulgaris	61	P
Leontodon spp.	6	P
Linum catharcticum	3	P
Lotus corniculatus	15	P
Lychnis flos-cuculi	9	P
Myosotis arvensis	3	P
Plantago lanceolata	9	P
Polygonum persicaria	27	P
Potentilla anserina	39	P

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
P. erecta	3	P
P. palustris	24	P
P. reptans	6	P
Primula veris	3	P
Prunella vulgaris	12	P
Ranunculus acris	24	P
R. aquatilis	3	P
R. bulbosus	24	P
R. ficaria	24	P
R. flammula	3	P
R. repens	15	P
Rumex acetosa	15	P
R. acetosella	12	P
R. crispus	9	P
R. longifolius	3	P
Sagina maritima	15	P
Senecio jacobaea	3	P
S. aquaticus	3	P
S. vulgaris	3	P
Spergularia marina	9	P
Stellaria alsine	42	P
S. graminea	9	P
Succisa pratensis	6	P

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
Trifolium pratense	12	P
T. repens	33	P
Vicia cracca	18	P
Viola tricolor	6	P
Acrocladium cuspidatum	36	P
Bryum sp.	3	P
Hylocomium splendens	55	P
Mnium undulatum	9	P
Physcomitrium pyriforme	3	P
Rhytidiadelphus squarrosus	30	P
Unvegetated ground	18	P

UNIT J: NON-MACHAIR AREAS

12 Samples

Average no. of species: 13.1

Total number of species recorded: 56

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
Agrostis canina	25	P
A. tenuis	17	P
Festuca ovina	8	P
F. rubra	83	5
Holcus lanatus	17	P
Lolium perenne	17	P
Phragmites communis	17	P
Poa pratensis	92	5
Carex arenaria	8	P
C. flacca	50	P
C. nigra	25	P
C. panicea	25	P
Iris pseudacorus	8	P
Juncus effusus	8	P
Luzula compestris	25	P
Orchis mascula	8	P
Triglochin maritima	8	P
Achillea millefolium	25	P
Anagallis minima	17	P
Armeria maritima	33	P
Bellis perennis	67	P
Calluna vulgaris	8	P

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
Caltha palustris	8	P
Centaurium littorale	33	P
Crepis capillaris	17	P
Daucus carota	17	P
Erodium cicutarium	8	P
Euphrasia officinalis	25	P
Galium verum	17	P
Hieracium spp.	25	P
Hypochaeris radicata	8	P
Leontodon spp.	33	P
Lotus corniculatus	42	P
Plantago lanceolata	67	4
P. maritima	17	P
Potentilla anserina	25	P
Prunella vulgaris	17	P
Ranunculus acris	67	P
R. bulbosus	25	P
R. repens	17	P
Rumex acetosa	17	P
R. acetosella	8	P
R. crispus	8	P
Senecio jacobaea	8	P
Stellaria graminea	8	P

SPECIES	FREQUENCY (PER CENT)	COMPUTED DOMIN AVERAGE
S. media	8	P
Succisa pratensis	8	P
Trifolium pratense	17	P
T. repens	58	P
Vicia cracca	25	P
Hylocomium splendens	8	P
Rhytidiadelphus squarrosus	50	P
R. triquetrus	8	P
Thuidium sp.	8	P
Peltigera rufescens	8	P
P. spuria	8	P
Unvegetated ground	8	P

Appendix 5

A selection of photographs of machair vegetation and other important machair landscape features.

The following plates accompany the text, and full descriptions and commentaries are contained in Chapters 6 and 7.

General

Plate 1. General view of machair landscape. Machair plain in centre, sand hills to the right, in the distance and foreground, and moribund dunes to the left in the distance are the main components visible. (Howbeg, South Uist)

Plate 2. Black land. Croft house located on better drained site. Note the scattered boulders and rock outcrops, evidence of poor drainage to the right middle distance, and the lazy beds below the croft house. (Carinish, North Uist)

Plate 3. Looking westwards out to sea from the edge of the black land over the machair (in the distance). Note how underlying geology produces a gently swelling ridge overlain by sand and extending out to sea. (Machair Robach, North Uist)

Plate 4. Vegetation in a natural state. A dense tangle of scrubby Betula, Salix and other shrubs on an island, untouched by man or domestic animals. Without the anthropogenic factor much of the Uists inland of the machair might resemble this. (Loch Druidibeg, South Uist)

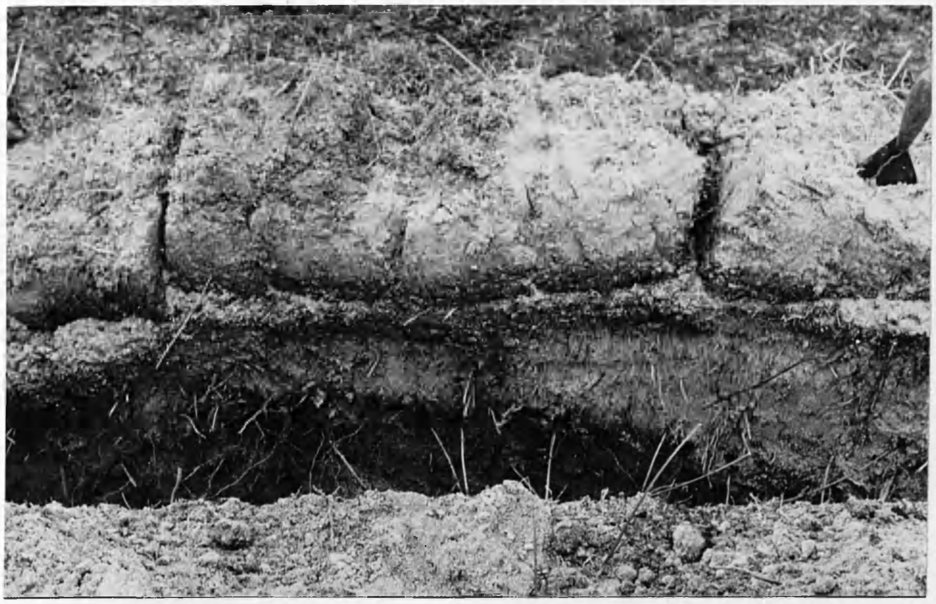


Plate 5. Machair soil section on sand hill vegetation (unit D). Note thinness of top organically enriched horizon and buried profile beneath. (Grogarry, South Uist)

Dune fronts (units A and B)

Plate 6. Dune front vegetation of unit A type. Dune building processes extend over approximately 20 m above high water mark, but embryo dunes are tiny. Note the line of low, formed dunes behind this zone. To the right a tombola connects Orosay Island to the mainland of South Uist and provides sheltered conditions which promote dune building. The structures in the distance are a seaweed processing works. (Boisdale, South Uist).

Plate 7. Foreshore immediately in front of active dune front (unit A). Note hummocks forming around seaweed. In this area colonisation is by Honkenya peploides. (West Geirinish, South Uist)

Plate 8. Main area of dune building in area immediately above that shown in Plate 7. Though foredunes are colonised by Ammophila arenaria, behind this is an older dune structure with eroded crest. (West Geirinish, South Uist)

Plate 9. Detail of active building zone at crest of new dunes (unit A) below older eroded machair surface. (West Geirinish, South Uist)

Plate 10. View of high, broken, eroded dunes (unit B), taken from foreshore of similar dune front at Ballivanish, Benbecula. (Beul an Toim, between Baleshore Island, North Uist and Ballivanish, Benbecula)

Plate 11. Heavily wave eroded dune front (unit B). Note foreshore with partly sand-covered seaweed but virtually no vegetation. (Ballivanish, Benbecula)

Plate 12. Closer view of dune front in Plate 11. Note eroded face with indurated layers, probably due to earlier building phases. Undercut Ammophila covered clods lie slumped at the bottom of the near vertical face, and at the interface between dune front and foreshore, fresh relocated beach sand has collected. (Ballivanish, Benbecula)

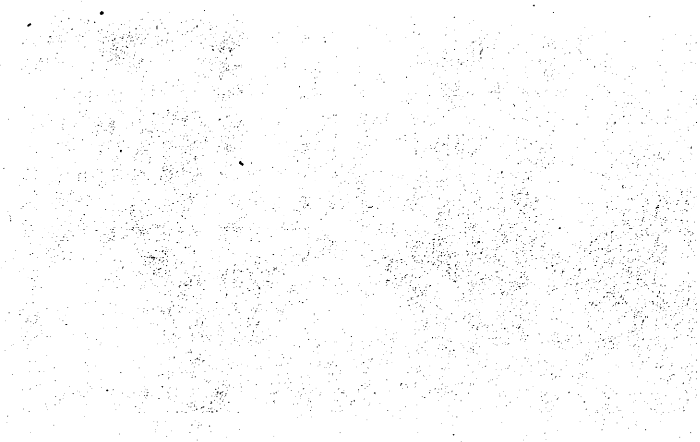
Plate 13. Vestigial dune front (unit B), with gently shelving beach affording little portection from winter storms. Note foreshore above high water with mixture of seaweed, stones and jetsam, and colonisation (temporary) of highest areas by Honkenya peploides. Dunes are backed by a line of sand hills (unit D). (Stilligarry, South Uist)

Plate 14. Dune front (unit B) with vigorous stands of Ammophila arenaria encroached upon by a cobble and shingle bank which is well sorted, and extends several metres into the dunes. (Baleshare Island, North Uist)

Dune back-slope (unit C)

Plate 15. General view of extensive dune back slope with tussocky vegetation (unit C) in right middle distance; on left in contrast is a line of high sand hills (unit D). (Balranald, North Uist)

Plate 16. Detail of hummocky, tussocked dune back slope (unit C) with Ammophila arenaria on mounds but not in hollows. Note flooded dune slack or winter loch on extreme left. (Drimore, South Uist)



Sand hills (unit D)

Plate 17. Breached and eroded sand hills (unit D) beyond fairly recently cultivated machair plain in foreground. (Askernish, South Uist)

Plate 18. Detail of steep, high sand hill vegetation (unit D) with evident soil creep and patches of erosion in foreground, right centre. Note scar caused by tractor in centre middle distance, and sheep grazing slopes, the probable cause of the erosion mentioned above. (Machair Robach, North Uist)

Plate 19. Sand cuesta (sub-unit D_3) rising above machair plain (unit E) to left. The steep, seawards facing slope can be seen extending northwards in the centre of the plate and in the right middle distance an erosion breach can be seen. The open, closely cropped Ammophila arenaria over a herbaceous Festuca rubra sward can be seen in the foreground. (Grogarry, South Uist)

Plate 20. 'Pimple dunes' (sub-unit D_2) showing a rapidly alternating vegetation pattern at a point 1 km from the shore. Note the strong apparent correlation between physiographic and vegetation patterns. (Drimore, South Uist)

Machair plain (unit E)

Plate 21. General view of the machair plain (unit E) from the seaward side. Note absence of relief and evidence of former cultivation on right. The machair plain ends in the fringe zone (unit H) at the first line of water in the centre distance. The croft houses are on black land. (Ormaclett, South Uist)

Plate 22. Narrow area of machair plain (unit E) almost free of Ammophila arenaria and dominated by cropped Festuca rubra. In this area where the underlying peneplained gneiss rises above sea level at the shore, there are no dunes. (Stoneybridge, South Uist)

Plate 23. Grazed (to left) and ungrazed machair plains (both unit E). The absence of grazing is due to the fenced enclosure of a small graveyard. Such ungrazed areas are most uncommon. (Ardivachar, South Uist)

Plate 24. Very extensive machair plain (unit E) extending almost to the buildings on the horizon. In the middle distance flooding picks out 'run-rig' plots associated with the ancient form of land division still practised in some places in the Uists, thought this tract had not been cultivated for few years past. In the fore-ground the intensively grazed machair plain has a certain amount of bare sand at the surface, but little Ammophila arenaria. (Iochdar, South Uist)

Plate 25. Uncultivated machair plain (unit E) in foreground, and beyond enclosed ploughed field with machair plain under present cultivation, with stubble of oat crop. In the former there is a thick sward of Festuca rubra and Poa pratensis with a few stems of Ammophila arenaria in the right foreground. (Baleshare Island, North Uist)

Plate 26. Machair plain with area cultivated in previous year in foreground (sub-units E_2 and E_1). Post in the foreground is about 50 cm high. Species details are in Chapter 6. (Grogarry, South Uist)

Plate 27. Intensively used machair plain (unit E) divided into fenced blocks by apportionment of formerly commonly held land. Several different stages of cultivation reflecting land use patterns and practices can be seen. (Garrynamonie, South Uist)

Plate 28. High machair plain (unit E) over 20 m above sea level merging imperceptibly into sand hills (unit D). Delimitation cannot be precise enough to allow mapping as discrete spatial components. (Balranald, North Uist)

Plate 29. Composite machair plain (unit E) and sand hill (unit D) areas. The rabbit burrows with associated bare sand patches pick out the sand hill vegetation, whilst the larger flat machair plain area in the middle distance is used as a football pitch and for grazing. (Tigharry, North Uist)

Dune slacks (unit F)

Plate 30. Large dune slack in summer. The dune shade vegetation (unit F) is clearly demarcated from the sand hills (unit D) to the right. There is no ecotone and the transition occurs at the level of maximum winter flooding. (Drimore, South Uist)

Plate 31. Extensive slack area in spring. In the foreground can be seen the matted vegetation (unit F) with Potentilla anserina and Poa pratensis being the most important species. In the distance can be seen the dwindling remnant of the winter loch. (Grogarry, South Uist)

Plate 32. Dune slack vegetation (sub-unit F_1) in high summer. The darker area in the middle distance, corresponds to the peripheral part of the slack and is a lush sward dominated by Poa pratensis and Cyperaceae. The lighter area in the distance is the centre of the slack with vegetation dominated by Potentilla anserina. In the foreground is the boundary of the unit, and the sand hills (unit D) which surround the slack. (Grogarry, South Uist)

Sea machair (unit G)

Plate 33. General view of sea machair vegetation (unit G). In the foreground is black land with remnants of cultivation rigs, the sea machair is in the middle distance and extending to the loch on the right, with high dunes in the distance. (Loch Paible, North Uist)

Plate 34. Sea machair (unit G) in detail. The mounds are tussocks formed around Armeria maritima plants. This area lies inland of a line of dunes just beyond the right side of the plate. (Gualann Strand, South Uist)

Fringe areas (unit H)

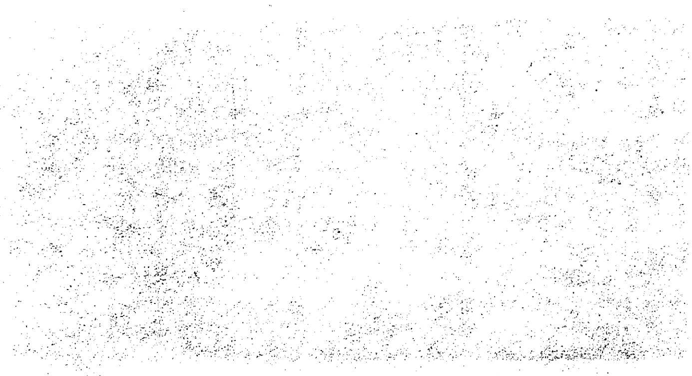


Plate 35. Extensive fringe area (unit H) around Loch Bee, South Uist, beyond sand hills (unit D) with rabbit warren in the foreground. By the lochside are piles of drying peats for fuel indicating the nature of the unit's substrate. (West Geirinish, South Uist)

Plate 36. A dense stand of Iris pseudacorus beside Loch a Mhachair at the eastern edge of Grogarry Machair (unit H). Other typical wet fringe vegetation facets are shown in the foreground. (Grogarry, South Uist)

Other features

Plate 37. Typical blow-out in sand hills (unit D). Note slumped clods undercut on left side. Active erosion is the dominant process in this example. (Grogarry, South Uist)

Plate 38. Close up of right section of Plate 37. Note recolonisation by Ammophila arenaria in very early stages on left side, with indurated sand beneath. Patches of damp sand visible indicate the relatively stable surface below the eroded crest of the right of the blow-out. (Grogarry, South Uist)

Plate 39. Corridor blow-out running at right angles to the shore through the line of dunes, undercutting a recently built concrete building. Disturbance associated with laying a telephone cable (seen running through the blow-out) may have been the initiating agency. (West Geirinish, South Uist)

Plate 40. Part of a giant blow-out, the largest in the Uists. The sand cliff on the left is about 3 m high and the whole feature is more than 12 m deep. Erosion is currently vigorous and can be seen exposing hard, indurated layers in the cliffs, below which the wind-rippled freshly moved sand can be seen, with recently undercut clods resting on this new surface. (Hougarry, North Uist)

Plate 41. Growing bulbs on machair - machair plain type (unit E) in uncultivated state. High hopes were held at one time for extensive development of this land in North Uist, involving reclamation of hundreds of hectares of land at Vallay Strand (see Plate 42). Recent evaluations are not encouraging and proposed schemes have been shelved. (Knockintorran, Bay Head, North Uist)

Plate 42. See over

Plate 42. Panorama across Vallay Strand. This enormous area of machair sand nearly 3 sq km in total extent, is almost enclosed by Vallay Island itself almost exclusively machair. Breaches open to the sea at each end of the island allow the strand to be covered to a depth of a few metres at each high tide, but exposed at the ebb. Reclamation of this area, proposed at one time, could be carried out by sealing these breaches. (Sollas, North Uist)

Table 1 — 7

Tables 1 - 9

Table 1

<u>Winds at Ballivanich, Benbecula</u>

Vector distribution, by strength group in total hours and frequency

Direction	350° 010°	020° 040°	050° 070°	080° 100°	110° 130°	140° 160°	170° 190°	200° 220°	230° 250°	260° 280°	290° 310°	320° 340°
Light (0-21 knots)	530	425	482	390	450	749	844	796	670	502	376	413
Frequency (%)	8.0	6.4	7.3	5.9	6.8	11.3	12.8	12.0	10.1	7.6	5.6	6.2
Moderate (22-33 knots)	83	24	56	21	72	261	328	266	183	177	126	105
Frequency (%)	4.9	1.4	3.3	1.2	4.2	15.4	19.3	15.5	10.8	10.4	7.4	6.2
Strong (> 33 knots)	4	0	4	1	7	32	41	27	13	27	19	12
Frequency (%)	2.1	0	2.1	0.5	3.7	17.1	22.0	14.4	6.9	14.4	10.0	6.8
Total Frequency (%) (All winds)	7.3	5.3	6.4	4.8	5.3	12.4	14.6	13.0	10.3	8.4	6.1	6.1

Bearing of resultant wind directions: light 78°; moderate 60°; strong 58°

Data from observations at Ballivanich Airport, Benbecula
1957, 59, 61, 63.

After Ritchie 1966, figure 24.

Table 2

Analyses of Calcium Carbonate in Machair Sand

Township	Percentage $CaCO_3$
South Uist	
Smerclett	60
Garrynamonie	62
North Boisdale	49
Daliburgh	30
Askernish	43
Bornish	52
Ormaclett	39
Howmore	55
Dremisdale	55
West Geirnish	62
Eochar	53
Benbecula	
Ballavanich	30
North Uist	
Baleshare	34
Paiblesgarry	38
Hosta	80
Baleloch	62
Balmartin	35
Sollas	74
Oronsay	52
Vallaquie	44

Data from North of Scotland College of Agriculture, Ballavanich

After Ritchie 1966, 1970.

Table 3

Stratigraphic Sequence at Northton, Harris

Site located at grid reference NF 982912 in extreme south-western Harris.

Archaeological period	Machair formation	Environmental conditions
Iron Age B	Stability	Open country
	Rapid deposition	Open country
	Slow deposition	Open country
Iron Age A	Stability	Shading
	Slow deposition	Open country
		Clearance
Beaker II	Stability	Woodland regeneration
Beaker I (1)	Rapid deposition	Open country
Neolithic II (2)	Stability	Woodland clearance
	Rapid deposition	Woodland
Neolithic I		

1 - 3080 $\pm$ B.C.

2 - 4100 $\pm$ 140 B.C.

See Simpson (1966)

After Evans (1971)

Table 4

Analyses of Machair Soils, Dremisdale, South Uist

Pit No.	Sample No.	Vegetation Unit	Depth (cm)	Moisture Content (%)	$CaCO_3$ (%)	Organic Matter (%)	pH	Munsell Soil Colour	Median Diameter of sand (mm)	Sample Altitude (m)	Mottling (cm)	Depth of Water-Table (in)
1	Standard	B (Moribund Dune Front)	0-15	19	59.7	5.6	-	10 yr 6/1	-	6.25	-	1.90
	a	"	3-5	3.8	57.4	1.4	8.5	-	0.26			
	b	"	5-8	25.8	48.6	11.7	7.7	-	0.30			
	c	"	33	-	56.2	0.7	8.9	-	0.22			
	d	"	76	5.8	52.7	0.4	8.5	-	0.67			
2	Standard	D	0-15	21	65.0	4.9	-	10 yr 5/2	-	5.5	Bluish bandings 56-127	1.37
	a	(Sand Hill)	38	7.3	52.7	0.4	9.6	-	0.35			
	b	"	128	22.6	55.8	0.5	8.9	-	0.35			
3	Standard	E	0-15	13	55.3	3.5	-	10 yr 6/2	-	12.5	-	-
	a	(Machair Plain)	5-13	10.4	48.1	3.8	8.0	-	0.29			
	b	"	23	18	44.6	8.4	8.0	-	0.29			
	c	"	51	7	51.9	0.4	9.0	-	0.31			
4	Standard	E	0.15	18	54.3	5.5	-	10 yr 5/1	-	7.0	Bluish bandings 33-153	1.67
	a	(Machair Plain)	15	-	46.6	8.6	7.9	-	0.31			
	b	"	30-48	8	49.7	0.7	8.8	-	0.31			
5	Standard	E	0-15	25	53.4	8.8	-	10 yr 4/1	-	6.0	Bluish bandings 25-102 in finer sand	1.00
	a	(Machair Plain)	5-10	28	45.8	12.4	7.4	-	0.31			
	b	"	46	6.8	48.8	0.3	9.1	-	0.27			
6	Standard	H	0-15	39	49.0	11.6	-	10 yr 6/22	-	5.0	In b sand distinctly blue	0.57
	a	(Machair Fringe)	58-69	76.4	41.1	11.1	7.8	-	0.34			
	b	"	71-81	31.8	39.2	1.4	8.3	-	0.28			
	c	"	81-102	48.8	19.6	7.3	7.6	-	-			

After Ritchie (1966) Figure 15

Table 5

Modified Domin Scale Used in Uists Survey

10:-	Cover	91% - 100%	($^9/_{10}$ - complete) of total area
9:-	Cover	76% - 90%	($^3/_4$ - $^9/_{10}$) of total area
8:-	Cover	51% - 75%	($^1/_2$ - $^3/_4$) of total area
7:-	Cover	34% - 50%	($^1/_3$ - $^1/_2$) of total area
6:-	Cover	26% - 33%	($^1/_4$ - $^1/_3$) of total area
5:-	Cover	11% - 25%	($^1/_{10}$ - $^1/_4$) of total area
4:-	Cover	4% - 10%	of total area
P:-	Less than 4% total cover (includes classes 1 - 3 of conventional scale)		

Table 6

Values Used in Transforming Domin Scale

Domin Number	Transformation Number
10	194
9	165
8	139
7	114
6	92
5	73
4	55
P	28

Derived from the relationship

$$\text{Transformed value} = (3.117 + 1.082 \times \text{Domin number})^2$$

Sources: Bannister (1966) and personal communications, 1970.

Table 7

Effects of Grazing on _Agrostis tenuis_ and _Carex flacca_ in Machair Plain Vegetation (Unit E Vegetation)

Two townships with different grazing pressures were examined. In South Uist 4 samples were taken on the machair plain at Dremisdale where this land was grazed at more than two times the stocking density per unit area, when compared with the generally similar machair plain at Baleshore Island, North Uist, where a like number of samples were taken. The contingency table below gives the computed cover average (C.C.A.), the method of calculation of which is described in Chapter 5, and in parentheses the number of samples in which the species was recorded in each area. Due to the smallness of the sample statistical evaluation by Chi-square or similar test is not possible.

	Agrostis tenuis	_Carex flacca_
Dremisdale	4 - (4)	- (0)
Baleshore	P (2)	6 (4)

Table 8

Machair Vegetation in Tiree

Principal components of derived units (includes only species with cover greater than 4%)

Species[1]	Mobile Dune		Stable Dune		Fixed Dune		Young machair		Mature machair		Older machair	
	Frequency[2]	Cover%[2]	Frequency	Cover%	Frequency	Cover%	Frequency	Cover%	Frequency	Cover%	Frequency	Cover
Bare ground	100	75	98	27.2	88	21.6						
Agropyron junceiforma	88	12	40	4								
Ranunculus spp.			48	4.6			64	4.9	88	5.7		
Galium verum			41	16.7	96	10.5	82	5.5	82	5.3		
Festuca rubra					98	19.6	100	27.8	98	20	100	16.8
Trifolium repens					90	8.5	98	13.7	96	12	96	8.6
Taraxacum laevigatum	8	5									26	4.1
Plantago lanceolata			44	9.5	78	7.7	92	11.3	90	13.1		
Lotus corniculatus					94	14.3	82	10.6	68	6.1	80	54.4
Senecio jacobaea							56	12.3				
Bellis perennis									78	7		
Rhytidiadelphus squarrosus									72	5.5		
Carex flacca											78	6.4
Holcus lanatus											48	7.2
Cynosurus cristatus											72	6

1. Order as in reference
2. Method of computation not specified

Based on Vose, Powell and Spence (1955) pp. 94–95

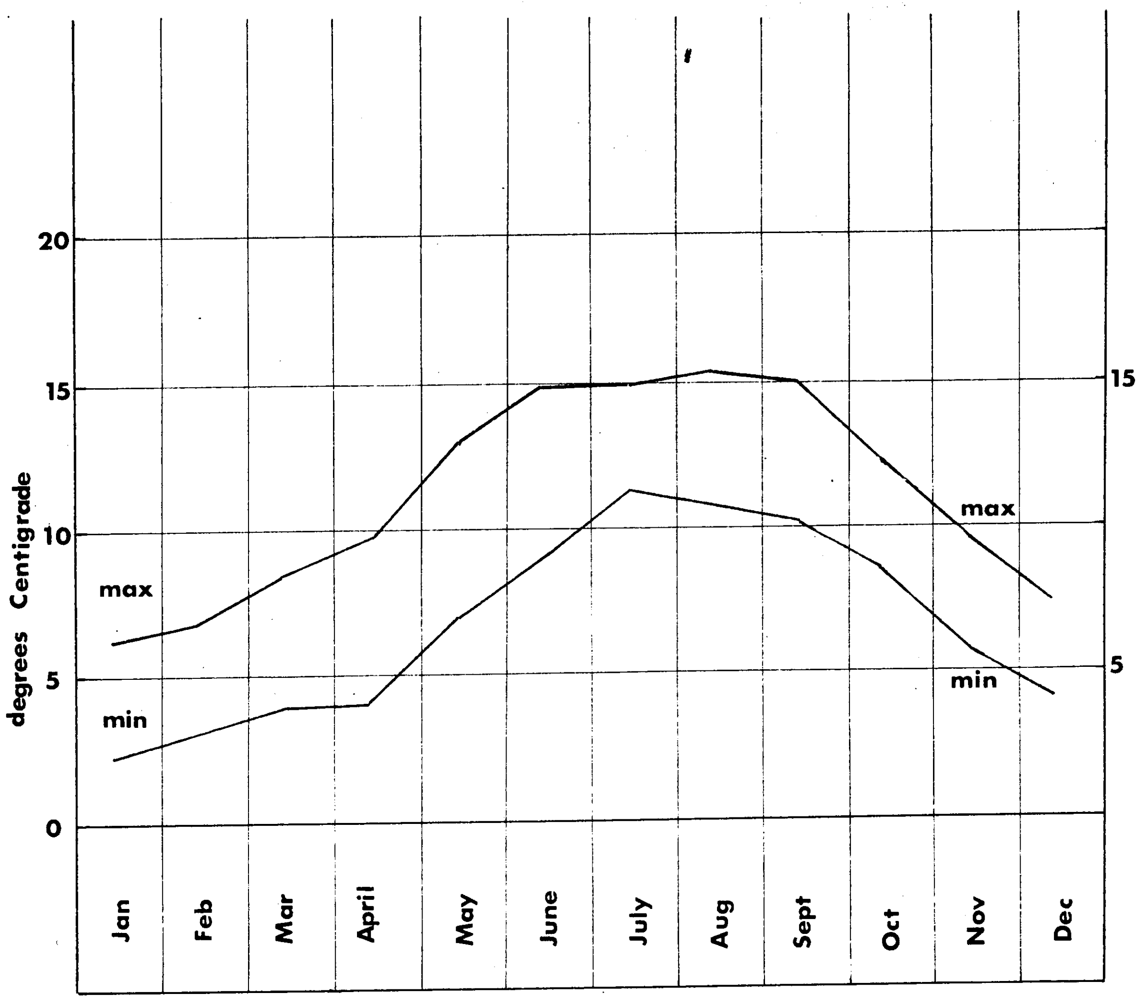
Table 9

The Hult-Senander Scale of Cover

Cover class (Degree of cover)	Cover range	Percentage cover range	Midpoint of range
1	up to $^{1}/_{16}$	up to 6.25%	$^{1}/_{32}$
2	$^{1}/_{16}$ - $^{1}/_{8}$	6.25 - 12.5%	$^{3}/_{32}$
3	$^{1}/_{8}$ - $^{1}/_{4}$	12.5 - 25%	$^{6}/_{32}$
4	$^{1}/_{4}$ - $^{1}/_{2}$	25 - 50%	$^{12}/_{32}$
5	more than $^{1}/_{2}$	more than 50%	$^{24}/_{32}$

Figures 1 - 18

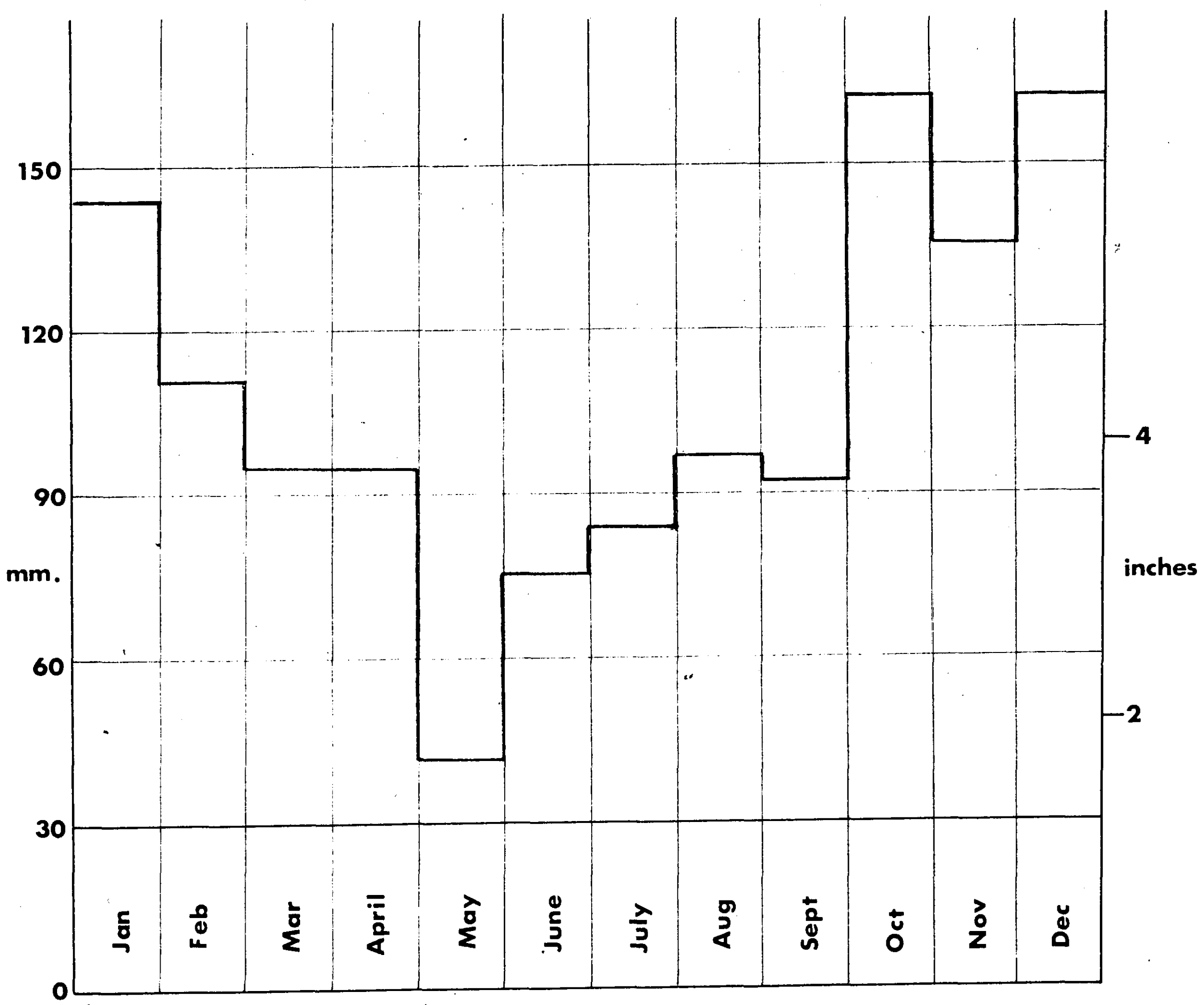
Fig I



Mean maximum and minimum temperatures 1949 - 1961

After Ritchie 1966a

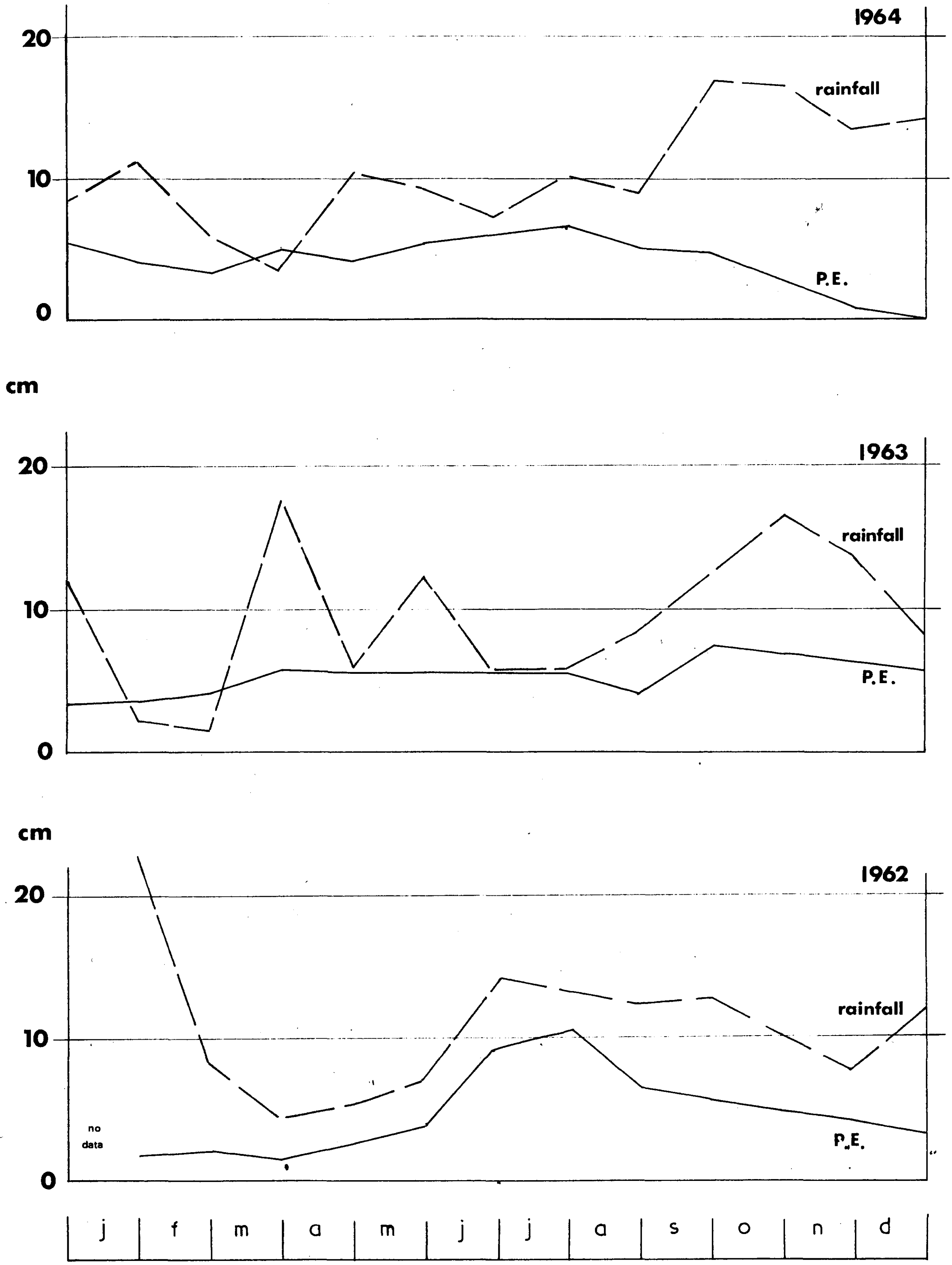
Fig 2



Average rainfall 1949-61

After Ritchie 1966a

Fig 3



Monthly rainfall and potential evapo-transpiration at Stilligarry, South Uist

After Ritchie 1966a

Fig 4

Soil analyses at Grogarry, South Uist

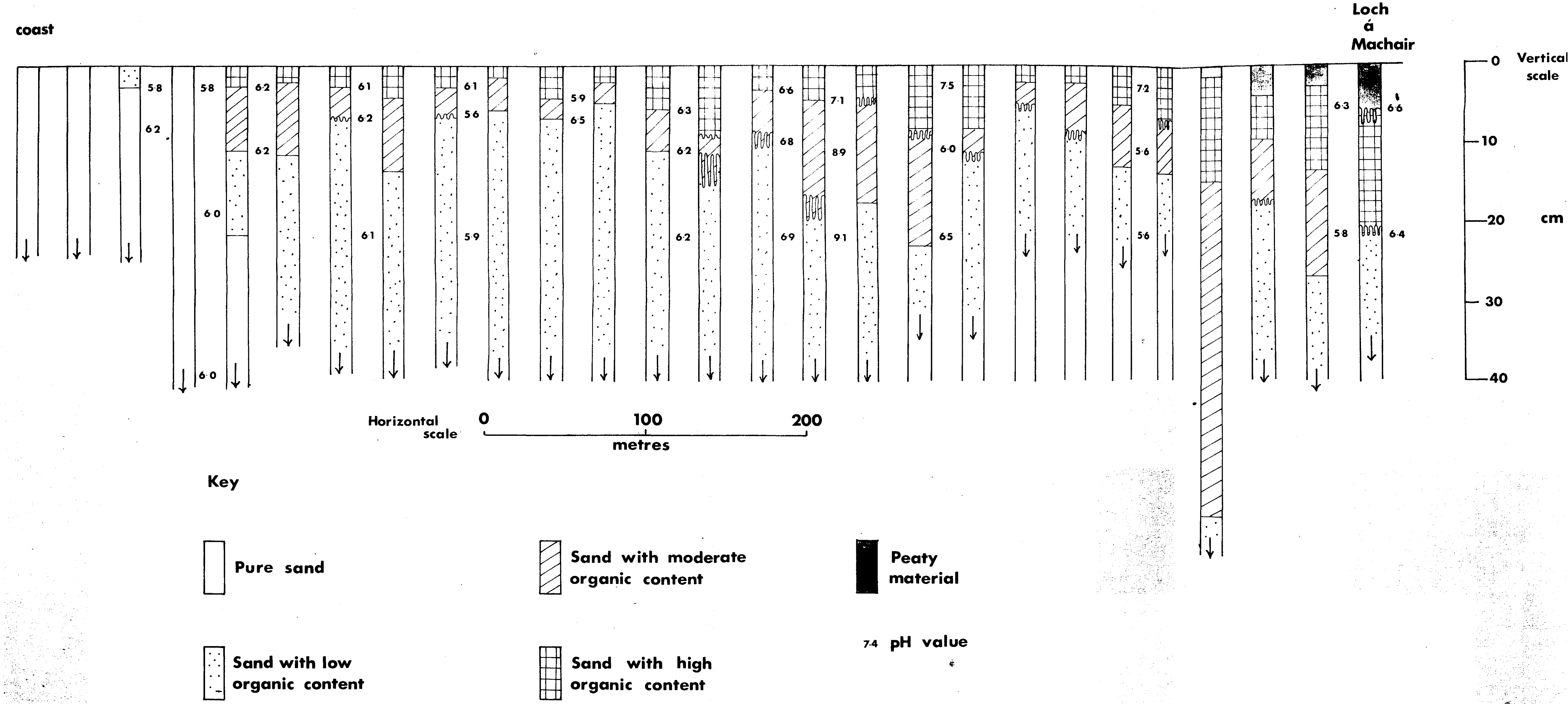


Figure 5

Biogeographical and Ecological Approaches to Vegetation

Organism and Environment	Scale	Main Direction of Approach
Individual plant and microhabitat	less than one square metre ↑	ecological
Population and ecological niche		
Community and habitat including man		biogeographical
Ecosystem	↓ more than one hectare	

Figure 6

Species list used in field work

for Uists Survey

DATE	LOCATION		ZONE
1. Unveg. Gr.	73 Epilo mon	145 Orchi pur	217 Trig pal
2. Achil mil	74 obs	146 str	218 Urtic dio
3. Agrop jun	75 pal	147 masc	219 Veron ana
4. rep	76 par	148 Osum reg	220 arv
5. Agros can	77 Equis arv	149 Papav dub	221 serpy.
6. sto	78 flu	150 Pedic pal	222 Vicia cra
7. ten	79 Eriop ang	151 Phrag com	223 Viola cur
8. Aira pra	80 Erodi cic	152 Plant cor	224 pal
9. Alopc gen	81 Eroph ver	153 lan	225 tri
10. pra	82 Eupho hel	154 maj	226 Zanni pal
11.Ammop are	83 Euphr mic	155 mar	227
12.Anaga ten	84 nem	156 Poa ann	228
13.Anthe cot	85 Festu ovi	157 pra	229
14.Antho odo	86 rub	158 tri	230
15.Anthy vul	87 Fumar bas	159 Polyc tet	231
16.Apium ini	88 Galiu apa	160 Polyg aeq	232
17. nod	89 her	161 avi	233
18.Arcti sul	90 pal	162 per	234
19.Armer mar	91 ver	163 Potam ber	235
20 Arrhe ela	92 Genti cam	164 col	236
21 Asple adi	93 Geran mol	165 nat	237
22 tri	94 Glaux mar	166 pec	238
23 Atrip has	95 Glyce flu	167 pol	239
24 lat	96 Helic pub	168 Poten ans	240
25 Avena str	97 pra	169 pal	241
26 Balde ran	98 Herac sph	170 Primu vul	242
27 Belli per	99 Hiera sp.	171 Prune vul	243
28 Bromu tho	100 Hippu vul	172 Pucci mar	244
29 Cakil mar	101 Holcu lan	173 Ranun acr	245
30 Calli int	102 Honke pep	174 aqu	246
31 sta	103 Hydro vul	175 bul	247 Acro cusp
32 Callu vul	104 Hypoc rad	176 fic	248 Barb fallax
33 Calth pal	105 glab	177 flammula	249 Hyloc splen
34 Capse bur	106 Iris pse	178 repens	250 Hypnum sp.
35 Carde fle	107 Junca art	179 tri	251 Mnium und
36 hir	108 buf	180 Rapha rap	252 Nostoc sp.
37 pra	109 bul	181 Rhina mon	253 Pelt ruf
38 Carex are	110 eff	182 ste	254 Pelt spur
39 dia	111 ger	183 Rumex ace	255 Plagio undul
40 distans	112 squ	184 acetosa	256 Polytri sp.
41 ech	113 Koele gra	185 crispus	257 Pseudo pur
42 flacca	114 Lamiu pur	186 obt	258 Rhyti squar
43 hos	115 Lemna min	187 Sagin mar	259 triqu
44 lep	116 Leont aut	188 nod	260 Thiud deli
45 nig	117 tarax	189 pro	261 Tort rur
46 ova	118 Ligus sco	190 sub	262
47 pul	119 Linum cat	191 Salix aur	263
48 ros	120 Loliu per	192 rep	264
49 Catab aqu	121 Lonic per	193 Samol val	265
50 Centa lit	122 Lotus cor	194 Schoe nig	266
51 nig	123 Luzul cam	195 Sedum acr	267
52 min	124 mul	196 ang	268
53 Ceras glo	125 syl	197 Senec jac	269
54 vul	126 Lychn flo	198 vul	270
55 Chrys seg	127 Lycop arv	199 Siegl dec	271
56 leuc	128 Matri mar	200 Silen mar	
57 Cirsi arv	129 mat	201 Sinap arv	
58 vul	130 Menth aqu	202 Sisym off	
59 Cochl dan	131 Menya tri	203 Sonch asp	
60 off	132 Monti fon	204 Sperg arv	
61 vir	133 lam	205 sal	
62 Crep bien	134 Myoso arv	206 Stell als	
63 Cynos cri	135 cae	207 med	
64 Daucu car	136 dis	208 gram	
65 Desch fle	137 sec	209 Tarax lae	
66 Drose rot	138 Myrio alt	210 off	
67 Dryop fil	139 Nastu off	211 Thali min	
68 spi	140 Nastu off	212 Thymu dru	
69 Eleoc mul	141 Odont ver	213 Trich cae	
70 pal	142 Oenan lac	214 Trifo pra	
71 pau	143 Ophio vul	215 rep	
72 Eleog flu	144 [illegible]	216 Trigl mar	

Fig 7

Species-area curves and analyses

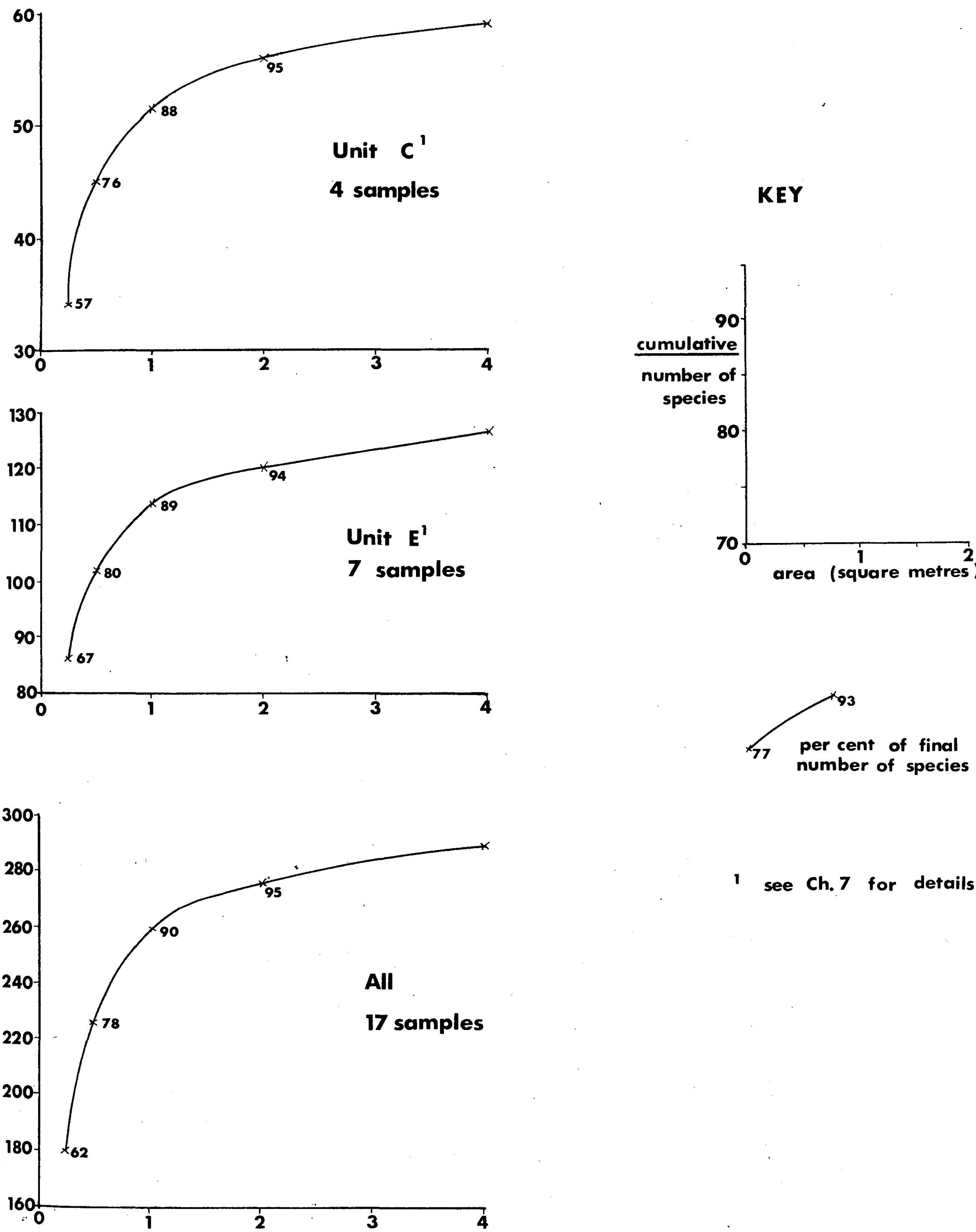


Fig 8 Blow-out at Grogarry

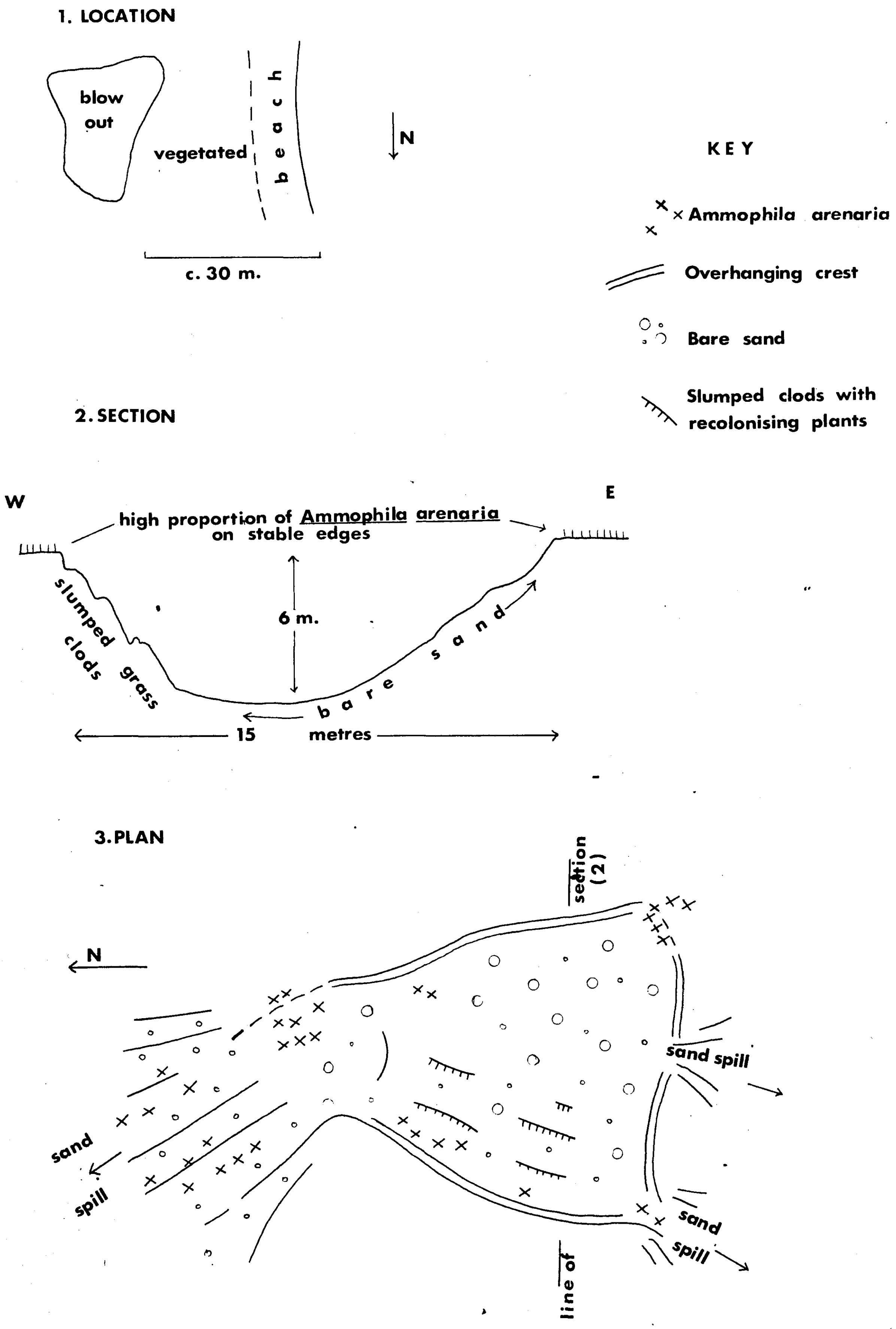
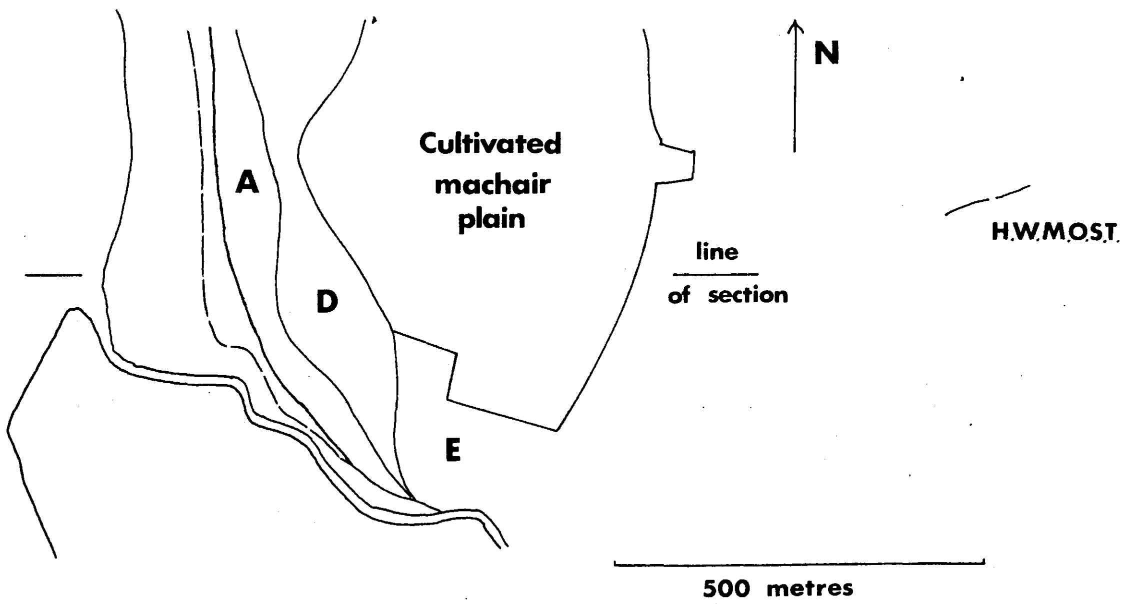


Fig 9 Dunes at Howmore

1. PLAN



2. SECTION

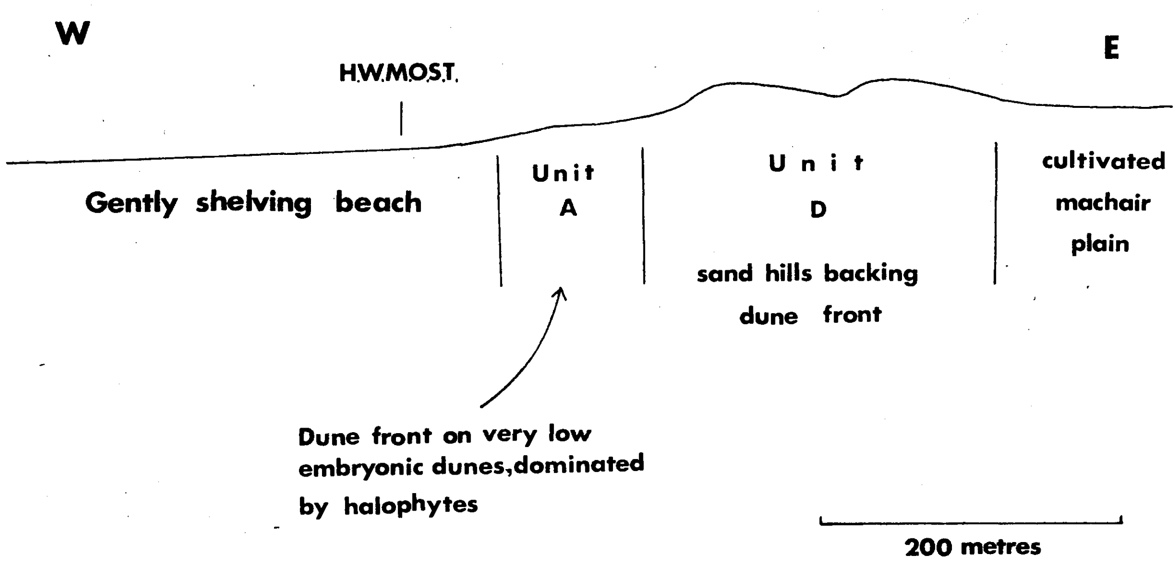
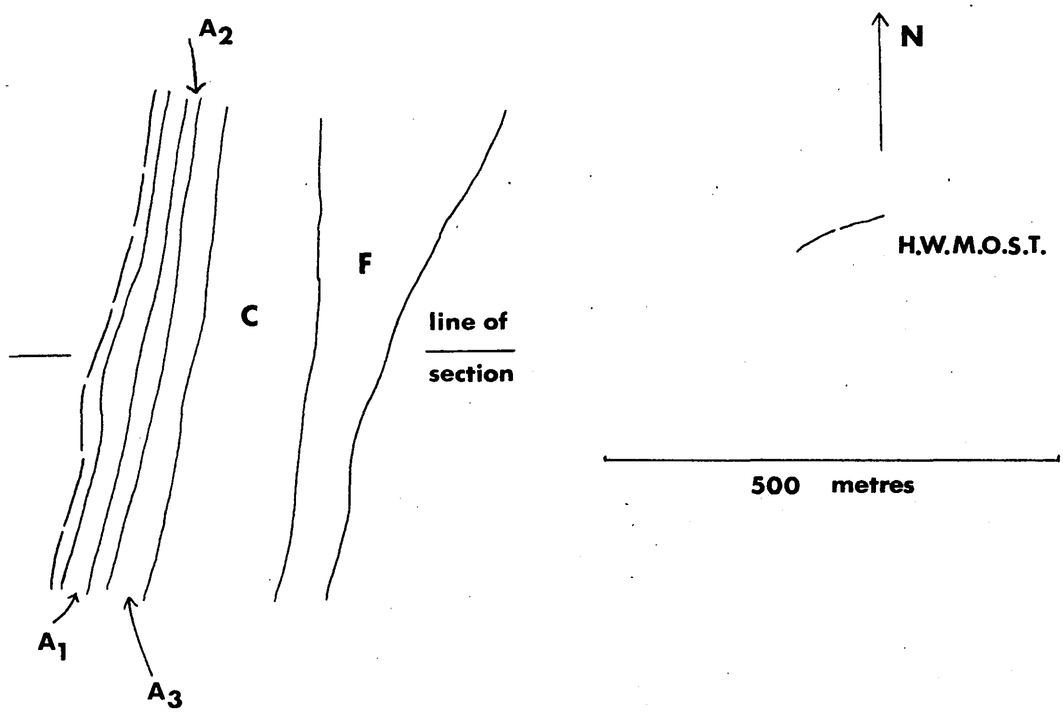
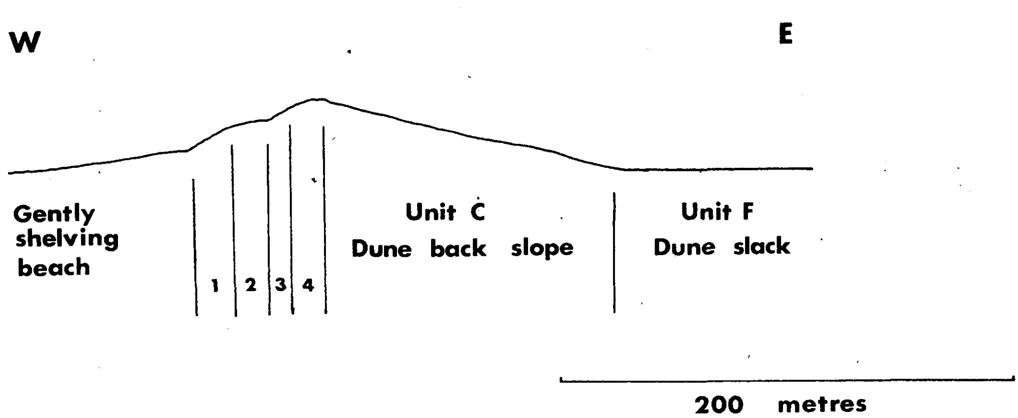


Fig 10 Dunes at Grogarry

1. PLAN



2. SECTION



Key

1 Cobble and shingle bank

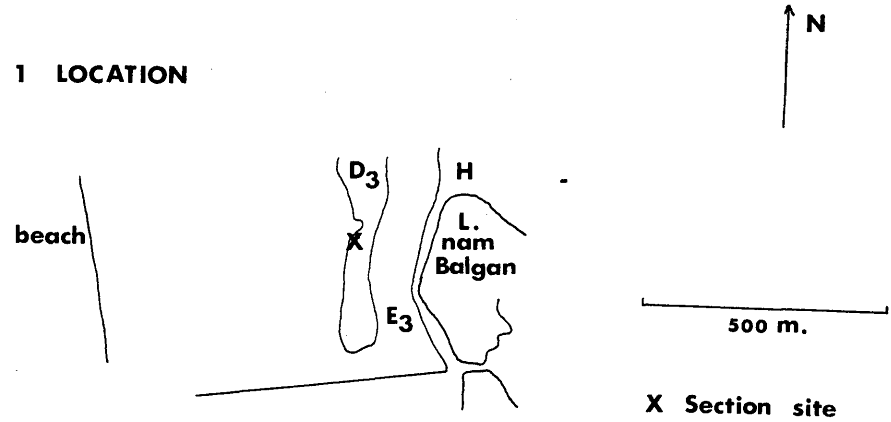
2 Sub-unit A_1 with sporadic cover of halophytes

3 Sub-unit A_2 with dense cover of A. arenaria on steep face

4 Sub-unit A_3 with near 100% cover

Fig 11 Blow-out section at Grogarry

1 LOCATION



2 SECTION

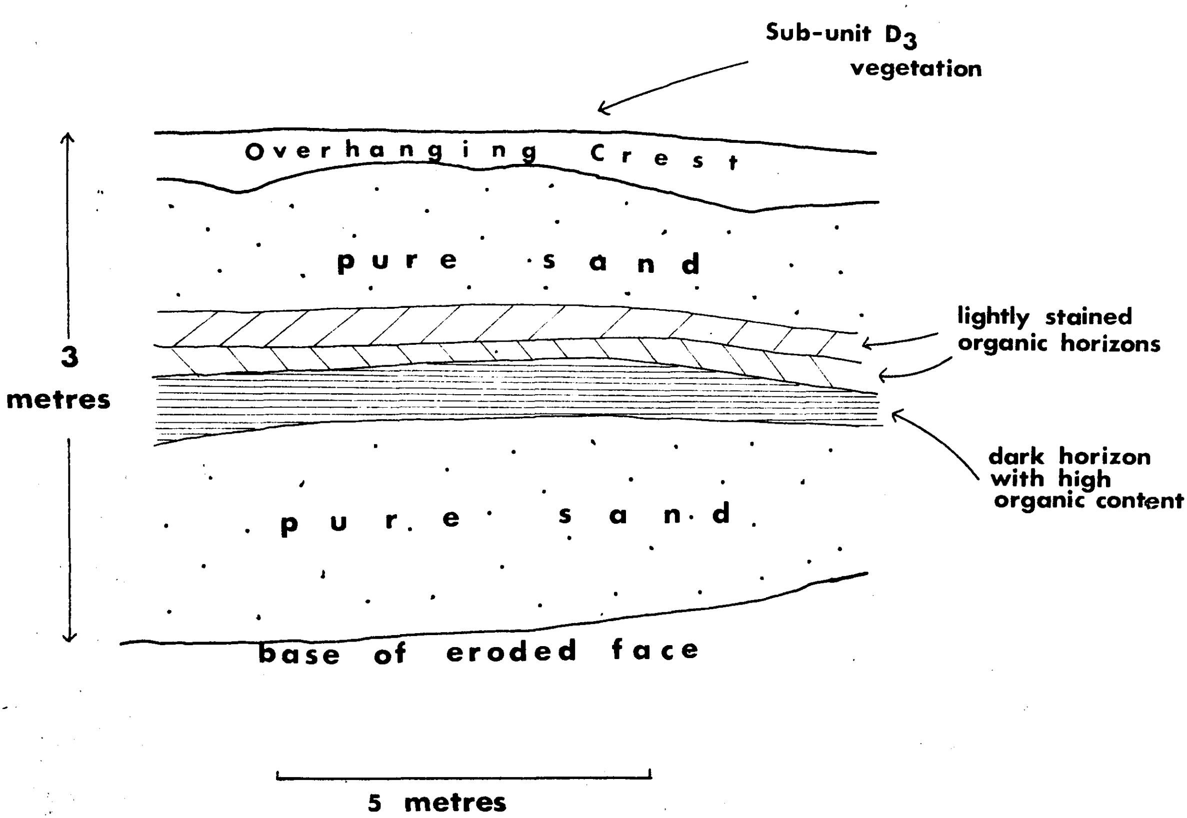


Fig 12

Soils and vegetation at Grogarry, South Uist

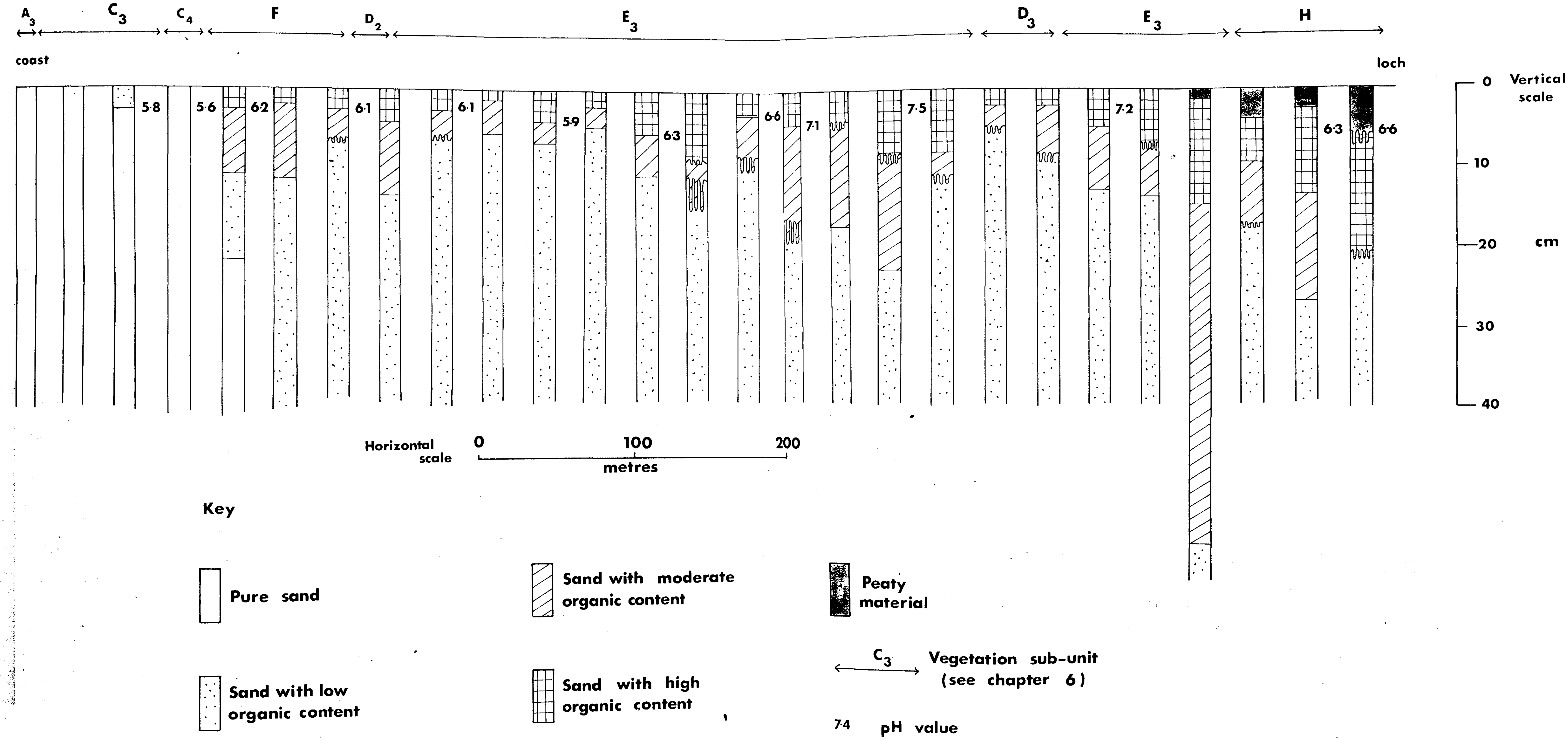


Fig 13 Soils and vegetation around Loch á Mhachair, Grogarry

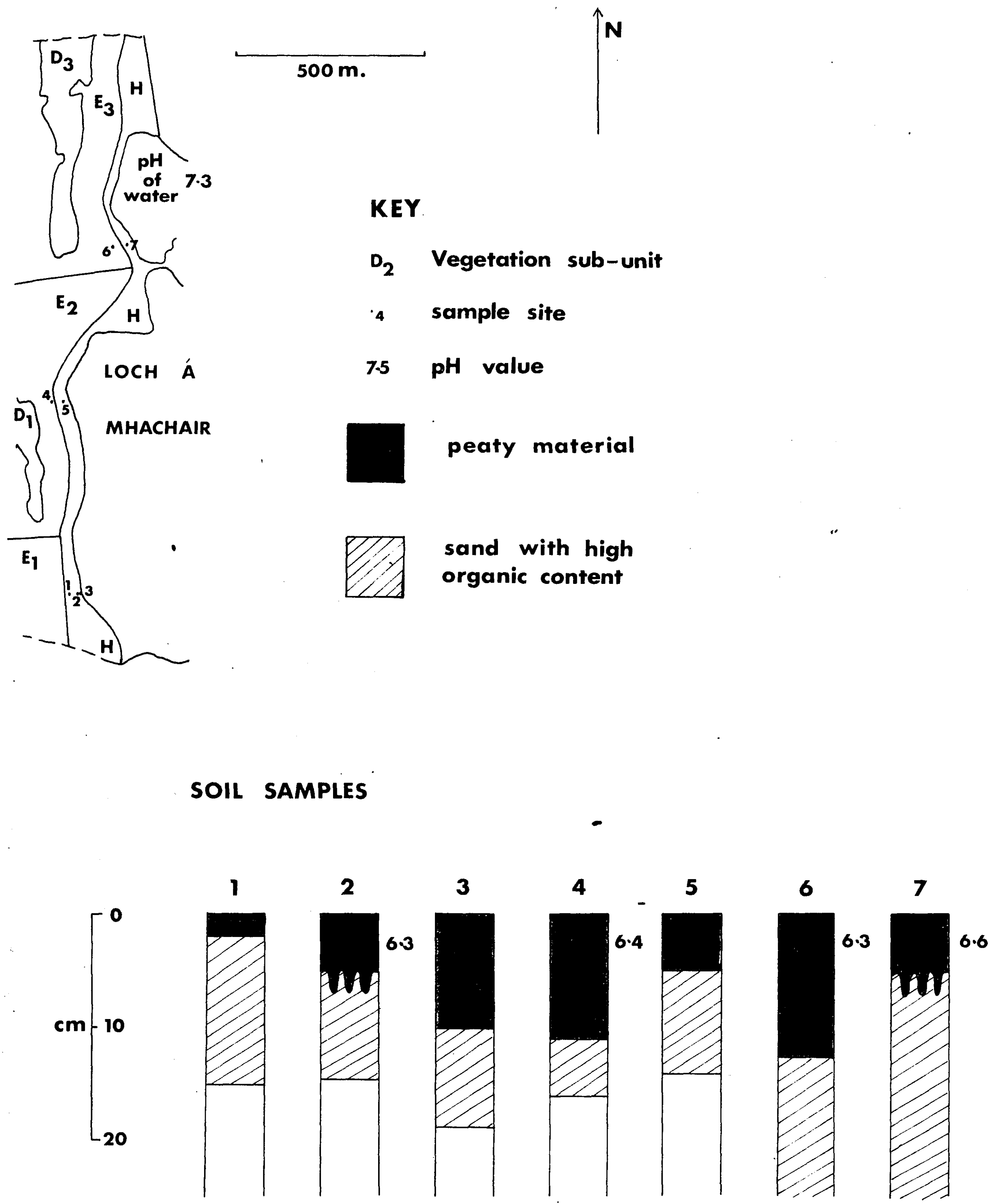


Figure 14

Comparison of Heavily Grazed and Less Heavily Grazed Areas in South Uist

The following data are based on examination of the machair area of 16 townships in the south part of South Uist. Of these 13 in the south have a stocking rate nearly three times that of the 3 northern townships, which have very extensive machair areas. In overall characteristics the vegetation at the two areas is extremely similar.

1. Southern South Uist (Smerclett to Kildonan) - Heavily Grazed.

   Average number of species in machair plain samples - 11.3

   Number of machair plain samples - 18

   Standard error of mean - 0.86

   Range of true mean at 90% level based on 't' distribution - 9.8-12.8

2. Central South Uist (Bornish to Stoneybridge) - Less Heavily Grazed.

   Average number of species in machair plain samples - 15.6

   Number of machair plain samples - 11

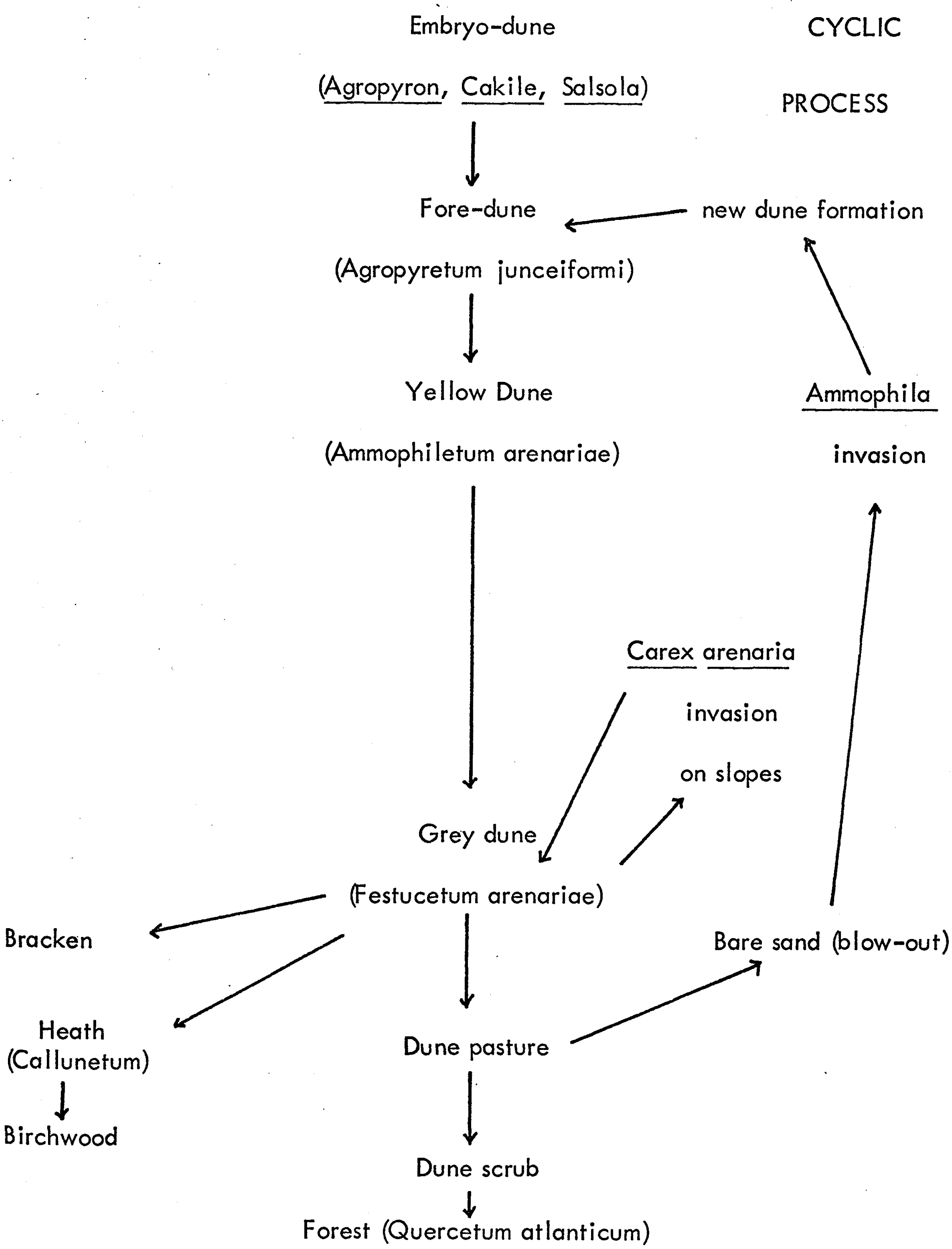
   Standard error of mean - 1.24

   Range of true mean at 90% level based on 't' distribution - 13.3-17.9

On this basis there is a probability of more than 90% that the means of any number of samples drawn from the two areas will not be the same.

Figure 16

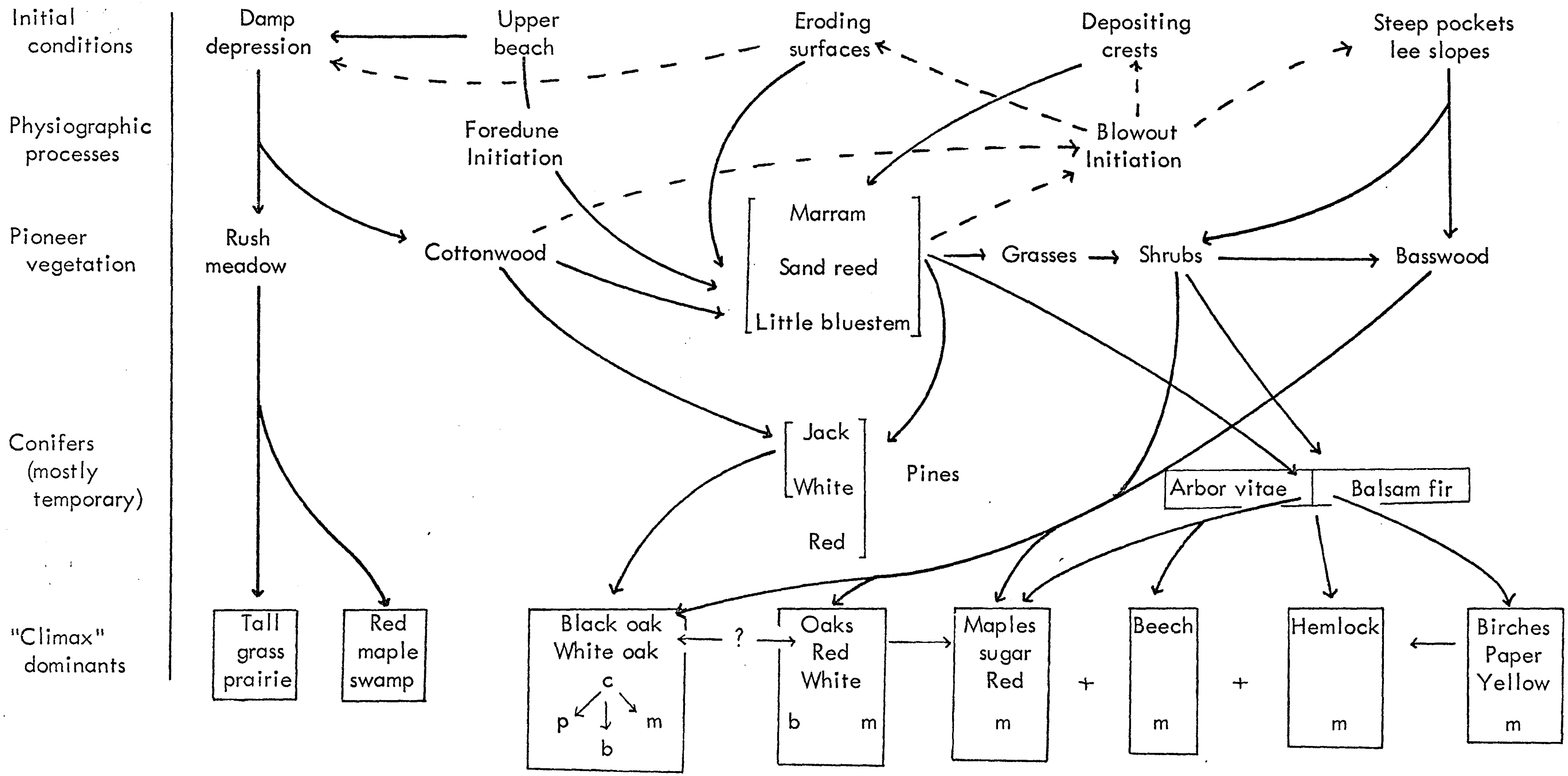
Dune Succession According to Chapman



After
Chapman (1964)

Figure 17

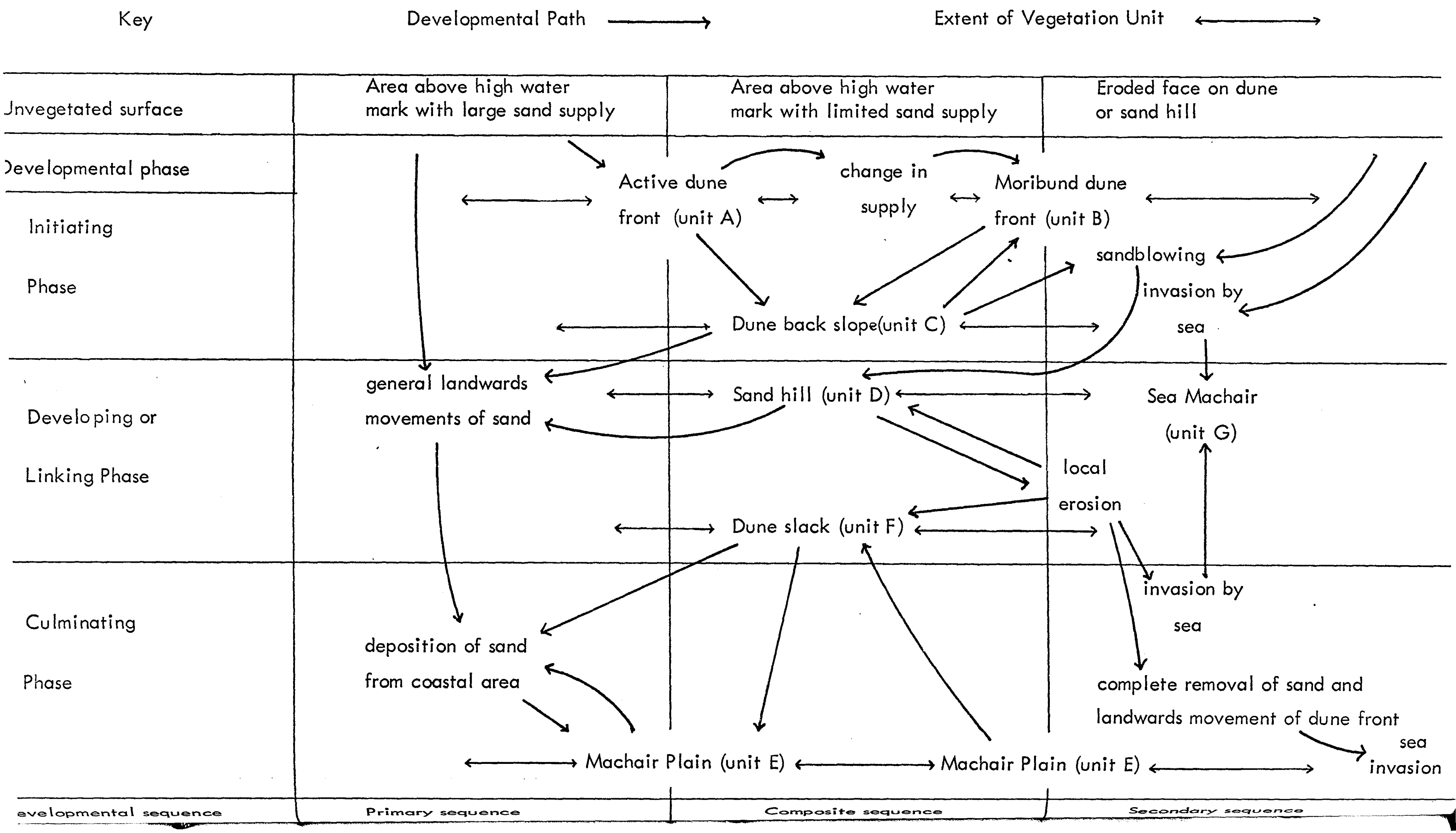
Alternative Dune Sequences according to Olson (1958)



Alternative dune successions. Beaches, foredunes, and blowout dunes provide diverse sites which undergo different successions. Centre of diagram gives oversimplified outline of "normal" succession, from dune-builders to jack or white pine to black oak-white oak with several undercover types: choke-cherry-poison ivy (c), "prairie" (p), blueberry-huckleberry (b), or mesophytic herbs (m), depending on topography, water table and biotic and fire history. Wet depressions (left) and protected lee slopes and pockets (right) may lead to richer forests including basswood, red oak and many mesophytic trees and herbs. Beech and hemlock are added in mesophytic pockets of Michigan and become more widespread northward; *in northern Mitchigan red oak-white oak blueberry (b) may take place of black oak on some dry dunes; pines, including red pine, are more widespread, and fir joins arbor vitae, basswood and birches near lake.*

Figure 18

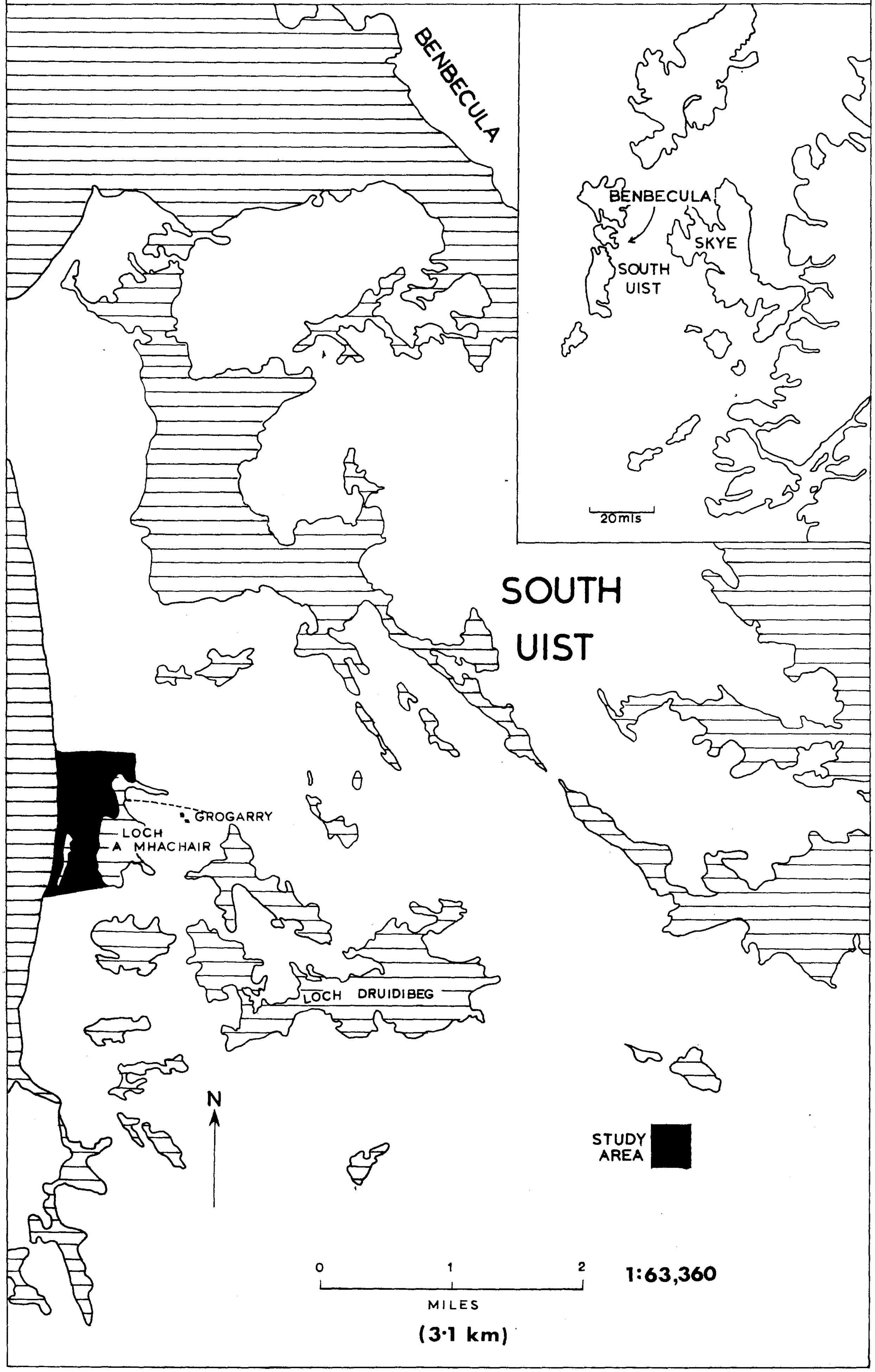
Hypothetical Sequence of Machair Development in the Uists



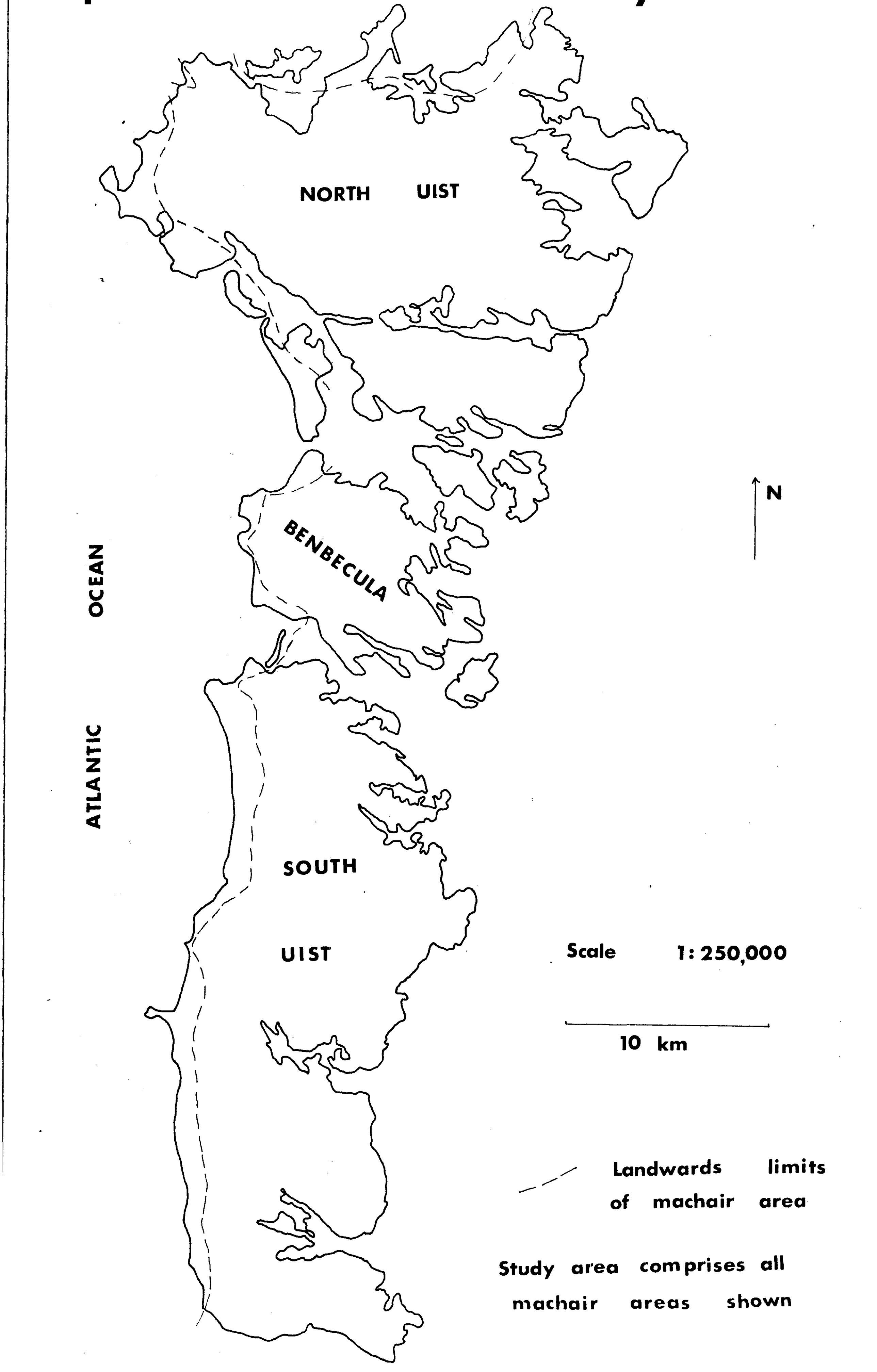
Maps 1 - 12

Map 1

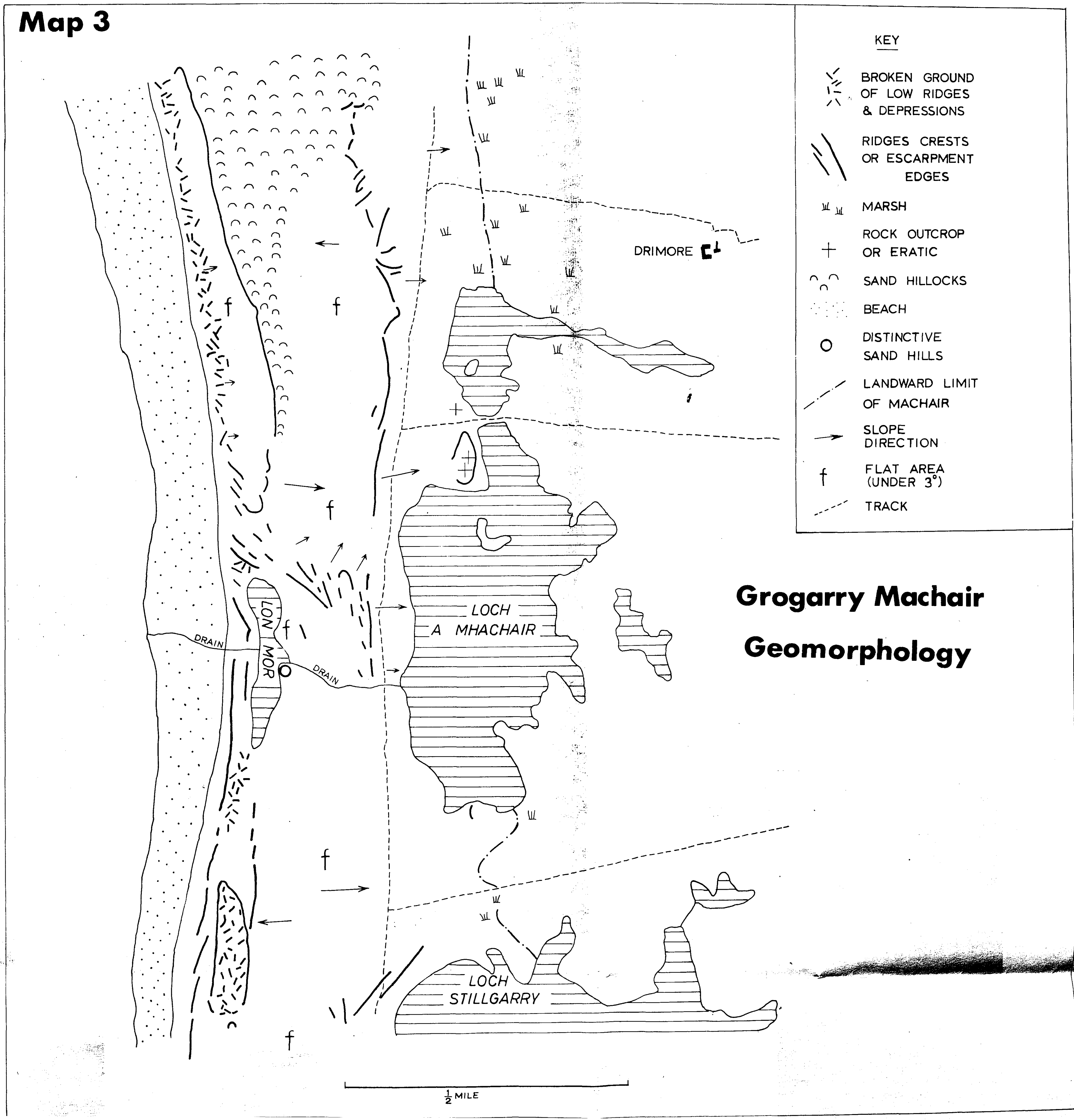
Location — Grogarry Machair Survey



Map 2 Location – Uists Survey

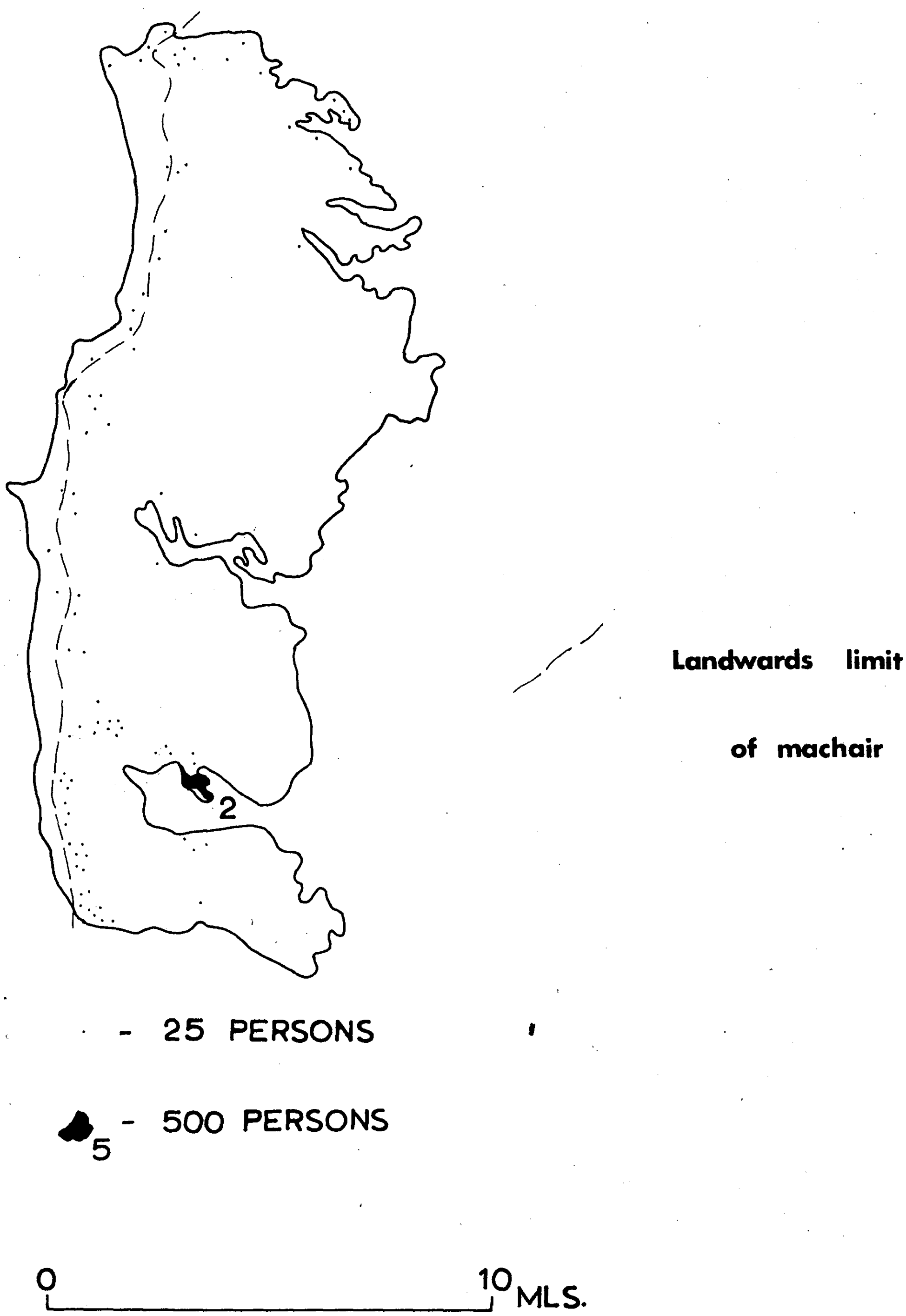


Map 3



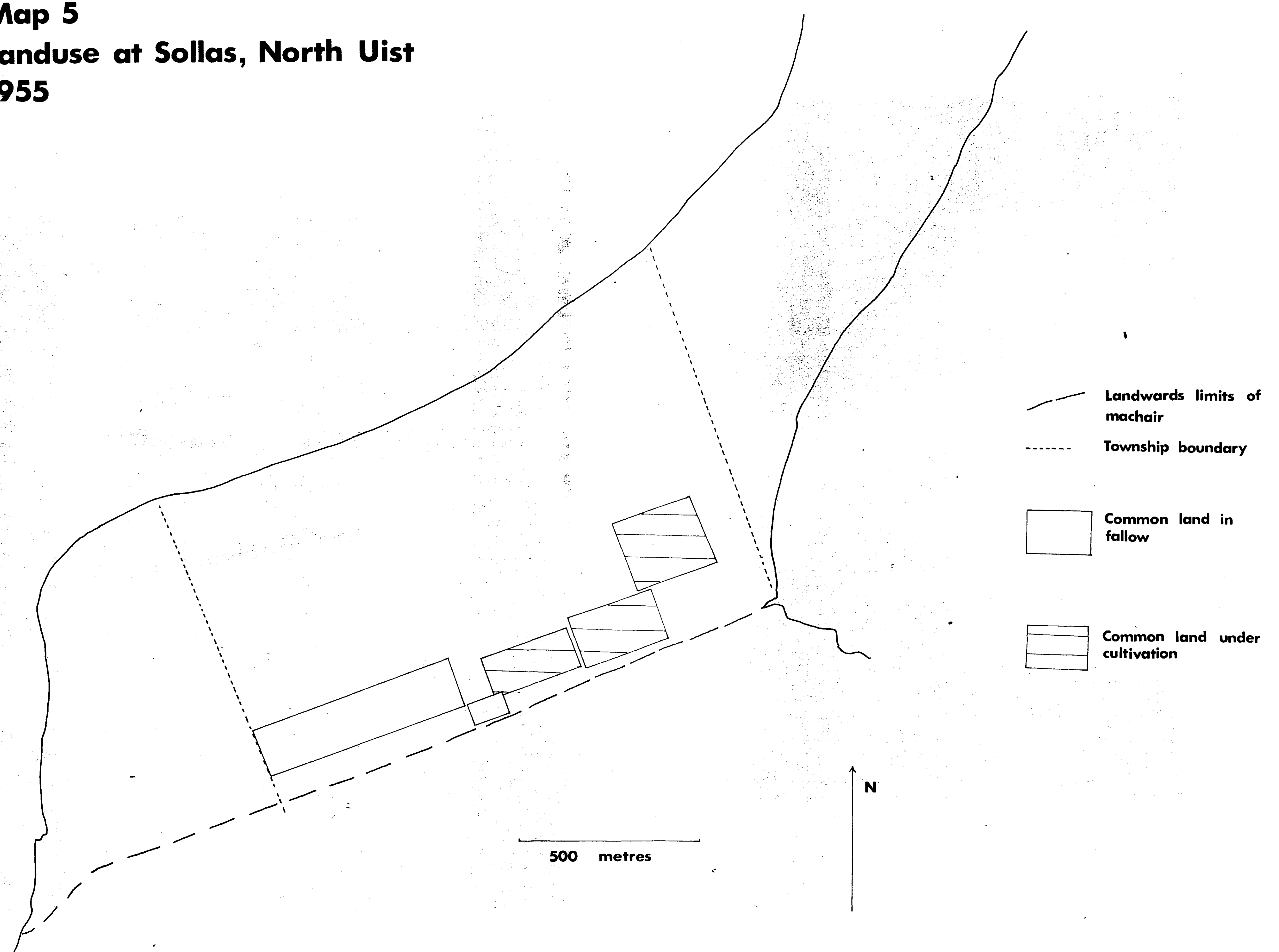
Map 3
KEY
BROKEN GROUND OF LOW RIDGES & DEPRESSIONS
RIDGES CRESTS OR ESCARPMENT EDGES
MARSH
ROCK OUTCROP OR ERATIC
SAND HILLOCKS
BEACH
DISTINCTIVE SAND HILLS
LANDWARD LIMIT OF MACHAIR
SLOPE DIRECTION
FLAT AREA (UNDER 3°)
TRACK
DRIMORE
LOCH A MHACHAIR
LON MOR
DRAIN
DRAIN
LOCH STILLGARRY
½ MILE
Grogarry Machair Geomorphology

Map 4



Population distribution in South Uist

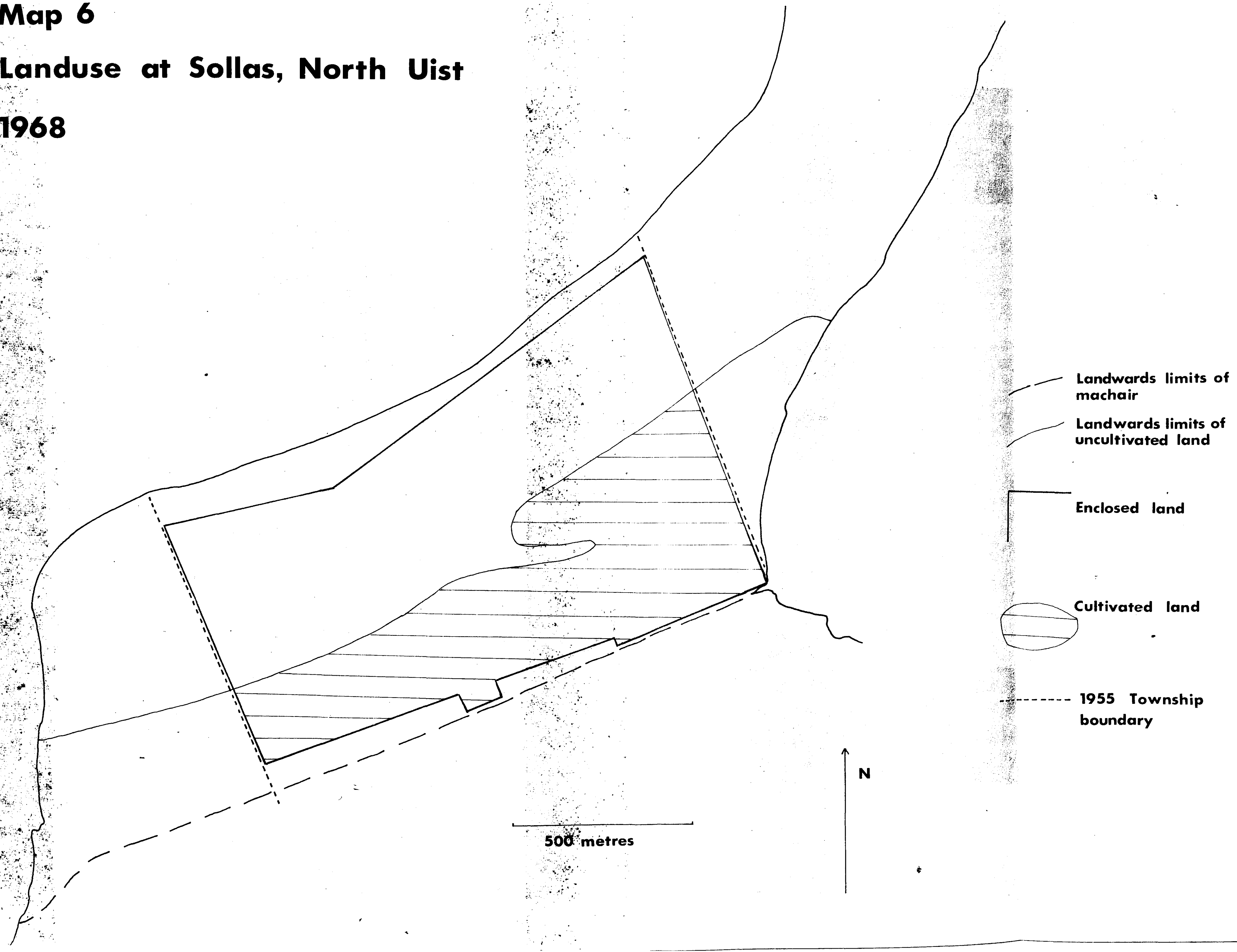
Map 5
Landuse at Sollas, North Uist
1955



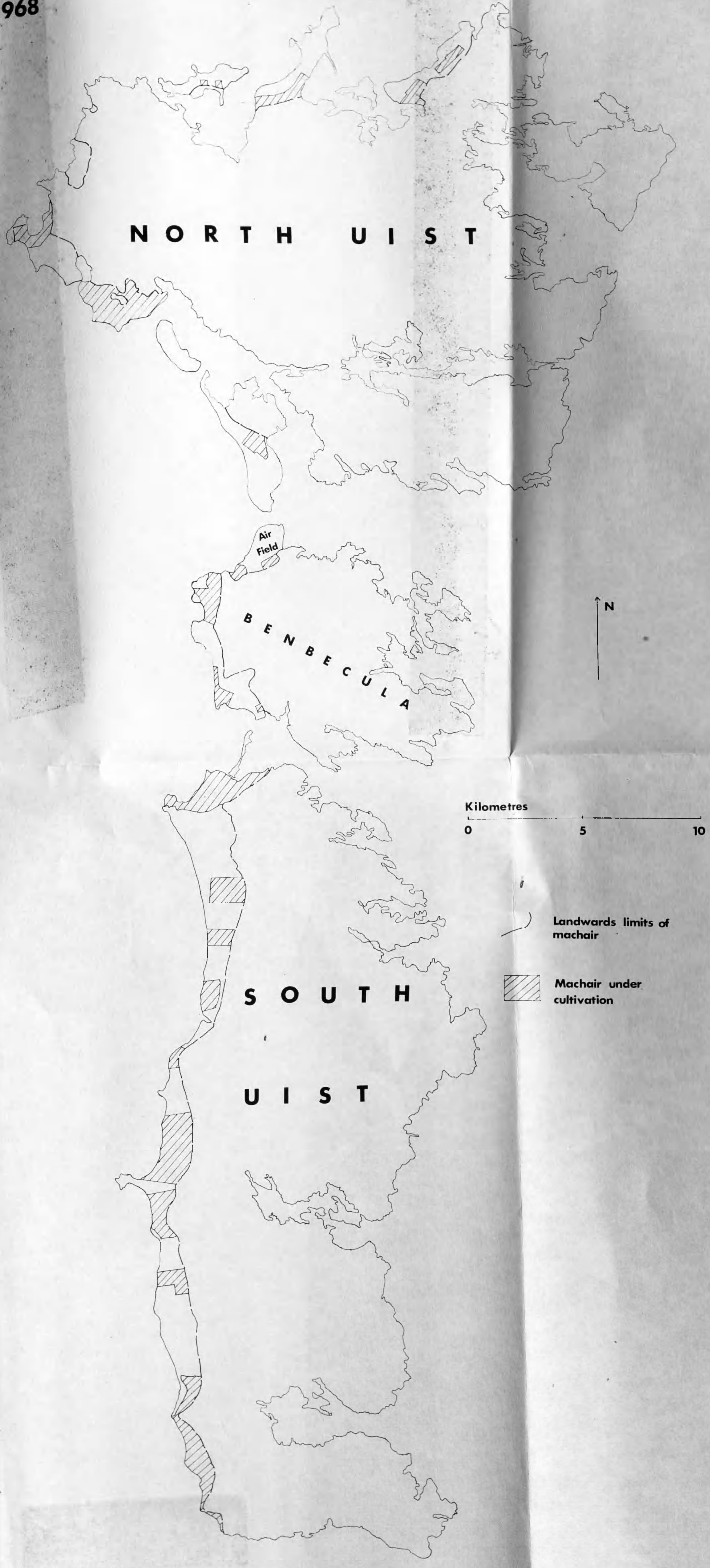
Map 6

Landuse at Sollas, North Uist

1968

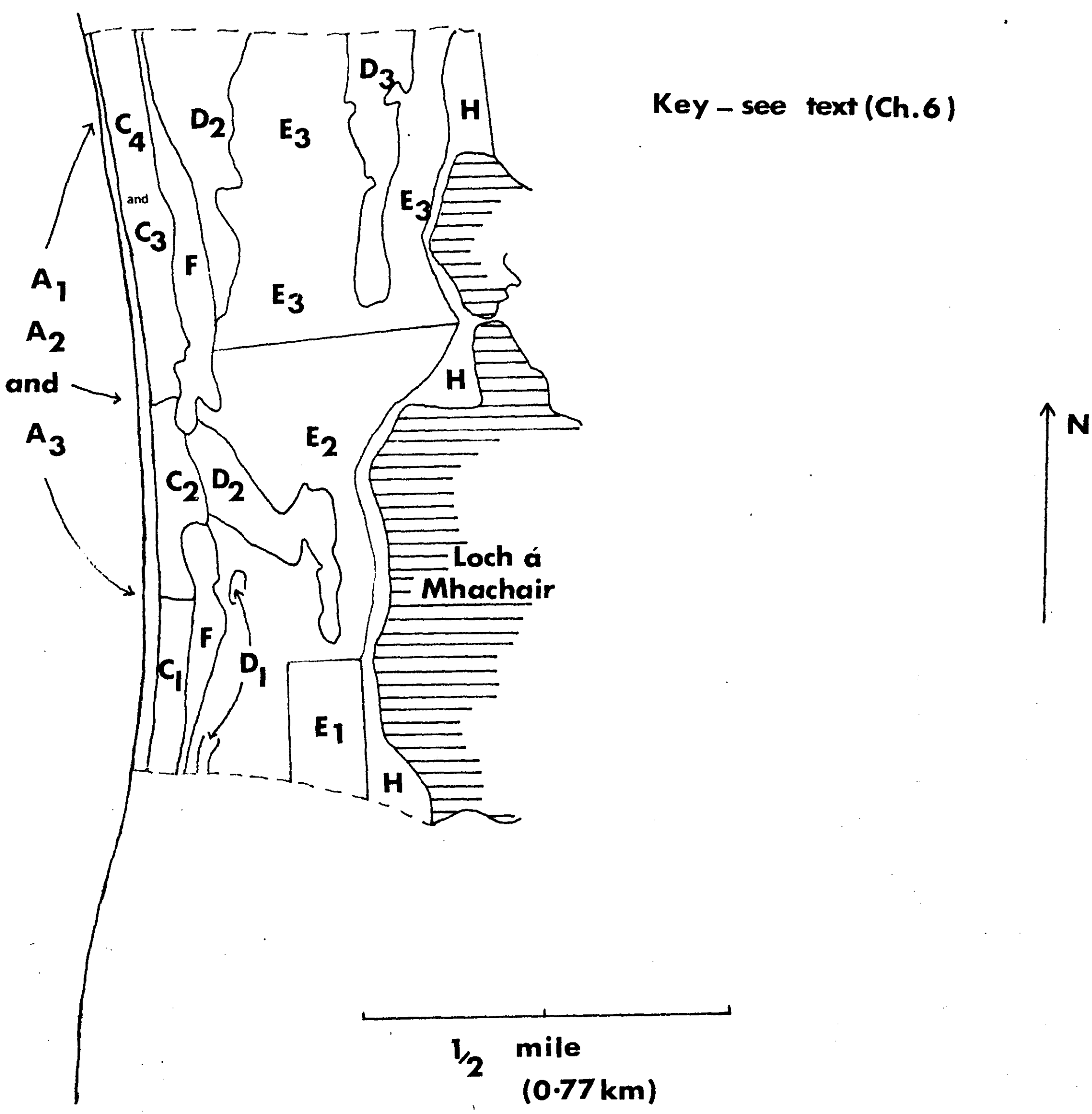


Map 7
Machair landuse in the Uists
1968



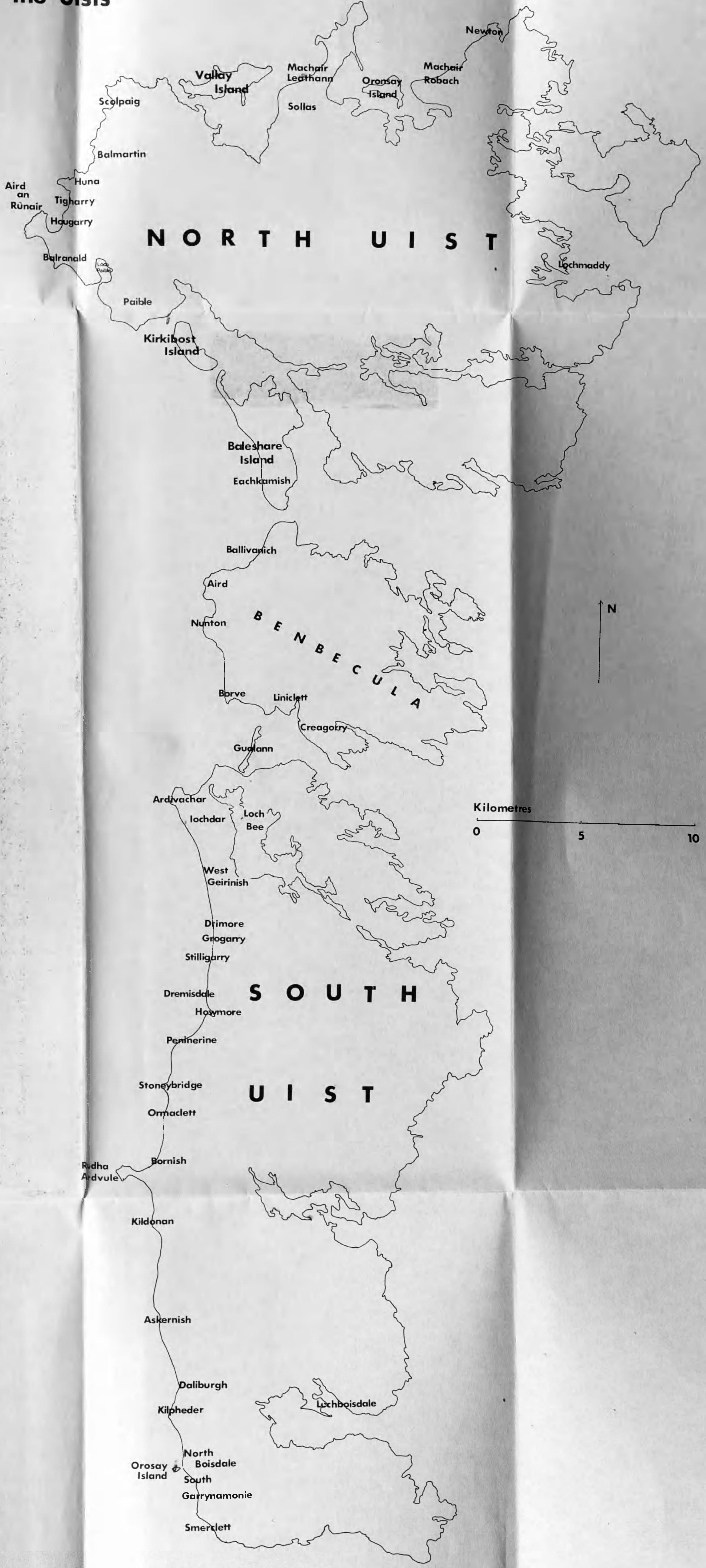
Map 8

THE VEGETATION OF GROGARRY MACHAIR



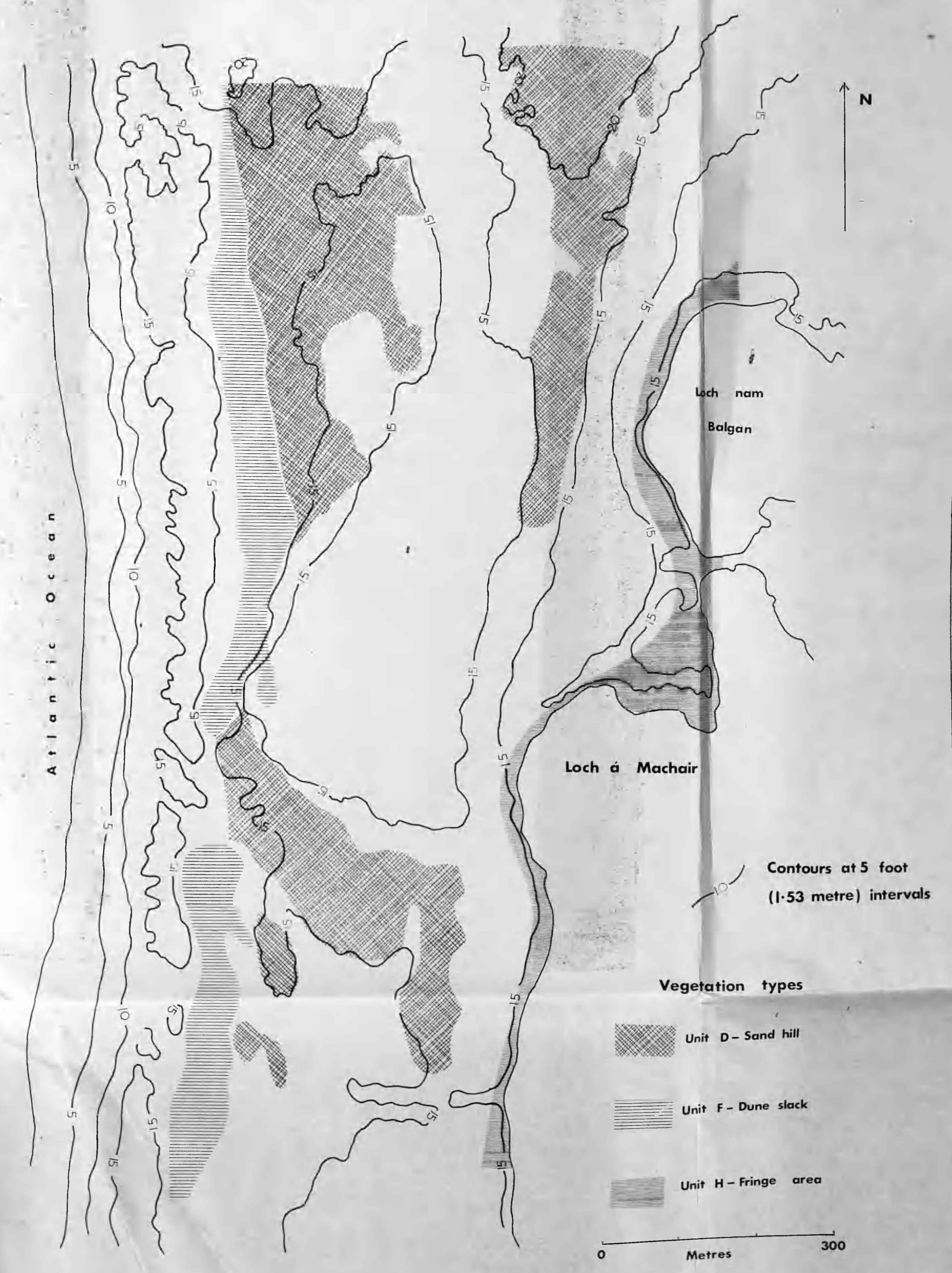
Map 9
Uists' Survey – Key sheet

Map 10
Principal locations in the Uists



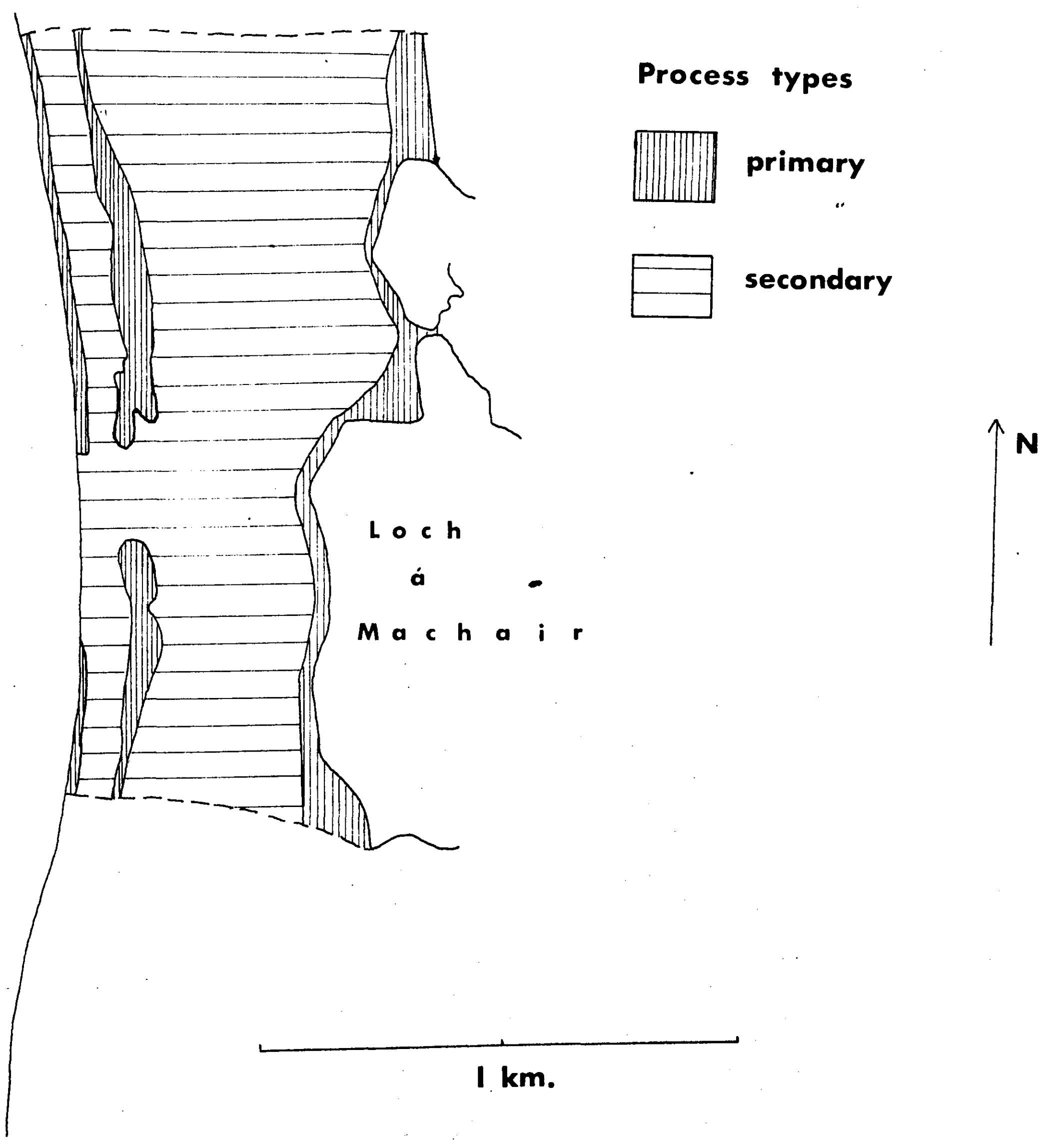
Map 11

Hypsometric correlation with selected types of vegetation at Grogarry, South Uist



Map 12

Dominant process type areas at Grogarry, South Uist



THE VEGETATION OF GROGARRY MACHAIR, SOUTH UIST.