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CHEMICAL AND ECOLOGICAL STUDIES ON PLANTS AND SOILS OF ULTRABASIC AND OTHER AREAS ON THE ISLAND OF RHUM, SCOTLAND.

A thesis submitted for the degree of

Doctor of Philosophy

in the

University of Stirling

by

JOHN HENRY H. LOONEY

Department of Biological Science
University of Stirling
November, 1982.

The contents of this thesis are the result of my own work, and have not been submitted in any form for a degree from any other University.

"... but the Remainder , by far the greatest part, may be judged wholly irreclaimable, consisting of steep Mountains, deep Mosses and Tracks of Land overspread with Rocks ... It has once been well wooded, and in some of the steep Gullies, inaccessible to cattle, the Oak, the Birch, the Holly and Rowan Tree, are still to be observed growing vigorously.

... from this Place, I made a Journey to the highest of these Mountains named Ascheval. From the shore we ascended through deep Mosses, whose surface would scarcely carry us,... The rest of the Ascent, was clambering amidst broken Rocks and falls of water; but among these Rocks, and among the straggling Junipers, I found such a Variety of rare Alpine Plants, as amply requited the Fatigue of the Journey. Some of them, the Inhabitants of the highest Alps in Switzerland, and others of Lapland and Spitsberg."

from the Rev. Dr. John Walker's
Report on the Hebrides of 1764 and 1771.

(McKay 1980).

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ABSTRACT

The climate, geology and vegetation history of the Island of Rhum are briefly described. Rhum has a large area of ultrabasic rock, mainly over 350m, which has distinctive soils and vegetation.

The vegetation of selected sites on several rock types was described from 32 transects with a total of 285 1x1m quadrats. At each quadrat a soil sample was taken and analysed chemically. The vegetation and soil data were ordinated (by DECORANA) and classified (by TWINSPAN). Twelve vegetation classes emerged which were related to previously described communities. The soil factors which were significantly correlated (r_s) with the ultrabasic classes were: total nickel, chromium and cobalt, pH and exchangeable nickel and calcium. There is a wide range of soils on the ultrabasic and most are unusual for this type since they have low Mg/Ca quotients and a sandy texture.

The above-ground parts of six species were analysed chemically and samples from the ultrabasic soils had fairly high concentrations of Ni and in some cases high Fe. Correlation coefficients for soil-soil, soil-plant and plant-plant elements provided some insight into selectivity and possible mechanisms of adaptation to the ultrabasic soils.

Soil solutions were extracted from 21 samples using a centrifugation technique and analysed chemically. Four of these analyses from contrasting soils were used as a basis for culture media for experiments to test the importance for plant growth of certain ions (Ca^{2+}, Mg^{2+}, Ni^{2+}, $H_2PO_4^-$ and Zn^{2+}). RGR's were measured in culture media with several ions varied in a factorial manner and there were two harvests (after 3 and 6 weeks). Ni^{2+} (0.2 mg l^{-1}) was mildly toxic to a non-ultrabasic race at Harvest 1 but there was no effect at Harvest 2. The implications of this are discussed. The non-ultrabasic race had a reduced RGR in the higher Ca and Mg concentrations (combined) in the solutions simulating those in the

Abstract (cont.)

ultrabasic soils, but grew best of all the races in the solutions simulating those from its site of collection. The plants grown in the culture media were analysed chemically and compared with the same species which occurred in the field. The experimental plants had lower concentrations of Fe, and higher of K, but in other respects were similar to the field plants.

Field experiments and observations were made on the effects of added major nutrients to barren areas and erosion. Unfortunately most of the nutrient addition experiments were lost, but earlier work was confirmed that nutrient-addition causes an increase in plant cover on exposed barren ultrabasic areas. Erosion is still rapidly occurring in some places.

No single factor can explain the distinctive vegetation of the ultrabasic areas on Rhum, but the following singly and in combination are probably important: high Ni (with its greatest effect in dry spells); fairly high soil pH (for Rhum); low major nutrients; soil physical factors, particularly its sandy texture, frost-heaving and erosion (probably resulting from past-burning and grazing). The effect of a high Mg/Ca quotient seems not to be important on Rhum.

ACKNOWLEDGMENTS

I would like to thank Professors W.R.A. Muntz and H. Meidner for the use of the facilities of the Department of Biological Science at the University of Stirling. I appreciate the permission of the Nature Conservancy Council allowing me to work on Rhum, and the support and facilities they provided for me, especially the help from Mr. Laughton Johnston and Mr. Angus MacIntosh. Thanks to Mr. Johannes Volker for many hours of friendship and discussion whilst on Rhum, for advice on geological matters and for the picture on the frontispiece. Dr. D. McC. Newbery is thanked for his helpful discussions, especially on statistics. Thanks also to Mrs. Ina Mack for typing this thesis in record time. I am indebted to my supervisor, Dr. J. Proctor, for his eternal enthusiasm and encouragement, and his unrelenting standards.

Finally, I would like to thank my parents for their support throughout this thesis, and special appreciation is extended to my wife Hilary, for her love, help and understanding.

CHAPTER ONE

INTRODUCTION

1.1 The Island of Rhum

Vegetation on serpentine and ultrabasic outcrops throughout the world is very variable, but it is often quite barren, or at least contrasts with surrounding vegetation (Proctor & Woodell 1975, see below). Throughout this thesis the term serpentine is usually used in the biological (or broader sense) to describe a group of ultrabasic (ultramafic) rocks not on Rhum, the soils derived from them, and the vegetation that is associated with them. I have used the narrower geological meaning of ultrabasic when referring to the rocks on Rhum, (however in Chapter 7 the different races of grass used from Rhum are referred to as serpentine or non-serpentine).

The Island of Rhum (latitude 57°3'N, longitude 6°27'W; Inner Hebrides, Scotland; National Grid Reference NM 37 98; Fig. 2.1.1:1) has the largest ultrabasic outcrop in Britain. It is almost devoid of plants in places and has a vegetation distinct from that found on the other rock types on the Island. This has been appreciated for some time: The New Statistical Account (of 1828)(MacLean 1845) notes a difference between the strong heather on the east and the grass on the west of the Island. It was with the acquisition of the Island in 1957 by the Nature Conservancy Council that the differences were described in detail in relation to the geology (McVean & Ratcliffe 1962; Ferreira 1970,1974). The four main vegetation regions correspond generally with the chief geological formations: the Torridonian sandstones in the north and east; the gabbro and ultrabasic rocks of the centre; the basalt and limestone to the north west; and the granophyre on the south west (Nature Conservancy Council 1974). This thesis concerns the vegetation on the ultrabasic complex of the Island.

The composition of the ultrabasic complex on Rhum is variable with important effects for the soils and vegetation. The types of ultrabasic rocks range from dunite (>90% olivine) and peridotite (>50% olivine with the rest a 3:1 ratio of plagioclase: pyroxene) through several intermediates, to nearly pure forms of the calcic plagioclase rock, hallivalite (>50% plagioclase, 5-10% pyroxene, the rest olivine). In general, the composition of olivine is represented as $(Mg\ Fe)_2\ Si_2O_4$, with the Mg: Fe ratio (for Rhum) about 4:1; while plagioclase is represented as $Ca\ Al_2\ Si_2\ O_8$ and $Na\ Al\ Si_3\ O_8$ with a Ca: Na ratio of 4:1 on Rhum. (J. Volker, personal communication). Many accessory minerals are found in ultrabasic rocks. Of particular interest on Rhum are chromite and magnetite. The content of these minerals can vary appreciably within ultrabasic rocks and on Rhum, chromite is highest in the Ruinsival series (J. Volker, personal communication), while magnetite is more variable across the Island. In one restricted area on Rhum the peridotite and dunite have been hydrothermally altered to the mineral serpentine (J. Volker, personal communication). This area, near the Ruinsival Bealach is the site of Transect 26 (Figure 1.1:1 and Section 2.1.1). (Emeleus & Forster 1979, have given more information on the igneous petrology of Rhum).

There is some uncertainty about the post-glacial vegetation of Rhum. Skye once had woodland, sometimes extensive (Birks 1973), but the former extent of the woodland on Rhum is less well known. Walker's Report on the Hebrides of 1764 & 1771 (McKay 1980, see frontispiece) mentions the island as having been well wooded and Dean Munro in 1549 (R.W. Munro 1961) mentions a forest on the island. In The (Old) Statistical Account of Scotland (McLean 1796) in reference to the number of deer on Rhum refers to

> "... a copse of wood that afforded cover ... while the wood throve the deer also throve; now that the wood is totally destroyed the deer are extirpated." (Nature Conservancy Council 1974).

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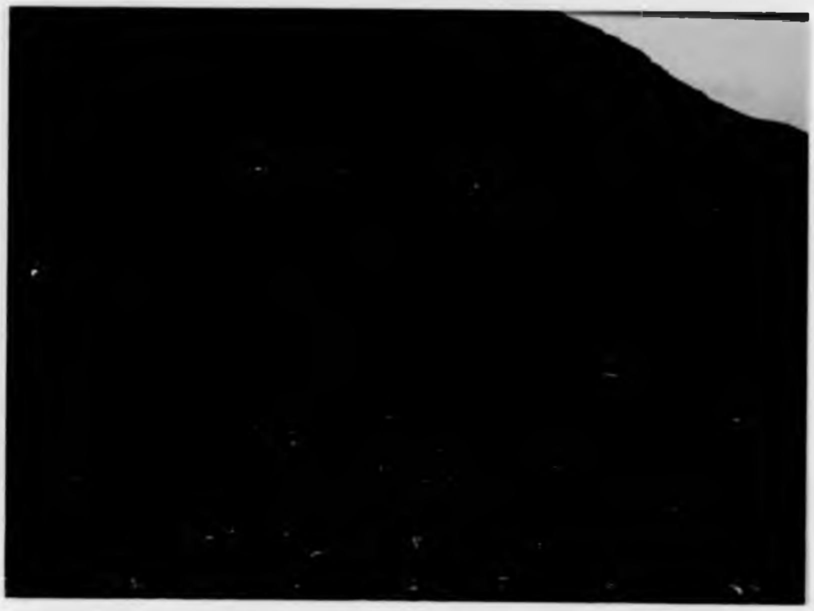

Fig. 1.1:1 Location of Transect 26 on the serpentinized dunite (ultrabasic). Note the sharp transition with the non-ultrabasic soils (which overlie peridotite) but are probably derived from much non-ultrabasic parent material .

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[illegible] 11. Location of Transect 2b on the [illegible] [illegible] (Transect 2). Note the sharp transition with the same [illegible] [illegible] [illegible] [illegible] [illegible]

It seems that the increase of man and grazing animals throughout the eighteenth century at least coincided with the disappearance of woodland. Heather burning was practised on Rhum and from the 1870's at least, it was not controlled and there is evidence of burning on Cnapan Breaca above 360m. (Nature Conservancy Council 1974).

The present vegetation on the ultrabasic soils is quite different from that of the surrounding soils on different parent materials. Often the change in vegetation at a geological boundary is very sharp and apparent at a distance of several km. (See Figs. 1.1:1 and 1.1:2). Several study areas were chosen with transects located on both sides of several of these boundaries. Lichens are often sensitive indicators of ecological conditions, and on Rhum generally do not grow as well as on ultrabasic rocks (Figure 1.1:3).

Experimental work on the soils and vegetation on Rhum since 1957 has shown that erosion and nutrient deficiency are important factors. Ragg & Ball (1964), in a survey of the soils on the ultrabasic area of Rhum found thin (5-10cm depth) immature surface soils overlying well-developed soils which, they concluded, could not have formed under the present sparse vegetation. Wormell (Nature Conservancy Council 1974) found that wind action was moving rocks both up and down slopes, and Ferreira & Wormell (1971) found a substantial (5-60%) increase in vegetation cover upon the addition of nitrogen-phosphorous-potassium fertilizer with calcium. Unfortunately their experiment had only one trial plot, and separation of the importance of the factors is not possible (see Chapter 8). Work in conducting irrigation water with relatively high calcium to magnesium-rich soils showed a marginal change in the vegetation over two years. Production studies related to deer grazing on herb-rich grasslands have found indications that both exposure and the nitrogen content of the soil

Fig. 1.1:2. Examples of vegetation contrasts between non-ultrabasic and ultrabasic soils.
Top: looking east across Coire Dubh, non-ultrabasic on left with ultrabasic (Hallivalite and Peridotite) on right.
Bottom: 'Sandy Coire' (NM 370 947), non-ultrabasic (T14) in foreground, ultrabasic (T13) centre, basic gabbro (T15) in left distance.

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[illegible] Examples of vegetation contrasts between non-ultrabasic and ultrabasic soils. [illegible]

Fig. 1.1:3. Lichens growing on a boulder of two rock types. The centre is gabbro (basic) and it is flanked by peridotite which has few epiphytes.

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Plate [illegible] Lichens growing on a boulder of two rock types. The centre is gabbro (basic) and it is flanked by peridotite which has few epiphytes.

may be critical limiting factors. (Nature Conservancy Council 1974).

Indications that other factors may be important are shown by Proctor (1971a,b), who found that a race of Agrostis canina from Hallival had nickel but not magnesium tolerance. However, in growth experiments with oats, he found that soils from the Hallival-Barkeval Bealach were not acutely nickel-toxic and the plants showed a significant response to fertilization. Research measuring the change in the vegetation cover from the removal of sheep grazing pressure from 1957 has shown a change in the community structure and competitive balance between species (Ball 1974).

The oceanic effect on the climate, which is apparent from other Hebridean recording stations, is not so strong for Kinloch (Fig. 2.1.1:1). Results of selected climatological measurements from Kinloch, from 1958-1968, are in Table 1.1:1. While the values are not representative of the variation across the island they give some indication of the island's weather. To supplement these data, a temperature-recording station was established on the Barkeval Bealach (NM 385 971, 490 m) from April 1981-January 1982. Temperatures reported are: air temperature, soil temperature at 1-cm depth under bare soil, and soil temperature at 1-cm depth under about 6cm mixed vegetation cover (including heather, grasses and herbs). The results are not complete because of equipment failure (Fig. 1.1:4). These results support the cool, wet, windy and cloudy reputation of western Scotland. The west of the island, (most often the windward side during wet weather) is noticeably drier, but the tops of the mountains are probably much wetter than the values for Coire Dubh indicate (Nature Conservancy Council 1974). Rhum lies in the area of western Scotland where the overall mean monthly evaporation potential does not exceed the mean monthly precipitation, (although it may for shorter spells, Nature Conservancy Council 1974).

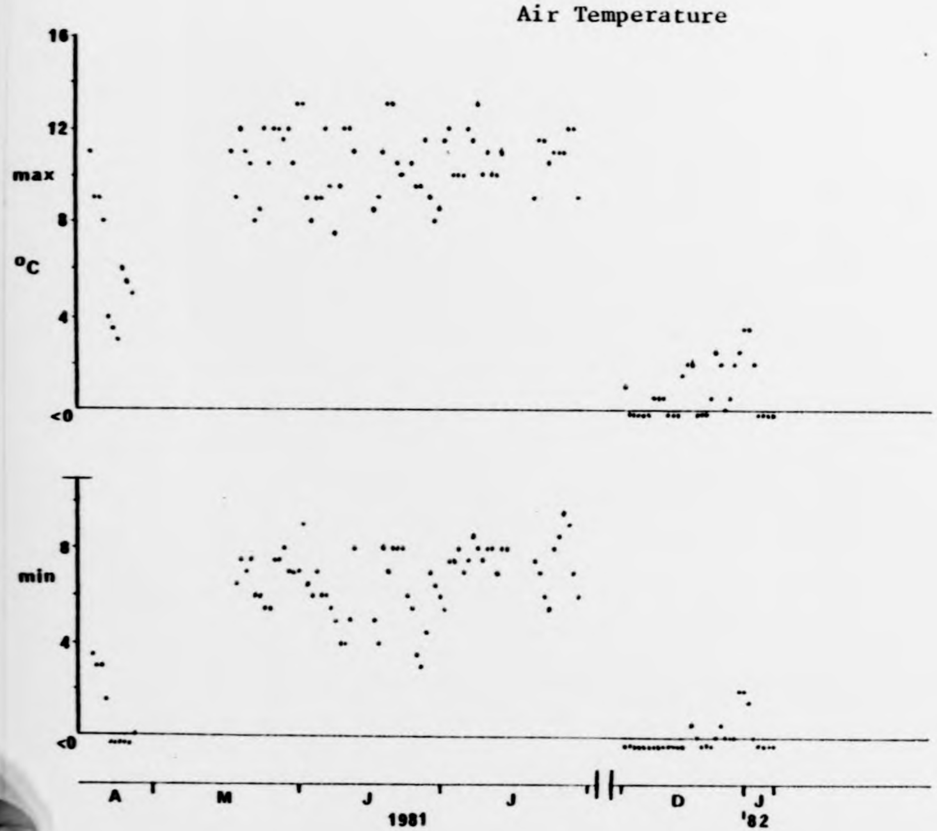
Table 1.1:1 Various climatological measurements from Kinloch, Isle of Rhum, for the period 1958-1968. Rainfall records for Harris and Coire Dubh are also given. (Nature Conservancy Council 1974) See Fig. 2.1.1:1.

	Mean Max Temp.°C	Mean Min Temp.°C	Average Rainfall (mm)	No. Rain Days *	No. Wet Days **	No. Days with air frost	No. Days with ground frost	Mean Wind Speed (m/s)	Average Rainfall Harris (mm)	Coire Dubh (mm)
Jan.	6.8	1.7	249	22.1	18.5	9.4	21.5	5.5	140	285
Feb.	7.3	2.0	147	17.9	14.6	8.7	17.2	5.0	78	137
Mar.	8.8	3.1	189	20.3	17.3	5.2	14.3	5.0	101	236
Apr.	11.2	4.0	142	18.6	15.4	4.3	12.0	4.2	82	171
May	13.9	6.0	135	17.1	14.8	1.0	6.0	4.0	74	190
Jun.	16.5	9.1	157	17.9	14.7	0.0	1.0	4.2	93	209
Jul.	16.6	10.0	165	18.9	16.0	0.0	0.7	3.8	108	232
Aug.	16.8	9.8	193	19.5	16.4	0.0	1.2	4.1	106	271
Sep.	15.6	9.5	237	20.8	18.1	0.0	1.7	4.1	147	322
Oct.	12.9	7.5	263	22.8	20.5	0.2	5.2	4.8	156	362
Nov.	9.3	4.0	227	21.7	18.7	4.4	15.0	4.4	130	249
Dec.	7.3	2.1	270	23.8	21.8	7.9	20.5	5.9	159	297
Year	11.9	5.7	2373	241.4	206.8	41.1	116.3	4.6	1374	2969

* = > 0.25mm ** = > 1.02mm

Fig.1.1:4 Daily minimum and maximum temperature data (from 30 minute recordings of air, and exposed and vegetated soil at 1cm depth)from April 1981 to January 1982 from the Barkeval Bealach (NM 385 971, 490m, location 2 on Fig. 2.1.1:1).

Air Temperature



Vegetated Soil Temperature

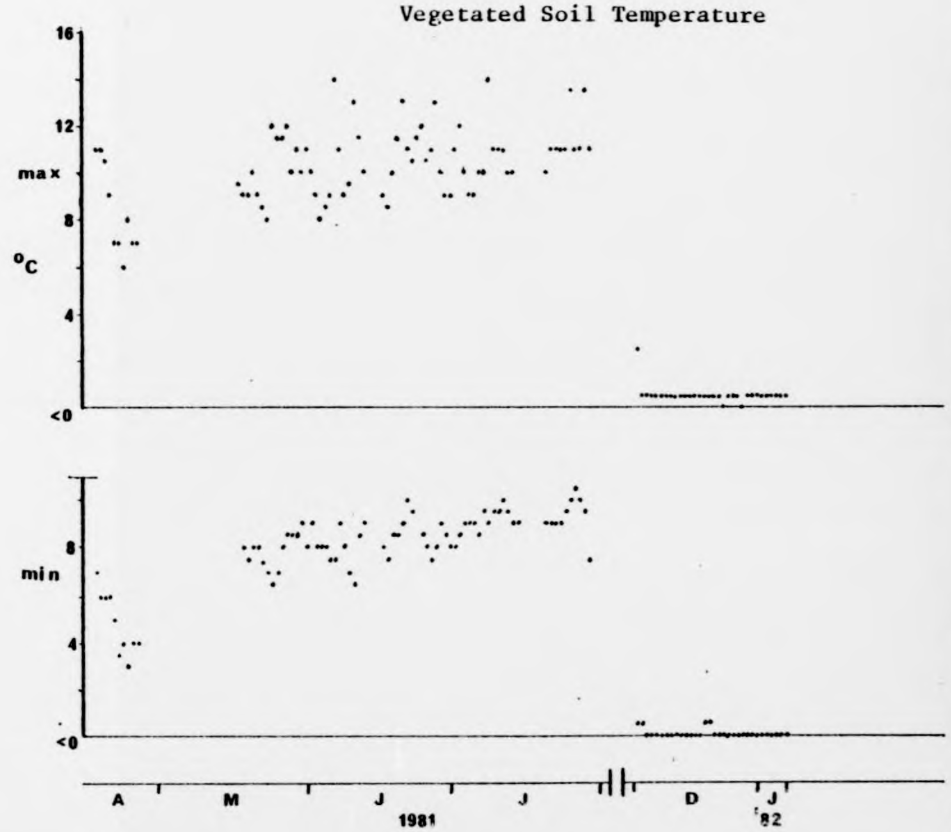
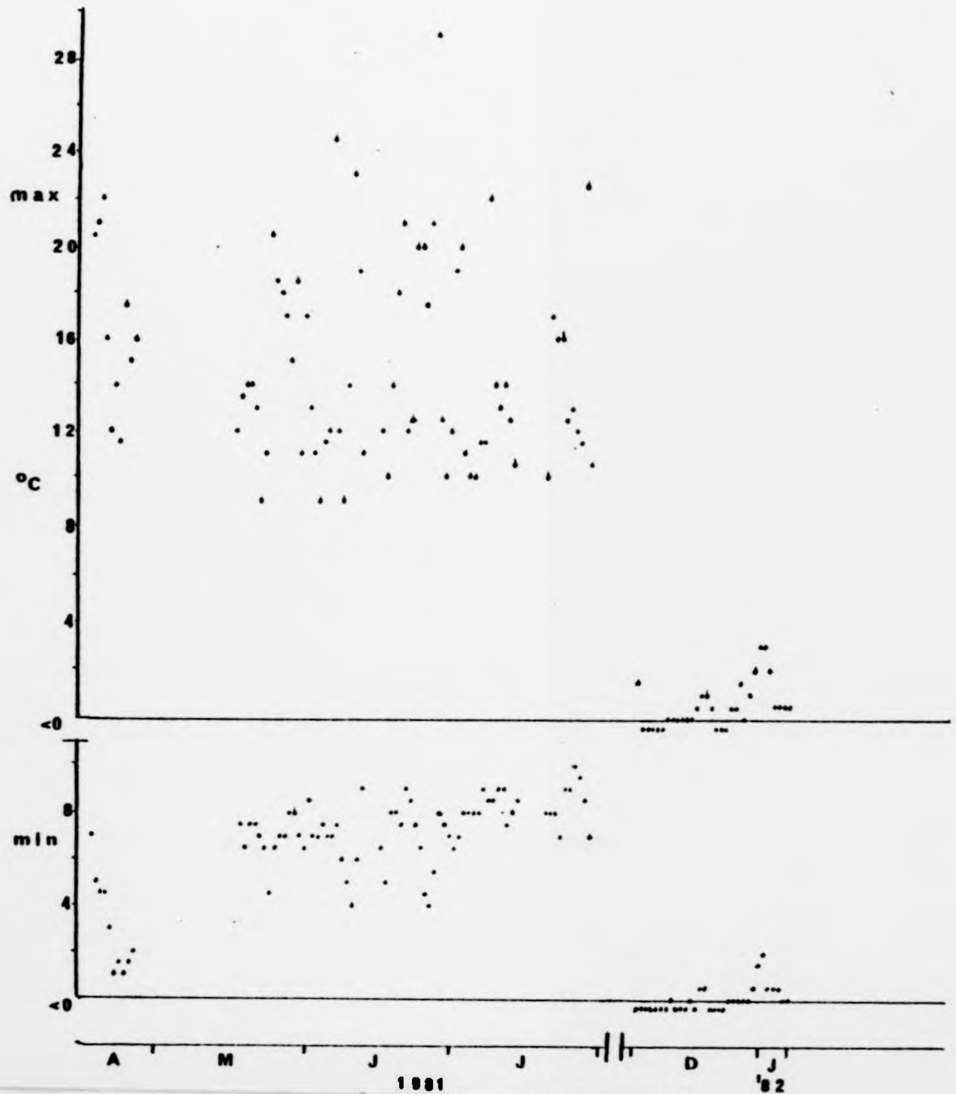


Fig.1.1:4 (cont.)

Exposed Soil Temperature



1.2 The aims of the research

The main aim of the research was to investigate and identify the possible causes of the poor vegetation cover and the distinctive flora on the ultrabasic mountains of Rhum. Several approaches to this problem were made.

The first requirement was for an adequate description of the vegetation, with measurement of the soil variables, for a range of areas. Previous work (Proctor & Woodell 1971, Spence 1970) had been restricted to small parts of the Island. To support this study, plant analyses were made and correlation coefficients between plant and soil metal concentrations calculated. Water culture experiments (with media based on soil solution composition) were made to test the response of the native races of *Agrostis canina* (a widespread plant on many soils on Rhum). Finally, preliminary field experiments were made but there were many difficulties with these (discussed in Chapter 8), and their contribution was less important.

CHAPTER TWO

Vegetation Description, Classification and Ordination.

2.1 INTRODUCTION

2.1.1 Transect location and vegetation description

A comprehensive survey of the ultrabasic formation was not possible as this rock-type covers a large part of Rhum (Fig. 2.1.1:1). Sampling areas were therefore selected subjectively which appeared to be representative of three major vegetation types, evident to myself on the island and recorded by previous workers (Ragg & Ball 1964, Proctor & Woodell 1971, Proctor 1971a, Ferreira 1974). These earlier studies proved a useful but insufficient basis for a detailed sampling programme in any one area of the ultrabasic. Ferreira's (1974) work was thorough across the island, but largely omitted the barren areas on the ultrabasic.

The three vegetation types sampled were: sparse vegetation on the ultrabasic soils, closed vegetation on the ultrabasic soils, and closed vegetation on the non-ultrabasic soils. No sparse vegetation on non-ultrabasic areas was found except on rocky slopes where vegetation developed (with virtually no soil) in mats overlying the rocks or in pockets. (Transect 17 is the only transect located on an area resembling these rocky slopes described here, but had more soil present and closed vegetation). The summit vegetation on the tallest mountain on the ultrabasic formation is markedly different from the summit vegetation on the tallest mountain on the non-ultrabasic, yet both have soils present (Fig. 2.1.1:2).

Transects were located in homogeneous areas of vegetation and on ground with a slope of 30^{o} or less. Each transect was usually 100m in length (50m in some cases) and sample positions were taken at 10m intervals from a randomly selected starting point. Regular samples were taken to facilitate the relocation of the positions, since the occurrence of a pattern in the vegetation or periodicity in environmental

Fig. 2.1.1:1 Map showing the area of Rhum included in this study. The ultrabasic section of the Island is mainly within the boundary drawn. Location 1 is the Harris rain gauge, Location 2 the Barkeval Bealach temperature recording station, Location 3 the Coire Dubh rain gauge, and Location 4 the Kinloch recording station. The numbers along the margins are National Grid co-ordinates (reproduced from the Ordnance Survey Map with the permission of the Controller of Her Majesty's Stationery Office, Crown copyright reserved).

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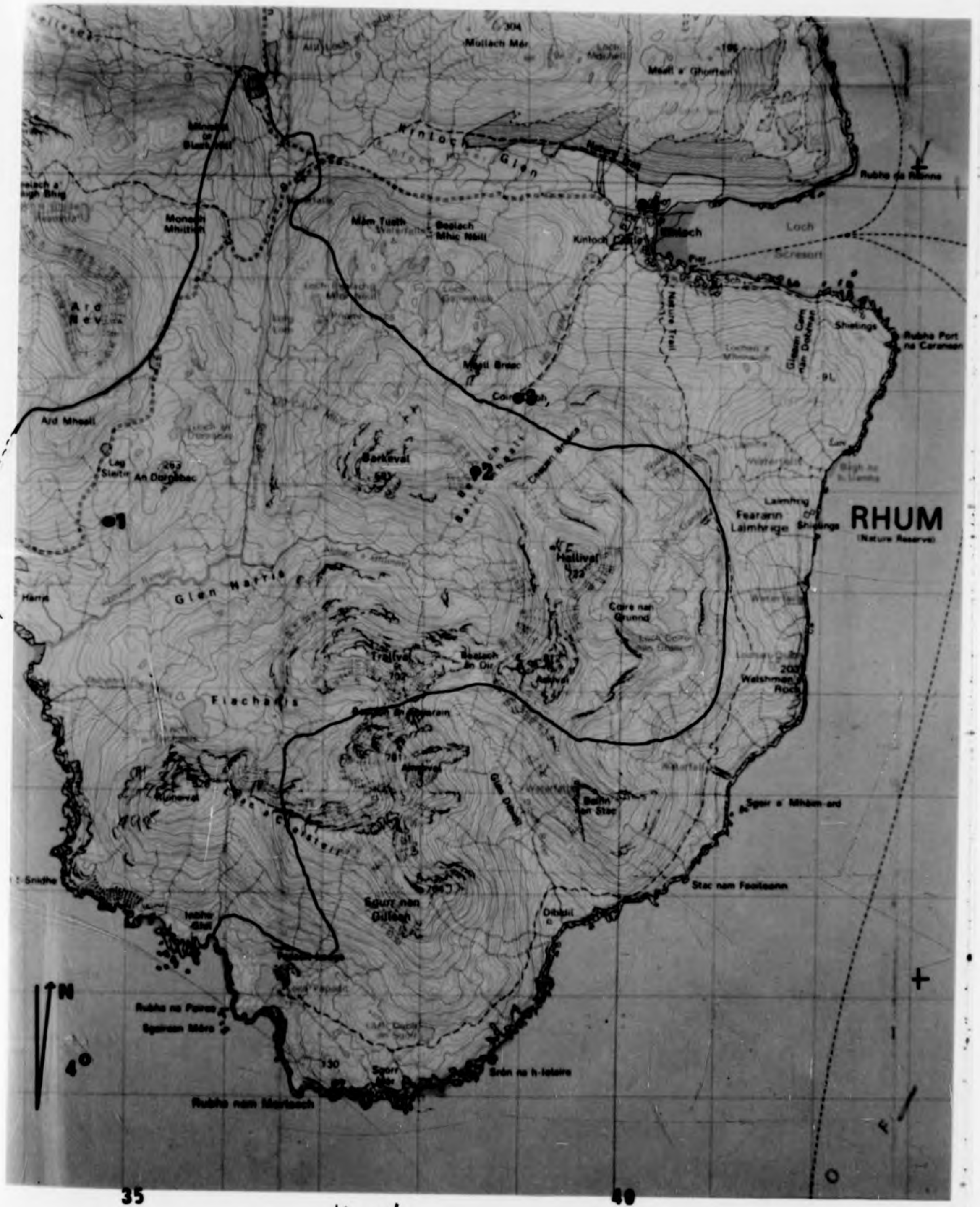

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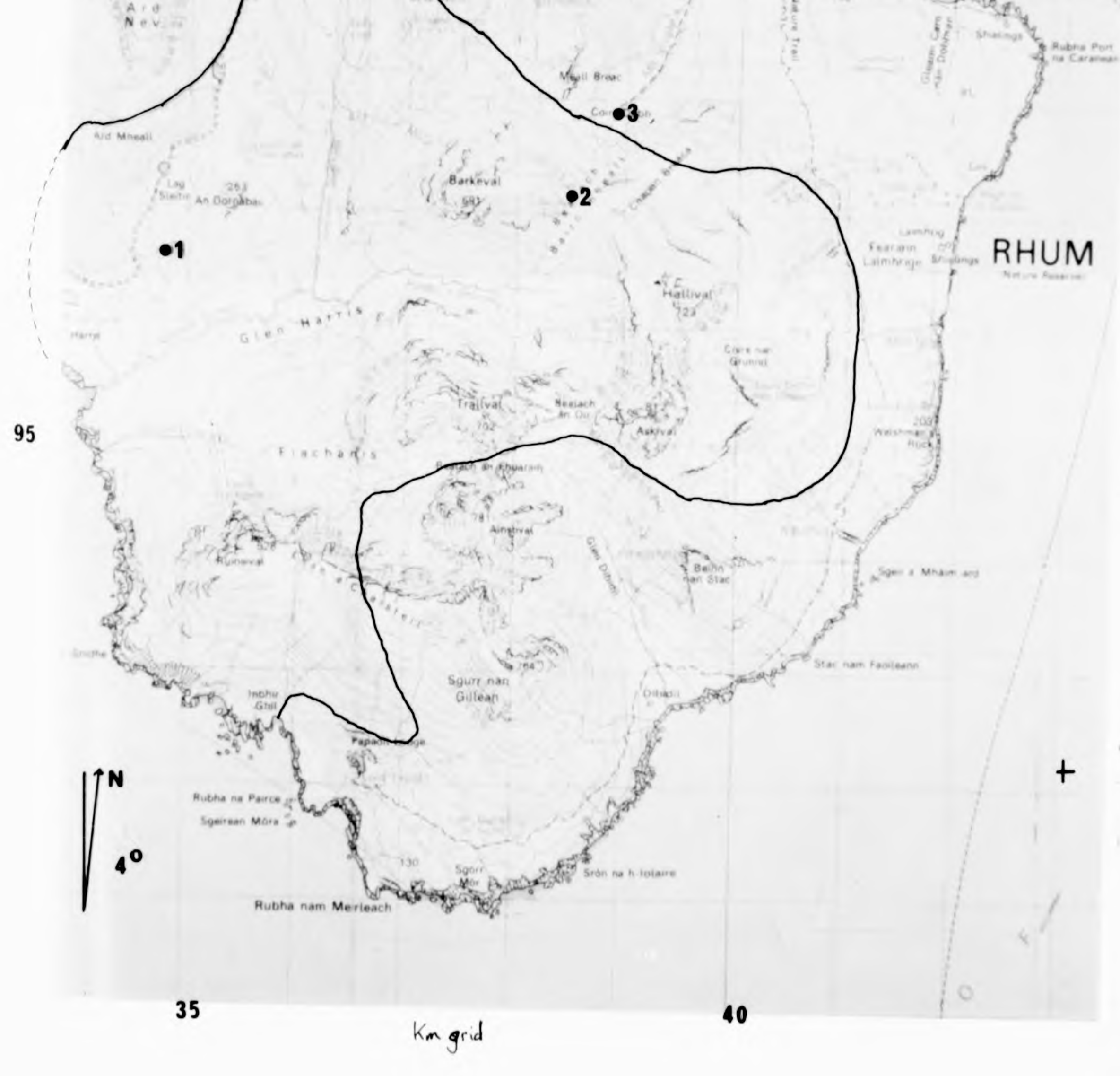
Km grid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Askival
Ainshval
Sgurr nan Gillean
Glen Harris
Fiachanis
Ard Nev
Ard Mheall
Meall Breac
Rubha nam Meirleach
Rubha na Pairce
Sgeirean Mòra
Papadil Lodge
Welshman's Rock
Stac nam Faoileann
Sròn na h-Iolaire
Rubha na Roinne
Mullach Mòr
Meall a' Ghoirtein
Mam Tuath
Bealach Mhic Nèill
Kinloch Castle
Rubha Port na Caranean
Lag Sleitir
An Dorneabai
Beinn nan Stac
Bealach An Oir
Bealach an Fhuarain
Ruineval
Dibidil
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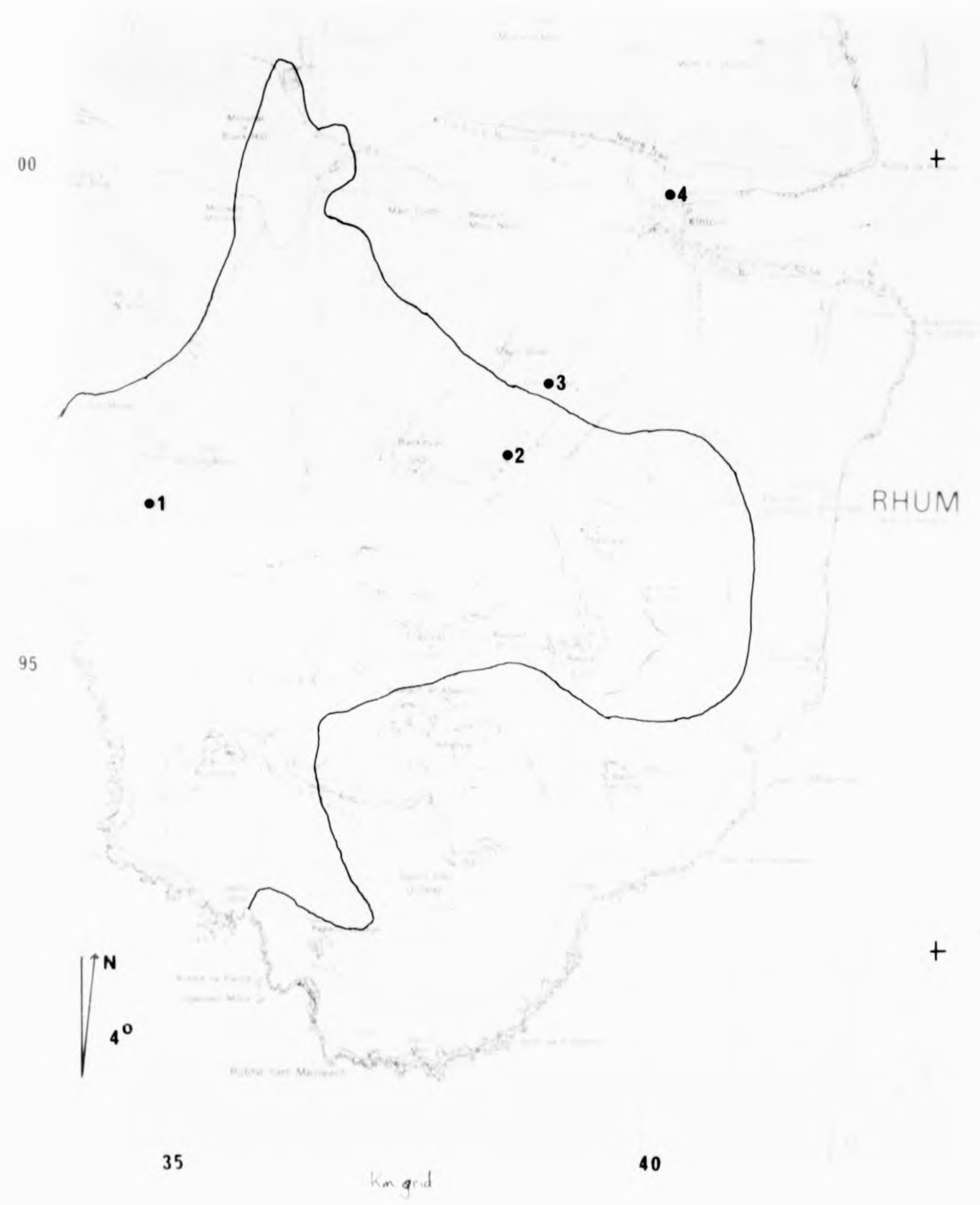
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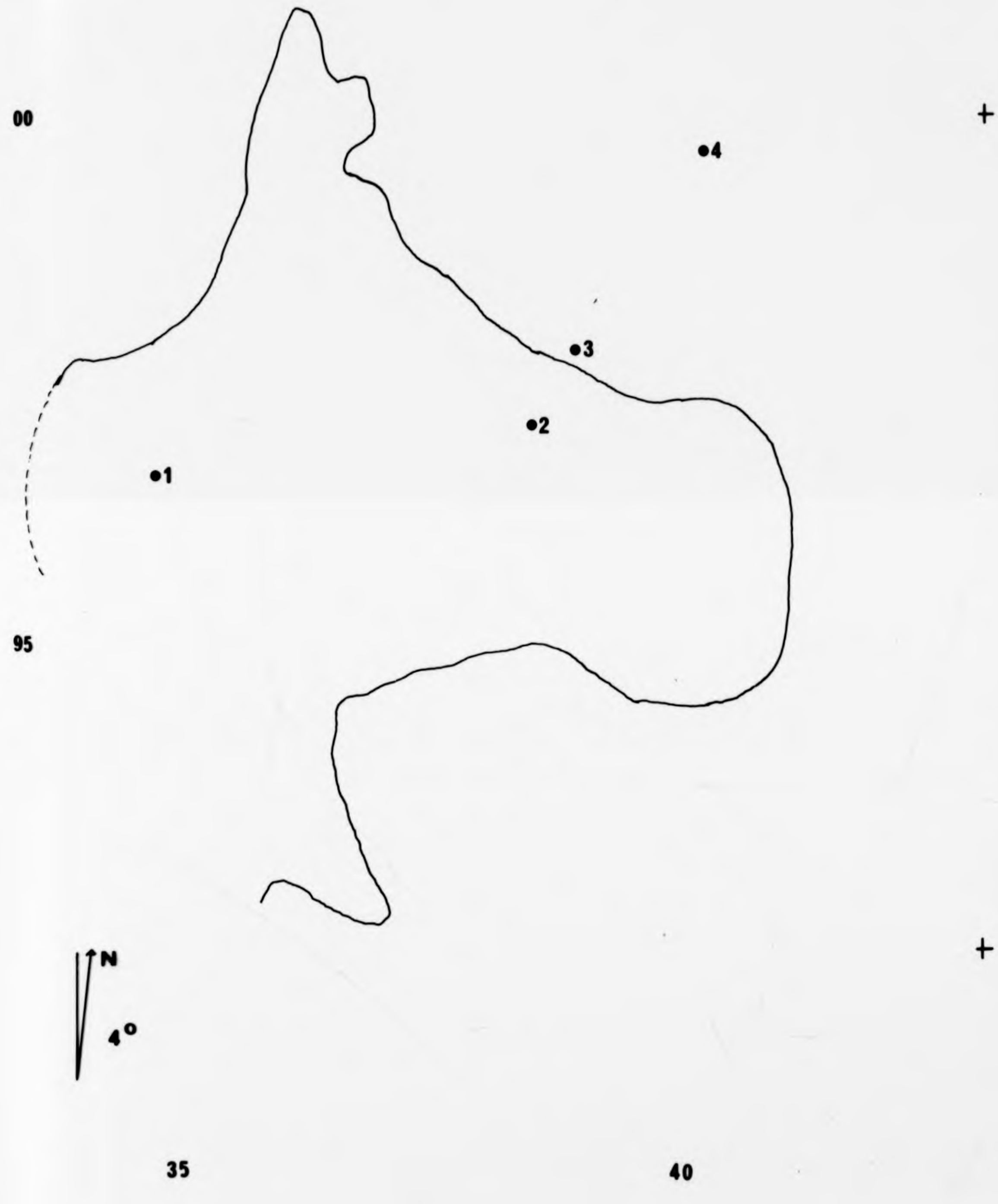
•4
N
4°
35
40
Km grid


00
95
35
40
1
2
3
4
N
4°


Mullach Mór
Kinloch Glen
Monadh Mhiltich
Mam Tuath
Bealach Mhic Néill
Kinloch
Loch Scresort
Nature Trail
Shielings
Coire Dubh
Barkeval
Ard Mheall
Glen Harris
Harris
Hallival
Trallval
Askival
Fiachanis
Sgurr nan Gillean
Stac nam Faoileann
Walshman Rock
Fearann Laimhrige
RHUM
(Nature Reserve)
Rubha nam Meirleach
Sgeirean Móra
Papadil Lodge
Dibidil

Km grid


RHUM
Kinloch
Minishal or Black Hill
Monadh Mhiltich
Ard Nev
Ard Mheall
Glen Harris
Harris
Barkeval
Hallival
Askival
Trallval
Sgurr nan Gillean
Papadil Lodge
Rubha na Pairce
Rubha nam Meirleach
Sròn na h Iolaire

Km grid


RHUM

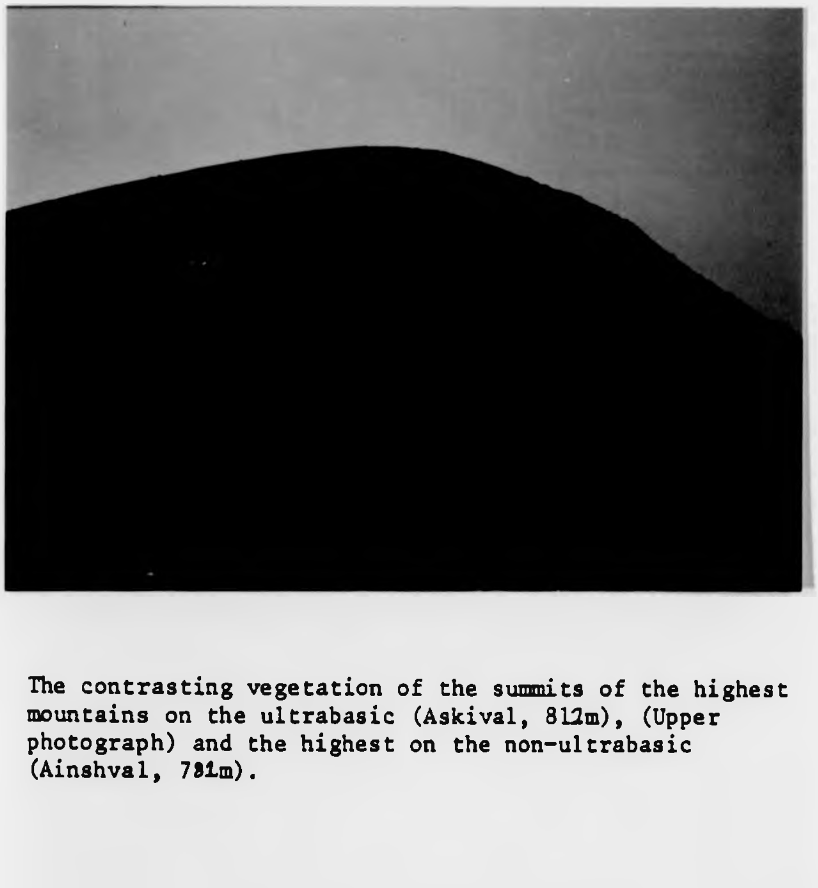


Fig. 2.1.1:2. The contrasting vegetation of the summits of the highest mountains on the ultrabasic (Askival, 812m), (Upper photograph) and the highest on the non-ultrabasic (Ainshval, 781m).

Fig. 2.1.1:2. The contrasting vegetation of the summits of the highest mountains on the ultrabasic (Askival, 812m), (Upper photograph) and the highest on the non-ultrabasic (Ainshval, 781m).

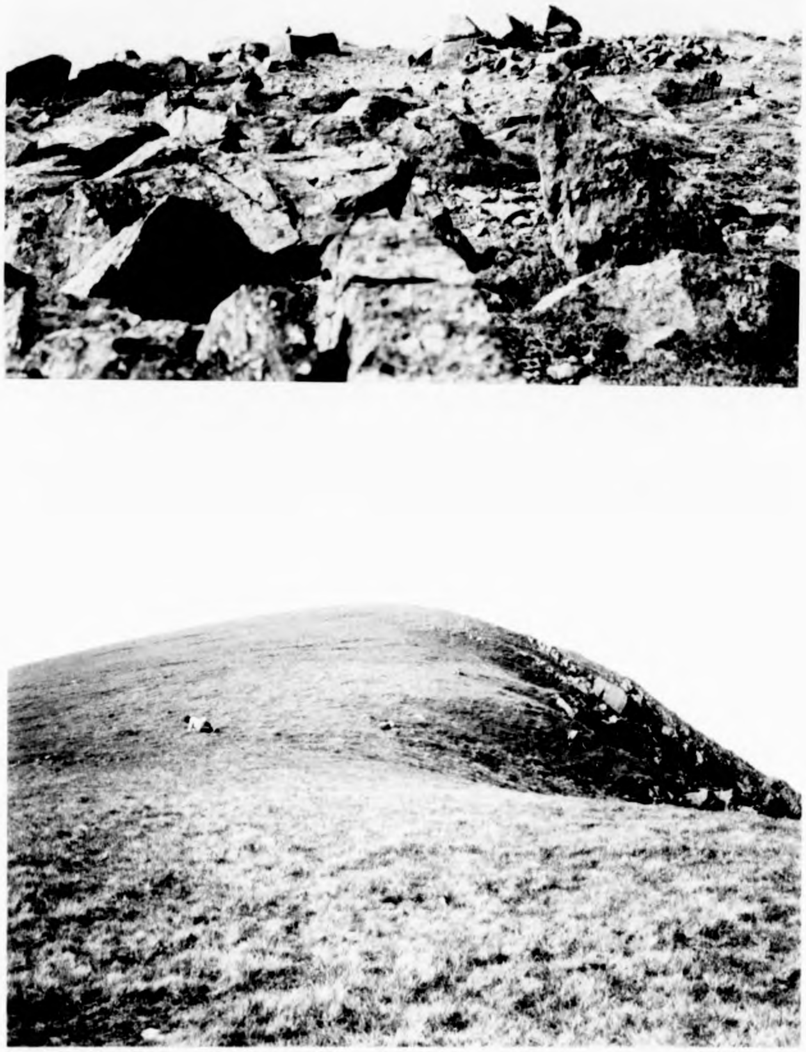


Fig. 2.1.1:2. The contrasting vegetation of the summits of the highest mountains on the ultrabasic (Askival, 812m), (Upper photograph) and the highest on the non-ultrabasic (Ainshval, 781m).

factors was considered unlikely to occur at the 10m scale across so many and such diverse areas. At each position on the transect, a soil sample (10x10x10cm) was taken, after removing surface vegetation and loose surface stones, and the vegetation was described using a 1x1m quadrat. The 1x1m quadrats were located along the transect with the soil sample in the top left corner. Each individual soil and vegetation sample is henceforth referred to by its quadrat number. Table 2.1.1:1 summarises the major features of each transect together with the intensity of sampling. Transects 1 to 4 were established in October, 1979 and the others in May-August 1980. Transects 2, 12, 19 and 29 have soils which possibly developed from more than one parent material, whilst transect 13 is located on glacial till which is derived mainly from periodotite and other ultrabasic rocks.

Kershaw (1973) and Mueller-Dombois & Ellenberg (1974) emphasise that the method of vegetation description chosen must be one that best suits the objectives of the research. For this study, the Domin Scale (Table 2.1.1:2) of cover abundance was adopted because it enables easy comparisons between different areas, conveys more quantitative information than the simple presence/absence method and is not as likely to overlook species with low cover/abundance, or is as time-consuming, as the point quadrat approach. This last consideration is important in view of the remote working conditions of Rhum. (All data were recorded by myself so any personal bias in assessing cover abundance will be consistent).

A 1x1m quadrat was chosen for the vegetation description so that whilst it was near the minimal area recommended for grasslands and heaths (Mueller-Dombois & Ellenberg 1974) it would be most representative of the local soil sample. A larger quadrat would be too laborious to record and more than one soil value would be needed to cater for the increased soil heterogeneity. Species identification and Domin numbers for every quadrat were checked twice, once by J. Proctor, after the first

Table 2.1.1:1 The number of quadrats, the location, and some features of the transects

Transect No.	Quadrat No.	National Grid Reference (All NM)	Underlying Parent Rock*	Altitude (Meters)	Overall Slope (Degrees)	Overall Aspect
1	1-10	394959	H	595	5	W
2	11-20	401962	H?P	375	5	SE
3	21-30	379972	G	570	5	E
4	31-40	387971	P	470	5	SE,NW**
5	41-50	397953	P	570	0	E
6	51-60	388974	P	350	20	NE
7	61-70	361939	P	440	5	E
8	71-80	356940	P	520	5	S
9	81-90	354947	UB	215	10	N
10	91-100	368959	D	200	0	W
11	101-110	341972	P	250	15	SW
12	111-120	361945	P?D	240	20	N
13	121-130	369948	GT	330	10	SW
14	131-140	372946	L	365	15	NW
15	141-150	367949	G	335	5	S
16	151-160	383953	G	520	10	S
17	161-170	378932	F	700	10	SW
18	171-180	369936	L	610	10	SW
19	181-190	371942	F?L	400	10	S
20	191-200	372954	P	610	5	NW
21	201-205	369953	P	520	10	W
22	211-215	378948	P	505	20	S
23	221-225	378941	F	745	5	S
24	231-240	382978	P	380	10	NE
25	241-250	386981	F	365	5	NW
26	251-260	360935	S	380	20	S
27	261-265	365932	P	420	25	W
28	271-280	361938	UB	425	5	SE
29	281-285	369972	P?UB	300	5	W
30	291-295	352967	P	200	5	S
31	301-310	372959	UB	290	10	W
32	311-315	378948	G	505	20	W

* H=Hallivalite P=Peridotite G=Gabbro UB=Ultrabasic Breccia D=Dunite GT=Glacial Till L=Lewisian Gneiss F=Felsite S=Serpentinized Peridotite and Dunite ? = Uncertain

** Transect crossed depression and aspect changed

Table 2.1.1:2 The Domin scale and its transformation (Bannister 1966)

	Domin scale	Transformed value
COVER about 100%	10	8.4
COVER 75-95%	9	7.4
COVER 50-75%	8	5.9
COVER 33-50%	7	4.6
COVER 25-33%	6	3.9
ABUNDANT , COVER about 20%	5	3.0
ABUNDANT , COVER about 5%	4	2.6
SCATTERED , COVER SMALL	3	0.9
VERY SCATTERED , COVER SMALL	2	0.4
SCARCE , COVER SMALL	1	0.2
ONE INDIVIDUAL , COVER SMALL	+	0.04

recording between April and August 1980 and May and September 1981. Some difficult identifications were confirmed on glasshouse grown material.

The nomenclature for higher plants follows Clapham, Tutin & Warburg (1962); for bryophytes, Watson (1968); and for lichens, Hawksworth, James and Coppins (1980).

2.1.2 Multivariate techniques

The large amount of data from the vegetation description was analysed by multivariate statistical methods. Greig-Smith (1980) argues that, especially for poorly known vegetation, these approaches reduce the complexity of the data to a manageable form, from which important inter-relationships can be highlighted. Gauch (1982) points out that they summarise the data and allow for an objective interpretation.

Gauch (1982); Hill & Gauch (1980); Clymo (1980), Gauch & Whittaker (1981), Gauch, Whittaker & Singer (1981), and Prentice (1977) have discussed the relative merits of different multivariate methods. The most satisfactory methods for this research, and those I have used, are the polythetic divisive method, TWINSPAN (Hill 1979a) for classification, and the improved reciprocal averaging, DECORANA (Hill 1979b) for ordination. The two techniques are similar, as TWINSPAN is based on two-way ordination space partitioning repeated at each level of the hierarchy on the basis of a fresh ordination axis.

While ordination was the primary multivariate technique for the analysis, to highlight the important inter-relationships, classification was used to identify vegetation classes. Vegetation data are often amenable to either method, but more recently Gauch & Whittaker (1981) recommend an integrated approach, which benefits from both techniques and aims at arranging classes along gradients. Classification is discussed first because the classes are later related to the ordination and the edaphic factors.

TWINSPAN (Two-way Indicator Species Analysis) is an improvement of the indicator species analysis proposed by Hill, Bunce & Shaw (1975). It differs in its approach, in that the indicator analysis in TWINSPAN is supplementary to the classification (two-way ordination space partitioning), and is not the major classification. TWINSPAN has been shown to be generally superior to most other classification techniques (Gauch & Whittaker 1981). It is flexible in its implementation, robust to data editing, random variation and outliers, and effective in extracting relationships. The classes were not determined to be interpreted as true vegetation classes in the sense of Braun-Blanquet (Poore 1955 , 1956; Moore 1962); but to help clarify relationships between the vegetation distribution and the edaphic variables.

DECORANA (Detrended Correspondence Analysis) is an improvement of the reciprocal averaging method of ordination (Hill 1973) that corrects two major faults in the original method of Hill (1973). These are the arch effect and the compression of the ends of the ordination axes. DECORANA's superiority over reciprocal averaging, principal components analysis and non-metric multi-dimensional scaling has been discussed by Hill and Gauch (1980), Gauch (1982) and Gauch et al. (1981). The ordination axes were used to interpret the relationships between the vegetation classes and the edaphic and environmental variables.

2.2 Classification by TWINSPAN

2.2.1 Introduction

The exact form of analyses by TWINSPAN is controlled by several input parameters to the program. Those recommended by Hill (1979a) were followed with slight operating modifications.

The data were stored as couplets of species numbers and transformed Domin values (Table 2.1.1:2). (TWINSPAN did not require this transformation as it is flexible for input, but as the same data matrix was utilized in the ordination this facilitated computing). All the vegetation data from the 283 quadrats (285 quadrats were sampled, but one had no vegetation and another became a footpath) are recorded in Appendices I and II. The Domin scale expressed species abundance and cover on a "logarithmic-type" scale, which are expressed in a linear relationship by the use of Bannister's transformed values (1966). The transformation combined with the pseudospecies cut levels of TWINSPAN (see below) allowed the data to be classified with emphasis on presence and absence, but incorporating some quantitative information.

Five cut levels of pseudospecies were used, as recommended, but the numbers defining each level were changed. Hill's (1979a) recommended values are for percent cover (0.00,0.02,0.05,0.10,0.20) and I chose values from the transformed Domin range (0.0, 0.4,0.9,2.6,3.0) to correspond to these recommended values. Pseudospecies cut levels allow the amount of a particular species in a quadrat to be used semi-quantitatively in the classification, by creating pseudospecies at the cut levels, and then qualititatively classifying the stands on the presence and absence of the pseudospecies. Hill (1979a), uses an example to help clarify this: Stand 1 has species A at 25% cover and Stand 2 has species A at 15% cover; therefore with pseudospecies cut levels of 0 and 20%, Stand 1 has Species A*1 and Species A*2 while Stand 2 only has Species A*1; a qualitative difference expressing quantitative information). As Hill (1979a) recommended, these levels were chosen to "reflect typical values of abundance, present, a little, a lot, and more or less dominant".

The other input parameters were set to the normal values, three of which need further explanation. All the pseudospecies cut levels were given equal weighting so that dominant species were not over-emphasised nor were rare species given more than their normal downweighting. All the pseudospecies cut levels were given equal potential as indicator species, which allows pseudospecies to be used as indicators in addition to real species. Finally no species was prevented from potentially being an indicator in the classification.

2.2.2 Results

The classes in TWINSPAN's hierarchical classification are formed by the successive objective division of refined polarized ordinations. There is no fully objective criterion for deciding at which level in the hierarchy to stop the classification dichotomy, and therefore this must be done by interpreting the classes formed. The classes I accepted are at different levels of the classification for the two main branches, (Fig. 2.2.2:1 and Table 2.2.2:1) reflecting the unevenness of the division at the first level. It is noteworthy that so many of the non-ultrabasic quadrats were separated from the ultrabasic quadrats in one branch at the first level.

The classes were accepted upon criteria discussed below, which were also supported by the ordination results (sections 2.3 and 2.4). The species by stands two-way table, produced by the classification, is shown in Appendix X.

The large number of quadrats and the possible number of classes produced after six levels (maximum possible is sixty-four), made the decision of which classes to accept complex. The criteria used to select the classes were: class size; whether the class could be split successfully; preference (mine) to stay within a classification level; the number of classes; the indicator and preferential species for each class; and an assessment of the stands in each class from field experience. The species classification was also used in the class selection, but its information was largely included in the preferential species.

The smallestclass TWINSPAN will create is set to five stands (or species). Classes 2 and 4 have n = 8 and are the smallest classes accepted. Connected with the acceptance of a class by its size is whether

FIGURE 2.2.2:1 Hierarchy of the TWINSPAN classification of the vegetation samples on Rhum. (n=283)

Group numbers and indicator species with pseudospecies cut levels (underlined) at each level of the classification, using abbreviations of the species names in Appendix II. Species listed in order of importance at each level.(*=no indicators)

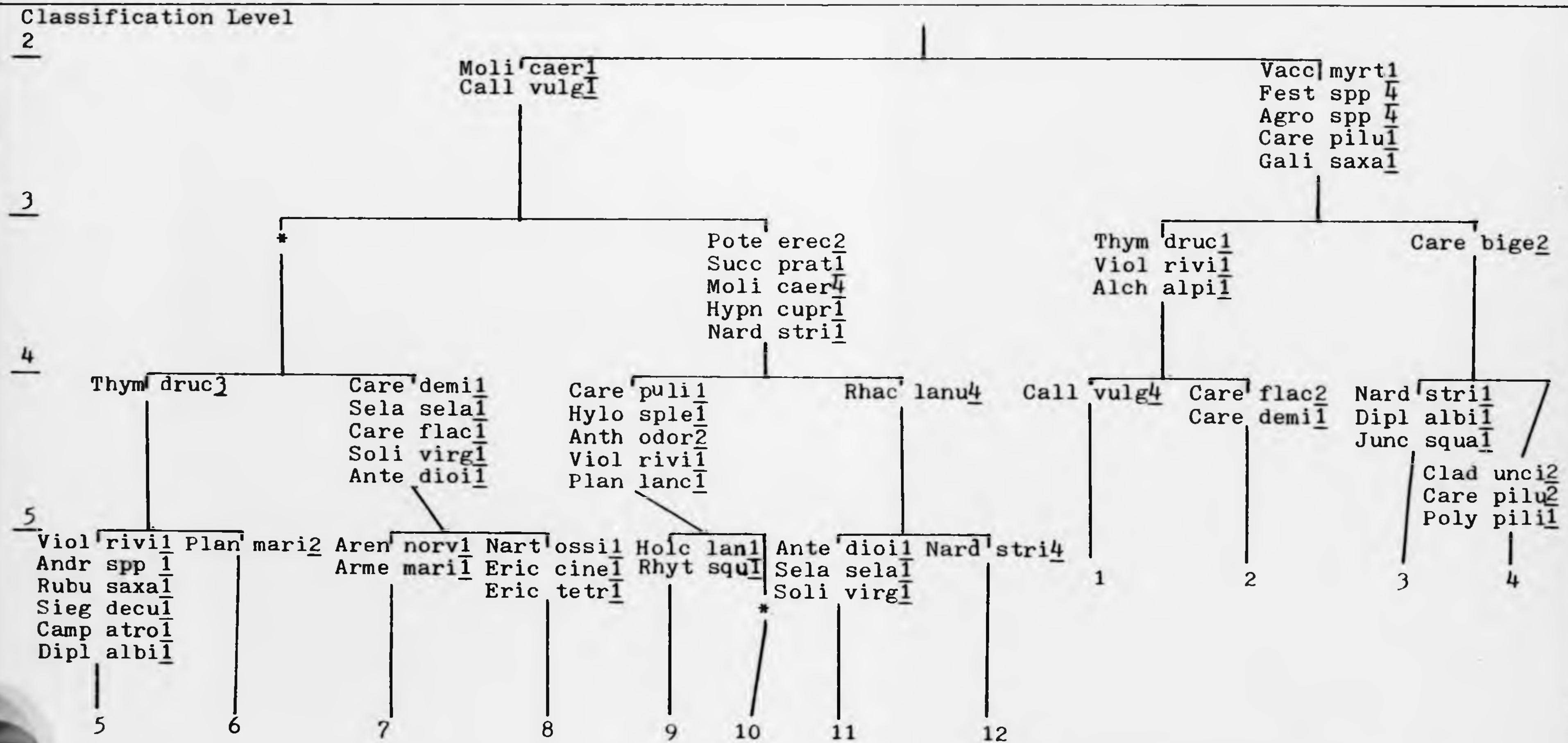


Table 2.2.2:1 TWINSPAN vegetation classes and quadrats.

Class No.	(n)	Quadrats*
1	(19)	152-160,164 166 168 169 170,198,211-214
2	(8)	2 7 10,311-315
3	(14)	28,171-177,184,221-225
4	(8)	161-163 165 167,178-180
5	(29)	4 6,17,22 30,32 34 40,58,151,191-197 199 200, 201-205,215,231 234 236,279
6	(21)	5,31 33 35-39,41-50,271 274 276
7	(45)	3,11 12 14,26,61 62 64-66 68-70,71-73 77-80,85 86,125 127 129,239 240,251 254-260,261-265,272 273 275 277 280
8	(28)	13 15 16 18-20,55,88 90,91 92 94-97 99 100,121-123 126 130,141,252 253,278,301 308
9	(12)	101-110,285,295
10	(28)	9,21 23 27,52,67,74-76,111-120,140,237 238,281 282,291-294
11	(28)	25,51 56 57 59 60,63,87 89,93 98,124 128,144 148 149,232 233 235,248,302-307 309 310
12	(43)	8,24,53 54,81-84,131-139,142 143 145-147 150, 181-183 185-190,241-247 249 250,283 284

* spaces separate quadrats in the same transect , commas separate quadrats in different transects.

it could be divided successfully. When a class is divided, if it produces a new class that is "unsuccessful" ($n<5$), then preference would be to accept the original class before division. This results, as mentioned above, in the accepted levels of classification differing for the two main branches. While, initially, one level was preferred for all classes, the two branches were interpreted at different levels because of the uneven division at the first level ($n = 234$ and $n = 49$). The number of classes was initially expected to be about sixteen (i.e. up to level 5 of the classification), but the final arrangement is intermediate to levels 4 and 5 of the classification.

The interpretation of the classes by their indicator and preferential species, and the stands in each class is both more involved and more subjective than implementing the other criteria. The species classification may be considered with the indicator and preferential species, and these are discussed in Section 2.2.3.

The assessment of the classes by the quadrats in them was used only to confirm how consistently neighbouring quadrats were classified together. The quadrats in the same transect fell into the same class (Table 2.2.2:1); with the transects being broken into subsets of several quadrats more often than single quadrats.

The first run of the DECORANA ordination showed no outlying quadrats (in the sense of Gauch 1982) though several were located at relatively large distances from the median position of their class. The omission of these quadrats from the data did not alter the classification down to the fourth level (Sections 2.3 and 2.4), nor did it alter the accepted groups at the fifth level, nor did it change the ordination significantly.

Whilst running TWINSPAN on the vegetation data set, several minor programming operating errors were discovered in the version loaded at Stirling. The results are, however, reported from this analysis. Later, it was possible to reanalyse the data set on another implementation of the TWINSPAN package at the Manchester Regional Computing Centre. The results for the two analyses were very similar with 14 quadrats changing classes in the 12 classes accepted. It is significant that every one of the 14 quadrats were reported by the program as either "mis-classified" or "borderline". Of slightly more importance was a change in the order of the species classification and several of the indicator species for the classes. However, since preferential species were used in the interpretation of the classes the results were exactly the same. Because the two analyses were so similar, with no important differences, the first analysis, from Stirling, is reported here.

2.2.3 Discussion

The 12 classes from the TWINSPAN classification were compared with described plant Associations and communities (Ferreira 1970, 1974; McVean & Ratcliffe 1962; Birks 1973; and Spence 1970). With the exception of the very barren Class 6, all other classes fit fairly well into accepted communities. (Table 2.2.3: 3). Class 8 is intermediate between several communities.

The indicator species (Fig. 2.2.2:1) and the 'preferential' species (>57% frequency, Table 2.2.3:1, equivalent to Constancy Classes IV and V), with reference to the general geological origin of the soil, were used to characterise each class and to identify the plant-communities. Further characteristics of the vegetation classes were used in the comparisons between the plant communities (Table 2.2.3:2).

The species classification was of additional use in determining which species were consistently represented in a class. However, the classes formed by the species classification were ordered by TWINSPAN to fit the species and stands two-way table (Appendix X), and did not always pertain to the stand (quadrat) class with the same number. This

TABLE 2.2.3:1 Percent Frequency of all Species with Frequency > 57% (50% for n < 9) in the Twelve TWINSPAN Vegetation Classes.

(Using abbreviations of the species names in Appendix II)

Species	Class Number 1	2	3	4	5	6	7	8	9	10	11	12
Agro spp	100	100	93	100	69	90	89	68	75	100	71	70
Alch alpi	79	75	-	-	-	-	-	-	-	-	-	-
Ante dioi	-	-	-	-	-	-	-	61	-	-	82	-
Anth odor	-	75	-	-	-	-	-	-	100	82	-	-
Call vulg	68	-	-	-	100	-	62	89	75	100	96	100
Care bige	-	-	86	100	-	-	-	-	-	-	-	-
C. demi	-	75	-	-	-	-	93	68	-	-	61	-
C. flac	-	88	-	63	-	-	67	-	92	82	-	88
C. pilu	84	-	57	63	-	-	-	-	-	-	-	-
C. puli	-	-	-	-	-	-	-	-	100	82	-	-
Desc cesp	-	63	-	-	-	-	-	-	-	-	-	-
D. flex	100	-	-	50	93	-	-	-	-	-	-	-
Eric cine	-	-	-	-	-	-	-	-	-	-	75	67
E. tetr	-	-	-	-	-	-	-	-	58	-	64	-
Euph spp	-	75	-	-	-	-	-	-	-	57	-	-
Fest spp	100	100	71	100	97	100	93	82	67	93	61	-
Gali saxa	-	-	93	100	-	-	-	-	-	-	-	-
Holc lana	-	-	-	-	-	-	-	-	75	-	-	-
Luzu camp	-	-	-	50	-	-	-	-	-	-	-	-
L. sylv	-	-	57	-	-	-	-	-	-	-	-	-
Moli caer	-	-	-	-	-	-	67	100	100	86	93	93
Nard stri	-	50	79	-	-	-	-	-	58	71	-	88
Nart ossi	-	-	-	-	-	-	-	64	-	-	75	56
Pedi sylv	-	-	-	-	-	-	-	-	75	-	-	-
Plan lanc	-	-	-	-	-	-	-	-	58	-	-	-
P. mari	-	-	-	-	-	90	84	75	-	-	-	-
Pote erec	74	100	93	100	-	-	-	-	100	100	89	98
Sela sela	-	-	-	-	-	-	58	-	-	57	71	-
Succ prat	-	-	-	-	-	-	-	-	100	71	71	84
Thym druc	95	100	-	-	93	86	84	93	-	96	89	-
Tric cesp	-	-	-	-	-	-	-	-	-	-	68	100
Vacc myrt	68	100	93	100	-	-	-	-	-	-	-	-
Viol rivi	84	100	-	-	83	-	-	-	92	100	68	-
Andr spp	-	-	-	-	62	-	-	-	-	-	-	-
Dipl albi	-	-	57	-	-	-	-	-	-	-	-	-
Hylo sple	-	50	-	-	-	-	-	-	92	79	-	-
Hypn cupr	58	100	79	88	-	-	-	-	92	100	-	79
Poly comm	-	-	64	-	-	-	-	-	-	-	-	-
P. pili	58	50	-	50	-	-	-	-	-	-	-	-
Rhac lanu	100	100	93	100	93	86	73	86	-	79	100	98
Rhyt squa	-	-	-	-	-	-	-	-	83	-	-	-
Clad unci	79	-	-	88	-	-	-	-	-	-	-	-

Table 2.2.3:2 The class means (with transformed standard deviations or standard errors) for the slope, aspect, altitude, no. of species in each quadrat, sum of the transformed domin no.s (A) for all species in each quadrat, and the transformed domin no. (B) for bare ground in each quadrat for the twelve TWINSPAN vegetation classes.

Class	Slope (degrees)	Aspect # (degrees)	Altitude (metres)	No. Species in each Quadrat	(A)	(B)
1 (n=19)	6.1 (1.8,0.9)	288 ***	564 (6.3,0.1)	17.5 (2.9,0.2)	31.9 + (5.7,0.8)	2.5 (0.4)
2 (n=8)	8.6 (2.2,0.9)	180 **	539 (16.5)	20.0 (0.5)	29.7 (3.4,0.2)	0.7 + (0.8,0.7)
3 (n=14)	4.1 (1.4,0.5)	245 ***	640 (26.1)	16.9 (1.5)	28.8 (3.1)	0.2 + (0.5,1.0)
4 (n=8)	10.0 (1.9)	225 ***	666 (16.5)	14.0 (0.5)	32.2 (2.2)	0.1 + (0.4,0.6)
5 (n=29)	3.6 (1.3,0.7)	42 *	522 (16.2)	11.5 (2.4,0.4)	11.5 + (3.4,1.1)	6.0 (0.3)
6 (n=21)	1.9 (0.2)	18 ***	514 (6.2,0.1)	6.8 (0.5)	6.1 (0.8)	6.8 (0.3)
7 (n=45)	4.2 (1.4,1.0)	281 **	420 (11.4)	13.7 (0.8)	9.2 + (3.0,1.2)	6.7 (0.3)
8 (n=28)	3.1 (1.1,0.7)	223 ns	299 (14.8)	14.2 (0.7)	9.1 (0.9)	7.1 (0.3)
9 (n=12)	8.2 (2.1,0.6)	227 ***	250 (6.2)	20.1 (1.2)	26.2 (3.3,0.2)	0.0 (0.0)
10 (n=28)	5.7 + (2.4,0.7)	78 *	318 (5.8,0.4)	24.6 (0.8)	32.3 (1.2)	1.8 (0.4)
11 (n=28)	5.0 (1.6,0.9)	113 **	316 (5.8,0.2)	19.6 (0.9)	23.1 (1.6)	4.2 (0.4)
12 (n=43)	7.3 (0.5)	158 **	357 + (18.9,1.9)	17.1 (2.8,0.2)	30.0 (1.0)	0.6 + (0.8,0.9)

The type of mean given depends on the normality of the data. Arithmetic means are given with a single value in parenthesis for standard error. Geometric means arising from log (base e) and square root transformations (the latter indicated by +) are given values with in parenthesis for the transformed mean followed by the transformed standard deviation.

For Aspect mean is determined after Gaile et al. (1980).
* $p<0.05$, ** $p<0.01$, *** $p<0.001$ significance levels for the mean values.
ns = not significant
Convention used : East = 0 , North = 90 , West = 180 , South = 270 .

Table 2.2.3:3 Plant communities, from several authors, which most closely correspond to the twelve TWINSPAN vegetation classes.

Class No.	Ferreira (1974)	McVean & Ratcliffe (1962)	Birks (1973)	Spence (1970)
1	Herb-rich Vaccinium-Calluna heath (1)	Vaccineto-Callunetum hepaticosum		-
2	Nardus grassland (2)	Low alpine Nardus-Pleurozium nodum & Nardus-Rhacomitrium provisional nodum (2)	Cariceto-Rhacomitretum lanuginosi-typicum (2)	-
3	Nardus Juncus squarrosus Bog (3)	Juncus squarrosus Bog (3)	Nardo-Juncetum squarrosi (3)	-
4	Rhacomitrium-Festuca-Vaccinium grassland	Festuceto-Vaccinetum Rhacomitrosum &/or Cariceto-Rhacomitretum lanuginosi (4)	Alchemilla alpina-Vaccinium myrtillus nodum	-
5	-	-	-	Festuca vivipara Juncus trifidus L. open sociation (5)
6 (6)	-	-	-	-
7	-	-	-	Arenaria norvegica Gunn. Cardaminopsis petraea (L.) Hiit. sociation (7)
8 (8)	-	-	-	-
9	Species-rich Agrostis-Festuca grassland (9)	Agrosto-Festucetum (9)		-
10	Herb-rich Calluna heath facies on Mg-rich soils (10)	Herb-rich facies of Callunetum vulgaris (10)	Calluna vulgaris Sieglingia decumbens assoc.(10)	-
11	Calluna-Tricophorum-Molinia Heath (11)	Trichophoreto-Callunetum & Molineto-Callunetium	Molinieto-Callunetum	-
12	Rhacomitrium-Calluna Heath (11)	Trichophoreto-Callunetum & Molineto-Callunetium.	Rhacomitreto-Callunetum	-

For footnotes see next page.

Table 2.2.3:3 .Footnotes

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(1) My class lacks Empe. spp.
(2) My class lacks Care. bige. and Tric. cesp.
(3) My class has a frequency of only 50% for Junc. squa.
(4) My class is intermediate to the two communities.
(5) Spence (1970) notes that on Hallival (on Rhum) Desc. flex. is more common then Fest. vivi.(spp.), which is true for my class.
(6) Class 6 is barren and is not a recognized community; Call. vulg., Plan. mari., Thym. druc., Rhac. lanu., Agro. spp.,and Fest. spp. are the only frequent species.
(7) My class did not have Card. petr. in the quadrats, but it was nearby. Also Desc. flex. was less frequent for my class and Care. demi. and Care. flac. were more frequent.
(8) Class 8 is intermediate between Classes 5 to 7 and 9 to 12.
(9) My class has less frequent Sieg. decu. and more frequent Moli. caer. and Holc. lana.
(10) My class has Sieg. decu. less frequently.
(11) Classes 11 & 12 are intermediate between the two communities, but are listed by the community to which they are most similar.

was probably due to the presence of more than one apparent gradient in the data (Section 2.4), with the result that the structure of the table was shifted to the right, thereby affecting the class numbers (species). TWINSPAN orders the body of the table on the diagonal from top left to bottom right, but in this data set the diagonal clearly does not include Classes 5-8. Further, in TWINSPAN, species that obviously show a poor relationship to the classification are termed unfaithful (Hill 1979a), and species classified with these can also be interpreted as showing a poor relationship to the classification.

Differences between the 12 TWINSPAN classes and the plant communities from the above authors could be partially attributed to: (i) difference in emphasis in sampling the vegetation; (ii) different quadrat sizes; and (iii) the use of objective instead of subjective methods.

Classes 5 to 8 were not included in the plant communities in Ferreira (1974), McVean & Ratcliffe (1962) and Birks (1973), as they were very barren, although Classes 5 and 7 do generally match those of Spence (1970). These and other discrepancies between my Classes and the described plant communities are in Table 2.2.3:3.

2.3 Ordination by DECORANA

2.3.1 Introduction

Ordination reduces the dimensionality of complex field data into a few dimensions often representing community patterns or environmental gradients that can be interpreted. The vegetation data were the same as those used for the TWINSPAN classification (n=283, Appendix I). All the input parameters of DECORANA were set to the default (standard) analysis.

2.3.2 Results

The eigen values for the ordination axes were: Axis I, 0.408; Axis II, 0.271; Axis III, 0.232; Axis IV, 0.169. Only Axes I-III were used in the interpretation because the eigen value for Axis IV was lower than the other axes. (Gauch 1982). The ordination scores of the quadrats for their first three ordination axes are given in Appendix IV. The ordination of the species for the first three axes are not included since their information is contained in the ordination of the quadrats (by reciprocal averaging, Hill 1973, 1979b). Also the information concerning the species distribution from the species ordination agreed well with the TWINSPAN species classification.

2.3.3 Discussion

The interpretation of the three axes for the ordination of the 283 quadrats was too difficult. Correlation coefficients between the axes and environmental parameters are useful, but with a large number of pairs of values it is a weak statistic. The groups from the TWINSPAN classification were therefore used to reduce the complexity further in a way suggested by Gauch (1982) (Section 2.4).

Overall, Axis I gave the clearest separation of the non-ultrabasic from the ultrabasic quadrats (Appendix XII).

2.4 The relationships of the TWINSPAN Classes to the DECORANA ordination axes.

2.4.1 The relationships for all quadrats.

All quadrats (n=283) were plotted on pairs of the three DECORANA ordination axes and each point was identified by the number of its TWINSPAN class. The classes separated well on the three axes. (Axes I and II are shown with the quadrats plotted by their class numbers in Appendix XI). One axis of the ordination considered alone may appear to illustrate a separation corresponding to a dichotomy found in the classification. However, when the points are located in the three-dimensional space (defined by Axes I-III) a fuller interpretation is possible, especially if there are interactions, between major gradients, which are represented as classes.

There was good agreement between DECORANA and TWINSPAN in the ordering of the quadrats. This was to be expected since the techniques are similar, especially for the calculation of the first axis of the ordination and the first division of the classification. (The small differences that do occur are due to the second polarized ordination performed by the TWINSPAN classification program which reorders the quadrats).

Further agreement is found between the techniques (which is axis separation corresponding to lower dichotomies in the classification). This confirms class similarity of quadrats and between-class differences. This is because while the second and third axes of the DECORANA ordination are orthogonal to the first axis and to each other, in TWINSPAN the successive dichotomies are fresh ordinations on subsets of the original data.

Level 2 in the Classification separates classes 5 to 12 from Classes 1 to 4, and as expected, this is expressed by Axis I of the ordination (Fig. 2.2.2:1 and Appendix XI). Level 3 of the classification further separates Classes 5 to 8 from Classes 9 to 12 and Classes 1 and 2 from Classes 3 and 4, which are primarily expressed by Axis II of the ordination, but improved by Axis I considered simultaneously. It is possible to continue in this manner and determine which of the three axes of the ordination best expresses the dichotomies of the classification but this is too detailed to pursue here.

For several of the classes there were outlying quadrats that distorted the classes' location. These were found to be quadrats with distinct vegetation, that may have been mis-classified.(Hill 1979a). Repetition of the analyses without these quadrats did not alter the ordination or the classification so they were retained. In the demarcation of the classes in Appendix XI they were not included in the classes' 'outline', but are individually ringed. (The outline is a line enclosing all the points of a class).

2.4.2 The relationships between vegetation classes using median values.

As the classes were clearly separated on Axes I to III, median values of each class can be used to express their most typical location on the axes (Table 2.4.2:1). Medians were used rather than means, because while the quadrats in each outlined class (Appendix XI) were approximately normally distributed, there were the few outlying quadrats to consider. Expressing the classes' location as their median value on each of the three axes (Fig. 2.4.2:1) allows the classes' attributes to be more readily interpreted, and is a considerable aid in understanding the data.

2.4.3 Discussion

TWINSPAN produced classes which could be interpreted in terms of plant Associations and communities already described. These classes were shown to be clearly distinct on the first three DECORANA ordination axes, and to be similarly related to each other by the two techniques.

To investigate the relationships between the general environmental parameters mentioned so far and the ordering of the classes along the ordination axes, Spearman's rank correlation coefficient (r_s) was computed (n=12) for the following variables taken in pairs: the axes with slope, altitude, the number of species per quadrat, the sum of the transformed Domin numbers for all species in each quadrat, and the

Table 2.4.2:1

The median values of the co-ordinate positions for Axes I-III for the twelve TWINSPAN vegetation classes.

Class No.	Axis I	Axis II	Axis II
1	203	206	146
2	203	156	96
3	273	81	158
4	271	165	139
5	155	228	167
6	184	258	88
7	113	237	91
8	76	209	168
9	29	68	60
10	86	133	104
11	66	171	196
12	90	106	195

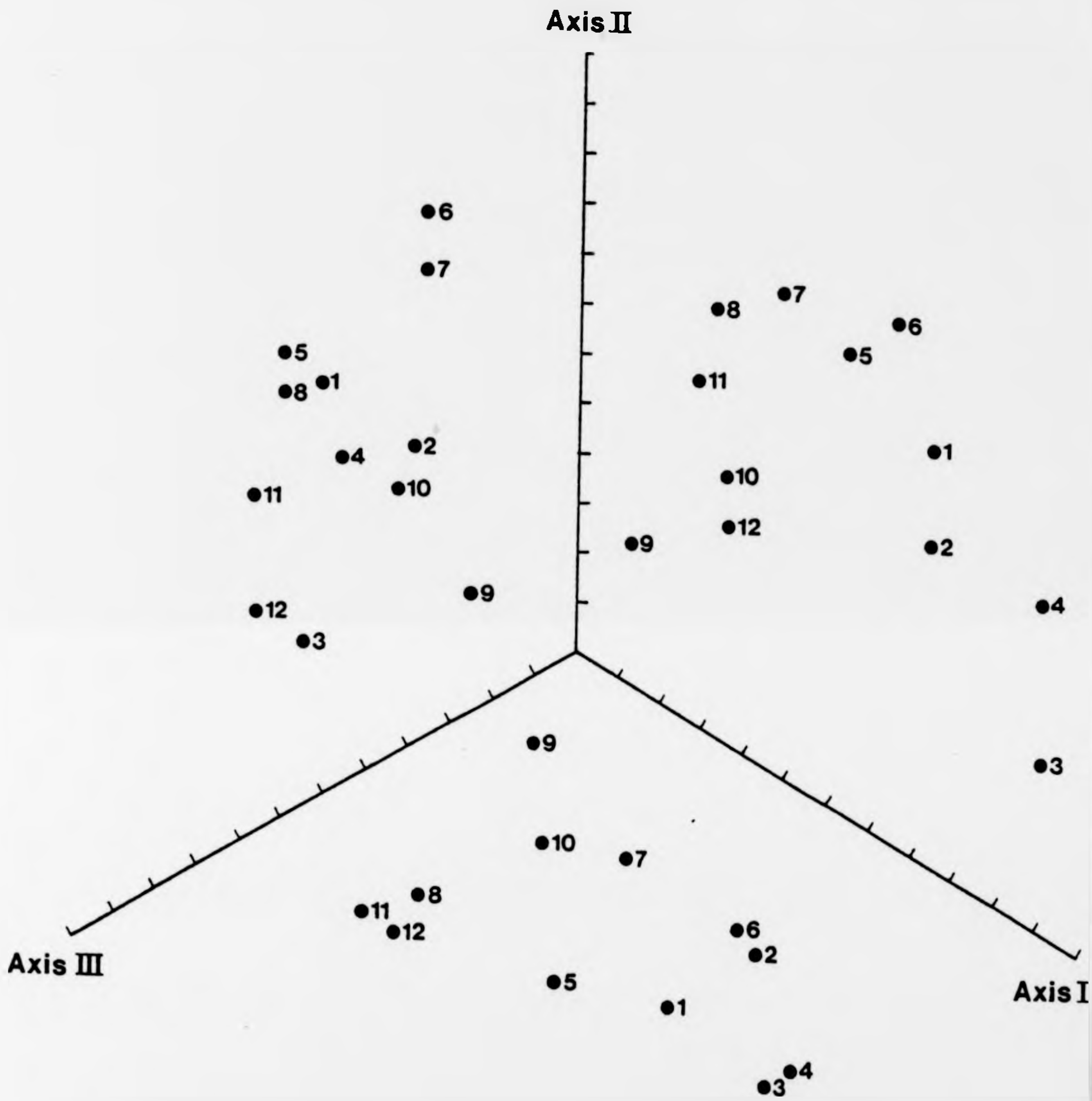


Fig. 2.4.2:1. The median locations of the twelve TWINSPAN vegetation classes on Axes I-III of the DECORANA vegetation ordination. Values for each class are in Table 2.4.2:1.

transformed Domin number for bare ground in each quadrat (Table 2.4.3:1). While strictly speaking significance tests are not valid in the interpretation of results from multivariate analyses (Gauch 1982), because the classes are not independent; it is more acceptable to use rank-order correlation to determine relationships between axes and other variables. By using a non-parametric correlation it is not attempted to show that the classes are significantly different from each other, but that the order for a variable corresponds significantly or not, to the classes' order on an axis.

Axis I is correlated positively ($p<0.001$) with altitude. This correlation reflects the fact that Classes 1 to 4 all had an upland distribution (Fig. 2.4.2:1). While these classes are also the non-ultrabasic classes, Class 12, also a non-ultrabasic class, is not as highly ranked on Axis I.

Axis II is correlated negatively with slope, the number of species per quadrat and the sum of the transformed Domin numbers, and positively with bare ground ($p<0.001$). The higher ranked classes should have gentler slopes, fewer species, less total cover and more bare ground. This corresponds well with classes 5 to 8 which are the least vegetated and are entirely located on the ultrabasic areas.

Axis III had no significant correlations with the variables discussed here.

Table 2.4.3:1 Spearman's correlation coefficients between the median coordinate positions on each of the axes of the DECORANA ordination, for the twelve TWINSPAN vegetation classification classes, and the means for the slope, altitude, no. of species in each quadrat, sum of the transformed Domin no.s (A) for all species in each quadrat, and the transformed Domin no. (B) for bare ground in each quadrat. (see Table 2.2.3:2) (* P<0.05 , ** P<0.01 , *** P<0.001) (n=12)

	Axis II	Axis III	Slope	Altitude	No. Species in each Quadrat	(A)	(B)
Axis I	0.0806	-0.0946	0.0946	0.9772 ***	-0.3713	0.2662	-0.1860
Axis II		-0.0280	-0.6014 *	0.0909	-0.7273 **	-0.6154 *	0.8616 ***
Axis III			-0.1608	-0.0350	-0.0280	0.0629	0.2207

CHAPTER THREE

Soil Analyses

3.1 INTRODUCTION

Exchangeable ions and total quantities of nickel, chromium and cobalt have been determined by many workers on serpentines, and I analysed these soil parameters on Rhum to provide a basis for comparison. The relevance of these analyses to plant-available quantities is dependent upon many variables and conditions (Nye & Tinker 1977), and will be discussed later. Also reported here are total analyses of nitrogen and phosphorus, for which the determination of plant-available fractions are particularly complex (Bartlett & James 1980, Batten 1978, Briggs 1974).

3.2 Materials and methods

3.2.1 General

The analytical methods used in this study follow those of Allen *et al.*(1974), except where noted. Analar (Analytical) Grade chemicals were used throughout. All glassware was rinsed in a chromic acid solution before the first use; and for subsequent uses all glass and plastic-ware was soaked in a dilute acetic acid bath for at least one hour and rinsed four times with deionized water.

3.2.2 Soil preparation

Soil samples were collected from each of the 285 quadrats in October 1979 for Transects 1-4, the rest from May to July 1980. Above-ground vegetation and larger stones (>1cm) were removed, and the soil sampled with a 10 x 10 x 10cm corer. The samples were stored, for up to three weeks, in sealed polythene bags before drying at about 35°C (Molloy & Lockman 1979). After drying the samples were lightly ground to pass a 2mm sieve and stored in sealed polythene bags.

The analyses were completed within fifteen months of air drying. Analyses were carried out on air-dry samples but the results are expressed on an oven-dry (105°C) basis.

From Transects 1-4 an additional sample was collected from 10-20cm depth. Analytical results for these deeper samples were not significantly different from those for the upper samples, and they were not continued.

3.2.3 Methods of soil analyses

pH was determined on a suspension of 10g soil in 10ml (20ml in about thirty, highly organic samples) deionized water. The suspension was stirred and left for 1h and the pH determined using a Corning-EEL Model 7 pH meter. Loss-on-ignition was measured by heating the soils to 450°C for about 2h.

Exchangeable cations were extracted by gently shaking a 5.00g subsample for 12h in 75ml of M ammonium acetate adjusted to pH 7.0. The suspension was filtered through Whatman's No. 40 filter paper and made up to 100.0 ml with the ammonium acetate solution. One drop of toluene was added to each sample and blank to prevent growth of micro-organisms, and the samples were stored at 5°C until analysis (within 6 weeks of the extraction).

Total nickel, chromium and cobalt were determined by digesting 0.500g of soil with 15ml of concentrated nitric acid for 6h. After this time the acid was clear and a small white residue (assumed to be silicon compounds) remained. The solution was filtered through Whatman's No.40 filter paper and made up to 100.0 ml with deionized water.

Total nitrogen and phosphorus were determined by digesting 0.500g of soil for 8h (until clear) in a sulphuric acid digestion mixture (Table 3.2.3:1). The solutions were made up to 100.0ml with deionized water and filtered through Whatman's No.40 filter paper.

Table 3.2.3:1 Sulphuric Acid digestion procedure.

Materials

30% hydrogen peroxide
concentrated sulphuric acid with 0.1% weight/volume selenium

Preparation

Sulphuric acid was heated until clear on a hotplate with 0.1% weight/volume selenium metal added; a 3.0m sodium hydroxide gas tap was fitted.

Procedure

The soil (about 0.5g) or plant (about 0.15g) material was weighed into the digestion flask and 3.0ml of the sulphuric acid mixture was added. 0.75ml of hydrogen peroxide was added, and when frothing stopped, another 0.75ml of hydrogen peroxide was added. The digestion flask was rotated to wash down material adhering to its side and the sample was digested at 330°C for 8h (until clear).

3.2.4 Chemical analyses

Lanthanum chloride (to obtain a concentration of lanthanum greater than 800mg l^{-1} in solution) was added to all samples and standards for the determination of magnesium and calcium, to prevent interference from other elements. Other ions and metals were determined in solutions without this addition.

All cations were analysed by atomic absorption spectrophotometry on a Perkin-Elmer 373 instrument (Perkin Elmer 1976, Walsh 1971).

Nitrogen and phosphorus were determined colorimetrically on a Technicon auto-analyser; nitrogen by the sodium phenate/hypochlorite method and phosphorus by the vanadomolybdate method (O'Neill & Webb, 1970).

3.3 Results and Discussion.

3.3.1 Introduction

The results of all the soil analyses are in Appendix III and are summarised in Table 3.3.1:1. Although the quadrats were spaced at 10m intervals along each transect, it is unlikely that this coincided with any environmental or vegetation pattern. Therefore mean values were used to summarise the soil variables for each transect, and an analysis of variance was computed. The between-transect variance was highly significant ($p<0.001$) for all fifteen soil variables (Appendix V). For each transect the data were checked for normality. Some needed no transformation but others were normalised by either square root or logarithmic (base e) transformations (Table 3.3.1:1, Appendix V). If the original distribution was used, the arithmetic mean is given, otherwise the geometric, (back-transformed) mean is reported.

3.3.2 pH and loss-on-ignition

The mean pH values for the transects (Table 3.3.1:1) differ between the ultrabasic areas (range 4.9 to 6.2, mean 5.6) and the non-ultrabasic areas (range 4.0 to5.1, mean 4.6). Although the Rhum ultrabasic soil pH values are relatively high, they are still generally lower than those that are usually found on serpentines (Shewry & Peterson 1976). pH is important because of its effect on ion solubility, ionic states and the availability of nutrients and metals to plants (Nye & Tinker 1977). (Also nickel toxicity is more likely to occur on serpentines at lower pH values, Proctor & Woodell, 1975).

The loss-on-ignition values (Table 3.3.1:1) were used to estimate the organic matter present in the soil. These values have been used by Jeffrey (1970) and Harrison & Bocock(1981) to determine the bulk density of soils, but Harrison & Bocock (1981) conclude that a

Table 3.3.1:1 The means for the soil data for each transect. (See App. V for information on the means)

Tran sect	pH	LOI	Total N *	Total P *	Exch K *	Exch Na *	Exch Ca *	Exch Mg *	Total Co *	Total Cr *	Exch Fe *	Total Ni *	Exch Ni *	Exch Zn *	Mg/Ca
1	5.0	15.2	3800	490	76.7	19.6	67.5	63.3	60	40	4.4	580	0.5	-	1.12
2	5.7	4.4	2050	470	22.0	12.1	75.6	119.6	140	80	2.2	2220	1.6	-	0.95
3	5.7	10.0	2700	430	41.1	16.3	136.7	160.8	100	90	3.2	1220	0.7	-	1.05
4	5.1	2.6	1230	460	13.1	4.9	9.5	11.6	110	60	1.0	2170	0.7	-	1.50
5	5.0	4.2	1070	180	11.8	5.0	8.0	10.8	110	70	1.2	2190	0.0	0.0	1.37
6	5.4	6.4	1680	220	31.6	18.3	146.9	91.5	100	50	2.1	2010	1.8	0.1	0.74
7	6.1	5.1	1340	250	38.0	45.3	312.4	251.0	120	100	0.4	1410	2.1	0.0	0.80
8	5.5	13.8	4130	1230	68.4	73.7	354.4	342.1	150	140	2.9	2180	7.3	0.0	0.95
9	5.1	23.6	6490	1280	85.9	235.1	455.4	195.4	110	180	4.5	690	3.4	0.4	0.54
10	6.2	2.8	1580	930	8.9	8.7	48.2	64.4	160	50	0.1	2740	3.0	0.0	1.34
11	6.2	54.4	11700	1570	382.5	404.6	1340	2100	130	80	2.7	1560	22.0	0.8	1.56
12	6.0	29.5	7670	1790	154.3	298.7	812.2	843.7	160	120	3.5	1400	8.6	0.4	0.98
13	6.1	3.9	1650	530	15.4	17.9	139.2	74.7	70	120	0.8	790	2.0	0.0	0.56
14	4.8	49.2	10260	1110	198.2	147.8	178.7	102.2	20	50	7.8	20	0.0	0.0	0.59
15	5.0	42.8	8940	1030	209.0	240.9	195.8	128.3	30	80	10.3	210	0.0	0.8	0.65
16	5.1	14.2	3520	800	70.5	26.0	63.7	58.2	50	70	3.8	420	0.0	0.3	0.83
17	4.5	17.1	3940	930	150.7	45.8	58.3	75.1	0	0	6.3	0	0.0	0.3	1.34
18	4.3	32.8	7590	1410	224.2	95.7	117.6	89.7	0	0	8.6	0	0.0	0.4	0.78
19	4.5	43.6	9040	880	229.0	129.3	102.7	92.3	0	20	8.6	0	0.0	0.6	0.98
20	5.3	3.0	900	290	7.8	1.2	6.1	9.6	150	60	1.0	2620	1.4	0.0	1.58
21	5.6	3.1	960	260	9.0	6.0	6.7	10.7	140	100	1.2	2500	0.0	0.0	1.57
22	5.2	8.3	2480	500	46.5	14.5	38.4	36.4	70	100	2.1	360	0.0	0.2	0.71
23	4.0	27.9	5840	1120	244.1	52.1	95.2	99.7	0	20	13.0	0	0.0	0.3	1.10
24	5.3	4.8	1790	400	12.8	28.1	50.3	44.3	130	80	2.0	2240	1.0	0.0	0.72
25	4.8	46.1	6710	840	308.6	213.8	127.8	102.2	0	30	11.8	50	0.0	0.7	0.79
26	6.2	4.3	2910	940	52.6	73.4	551.4	794.0	150	120	0.0	2720	6.8	0.0	1.52
27	6.1	2.2	1000	470	19.8	23.2	135.2	117.4	140	90	2.0	2990	4.0	0.0	1.30
28	6.0	2.7	1280	610	14.9	14.8	77.1	82.3	140	80	0.8	2140	0.0	0.0	1.08
29	4.9	50.4	8940	910	369.7	257.8	700.5	557.9	90	120	14.3	480	2.8	1.9	0.80
30	5.5	30.4	8610	1380	197.3	207.0	692.1	783.7	180	100	8.6	1410	3.2	0.8	1.13
31	5.3	6.4	2410	740	17.3	9.5	48.7	33.5	120	60	1.9	1830	0.0	0.1	0.72
32	5.0	15.1	3650	750	113.6	41.6	86.4	89.8	0	60	6.4	0	0.0	0.0	1.04

LOI = Loss-on-Ignition * = ug g-1 - = not determined

No detectable Cr or Cu in any of the quadrats (<0.1 ug g-1).

different equation is necessary for each soil type, making application of their equations inappropriate in this study. However, exchangeable, total and soil solution ions are only estimates of the fraction of the ions in the soil that are available to plants in any case, whether expressed on a weight or volume basis. Also, while organic matter is part of the exchange complex, the quantity and mechanisms of exchange are unknown and can again only be estimated (Nye & Tinker, 1977). Water loss from clay particle decomposition at 450°C was not expected to cause significant error in the organic matter estimation by loss-on-ignition, because of the sandy nature of many of the soils on Rhum. The ranges for loss-on-ignition for the ultrabasic transects (2.2-54.4%) and non-ultrabasic transects (14.2-49.2%) overlap, but the mean value for the ultrabasic transects is lower (13.9 compared to 30.8%).

3.3.3 Exchangeable bases

Bohn et al.(1979) suggested that the sum of exchangeable bases can vary from 1-60m-equiv. $100g^{-1}$ from coarse to fine textured soils, and that in productive soils, the proportions of cations generally are $Ca^{++}>Mg^{++}>K^{+}\approx Na^{+}$.

The sum of the exchangeable bases varies from 0.143 to 26.8m-equiv. $100g^{-1}$ (mean =4.30) on the ultrabasic transects and from 1.10 to 3.24m-equiv. $100g^{-1}$ (mean 2.18) on the non-ultrabasic transects (Table 3.3.3:1). The lowest exchangeable bases sums found were from four barren ultrabasic transects, (T4,5,20 and 21, < 0.250 m-equiv.$100g^{-1}$). However, other barren ultrabasic transects (T13,26 27 and 28) have sums of exchangeable bases equal to or higher than several transects with closed vegetation. Therefore low total exchangeable bases are not invariably associated with barrenness. Also, on Rhum, the proportion of the bases are usually ranked Mg>Ca>K>Na, with Fe and Ni in less proportion, on both the ultrabasic and non-ultrabasic transects (Table 3.3.3:2).

Table 3.3.3:1 Mean exchangeable cation concentrations (m-equiv 100g-1 calculated from Table 3.3.1:1 and their sum for each transect.

Tran-sect No.	Exch Na *	Exch K *	Exch Ca *	Exch Mg *	Exch Fe *	Exch Ni *	Total *
1	0.085	0.196	0.337	0.521	0.016	0.002	1.16
2	0.053	0.056	0.377	0.984	0.008	0.006	1.48
3	0.071	0.105	0.682	1.32	0.012	0.002	2.20
4	0.021	0.034	0.047	0.095	0.004	0.002	0.20
5	0.022	0.030	0.040	0.089	0.004	0.000	0.19
6	0.080	0.081	0.733	0.753	0.008	0.006	1.66
7	0.197	0.097	1.56	2.07	0.001	0.007	3.93
8	0.321	0.175	1.77	2.82	0.010	0.025	5.12
9	1.02	0.220	2.27	1.61	0.016	0.012	5.15
10	0.038	0.023	0.241	0.530	0.000	0.010	0.84
11	1.76	0.978	6.71	17.3	0.010	0.075	26.8
12	1.30	0.395	4.05	6.94	0.013	0.029	12.7
13	0.078	0.039	0.695	0.615	0.003	0.007	1.44
14	0.643	0.507	0.892	0.823	0.028	0.000	2.89
15	1.05	0.535	0.977	1.06	0.037	0.000	3.65
16	0.113	0.180	0.318	0.479	0.014	0.000	1.10
17	0.199	0.385	0.291	0.618	0.023	0.000	1.52
18	0.416	0.573	0.587	0.738	0.031	0.000	2.35
19	0.562	0.586	0.512	0.760	0.031	0.000	2.45
20	0.005	0.020	0.030	0.079	0.004	0.005	0.14
21	0.026	0.023	0.033	0.088	0.004	0.000	0.17
22	0.063	0.119	0.192	0.300	0.008	0.000	0.68
23	0.227	0.624	0.475	0.821	0.047	0.000	2.19
24	0.122	0.033	0.251	0.365	0.007	0.003	0.78
25	0.930	0.789	0.638	0.841	0.042	0.000	3.24
26	0.319	0.135	2.75	6.54	0.000	0.023	9.76
27	0.101	0.051	0.675	0.966	0.007	0.014	1.81
28	0.064	0.038	0.385	0.677	0.003	0.000	1.17
29	1.12	0.946	3.50	4.60	0.051	0.010	10.2
30	0.900	0.505	3.45	6.45	0.031	0.011	11.3
31	0.041	0.044	0.243	0.276	0.007	0.000	0.61
32	0.181	0.291	0.431	0.739	0.023	0.000	1.67

Most of the bases and metals analysed correlated (r_s) significantly with loss-on-ignition; the correlations were positive for nitrogen, phorphorus, potassium, sodium, calcium, magnesium, iron and zinc and negative for total cobalt and nickel (Table 3.3.3:3). This is in part attributable to the higher cation exchange capacity (c.e.c.) of soils with high organic matter. Also, the nitrogen and phosphorus would be high in soils with high organic matter because they are important constituents of it.

Ten of the ultrabasic transects have exchangeable potassium below 20 $\mu g\ g^{-1}$ (Table 3.3.1:1), which is below the range given in Allen et al.(Table 3.3.3:3), and it is possible that low potassium is a limiting factor for the vegetation. Allen's values (Table 3.3.3:3) are used as an indication of the ranges of soil parameters. Low exchangeable potassium possibly results from low concentrations in the parent materials as the ultrabasic transects do have significantly less potassium than the non-ultrabasic (Table 3.3.3:3). Also, low organic matter and the high leaching rate under the high rainfall could contribute to the low potassium concentration. The importance of major nutrients seems to vary from site to site (Proctor & Woodell 1975).

Six of the ultrabasic transects have exchangeable sodium below 10.0 $\mu g\ g^{-1}$ (Table 3.3.1:1), again with this value below Allen's (Table 3.3.3:3). However sodium is not known to be an essential element for non-haloptytic plants. For Transects 14, 15, 19 and 25 though, sodium exceeds twenty per-cent of the sum of the bases (Table 3.3.3:2), and could be influencing the vegetation. None of these transects are probably near enough to the sea to be affected by spray, and the sodium is probably supplied from the parent rock.

The proportion of calcium in the sum of the bases is lower than Bohn et al. (1979) suggest and it is generally exceeded on Rhum by magnesium (Table 3.3.3:2). However the calcium-rich plagioclase in

Table 3.3.3:2 Mean exchangeable cation concentrations expressed as a percentage of the sum of exchangeable cations (from Table 3.3.3:1) for each transect.

Transect No.	Exch Na %	Exch K %	Exch Ca %	Exch Mg %	Exch Fe %	Exch Ni %	Total %
1	7.3	16.9	29.1	45.0	1.4	0.2	99.9
2	3.6	3.8	25.4	66.3	0.5	0.4	100.0
3	3.2	4.8	31.1	60.3	0.5	0.1	100.0
4	10.3	16.7	23.2	46.8	2.0	1.0	100.0
5	11.9	16.2	21.6	48.1	2.2	0.0	100.0
6	4.8	4.9	44.1	45.3	0.5	0.4	100.0
7	5.0	2.5	39.7	52.6	0.0	0.2	100.0
8	6.3	3.4	34.6	55.1	0.2	0.5	100.1
9	19.9	4.3	44.1	31.2	0.3	0.2	100.0
10	4.5	2.7	28.6	62.9	0.0	1.2	99.9
11	6.6	3.7	25.0	64.4	0.0	0.3	100.0
12	10.2	3.1	31.8	54.5	0.1	0.2	99.9
13	5.4	2.7	48.4	42.8	0.2	0.5	100.0
14	22.2	17.5	30.8	28.4	1.0	0.0	99.9
15	28.7	14.6	26.7	28.9	1.0	0.0	99.9
16	10.2	16.3	28.8	43.4	1.3	0.0	100.0
17	13.1	25.4	19.2	40.8	1.5	0.0	100.0
18	17.7	24.4	25.0	31.5	1.3	0.0	99.9
19	22.9	23.9	20.9	31.0	1.3	0.0	100.0
20	3.5	14.0	21.0	55.2	2.8	3.5	100.0
21	14.9	13.2	19.0	50.6	2.3	0.0	100.0
22	9.2	17.4	28.2	44.0	1.2	0.0	100.0
23	10.3	28.4	21.6	37.4	2.1	0.0	99.8
24	15.6	4.2	32.1	46.7	0.9	0.4	99.9
25	28.7	24.4	19.7	26.0	1.3	0.0	100.1
26	3.3	1.4	28.2	66.9	0.0	0.2	100.0
27	5.6	2.8	37.2	53.3	0.4	0.8	100.1
28	5.5	3.3	33.0	58.0	0.3	0.0	100.1
29	11.0	9.3	34.2	44.9	0.5	0.1	100.0
30	7.9	4.4	30.4	56.8	0.3	0.1	99.9
31	6.7	7.2	39.8	45.2	1.1	0.0	100.0
32	10.9	17.5	25.9	44.4	1.4	0.0	100.1

Table 3.3.3:3 The mean concentrations (with ranges below) of elements in soils from the ultrabasic (UB) and non-ultrabasic (Non) transects; the level of significance of the F ratio for the differences for each element between the UB and Non transects; and the correlation coefficients (Spearman's) between soil loss-on-ignition and elements (for the UB and Non transects combined). The element concentration ranges expected in 'Typical' soils (Allen et al. 1974) are given in the first column.

Element	Type of Analysis	'Typical' Soils	UB (n=24)	Non (n=8)	F-ratio	LOI Correlation Coefficient (1
N	Total	1000-15000	3640 900-11700	6320 3520-10260	*	0.953 ***
P	Total	100-2000	720 180-1790	980 750-1410	ns	0.658 ***
K	Exch	50-500	79 7.8-382.5	192 70.5-308.6	*	0.936 ***
Na	Exch	20-200	85 1.2-404.6	94 26.0-213.8	ns	0.841 ***
Ca	Exch	100-2000	267 6.1-1340	104 58.3-102.2	ns	0.558 ***
Mg	Exch	40-500	288 9.6-2100	88 58.2-102.2	ns	0.516 ***
Co	Total	1-60 Min. 0.2-1 Org.	120 30-180	10 0-50	***	-0.514 ***
Cr	Total	10-200	90 40-180	30 0-50	***	-0.164 ns
Fe	Exch	50-1000	3.1 0-14.3	8.3 3.8-13.0	***	0.861 ***
Ni	Total	5-500	1700 210-2990	60 0-420	***	-0.747 ***
Ni	Exch	not given	3.0 0-22.0	0.0 -	ns	-0.098 ns
Zn	Exch	1-40	0.28 0-1.9	0.33 0-0.7	ns	0.803 ***

(1) n=32 except Zn where n=28   Min. = Mineral soils Org. = Organic soils

* P<0.05 *** P<0.001

hallivalite results in some of the ultrabasic soils having a very low (for serpentines) magnesium/calcium quotient. The quotients are lower than nearly all previously reported for serpentine soils (Proctor & Woodell 1975). Calcium varies widely in serpentine soils (Proctor & Woodell 1975), and is probably a major factor in accounting for intra-and inter-site differences in vegetation.

Exchangeable magnesium in the ultrabasic transects, (Table 3.3.1:1) is generally lower than the concentrations from other serpentine areas in Proctor & Woodell (1975), and in some cases below those in Shewry & Peterson (1975).

None of the transects attained the lower value of Allen (Table 3.3.3:3) for exchangeable iron. This indicates the complexity of determining iron in solution (Nye & Tinker 1977), as the iron concentrations in plants analysed from Rhum are very high (see below).

Nickel is important in many serpentines (Proctor & Woodell 1975, Shewry & Peterson 1976) and has been shown to be toxic at a concentration as low as 0.1-0.18 mg l^{-1} in solution (Wong & Bradshaw 1982). However the states of nickel in the soil are complex as nickel is often strongly bound to sites on soil particles and organic matter (Russell 1973, Nye & Tinker 1977), which renders the problem more difficult. In barren ultrabasic transects (T4, 10,20 and 27) nickel ranged from 0.8-3.5% of the total exchangeable bases (Table 3.3.3:2). This is a relatively high proportion and might suggest a possible influence of nickel in those soils.

Exchangeable zinc is a low proportion of total bases in the soil samples where it was determined (n=245), however it may be important and is discussed later.

3.3.4 Total analyses

Total nitrogen is highly correlated with loss-on-ignition (Table 3.3.3:3), which is to be expected because of the importance of

Nitrogen in organic compounds. While total nitrogen is near Allen's values (Table 3.3.3:3) this gives no indication of its availability to plants or the status of nitrogen in the soil. Nutrient deficiency has often been considered as an important factor in the ecology of serpentine soils (Proctor & Woodell 1975).

Phosphate is most readily available to plants at pH 6-7 (Bohn et al. 1979). Because of the relatively high soil pH's, combined with the amounts of phosphate present (Tables 3.3.1:1 and 3.3.3:3), of which over one half will be in organic compounds (Allen et al. 1974), it is possible that phosphorus is not acting as a limiting factor at most transects. However, it is impossible to predict phosphate in solution from total phosphorus (Nye & Tinker 1977).

Total cobalt (Table 3.3.1:1) correlated negatively with loss-on-ignition (Table 3.3.3:3), probably indicating the lower organic matter present on the ultrabasic transects, however cobalt has been shown to be toxic to plants (Austenfeld 1979). The concentrations found in the ultrabasic soils are similar to those in Proctor & Woodell (1975).

The concentrations for total chromium elsewhere (Proctor & Woodell 1975, Shewry & Peterson 1976) are generally much higher for other serpentine locations than those from Rhum (Tables 3.3.1:1 and 3.3.3:3). However chromium is variable in ultrabasic rocks and is known to be at relatively low concentrations in Rhum rocks (J. Volker, personal communication).

Total nickel (Table 3.3.1:1) was negatively correlated with loss-on-ignition (Table 3.3.3:3), with less organic matter present in the transects with higher total nickel. The total nickel concentrations are similar to many other British serpentine areas (Proctor & Woodell 1975 and Shewry & Peterson 1976), but do not reach the high nickel concentrations that are found on some foreign serpentine soils.

3.4 Multivariate analysis of the soil variables.

3.4.1 Introduction

As noted in the last chapter, multivariate analysis is an efficient method of summarising data and determining relationships within them (Gauch 1982). The vegetation classes will be discussed in relation to the soil variables in chapter four.

Multivariate analysis is also useful to investigate interrelationships between the different soils. Webster (1977) discussed the application of multivariate techniques to soil classification and survey (generally using principal components analysis). However, DECORANA has been shown to be a superior ordination technique, and was used to ordinate the soil data. TWINSPAN was used to classify the soil data and while true classes may not exist, classification helps define groups on the ordination.

The mean values for the soil variables measured (Table 3.3.1:1) were used in the multivariate analyses after rescaling. The values for exchangeable zinc were not included in the analysis since it was not determined for all transects, and the magnesium quotient was not included since it is a derived quantity (Webster 1977). Mean transect values, rather than those for individual quadrats, were used for the analyses to reduce the complexity (After Gauch 1980, 1982). Each variable was rescaled(from 0-1), transforming all the variables to the same scale, so that the different ranges for the variables did not affect the analyses (Gauch 1982).

For both DECORANA (Hill 1979b) and TWINSPAN (Hill 1979a) all the operating parameters were set to the recommended values, except for the pseudo species cut levels in TWINSPAN. These new cut levels (0.0, 0.2, 0.4,0.6,0.8), were set to divide the range of values (0-1) into five equal classes, since all parameters had been rescaled to this range.

3.4.2 Results

The two multivariate techniques used to analyse the soil data produced results that agreed well. Most of the information in the soil data was expressed in the first axis of the ordination (eigen value = 0.36368). The second axis, while having a much lower eigen value (0.03364), further separated the transects and contributes to the interpretation. Further axes had very low eigen values and did not contribute new information.

The ordination scores for each transect for the first two axes (Table 3.4.2:1) are plotted in Figure 3.4.2:1. Also marked on the figure are the groups from the TWINSPAN classification. The larger Groups 1 and 5, are clearly shown with intermediate Groups 2-4.

Group 1 consists mainly of the transects that are located on the non-ultrabasic soils,clearly separating the ultrabasic from the non-ultrabasic transects. Transect 15 (on gabbro, a basic rock) is included in the non-ultrabasic group.

Group 5 consists entirely of the more-or-less barren transects on soils from a range of ultrabasic rocks (dunite, peridotite, and hallivalite).

Groups 2 and 3 both consist of transects located on well-vegetated ultrabasic soils, while Group 4 consists of transects (1, 16, 22) that are located in Bealachs (Gaelic for col, saddle between two mountains), and Transect 8, which is at the same altitude though not in a Bealach.

It is noteworthy that the "species" (soil variable) ordination scores (Table 3.4.2:2) for nickel, cobalt and chromium are distantly located from loss-on-ignition and major nutrients. This is discernible from an appraisal of the transects in the groups and their location on the ordination plot (Figure 3.4.2:1).

Table 3.4.2:1 The transect ordination scores for Axes 1 & 2 from the DECORANA ordination of the soil data by transect means.

Transect No.	Axis I	Axis II
1	100	20
2	187	29
3	152	19
4	208	31
5	215	24
6	182	38
7	177	37
8	143	54
9	100	44
10	201	41
11	83	104
12	105	73
13	170	8
14	28	38
15	40	34
16	101	14
17	20	29
18	9	41
19	7	39
20	221	34
21	214	15
22	137	0
23	0	22
24	191	29
25	11	36
26	167	67
27	198	38
28	198	24
29	50	50
30	96	58
31	176	25
32	56	5

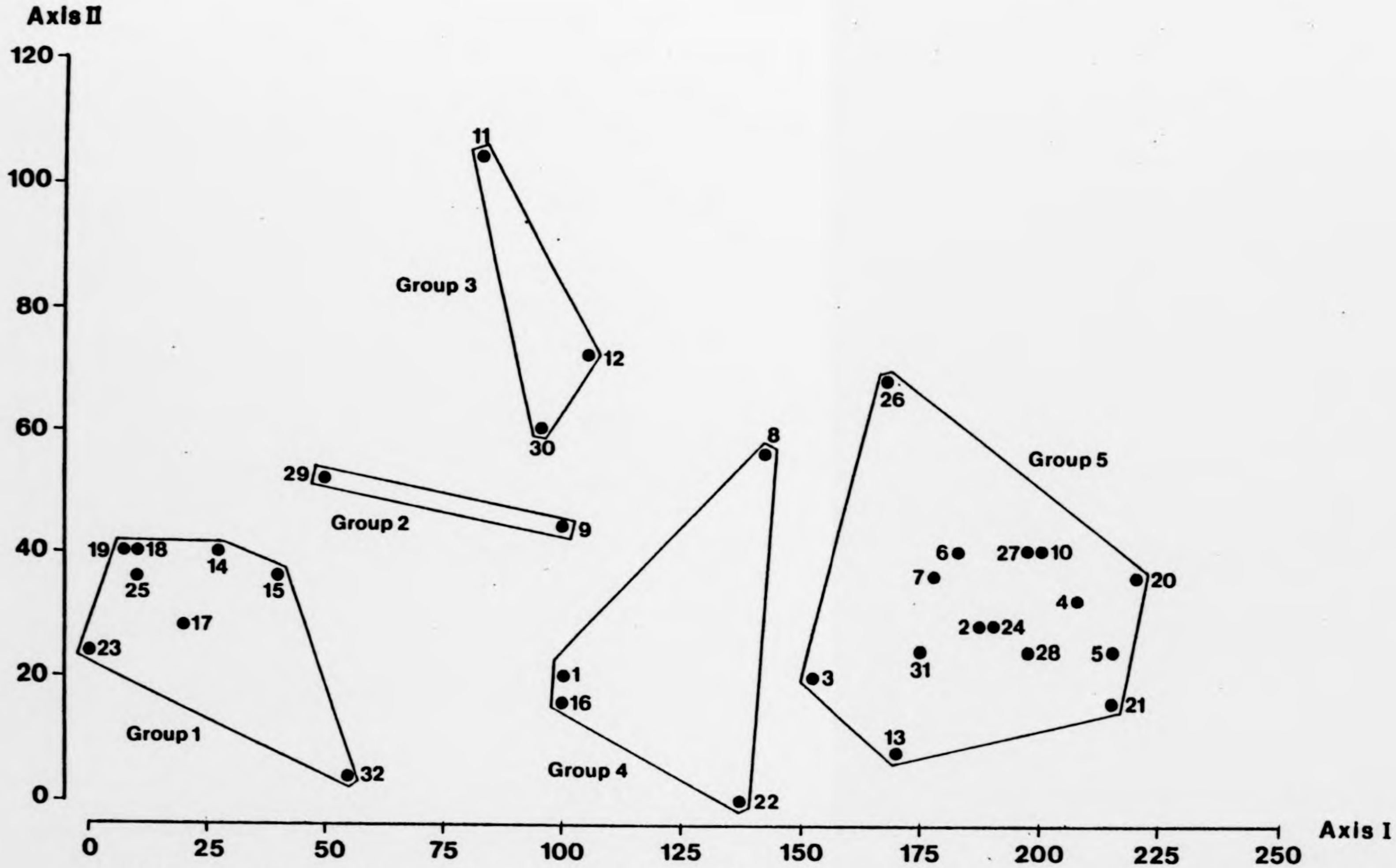


Fig.3.4.2:1. Plot of Axes I and II of the soil data DECORANA ordination of the transects, with the soil data TWINSPAN classification groups indicated. (Numbers next to the points are transect numbers).

Table 3.4.2:2 The order and ordination scores for the soil variables in the soil data ordination by DECORANA, for Axis I of the 'species ordination'.

Soil Variable	Ordination Score
Total Ni	288
Total Co	237
pH	189
Total Cr	168
Exch Ni	140
Exch Mg	103
Exch Ca	101
Total P	85
Exch Na	26
Total N	-4
Exch Fe	-14
Loss-on-ignition	-51
Exch K	-65

Exch = Exchangeable

Axis II separated the transects with higher milliequivalent cation totals from the transects with lower totals, especially Groups 2 and 3.

3.4.3 Discussion

While the soil ordination and classification results help the interpretation of the vegetation distribution, care must be taken in interpreting causality from correlations. Spearman's correlation coefficients (r_s) were calculated between Axes I and II of the ordination and the soil variables (Table 3.4.3:1). Additionally, Spearman's correlation coefficients were calculated between Axes I and II and the arithmetic means for each transect for: the number of species in each quadrat, the sum of the transformed Domin numbers for all species in each quadrat, and the transformed Domin number for bare ground in each quadrat (Table 3.4.3:1).

As would be expected, the soil variable data which were ordinated correlated strongly with the axes and a strong agreement exists between the order of the ordination of the soil variables (Table 3.4.2:2) and the order and magnitude of their correlation coefficients.

The correlation between Axis I and the different measurements are useful in describing the separation between the ultrabasic and non-ultrabasic transects (Table 3.4.3:1). Total cobalt and nickel, pH and bare ground are highly positively correlated with Axis I. Loss-on-ignition, total nitrogen and phosphorus, exchangeable potassium, sodium and iron, the number of species in each quadrat and the sum of their transformed Domin numbers all have high negative correlations with Axis I. The soil variable ordination further supports the separation of ultrabasic and non-ultrabsasic transects (Table 3.4.2:2). From this one can see the strong relationship between the vegetation and the

Table 3.4.3:1 The Spearman's correlation coefficients between the first two axes of the soil data ordination and the transect means (Table 3.3.1:1) for the soil variables; and the mean number of species in each quadrat , the sum of the transformed Domin no.s (A) for all species in each quadrat, and the transformed Domin no. (B) for bare ground in each quadrat.

Variable	Axis I	Axis II
pH	0.6194 ***	0.1979 ns
Loss-on-ignition	-0.8980 ***	0.3495 *
Total N	-0.8929 ***	0.4519 **
Total P	-0.6829 ***	0.5754 ***
Exch K	-0.9412 ***	0.3715 *
Exch Na	-0.7747 ***	0.6110 ***
Exch Ca	-0.4634 **	0.6642 ***
Exch Mg	-0.4385 **	0.6763 ***
Total Co	0.6911 ***	0.3929 *
Total Cr	0.2960 *	0.2004 ns
Exch Fe	-0.8658 ***	0.1297 ns
Total Ni	0.8813 ***	0.1805 ns
Exch Ni	0.2443 ns	0.6652 ***
No. Species	-0.4991 **	0.3236 *
(A)	-0.7173 ***	0.1197 ns
(B)	0.8287 ***	-0.1724 ns

ns not significant , * P<0.05 , ** P<0.01 , *** P<0.001

different soil measurements.

Axis II helps separate Group 1 from Groups 2 and 3, separating the non-ultrabasic vegetated transects from the ultrabasic vegetated transects. While many of the soil variables that correlated negatively with Axis I are positively correlated with Axis II (Table 3.4.3:1) exchangeable magnesium, calcium and nickel correlate more strongly with Axis II than Axis I. Exchangeable nickel however, is the variable that best separates Group 1 from Groups 2 and 3 by considering the correlations. It is noteworthy that the number of species in each quadrat also correlates positively with Axis II, supporting the observation that ultrabasic areas (when vegetated), often have a richer species composition (Proctor & Woodell 1975).

CHAPTER FOUR

Relationships Between the Vegetation Classes and the Soil Variables.

4.1 Introduction

The twelve vegetation classes (Section 2.2) are related to the vegetation ordination (Section 2.3) by using the class mean values for each of the soil variables (Table 4.1:1). This method of integrated analysis is similar to that recommended by Gauch & Whittaker (1981) and Gauch (1982).

It has been argued in Chapter two that the vegetation classes cannot be tested statistically. This probably applies to the soil parameters associated with each class and hence no tests of probability are attempted between the soils. Spearman's (r_s) correlation coefficients (Table 4.1:2), were calculated (it was determined there were no effects from spurious points by plotting) between the mean soil values for each class (Table 4.1:1), and the median coordinate positions for each class on Axes I-III of the vegetation ordination (Table 2.4.2:1). These correlations help the judgment of possible causality of vegetation by soil factors but they must be used with caution.

Additionally, Pearson's (r) correlation coefficients were calculated between all quadrats (n=283), and the soil variables, to determine if the use of the classes had reduced the variability of the data and affected the results. There was strong agreement between the Spearman's correlation coefficients (Table 4.1:2) and the Pearson's correlation coefficients. Between the three axes, the axis where Pearson's correlation was the highest (for a soil variable) was usually the same axis as was significantly correlated by Spearman's (e.g. Pearson's correlation coefficients for pH were: Axis I, -0.482; Axis II, 0.327; Axis III, -0.393; and Spearman's correlation was also highest with Axis I). The only differences between the two correlations (Table 4.1:2 for Spearman's) were: exchangeable calcium

Table 4.1:1 The means for the soil data for the twelve 'Twinspan' vegetation classes in ug g-1.
(See Appendix VI for information on these means.)

Group No.	pH	LOI	Total N *	Total P *	Exch K *	Exch Na *	Exch Ca *	Exch Mg *	Total Co *	Total Cr *	Exch Fe *	Total Ni *	Exch Ni *	Exch Zn *	Mg/Ca
1	5.0	14.0	3410	760	72.4	25.0	46.3	54.2	50	60	3.9	290	0.0	0.17	1.01
2	5.1	16.7	4250	750	106.7	33.9	90.2	105.0	40	50	6.4	90	0.0	0.00	1.16
3	4.3	31.1	6150	1210	224.9	66.8	111.2	98.0	10	10	9.2	0	0.0	0.33	0.88
4	4.4	18.5	4610	960	186.9	69.9	77.9	78.2	0	0	7.3	0	0.0	0.37	1.02
5	5.3	3.8	1280	350	12.4	3.2	11.5	12.9	120	70	1.5	2040	0.1	0.00	1.13
6	5.1	3.3	1150	280	12.3	6.9	11.0	14.9	110	60	0.6	2130	0.0	0.00	1.39
7	6.0	5.4	2080	690	31.1	32.1	238.3	231.8	130	110	0.6	2040	3.8	0.00	0.97
8	5.8	3.9	1760	640	13.9	13.7	77.2	67.7	120	80	1.4	2060	2.2	0.00	0.88
9	6.0	53.1	11800	1620	369.0	382.4	1273.3	1870.5	140	100	3.5	1340	18.8	0.03	1.47
10	5.6	20.7	5980	950	133.6	150.4	488.8	493.3	140	90	4.4	1550	3.7	0.24	0.99
11	5.4	9.3	2740	630	33.8	32.8	122.6	84.0	100	70	3.1	1590	0.6	0.14	0.71
12	4.8	45.7	8940	1010	257.2	224.3	168.4	125.0	10	50	10.8	60	0.4	0.41	0.74

LOI = Loss-on-Ignition * = ug g-1

Table 4.1:2 Spearman's correlation coefficients between the median coordinate postions for the twelve TWINSPAN vegetation classes , on each of the axes of the ordination , and the mean values for the soil variables. (See Table 4.1:1) (n=12)

Soil Variable	Axis I	Axis II	Axis III
pH	-0.7891 ***	0.2211	-0.3018
LOI	-0.0525	-0.9580 ***	-0.0629
Total N	-0.0525	-0.9580 ***	-0.0629
Total P	0.0806	-0.8881 ***	-0.1329
Exch K	-0.0035	-0.9441 ***	-0.0559
Exch Na	-0.1856	-0.8881 ***	-0.1399
Exch Ca	-0.5009 *	-0.6434 *	-0.1678
Exch Mg	-0.3888	-0.6573 **	-0.3287
Total Co	-0.7321 **	0.1748	-0.3916
Total Cr	-0.7916 ***	0.2238	-0.2517
Exch Fe	0.3783	-0.7902 ***	0.2587
Total Ni	-0.4842 +	0.7426 ***	-0.0981
Exch Ni	-0.8644 ***	-0.1233	-0.1015
Exch Zn	-0.0799	-0.8194 ***	0.0218
Mg / Ca	0.1684	0.0806	-0.7916 ***

LOI = % Loss-on Ignition

+ P<0.055 , * P<0.05 , ** P<0.01 , *** P<0.001

All other correlations not significant.

(Pearson's negatively with Axis III), exchangeable magnesium (Pearson's negatively with Axis III), and exchangeable nickel (Pearson's positively with Axis III).

4.2 Interpretation and discussion of vegetation classes.

Several relationships between the vegetation classes are clearly represented by their positions on the ordination axes (Fig. 2.4.2:1), and are related to soil differences.

Axis I separates most of the non-ultrabasic from the ultrabasic vegetation classes, and is significantly negatively correlated with the soil pH, exchangeable nickel, total chromium and cobalt, and less significantly negatively correlated with exchangeable calcium and total nickel (Table 4.1:2). However, in interpreting the correlation it is necessary to consider if it is due mainly to the soil's effect on the vegetation or the vegetation's effect on the soil.

The difference of one pH unit between the ultrabasic and non-ultrabasic classes is important (Etherington 1975), though heathy vegetation can reduce soil pH (Grubb & Suter 1971). However, it seems likely that the primary effect is due to the higher base supply from the ultrabasic rocks (Proctor & Woodell 1975). High total chromium, cobalt and total and exchangeable nickel are well known constituents of serpentine rocks (Proctor & Woodell 1975, Shewry & Peterson 1975). It is possible that the contrast in vegetation between the non-ultrabasic and ultrabasic classes, along Axis I, is primarily due to soil differences for these heavy metals and pH. The other soil variables measured were not related to the change in the vegetation along this axis. The vegetation is not likely to concentrate toxic metals in the soil, more likely effects on metal concentrations (expressed on a weight basis), would be a 'dilution' by the vegetation contributing organic matter, which would usually contain a lower total concentration of the metals than mineral soils. Total nickel is probably more important in the interpretation of this axis than its correlation coefficient (Table 4.1:2) indicates. Correlation coefficients are more useful for gradients than abrupt changes, such as occur for nickel along Axis I (Table 4.1:1). The negative correlation with exchangeable calcium is less readily interpretable, but probably indicates the lower calcium concentrations present on the non-ultrabasic soils.

It is of interest to consider the metal concentrations on a unit volume basis. Initially, I intended to use Jeffrey's (1970) equation but a paper published after my soil work had finished (Harrison & Bocock 1981), has indicated the necessity of using equations determined for each soil. However, a general indication of the bulk density can be obtained by using Jeffrey's equation in Harrison & Bocock (1981): Bulk density ($g\ ml^{-1}$) = 1.562 - 0.727 $\log_{10}$ loss-on-ignition(%). Expressing total nickel on a $\mu g\ ml^{-1}$ basis slightly reduces the difference between the non-ultrabasic (1-4) and vegetated ultrabasic (9-11) classes, but increases the differences between the non-ultrabasic, (1-4) and the barren ultrabasic (5-8) classes. (Class 12 is somewhat intermediate between ultrabasic and non-ultrabasic).

Axis II primarily separates the more barren ultrabasic classes (5-8) from the vegetated ultrabasic classes (9-12), but also further separates the non-ultrabasic classes (1-4)(Fig. 2.42:1). Axis II is significantly negatively correlated with loss-on-ignition, total nitrogen and phosphorus, exchangeable potassium, sodium, calcium, magnesium, iron and zinc, and positively with total nickel (Table 4.1:2). While many of these variables are plant nutrients and would therefore be expected to be strongly associated with the amount of vegetation and organic matter present (because of plant interactions with the soil), the opposite significant correlation with total nickel is important. As above, this potentially toxic metal is unlikely to be affected by the vegetation (as a total measurement), except by 'dilution' with organic matter. It is possible therefore that total nickel is in some way involved in the barrenness of these sites (through a plant-available form).

Of additional importance is the fact that total cobalt and chromium and exchangeable nickel are not correlated with the barrenness of the ultrabasic sites, indicating the relative unimportance of cobalt and chromium, and that exchangeable nickel is an inappropriate measure of the fraction of nickel that may be affecting the vegetation. Nickel is known to bind with various sites, particularly in organic soils (Nye & Tinker 1977).

It is possible that the importance of total nickel in the barrenness of ultrabasic Classes 5-8 is not as clear as these correlations might indicate. The 'dilution' effect of organic matter on the concentration of metals in the soil (mentioned above), must be considered for the vegetated ultrabasic Classes 9-11. It is possible that these soils had higher concentrations of metals, particularly nickel, in their mineral states, and that the higher organic matter is 'diluting' the nickel (Table 4.2:1). However, when considered on a bulk-density basis, ($\mu g\ ml^{-1}$) the difference between the barren ultrabasic classes (5-8) and the vegetated ultrabasic classes (9-11) are even more extreme.

Axis III correlates significantly negatively with the derived magnesium/calcium quotient, but is not readily interpreted from the classes.

Exchangeable zinc is related to the vegetation classes and the ordination axes. The probable higher cation exchange capacity of the vegetated classes may explain the higher zinc concentrations for these classes, when compared to the barren classes. However, zinc is of interest because of its similar ionic radius to that of nickel and the possibility of its competing with nickel for binding sites in the soil and activation sites on plants (Chapin 1980). Zinc is discussed more fully in Chapter 7.

CHAPTER FIVE

Plant Analyses

5.1 Introduction

5.1.1 Introduction and sample collection

The concentrations of nutrient ions and heavy metals, in plants growing on serpentine soils, can be useful in determining relationships between the soil factors and the vegetation (Lyon et al. 1971, Johnston & Proctor, 1979, Proctor et al. 1980). Five species were chosen and collected for analysis and correlation with the soil analyses to investigate these relationships. Agrostis canina, Calluna vulgaris, Festuca vivipara, Plantago maritima, and Rhacomitrium lanuginosum were collected from eight transects (T 1, 2, 4, 7, 16, 18, 22 and 32) in July 1980. These transects were chosen from field observations from the descriptive work to represent a range of sites and plants within 1 m^2 of a randomly chosen quadrat were sampled.

Arenaria norvegica ssp. norvegica was collected from transect 7 and analysed because of its restricted distribution on Rhum and preference for ultrabasic localities.

5.1.2 Methods and materials of plant analysis.

After collection the plant material was washed four times in deionised water and dried at 60°C for 3d. It was then stored in sealed polythene bags until February 1982 when it was re-dried at 60°C for 3d and stored in a desiccator.

Two digestion methods were used. For the determination of the metals each plant sample was subsampled and about 0.3-0.5g was wet ashed with three replicates (four for Rhacomitrium lanuginosum) in 7.5ml of concentrated nitric acid at 120°C, for 3h or until clear. For the determination of nitrogen, three replicates of the plant samples (except for Festuca vivipara from Quadrats 151 and 171 and Agrostis canina from Quadrat 11, which had insufficient material remaining for analysis) were wet ashed in a sulphuric acid digestion mixture (Allen et al. 1974, Table 3.2.3:1) at 330°C until clear (for at least 8h). All digests were made up to 100ml with deionised water and filtered through Whatman's No. 42 filter paper.

Chemical analyses of these solutions followed the methods described for the soil analyses (Section 3.2.4).

5.2 Results

The typical concentrations of elements in plant material from non-metalliferous soils are shown in Table 5.2:1. Previous work on serpentine sites has included some plant analyses of the same genera (and often species) as analysed from Rhum (Table 5.2:2). The results of all the plant analyses for the Rhum plant samples are in Appendix VII and are summarised in Tables 5.2: 3-8.

Agrostis canina.

The concentrations for all the metals measured for Agrostis canina varied significantly between the different samples. The concentration of nitrogen and potassium all fall within the typical range (except for Quadrat 61 for potassium, which is slightly below the lower limit). The concentrations of calcium are much lower than the value in Allen (1974) Table 5.2:1) but are higher than the values from other analyses from serpentine sites (Table 5.2:2). The concentrations of magnesium for two of the samples (Q.31 and Q.61) are higher than Allen's range and are similar to the other serpentine values. It is noteworthy that the concentration of iron in most of the samples is much higher than Allen and even higher than the values from the other serpentine sites.

Table 5.2:1 The typical elemental concentrations of some elements in plant material. (From Allen et al. 1974)

Element	Concentration (ug g-1)
N	10 000 - 30 000
K	5 000 - 30 000
Na	200 - 3 000
Ca	3 000 - 25 000
Mg	1 000 - 5 000
Co	0.1 - 0.6
Cr	0.05 - 0.5
Fe	40 - 500
Ni	0.5 - 5
Zn	15 - 100

Table 5.2:2 The metal concentrations (ug g-1) and Mg/Ca quotients in above-ground parts of selectec species from British serpentines.

Species	K	Na	Ca	Mg	Co	Cr	Fe	Ni	Zn	Mg/Ca	Location
Aerostis											
canina	-	-	1500	5500	-	-	-	-	-	3.7	Greenhill 1
A. canina	-	-	1700	4600	-	-	-	-	-	2.7	Towanreef 1
A. canina	-	-	1500	3400	-	-	-	-	-	2.3	Coyles of Muick 1
A. canina	-	-	1900	8300	-	-	-	-	-	4.4	Hallival 1
A. canina	-	-	1200	2400	-	-	-	-	-	2.0	Meikle Kilrannoch I 1
A. sto-	-	-	-	-	-	-	-	-	-	2.0	Hamar summit 2
lonifera	-	-	-	-	-	-	-	-	-	1.3	Hamar slope 2
A. canina	-	-	300	5730	96	83	2700	151	-	19.1	Greenhill 3
A. canina	-	-	1000	6245	17	45	3500	130	-	6.2	Towanreef 3
A. canina	4400	240	500	9500	15	89	240	59	19	19.0	Meikle Kilrannoch I 4
Calluna											
vulgaris	3500	-	5500	7000	38	72	4400	150	-	1.3	Greenhill 5
C. vulgaris	3600	-	5400	3700	12	28	1200	86	-	0.7	Towanreef 5
C. vulgaris	-	-	-	-	-	-	-	-	-	1.1	Hamar summit 2
C. vulgaris	-	-	-	-	-	-	-	-	-	0.7	Dalepark 2
C. vulgaris	-	-	-	-	-	-	-	-	-	1.8	Greenhill 2
C. vulgaris	7470	1670	1940	5320	20	50	2380	125	-	2.7 +	Greenhill 6
C. vulgaris	5400	2450	1370	7800	46	76	4300	171	-	5.7 +	Towanreef 6
C. vulgaris	4130	1500	3860	1590	4	19	260	14	-	0.4 +	Lizard,Cornwall 7
C. vulgaris	21000	-	17000	6400	11	60	400	73	16	0.4	Lime Hill 8
Festuca											
vivipara	-	-	-	-	-	-	-	-	-	1.5	Hamar summit 2
F. rubra	-	-	-	-	-	-	-	-	-	0.8	Hamar slope 2
F. rubra	-	-	-	-	-	-	-	-	-	1.0	Dalepark 2
F. ovina	-	-	-	-	-	-	-	-	-	1.6	Greenhill 2
F. rubra	-	-	900	4700	12	49	2130	91	-	5.2	Towanreef 3
F. rubra	42000	160	450	7200	17	76	160	63	12	16.0	Meikle Kilrannoch I 4
F. rubra	27000	150	530	6570	10	53	210	52	12	12.4	Meikle Kilrannoch II 4
Plantago											
maritima	-	-	-	-	-	-	-	-	-	0.7 +	Hamar summit 2
P. maritima	-	-	4740	10370	-	6	-	58	-	2.2	Hamar 9
P.lanceolata	35000	-	27000	20000	21	70	260	80	-	0.7	Lime Hill 8
Rhacomitrium											
lanuginosum	1300	-	230	22000	89	120	21000	470	-	96.0	Greenhill 5
R. lanu.	750	-	330	5800	26	220	6400	160	-	18.0	Towanreef 5
R. lanu.	15000	170	100	13000	20	130	3100	130	63	130.0	Meikle Kilrannoch I 10
R. lanu.	15000	140	78	12000	17	80	2500	110	69	154.0	Meikle Kilrannoch II 10
R. lanu.	740	-	150	560	-	-	260	-	-	3.7 +	Rhum 11
R. lanu.	15000	-	430	1400	11	73	650	33	-	3.3	Lime Hill 10

1 Proctor (1969) 2 Sheury & Peterson (1975) 3 Johnston & Proctor (1977) 4 Johnston & Proctor (1980)
5 Johnston (1974) 6 Marrs (1977) 7 Marrs & Proctor (1978) 8 Johnston & Proctor (1979)
9 P.R. Sheury (unpublished) 10 Johnston (1976) 11 Bates (1978) + my calculation - not reported

Table 5.2:3 The metal concentration (ug g-1 dry weight) of elements in the upper parts of *Agrostis canina*. Means with Standard Errors below. (n=3)

Quadrat	N	K	Na	Ca	Mg	Co	Cr	Fe	Mn	Ni	Zn	Mg/Ca
2	13000	6930	280	1010	1580	<0.1	<0.1	980	154	<0.1	123	1.6
	170	720	50	35	450			300	8		21	0.4
11	-	6300	330	1030	1010	<0.1	<0.1	340	83	<0.1	68	1.0
		480	21	84	40			120	4		5	0.0
31	13100	6780	440	1120	7310	16	16	4400	155	88	63	6.6
	270	320	41	53	760	0.1	0.1	720	5	6	4	0.6
61	10100	4520	310	1610	6380	16	16	5350	208	86	71	3.8
	360	200	22	110	1960	0.3	0.3	1900	11	29	5	1.0
151	11700	6860	210	1190	1910	16	11	2050	280	<0.1	100	1.6
	430	670	11	92	130	0.5	6	300	34		9	0.2
211	10800	6820	280	1480	1770	16	15	1430	182	<0.1	126	1.2
	360	490	49	140	220	0.3	0.3	270	26		4	0.1
311	11600	7560	320	1080	1100	5	10	3690	216	<0.1	124	1.0
	200	200	52	50	190	5	5	1420	4		11	0.1

- not determined

Table 5.2:4 The metal concentration (ug g-1 dry weight) of elements in the upper parts of Calluna vulgaris.
Means with Standard Errors below. (n=3)

Quadrat	N	K	Na	Ca	Mg	Co	Cr	Fe	Ni	Zn	Mg/Ca
2	13900	5830	630	2250	1580	<0.1	<0.1	450	<0.1	32	0.7
	30	66	27	100	90			12		1	0.0
11	11700	3740	700	2750	2120	<0.1	<0.1	460	5	23	0.8
	260	310	110	160	46			98	5	4	0.0
31	13100	5010	660	2940	4940	<0.1	16	2500	48	46	1.7
	100	29	43	48	570		0.3	480	10	16	0.2
61	13000	4020	1010	2860	2890	<0.1	<0.1	1180	16	59	1.0
	520	140	110	110	180			260	0.5	7	0.1
151	12500	6120	750	2670	2700	16	16	2350	<0.1	44	1.0
	260	83	20	79	42	0.3	0.3	250		7	0.0
211	13000	6420	550	3210	1980	<0.1	<0.1	1270	<0.1	35	0.6
	230	250	64	29	110			260		1	0.0

Table 5.2:5 The metal concentration (ug g-1 dry weight) of elements in the upper parts of *Festuca vivipara*.
Means with Standard Errors below. (n=3 except Q171:n=2)

Quadrat	N	K	Na	Ca	Mg	Co	Cr	Fe	Ni	Zn	Mg/Ca
2	10400	3640	180	780	950	<0.1	<0.1	580	<0.1	81	1.2
	420	280	6	36	40			50		22	0.1
11	8000	5600	180	880	1480	<0.1	<0.1	900	<0.1	40	1.6
	390	770	20	80	260			230		8	0.2
31	10800	3740	330	1360	10500	16	16	5290	98	34	7.6
	30	460	3	170	2390	0.2	9	1500	32	4	0.9
61	9200	3030	240	1130	3750	16	5	3150	36	31	3.2
	940	160	16	230	1140	0.3	5	740	13	3	0.4
151	-	5770	280	880	1840	5	10	1730	<0.1	50	2.1
		600	45	35	80	5	5	50		3	0.2
171	-	4300	240	750	480	<0.1	<0.1	140	<0.1	69	0.6
		1500	55	42	5			10		34	0.0
211	9600	6520	270	990	1070	<0.1	<0.1	840	<0.1	45	1.1
	720	310	25	39	130			140		7	0.1
311	8900	5420	280	950	520	<0.1	<0.1	240	<0.1	59	0.5
	900	530	0	16	20			20		14	0.0

– not determined

Table 5.2:6 The metal concentration (ug g-1 dry weight) of elements in the upper parts of Plantago maritima. Means with Standard Errors below. (n=3)

Quadrat	N	K	Na	Ca	Mg	Co	Cr	Fe	Ni	Zn	Mg/Ca
2	11200	5260	2900	3120	9850	13	16	6420	84	110	3.2
	330	200	390	140	1570	3	3	1120	12	9	0.6
11	11100	5930	1830	4670	13100	28	15	8600	240	46	2.8
	420	320	110	160	1890	0.4	3	1650	34	7	0.3
31	11000	6540	5160	4220	28400	22	25	10400	240	55	6.7
	640	620	870	130	4610	3	2	1820	40	2	1.1
61	9000	4080	1550	4960	29300	28	38	15100	350	75	6.1
	430	430	280	270	8290	5	5	4470	82	5	2.0
151	11000	9530	4510	3200	5500	10	17	3340	27	131	1.7
	1650	1670	460	100	610	0	3	600	3	15	0.1
211	12500	5270	3330	3910	12200	16	41	10200	83	110	3.0
	850	760	630	310	3340	3	11	2930	23	17	0.7
311	12100	9670	4260	4360	4950	7	13	2330	45	97	1.1
	2000	250	180	70	150	3	7	810	26	11	0.0

Table 5.2:7 The metal concentration (ug g-1 dry weight) of elements in the upper parts of <u>Rhacomitrium lanuginosum</u>.
Means with Standard Errors below. (n=4 except Nitrogen:n=3)

Quadrat	N	K	Na	Ca	Mg	Co	Cr	Fe	Ni	Zn	Mg/Ca
2	6500	900	240	1640	6150	10	10	5770	54	30	3.8
	260	120	38	260	2060	0.2	4	1050	22	2	1.2
11	6400	910	230	1120	4970	12	7	4720	47	27	4.4
	580	90	31	90	2400	2.5	5.0	2680	27	4	1.9
31	7200	880	290	1510	24600	20	20	15500	250	30	16.1
	90	100	12	50	3060	0.1	0.1	2260	23	5	1.5
61	6300	590	270	2860	12200	15	20	10800	160	40	4.4
	170	70	15	320	1200	2.9	0.1	880	14	4	0.4
151	7700	930	380	1960	18500	22	37	22400	160	42	8.9
	290	110	60	330	5220	4.6	5.0	3910	37	5	1.2
171	6200	1190	320	660	670	10	<0.1	810	<0.1	36	1.0
	180	110	79	60	37	0.0		160		6	0.1
211	8600	1200	270	1310	4280	10	20	8080	35	31	3.3
	260	30	23	60	350	0.0	0.1	240	3	1	0.4
311	7800	920	90	700	910	8	10	2980	<0.1	22	1.3
	220	50	5	40	50	2.5	0.0	180		1	0.0

Table 5.2:8 The metal concentration (ug g-1 dry weight) of elements in the upper parts of _Arenaria norvegica_ ssp. _norvegica_ (from 073). Means with Standard Errors below. (n=3; except Flower, n=1)

Part	K	Na	Ca	Mg	Co	Cr	Fe	Ni	Zn	Mg/Ca
Shoot	13200	870	360	9580	50	25	5960	215	50	27.8
	870	92	10	630	0.3	0.2	290	17	9	0.8
Flower	6180	1770	1030	8530	147	0	2940	147	60	8.3

Also noteworthy are the higher concentrations of cobalt and chromium in Quadrats 31, 61 and 151 and nickel in Quadrats 31 and 61. While these are higher than the values in Allen they do not attain the high levels found in analyses from the other serpentine sites.

Calluna vulgaris.

For Calluna vulgaris the concentrations for the elements varied significantly between the samples except for zinc. Nitrogen and potassium concentrations were within the range given by Allen, except for Quadrats 11 and 61 for potassium. For these, potassium was lower but agreed with values from other serpentine areas. The calcium concentrations were generally below Allen's range and were intermediate for the values from other serpentine areas. The magnesium concentrations in C.vulgaris were within the range in Allen and were generally lower than values from other serpentine areas. Again the concentration of iron and heavy metals are quite high compared to Allen, but not as high as other values from serpentine areas.

Festuca vivipara.

For Festuca vivipara the variance between the samples was significant for all the elements analysed except for nitrogen and zinc. For nitrogen the range of values was generally below the range in Allen, while zinc was within Allen's range. The concentrations for both potassium and sodium were in the low end of Allen's ranges and for potassium the concentration was below the values found for F.rubra from Johnston & Proctor (1980). Again, the concentration of calcium was below the range given in Allen and is generally higher than values from other serpentine areas. The concentration of magnesium varied widely between the different quadrats with the non-ultrabasic quadrats (Q.171, Q.311) below Allen's range, with one ultrabasic quadrat (Q.31) far above it. The other ultrabasic quadrats had magnesium concentrations that were low when compared to other serpentine areas. The concentration of iron was high for the ultrabasic quadrats but was within Allen's range for the non-ultrabasic quadrats. Quadrats 31 and 61 had iron concentrations higher than the other serpentine areas. The heavy metal concentrations for cobalt, chromium and nickel were higher for several of the ultrabasic quadrats than Allen's values and were similar to other serpentine areas.

Plantago maritima.

The concentrations of the elements analysed in Plantago maritima varied significantly between the samples except for nitrogen. (The material analysed was the upper part of P.maritima but included the 'woody' stock of the plant). For nitrogen the concentrations for the samples fell within the low end of Allen's range except for Q.61. The concentration of sodium was much higher for P.maritima than the other species analysed, exceeding the range in Allen in several quadrats (Q.31, 151, 311).

The concentrations of calcium were much higher as well, with the sample concentrations all within Allen's range. Magnesium concentrations were correspondingly high, all exceeding the range given by Allen. The resulting Mg/Ca quotients are higher than the few others reported from serpentine areas. Iron again is much higher, with all sample concentrations much higher than Allen's values, and the heavy metal concentrations in the samples are all higher than Allen. The sodium concentrations for Plantago maritima are noteworthy, since a maritime species is accumulating high concentrations, even when distantly removed from the sea, as previously found by Johnston & Proctor (1980).

Rhacomitrium lanuginosum.

For Rhacomitrium lanuginosum all the metals analysed varied significantly between the samples. The potassium concentration for all the quadrats on Rhum are generally below the range of values reported from other serpentine areas, while the concentrations of sodium in the quadrats are generally higher than the reported sodium values. The concentration of calcium is higher than most of the other serpentine areas, with magnesium for the ultrabasic quadrats quite high compared to other serpentine areas. The concentration of iron again is quite high compared to other serpentine sites while the heavy metals concentrations from the quadrats are generally lower than other serpentine areas.

The metal concentration of *Arenaria norvegica ssp.norvegica* is noteworthy. The shoot levels of potassium sodium and zinc correspond well with Allen's ranges while calcium is very low and magnesium, iron, cobalt, chromium and nickel are all very high. Also noteworthy are the different concentrations between the shoot of the plant and the flowers for these metals. Calcium is much higher in the flowers resulting in a lower magnesium/calcium quotient and there is less iron, chromium and nickel. There is also less potassium though more sodium and cobalt. The mechanisms here are best compared to the results in Proctor & Woodell (1975) for *Centaurea paniculata* and *Alyssum bertolonii* to realise the complexity of the problem.

It is noteworthy that the concentrations of the metals in the species often were significantly different between the ultrabasic and non-ultrabasic quadrats.

5.3 Discussion of correlations with the soil analyses.

Correlation coefficients (r) were calculated between the metal concentrations within each species, within the soils at the site of occurrence for each species, and between these plants and soils (Proctor *et al.* 1980). Only the coefficients where $P<0.01$ have been reported (chance significant correlations would be expected at a lower level of probability), and are discussed by species. (It is emphasised that the analyses and correlations are for shoots only). The representation of plant-available quantities by soil total nitrogen, cobalt, chromium and nickel and exchangeable cations must be considered in the interpretation of the correlations. All correlations for exchangeable nickel were not significant and the soil nickel correlations reported are for total nickel.

While some of the correlations for Agrostis canina (Table 5.3:1) are attributable to differences between ultrabasic and non-ultrabasic quadrats (e.g. high soil cobalt and high soil nickel on the ultrabasic; soil potassium and soil sodium; plant cobalt and plant chromium), several indicate possible preferential or selective ion absorption or translocation by the plant. It is noteworthy that nickel, magnesium and iron are highly correlated within plants of A.canina but not within the soils nor between the plants and soils. Also noteworthy are the correlations for the magnesium/calcium quotient with nickel and with magnesium but not with calcium; even though there is a correlation between magnesium and calcium in the soil. These results tend to support a selective absorption of magnesium (and possibly iron) with increasing plant nickel (Proctor & Woodell 1975). The negative correlations between plant zinc and soil nickel and cobalt might indicate competitive absorption or translocation between these ions.

For Calluna vulgaris several of the correlations again can be attributed to differences between ultrabasic and non-ultrabasic quadrats (Table 5.3:2). Also magnesium is again correlated with nickel as is the magnesium/calcium quotient, possibly suggesting an increased magnesium absorption or translocation.

There were many more significant correlations for Festuca vivipara

Table 5.3:1 Correlation coefficients (Pearson's) (P<0.01) between metal concentrations : within plants of <u>Agrostis</u> <u>canina</u> ; within soils at sites of occurence of this species ; and between these plants and soils. (Soil Ni corr. are for Total Ni).

Plants			Soils			Plants-Soils		
N - Ca	-0.883	**	K - Na	0.803	**	Co - N	-0.914	***
Mg - Ni	0.988	***	Na - Ca	0.813	**	Cr - N	-0.906	***
Co - Cr	0.929	***	Ca - Mg	0.863	**	Zn - Co	-0.829	**
Fe - Ni	0.819	**	Co - Ni	0.898	***	Zn - Ni	-0.972	***
Mg - Fe	0.792	+						
Mg/Ca - Mg	0.954	***						
Mg/Ca - Ni	0.920	***						

\+ the value of 0.798 corresponds to P=0.01 , ** P<0.01 , *** P<0.001

Table 5.3:2 Correlation coefficients (Pearson's) (P<0.01) between metal concentrations : within plants of <u>Calluna</u> <u>vulgaris</u> ; within soils at sites of occurence of this species ; and between these plants and soils.(Soil Ni corr. are for Total Ni).

Plants			Soils			Plants-Soils		
Mg - Ni	0.949	***	N - K	0.843	**	K - Mg	-0.845	**
Cr - Fe	0.920	**	Na - Ca	0.886	**	K - Co	-0.913	**
Mg/Ca - Mg	0.981	***	Ca - Mg	0.845	**	Zn - Fe	-0.936	***
Mg/Ca - Ni	0.938	***	Co - Ni	0.881	**			

** P<0.01 , *** P<0.001

than for the other species analysed, with again many attributable to the differences between ultrabasic and non-ultrabasic quadrats (Table 5.3:3). It is noteworthy that iron, magnesium and the heavy metals cobalt, chromium and nickel are all highly correlated in the plants, and that they are correlated with the magnesium/calcium quotient. Of particular interest is the correlation between calcium and magnesium, cobalt, iron and nickel, which indicates a possible preferential absorption and ameliorative effect of calcium. Calcium has often been considered as ameliorating the effects of heavy metals (Proctor & Woodell 1975) and these results support this idea. Again a possible ameliorative effect of magnesium needs to be considered (Proctor & McGowan 1976). Also of interest is that zinc in the plant correlates positively with soil nitrogen while negatively with soil nickel, and that the plant magnesium/calcium quotient is positively correlated with soil nickel.

The correlation coefficients for Plantago maritima (Table 5.3:4) must be interpreted considering the plant analysed included the 'woody' stock, part of which is root. P.maritima is the only species analysed where the plant and soil concentrations of cobalt, chromium and nickel were correlated. Also plant magnesium, iron and nickel were correlated, and the magnesium/calcium quotient correlated with nickel, again suggesting a possible amelioration for nickel. The zinc concentration is negatively correlated with both plant and soil nickel again indicating a possible competitive interaction.

For Rhacomitrium lanuginosum (Table 5.3:5) the plant is not actually growing in the soil. Again, in the plant material magnesium, iron and nickel are all correlated and the magnesium/calcium quotient is correlated with nickel, indicating possible preferential absorption or translocation for these elements.

Table 5.3:3 Correlation coefficients (Pearson's) (P<0.01) between metal concentrations : within plants of _Festuca vivipara_ ; within soils at sites of occurence of this species ; and between these plants and soils.(Soil Ni corr. are for Total Ni).

Plants			Soils			Plants-Soils		
Ca - Mg	0.897	***	N - K	0.782	**	Ca - N	-0.817	**
Ca - Co	0.845	**	K - Na	0.922	***	Fe - Ni	0.785	**
Ca - Fe	0.912	***	K - Co	-0.839	**	Zn - N	0.861	**
Ca - Ni	0.909	***	Na - Ca	0.785	**	Zn - Ni	-0.763	+
Ca - Zn	-0.766	**	Ca - Mg	0.820	**	Mg/Ca - Ni	0.779	**
Mg - Co	0.833	**	Co - Ni	0.901	***			
Mg - Cr	0.871	**						
Mg - Fe	0.963	***						
Mg - Ni	0.988	***						
Co - Cr	0.785	**						
Co - Fe	0.935	***						
Co - Ni	0.857	**						
Cr - Fe	0.893	***						
Cr - Ni	0.818	**						
Fe - Ni	0.951	***						
Mg/Ca - Ca	0.884	***						
Mg/Ca - Mg	0.996	***						
Mg/Ca - Co	0.850	**						
Mg/Ca - Cr	0.894	***						
Mg/Ca - Fe	0.977	***						
Mg/Ca - Ni	0.974	***						

+ the value of 0.765 corresponds to P=0.01 , ** P<0.01 , *** P<0.001

Table 5.3:4 Correlation coefficients (Pearson's) (P<0.01) between metal concentrations : within plants of *Plantago maritima* ; within soils at sites of occurence of this species ; and between these plants and soils.(Soil Ni corr. are for Total Ni).

Plants			Soils			Plants-Soils		
K - Fe	-0.871	**	K - Na	0.803	**	Co - Co	0.957	***
Mg - Fe	0.878	**	Na - Ca	0.813	**	Co - Ni	0.854	**
Mg - Ni	0.890	**	Ca - Mg	0.863	**	Cr - Cr	0.807	**
Co - Cr	0.844	**	Co - Ni	0.989	***	Ni - Co	0.835	**
Co - Ni	0.938	***				Ni - Ni	0.827	**
Co - Zn	-0.801	**				Zn - Ni	-0.827	**
Fe - Ni	0.859	**						
Ni - Zn	-0.798	**						
Mg/Ca - Mg	0.979	***						
Mg/Ca - Fe	0.838	**						
Mg/Ca - Ni	0.813	**						

** P<0.01 , *** P<0.001

Table 5.3:5 Correlation coefficients (Pearson's) (P<0.01) between metal concentrations : within plants of *Rhacomitrium lanuginosum* ; within soils at sites of occurence of this species ; and between these plants and soils.(Soil Ni corr. are for Total Ni).

Plants			Soils			Plants-Soils		
Na - Zn	0.849	**	N - K	0.782	**	Ca - Fe	-0.897	***
Mg - Co	0.938	***	K - Na	0.922	***	Fe - Mg	-0.773	**
Mg - Fe	0.882	***	K - Co	-0.839	**	Cr - Mg	-0.763	+
Mg - Ni	0.980	***	Na - Ca	0.785	**			
Co - Cr	0.783	**	Ca - Mg	0.820	**			
Co - Fe	0.936	***	Co - Ni	0.901	***			
Co - Ni	0.895	***						
Cr - Fe	0.946	***						
Fe - Ni	0.821	**						
Mg/Ca - Mg	0.949	***						
Mg/Ca - Co	0.840	**						
Mg/Ca - Ni	0.910	***						

+ the value of 0.765 corresponds to P=0.01 , ** P<0.01 , *** P<0.001

CHAPTER SIX

Soil solution Analyses.

6.1 Introduction

A useful estimate of plant-available ions and nutrients is obtained using soil solutions (Nye & Tinker 1977). Previous work using soil solution estimates have reproduced tissue metal concentrations and symptoms broadly resembling those from field grown plants or grown on soil from serpentine sites (Anderson et al.1973, 1979; Johnston & Proctor 1981). Soil solutions were determined for comparison with other workers and are used as a basis for growth experiments (Chapter 7). Soil solutions were measured on soils that were determined both by reference to exchangeable analyses and soil multivariate analysis (Chapter 3), and then randomly within a transect.

Adams et al.(1980) found centrifugation and column-displacement methods produced similar results for soil solution, but soil-solution concentrations can vary with the wetness of the soil analysed (Nye & Tinker 1977). Russell (1973) points out that nitrate, chloride and sodium behave as if they are all in solution at all times, and therefore vary inversely with moisture changes, while potassium concentration is relatively unaffected by these changes. Calcium and magnesium behave similarly to nitrate, chloride and sodium (Nye & Tinker 1977). Russell (1973) finds phosphate independent of soil solution concentration, and Nye & Tinker (1977) stress the relationship between labile phosphate and phosphate in solution cannot be predicted. However, the relationships for these ions are complex and affected by many factors.

6.2 Materials and Methods

Soil solutions were extracted by the method of Anderson et al.(1973). Air-dried soil was brought to field capacity (see below), with deionised water and maintained moist for 3d. The soil was then centrifuged at 12000g for 1h at $0^{o}C$, the supernatant collected and filtered through Whatman's No. 42 filter paper. The solution was stored at $-20^{o}C$ until analysed.

Field capacity was used since on Rhum, soils are most often at this degree of saturation because of high rainfall and low potential evapotranspiration (Ragg & Ball 1964, Pomeroy 1974, Nature Conservancy Council 1974). The term field capacity, as used in this work (in the lab.), means the soil was moistened with deionised water until it drained into a dish below the pot containing the soil. The soil was then kept thus moistened with water for 3d, with the dish below kept so that it was just moist.

Exchangeable cations were determined as for the other soil measurements (Section 3.2.4). Chloride was determined in the soil solution extracts by a silver chloride titration on a Buckler-Cotlove Chloridometer Automatic Titrator (Cotlove et al.1958). Phosphate was determined in the soil solution extracts colorimetrically, after Allen et al.(1974) on a Cecil Instruments CE272 UV Spectrophotometer.

6.3 Results and discussion.

The soil solutions reported (Table 6.3:1) can be regarded as representing most of the ions at their most diluted state, and that for drier soil conditions, the concentrations would be higher. This is especially important for the magnesium and nickel levels because of their possible effects on vegetation. Further analyses could not be made because of insufficient quantities of solution.

A wide range of ionic concentrations have been reported from soil solutions (Epstein 1972; Bohn 1979, Russell 1973 and Nye & Tinker 1977). The soil solutions from Rhum tend to have high values for phosphate, iron and zinc and a low value for calcium.

Comparisons with soil solution values from other serpentine sites (Proctor et al.1981),showed several differences for the Rhum

Table 6.3:1 Soil solution values for pH, phosphate, potassium, sodium, calcium, magnesium, chloride, copper, iron, nickel, zinc and the magnesium/calcium quotient. Expressed as mg l-1, see text.

Quad-rat	pH	Phos-phate	K	Na	Ca	Mg	Cl	Cu	Fe	Ni	Zn	Mg/Ca
31	5.4	1.3	3.6	9.1	1.2	3.3	16.8	0.1	0.7	0.1	0.04	2.8
34	5.2	2.3	8.1	11.0	1.2	4.5	21.1	0.1	0.9	0.0	0.00	3.8
35	4.5	1.3	3.4	7.4	1.2	5.1	14.8	0.1	0.1	0.1	0.06	4.2
38	4.9	0.0	8.4	11.1	2.0	7.3	19.9	0.1	0.6	0.0	0.08	3.7
62	6.1	2.8	1.1	18.4	2.3	7.0	28.7	0.0	0.0	0.0	0.07	3.0
64	6.1	0.0	1.5	14.7	1.9	7.4	19.9	0.0	0.2	0.1	0.04	3.9
65	6.2	0.5	1.3	18.2	3.0	9.6	21.1	0.0	0.2	0.0	0.00	3.2
68	5.6	2.2	2.2	20.5	2.8	8.5	26.0	0.0	0.1	0.1	0.02	3.0
92	5.7	0.0	1.8	7.9	1.0	3.4	11.7	0.0	2.6	0.1	0.04	3.4
93	5.1	0.8	5.7	6.0	0.9	3.2	16.5	0.1	0.2	0.0	0.05	3.6
97	6.1	2.5	3.1	7.6	1.0	4.9	11.7	-	0.5	0.0	0.08	4.9
100	6.4	0.0	3.1	15.6	1.9	8.8	18.5	0.1	1.4	0.2	0.07	4.6
151	4.9	0.2	2.8	4.5	0.5	1.2	11.7	0.0	0.1	0.0	0.00	2.4
153	4.6	0.4	6.7	10.6	0.9	1.5	29.6	-	0.3	0.0	-	1.7
155	4.9	2.3	5.6	3.4	0.7	2.0	15.5	0.0	0.1	0.0	0.02	2.9
172	4.6	0.6	16.5	19.6	2.7	7.9	24.6	0.1	4.1	0.0	0.16	2.9
192	4.8	0.0	3.4	5.1	0.8	4.5	14.6	0.0	0.7	0.0	0.04	5.6
193	4.8	2.2	5.9	5.0	0.9	4.6	12.1	0.0	0.7	0.0	0.02	5.1
196	4.5	0.4	8.5	5.4	1.5	7.5	11.7	0.2	0.4	0.2	0.16	5.0
198	5.0	0.0	5.4	5.3	1.0	3.5	11.9	0.0	0.9	0.0	0.03	3.5
215	4.5	2.2	1.5	6.0	1.5	2.7	13.6	0.0	0.1	0.0	0.02	1.8

- not determined   Cr below detection limit (0.1 mg l-1) for all quadrats analyses. The magnesium/calcium quotients were lower on Rhum than for other Scottish serpentines, while the chloride concentrations were higher (with the exception of the Keen of Hamar in Shetland). This almost certainly reflects the site's proximity to the sea. The value for nickel was near the detection limit of the instrument (0.1 mg l^{-1}), and the higher values recorded were 0.2 mg l^{-1} in two samples, five had 0.1 mg l^{-1}, the rest fell below this. Other British serpentine sites (except Meikle Kilrannoch) show a similar range of nickel concentration. Soil solution potassium and sodium are higher on Rhum than most of the other serpentine sites, with the Keen of Hamar having higher values (again possibly reflecting oceanic effects), while the soil solutions from Meikle Kilrannoch have values similar to those from Rhum. Phosphate values are generally similar and relatively high in serpentine sites and the Rhum soils are no exception to this.

The bases in the soil solutions were also considered in m-equiv. l^{-1} (not reported) and as a proportion of the sum of their total (Table 6.3:2). The total bases in m-equiv. l^{-1} were far below the values given in the above literature for normal solutions, an expected result since the soil solutions were measured at their wettest (most dilute) condition. However, the proportion of nickel in these dilute soil solutions is noteworthy, ranging from 0.2-0.6% in six of the soil solutions from quadrats from ultrabasic areas. Also the proportion of sodium and magnesium in the soil solution is high, with the proportion of calcium generally low (<10%).

6.4 Relationships between soil solution and exchangeable bases.

Correlation coefficients (r) were determined for each cation between the soil solution values and the exchangeable values for the 21 quadrats where both were measured. Additionally, correlation

Table 6.3:2 Mean soil solution cation concentrations expressed as a percentage of the sum of the cations (from Table 3.3.5:1 in m. equiv l-1) for each quadrat.

Quad-rat	K %	Na %	Ca %	Mg %	Fe %	Ni %	Total %
31	10.8	46.7	7.1	32.1	2.9	0.4	100.0
34	18.0	41.7	5.2	32.3	2.8	0.0	100.0
35	9.7	35.9	6.7	46.9	0.4	0.3	99.9
38	15.1	34.0	7.0	42.3	1.5	0.0	99.9
62	1.8	52.7	7.6	37.9	0.0	0.0	100.0
64	2.7	45.9	6.8	43.8	0.5	0.2	99.9
65	1.9	44.7	8.5	44.6	0.4	0.0	100.1
68	3.1	49.7	7.8	39.0	0.2	0.2	100.0
92	5.6	42.2	6.1	34.3	11.4	0.4	100.0
93	20.2	36.1	6.2	36.4	1.0	0.0	99.9
97	9.0	37.6	5.7	45.7	2.0	0.0	100.0
100	4.8	41.6	5.8	44.3	3.1	0.4	100.0
151	18.2	49.5	6.3	25.0	1.0	0.0	100.0
153	21.1	56.8	5.5	15.2	1.4	0.0	100.0
155	28.9	29.9	7.1	33.3	0.8	0.0	100.0
172	19.1	38.6	6.1	29.5	6.7	0.0	100.0
192	11.7	29.8	5.4	49.7	3.4	0.0	100.0
193	18.5	26.6	5.5	46.4	3.1	0.0	100.1
196	18.6	20.2	6.4	53.0	1.2	0.6	100.0
198	18.7	31.3	6.8	39.0	4.3	0.0	100.1
215	6.3	43.5	12.5	37.0	0.7	0.0	100.0

coefficients (r) were determined for each cation (when expressed as a proportion of the total bases as m-equiv. l^{-1}), between soil solution and exchangeable values (Table 6.4:1). The correlation between soil solution pH and the pH for each soil was also determined.

Expressing the cations as a proportion of the total for each quadrat improved the correlation between soil solution and exchangeable cations for magnesium and potassium (Table 6.4:1). For the other cations the correlation was reduced, often to a non-significant value. This relationship was investigated to determine if the relationship between exchangeable and soil solution cations could be improved by this expression. However, since it was not, this relationship is not considered further.

Magnesium, calcium and sodium correlated well between the two measurements, with the relationship between soil solution and exchangeable analyses apparently showing a saturation curve (Fig. 6.4:1). While the factors affecting these two measurements are complex and varied (Nye & Tinker 1977), the results support a relationship between them. While one cannot predict soil solution values from exchangeable, for these cations there seems to be a relationship for the soils measured. The magnesium/calcium quotients correlated well ($r = 0.783$, $p<0.001$), supporting this.

Potassium and iron also correlated highly between the soil solution and exchangeable values, but this is due to the location of a few extreme points (Fig. 6.4:1). With the removal of these points the correlation between the soil solution and exchangeable levels for both of these cations is no longer significant. (However a relationship may exist and not be illustrated by these data). Potassium was noted above not to vary inversely with the water concentration in the soil solution, so with the low exchangeable potassium values in the data (except one point), it is possible that the information is insufficient to define a

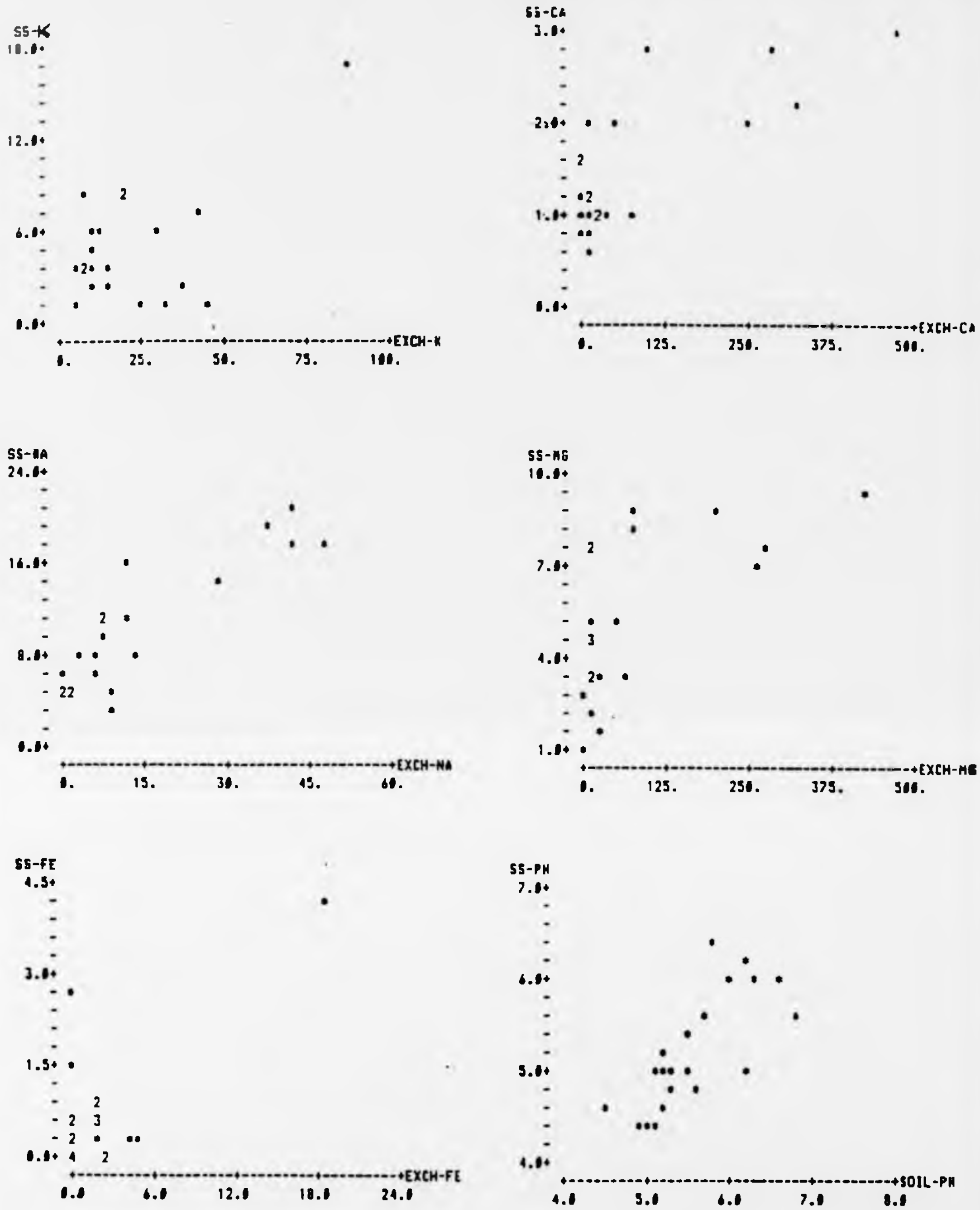
Table 6.4:1 Correlation coefficients (r) between soil solution and exchangeable cations. (n=21)

Cation		Soil solution (mg 1-1) and exchangeable (ug g-1) cations		Both expressed as percent composition in m-equiv. 1-1	
K	(1)	0.537	**	0.794	***
Na		0.893	***	0.307	ns
Ca		0.778	***	0.539	**
Mg		0.645	***	0.747	***
Fe	(1)	0.716	***	0.056	ns
Ni	(2)	0.454	*	0.345	ns
Zn		0.353	ns	-0.124	ns

ns not significant , * $P<0.05$, ** $P<0.01$, *** $P<0.001$

(1) For potassium and iron the correlation coefficients were influenced by a few points (see Fig 6.4:1) and are not significant if these are removed.

(2) For nickel the values for the soil solution are near the detection limit. (see Fig 6.4:1)



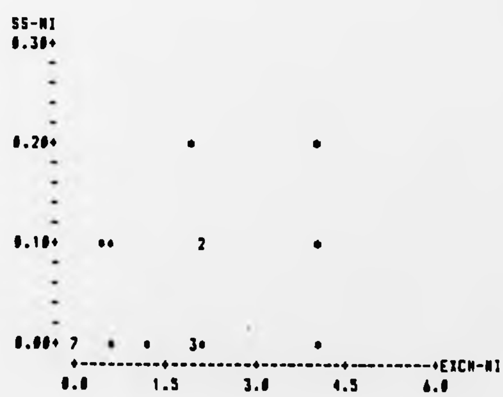


Fig.6.4:1. Graphs showing the relationship between soil solution (SS) (mg l^{-1}) and exchangeable (Exch) (µg g^{-1}) measurements of several elements. Where more than one point occurred at a locus the number of points is plotted.

relationship. Iron's status in the soil is too poorly understood to examine a relationship.

Nickel correlated significantly between soil solution and exchangeable values, but since the levels measured are so near the detection limit of 0.1 mg l^{-1} this relationship is possibly invalid. Nickel has been shown to be toxic at the levels in the soil solution (Wong & Bradshaw 1982), and from Fig. 6.4:1 one can see that if nickel was present in the soil solution it was also present in the exchangeable fraction. Again however the situation is complex; with ions in low concentrations, such as toxic ions, often having binding sites in the soil with high affinities (Nye & Tinker 1977).

Zinc was not discussed because it did not correlate significantly between soil solution and exchangeable, again probably due to low concentrations of both measurements.

pH correlated well ($r=0.784$, $p<0.001$) between the determinations as described in the Section 3.2.3 and the pH of the soil solutions (Fig. 6.4:1).

Growth of serpentine and non-serpentine races of *Agrostis canina* in solution-culture media simulating soil solutions on Rhum.

7.1 Introduction

Two experiments were designed using solution-culture techniques to investigate some of the plant adaptations and important chemical factors suggested by the ordinations and chemical analyses described earlier.

Many of the previous experiments which have been made on serpentine plants and soils are open to serious criticism. Crop plants, particularly oats, (*Avena sativa*) have often been investigated because of their well-documented nickel-toxicity symptoms (Hunter & Vergnano 1953, Spence & Millar 1963, Proctor 1971a, Proctor & McGowan 1976). Although these are useful for pointing to acute toxicities, explanations of adaptations to serpentine soils must involve native plants. But even work with native plants has often been of limited value. For example, in experiments with serpentine soils and races (Proctor 1971a, Hart 1977, 1980) the plant-available ions causing the symptoms are unknown. In culture solution work conventional full nutrient media have often been used and these have a very different composition from those likely to be found in the soils in nature (Madhok & Walker 1969, Main 1974, Marrs & Proctor 1976). In other experiments, the plant response measured has been for a single characteristic (usually growth in length of a single adventitious root) for a few days in single salt (+calcium nitrate) solutions (Wilkins 1957, Wong & Bradshaw 1982).

Reasons for using indigenous races of *Agrostis canina* from both ultrabasic and non-ultrabasic sites include: the material investigated is directly related to the problem and tests if adapted races are present; the races will be adapted to similar environmental conditions;

and no problems of validity or comparison arise as when using crop species. There is sufficient work recorded in the serpentine and heavy-metal ecological literature to accept that a toxicity problem is quite often present, especially for crop species (Antonovics, Bradshaw & Turner 1971, Proctor & Woodell 1975). However, several species, particularly grasses, have been shown to be able to develop tolerant races and grow with some success on potentially toxic soils (Cox & Hutchinson 1980, Johnston & Proctor 1981). It is necessary therefore to use experimental material from the area involved.

Problems with the difficulties of solution work have been recognised.Clymo (1962) used actual soil solutions, and solutions made to simulate these, from the areas he studied as culture media, in his work on the calcicole/ calcifuge problem with Carex demissa and C. lepidocarpa. Johnston & Proctor (1981) in their investigation of a serpentine race of Festuca rubra, successfully used culture media which simulated soil solutions (extracted by a centrifugation method). Their methods were used as the basis for the experiments reported here, I modified their techniques by using relative growth rates from two harvests rather than final dry weight as a measure of plant response (Hunt 1978).

I made two experiments to test the effect of different concentrations of nickel, magnesium and calcium (which the ordination and analyses had suggested were important distinguishing features between the Rhum ultrabasic and non-ultrabasic soils), on tillers of Agrostis canina collected from both types of soil. It was hoped that the experiments would help explain the causes of the vegetative differences between ultrabasic and non-ultrabasic soils.

7.2 Methods

7.2.1 Preparation and analysis of plants.

Agrostis canina was collected in July 1980 from two ultrabasic areas (clone S1 from Quadrat 61, S2 from Quadrat 31) and from a non-ultrabasic area (clone NS from Quadrat 151). These locations were chosen initially from field observation as representative of a range of sites and from their chemical analyses, and allow comparison with the analysis of field grown A. canina.

The clones were grown for over a year in John Innes No. 2 compost (this soil has a low concentration of heavy metals and an exchangeable magnesium/calcium quotient of 0.16, Johnston 1976) in a glasshouse. They were re-potted in fresh potting compost at regular intervals and in November 1981 wertransferred to a growth room with a 16h day and temperature of 12-16°C until tillers were cut in February 1982. The plants were split into single tillers by cutting below the first node from the apex, and were supported in glass sleeves and rooted in a solution of 0.1 g l^{-1} calcium nitrate (25 mg l^{-1} (Ca^{+2}) in a growth room with a 16h day and a temperature of 16°C. This Ca concentration was used because pretreatment concentrations can be important in the interpretation of results (Rorison 1969). Johnston & Proctor (1981), showed 0.2 g l^{-1} calcium nitrate to be beneficial in root development, but I decided to use a lower concentration in view of the very low calcium concentrations in the Rhum soils. The tillers were slow to root and had to be kept in solution for 3 weeks (the solution level was maintained with deionised water), before they were ready. Just before the experiments, rooted tillers of the three clones of uniform size were selected and thoroughly rinsed in deionised water. Six randomly chosen tillers of each race were then dried, weighed and analysed to give initial weight and chemical composition values.

All chemical analyses were carried out as described in Chapter

5, except the plants were rinsed twice (rather than four times) in deionised water. Root analyses were not made because Johnston & Proctor (1981) had found that shoot analyses enabled the most important conclusions to be drawn. Moreover, in my experiment, the roots occasionally had negative relative growth rates (see below, Fig. 7.3.1:3) indicating root sloughing, and their small weights would have necessitated combining replicates and hence losing tests of significance.

Relative growth rates (RGR) were calculated to express the plants' response (Hunt 1978). RGR's have the advantage of removing the effect of initial differences in size by using a rate equation. (Since the stage of its life cycle that a plant is in can affect its growth rate, the different clones were tillered at the same time to increase the probability that they would be at a similar stage).

To interpret the results, an analysis of variance was calculated, using the GENSTAT ANOVA programs, for the RGR's and the elemental concentrations of the shoots. Significant differences were tested using the restricted Least Significant Difference.

7.2.2 Solution culture techniques.

Solutions simulating the soil solutions from the clones' sites of collection (Section 7.2.3) were used in the experiment. The culture solutions were contained in 600-ml beakers wrapped in aluminium foil. Each beaker had one plant tiller, in a glass sleeve, in a hardboard cover, suspended in the solution. The solutions were freshly made up and changed weekly and topped up daily with deionised water. The pH for each solution was measured at the beginning and end of every week. It was hoped to make the experiments at temperatures resembling those on Rhum, but because of the slow rooting time of the tillers and the slow growth of the clones in soil culture, it was decided to use 20°C. Both experiments were conducted for six weeks with an intermediate harvest at three weeks for Experiment 1. At each harvest the plants harvested were washed twice in deionised water, oven-dried at 60°C, their weights recorded and the shoots analysed.

7.2.3 Experiments 1 and 2

Experiment 1 was a factorial combination of the three races of A. canina, with two concentrations each of nickel, magnesium and calcium, replicated three times for two harvests (3x2x2x2x3x2 = 144 pots). In the following account: +Ni means added nickel, ONi not added; magnesium and calcium are denoted by suffixes Mg_H and Ca_H (high) and Mg_L Ca_L (low).

The experimental solutions were based on the soil solutions from Quadrats 62 and 64 for ultrabasic areas, and Quadrats 151 and 153 for the non-ultrabasic (Table 6.3:1 and Table 7.2.3:1). Insufficient solution had been available for complete analysis of the soil solutions. For the nutrients (which had been determined) the mean concentration from the four quadrats were used in the culture solutions; for Mg_H and Ca_H the mean was for Quadrats 62 and 64, while Mg_L and Ca_L the mean was for Quadrats 151 and 153. For nickel it was decided to use the highest value found in the soil solutions measured (0.2 mgl^{-1}, Quadrats 100 and 196, Table 6.3:1), because nickel was low in the ultrabasic Quadrats 62 and 64, and I was anxious to establish the likelihood of nickel toxicity. Thus if the highest recorded soil-solution concentration had no effect, then nickel toxicity was unlikely in the Rhum soils.

Ammonium, nitrate and sulphate were not determined in the soil solutions and were initially estimated by comparison to the soil solution values from Meikle Kilrannoch (Johnston & Proctor 1981). This was done using ratios based on the phosphate determinations of the two sites. For ammonium and sulphate this estimate was followed, but the final concentration of nitrate in the solution was the quantity necessary to balance the magnesium and calcium ions (the quantity used was very near the estimate). When magnesium and calcium were varied below the high concentrations,

Table 7.2.3:1 The mean element concentrations (mg l-1) of the soil solutions (from Quadrats 62 & 64) for ultrabasic (UB) and (from Quadrats 151 & 153) for non-ultrabasic (Non) solutions; and the element concentrations of the culture solutions used in Experiments 1 and 2.

Element	Soil Solution UB	Soil Solution Non	Culture Solution Exp. 1	Culture Solution Exp. 2 UB	Culture Solution Exp. 2 Non
N (as NH4+)	nd		0.16	0.26	0.06
(as NO3-)	nd		37.0	36.7	36.7
P *	1.4	0.3	0.87	1.40	0.30
K	1.3	4.8	3.13	1.97	5.28
Na	16.6	7.6	12.2,13.9,23.8,25.4 #	17.0	21.8
Ca	2.1	0.7	0.7,2.1	2.1	0.7
Mg	7.2	1.3	1.2,7.3	7.2	1.2
B	nd		0.271	0.268	0.268
Cl	24.3	20.7	21.27	27.52	17.65
Cu	<0.1	<0.1	0.002	0.002	0.002
Fe	0.1	0.2	0.150	0.095	0.201
Mn	nd		0.050	0.049	0.049
Mo	nd		0.0078	0.0077	0.0077
Ni	0.1	0.0	0.0,0.2	0.0,0.2	0.0,0.2
S (as SO4--)	nd		0.598	0.665	0.592
Zn	0.05	0.00	0.0050	0.0548	0.0049

nd not determined

* P as PO_4^{3-} in soil solution , as $H_2PO_4^-$ in culture solution

Where the concentrations were altered in an experiment all concentrations are given.

sodium nitrate was used to maintain the nitrate concentration. This resulted in higher sodium concentrations inversely with lower magnesium and calcium in solution, but Johnston & Proctor (1981) found this to be unimportant in similar work. For the micronutrients B, Cu, Mn, Mo and Zn, one-tenth of the Hoagland & Arnon (1950) concentrations were used, after Johnston & Proctor (1981). While zinc was considered to be possibly important (it is experimentally altered in Experiment 2), it was felt necessary to use the lower concentration of one-tenth Hoagland & Arnon's value instead of the value measured from Rhum, to be able to separate any possible zinc response from calcium or magnesium responses between the two experiments. The soil solution and culture-solution values used are in Table 7.2.3:1 and the chemicals used in the different culture media are in Table 7.2.3:2.

Experiment 2 was designed to test the importance of further differences of the two soil-solution types (ultrabasic and non-ultrabasic) by altering the concentrations of phosphate, potassium, chloride, iron, and zinc to simulate the chemical composition of the two solution types. Ammonium and sulphate were also altered since they are the paired ions of two of those altered (Tables 7.2.3:1 and 2). Experiment 2 was a factorial combination of two races of A.canina, with two concentrations of nickel, in the two solution types (UB and Non) replicated three times with one harvest (2x2x2x3x1 = 24 pots). Difficulties obtaining sufficient tillers prevented the use of race S2 in this experiment and unfortunately allowed only one harvest. Analysis of the results and shoots were as for Experiment 1.

7.3 Results

7.3.1 Relative Growth Rates

The abbreviations used for the different relative growth rates in the two experiments are summarised in Table 7.3.1:1. For RGR calculations

Table 7.2.3:2 The composition of the culture media in Experiments 1 and 2. (μ moles l^{-1}).

Chemical	Experiment 1	Experiment 2 UB	Experiment 2 Non-UB
NaCl	520	726	362
KCl	80	50.4	135
Na_2SO_4	5.205	5.153	5.153
$NH_4H_2PO_4$	9.0	14.4	3.1
NaFeEDTA	2.69	1.70	3.60
H_3BO_3	4.6	4.55	4.55
$CuSO_4.SH_2O$	0.032	0.032	0.032
$MnSO_4.4H_2O$	0.91	0.90	0.90
$(NH_4)_6MO_7O_{24}.4H_2O$	0.0074	0.0073	0.0073
$ZnSO_4.7H_2O$	0.076	0.839	0.075
$Mg(NO_3)_2.6H_2O$	50,300	297	50
$Ca(NO_3)_2.4H_2O$	17.5,52.5	52.5	17.5
$NaNO_3$	70,500,570	-	564
$Ni(NO_3)_26H_2O$	0,3.4	0.3.4	0,3.4

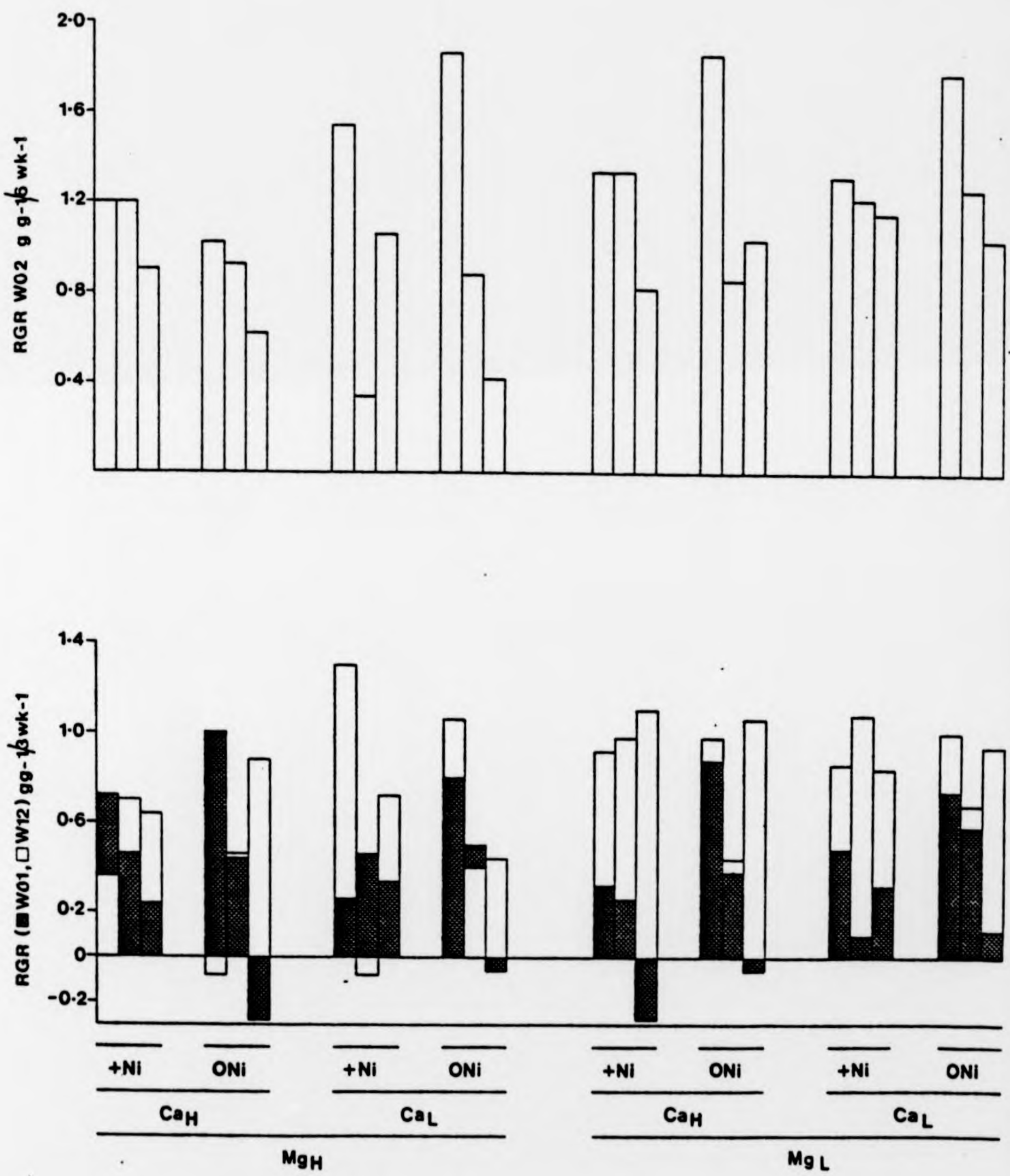
Table 7.3.1:1 The abbreviations used for Relative Growth Rates in Experiments 1 and 2.

RGR	Relative Growth Rate
RGRW02	RGR Whole plant from initial to Harvest 2.
RGRW01	RGR Whole plant from initial to Harvest 1.
RGRW12	RGR Whole plant from Harvest 1 to Harvest 2.

RGRS refers to the corresponding values for shoots, RGRR for roots. For experiment 2 there was only one harvest.

Figs. 7.3.1:1-3 The mean RGR's (harvest 1 shaded) for the different treatments and harvests in Experiment 1. In each group of histograms the order for the clone type is NS (non-serpentine for Quadrat 151), S1 (ultrabasic from Quadrat 61), and S2 (ultrabasic from Quadrat 31). Abbreviations for RGR's and plant parameters are in Table 7.3.1:1. Plant dry weights are in Appendix VIII.

Fig. 7.3.1:1



2·0
1·6
1·2
0·8
0·4
RGR W02 g g-1 5 wk-1
1·4
1·0
0·6
0·2
0
-0·2
RGR (■W01, □W12) gg-1 3 wk-1
+Ni
ONi
+Ni
ONi
+Ni
ONi
+Ni
ONi
CaH
CaL
CaH
CaL
MgH
MgL

Fig.7.3.1:2

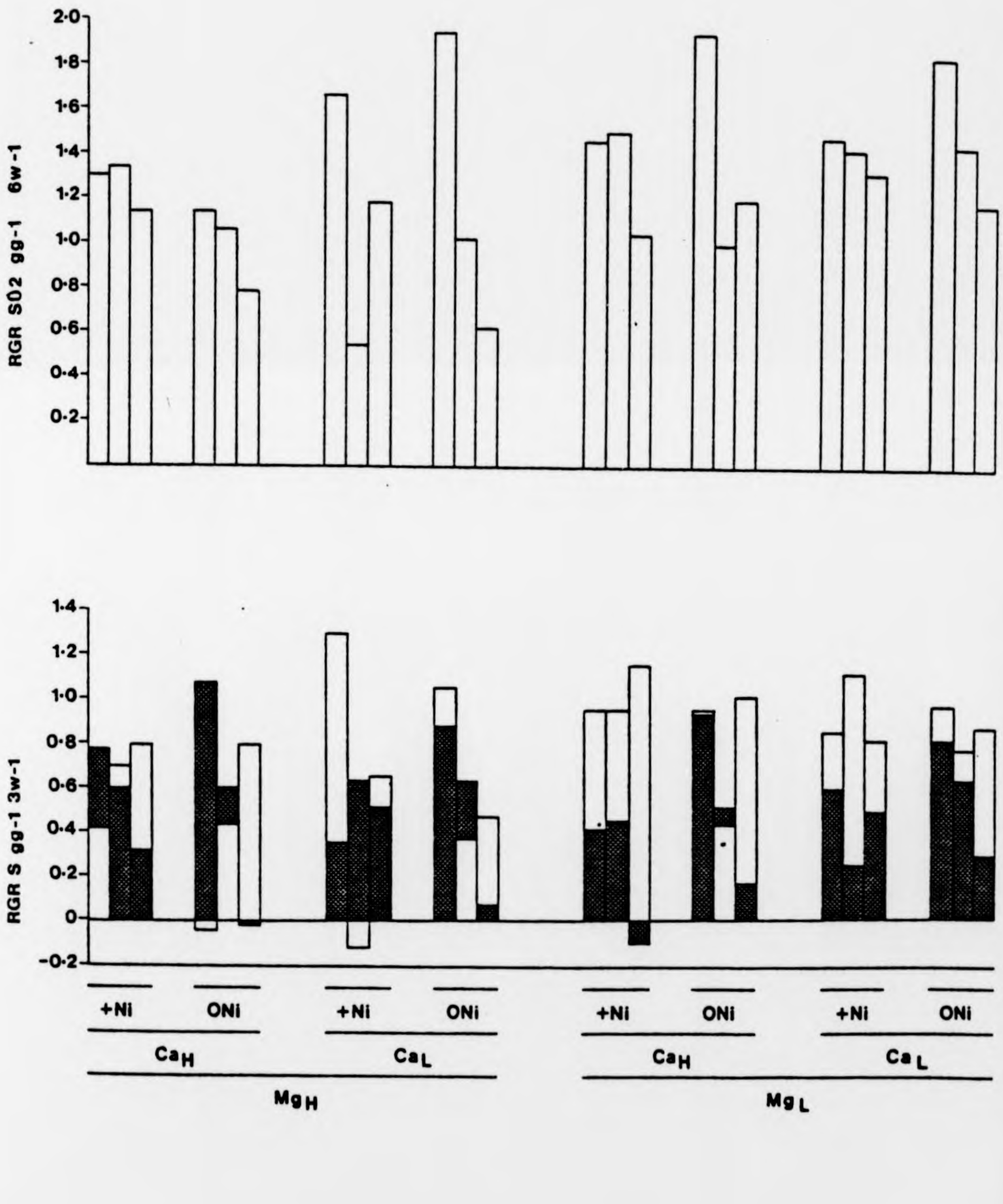

RGR S02 gg-1 6w-1
2·0
1·8
1·6
1·4
1·2
1·0
0·8
0·6
0·4
0·2
RGR S gg-1 3w-1
1·4
1·2
1·0
0·8
0·6
0·4
0·2
0
-0·2
+Ni
ONi
+Ni
ONi
+Ni
ONi
+Ni
ONi
Ca_H
Ca_L
Ca_H
Ca_L
Mg_H
Mg_L

Fig.7.3.1:3

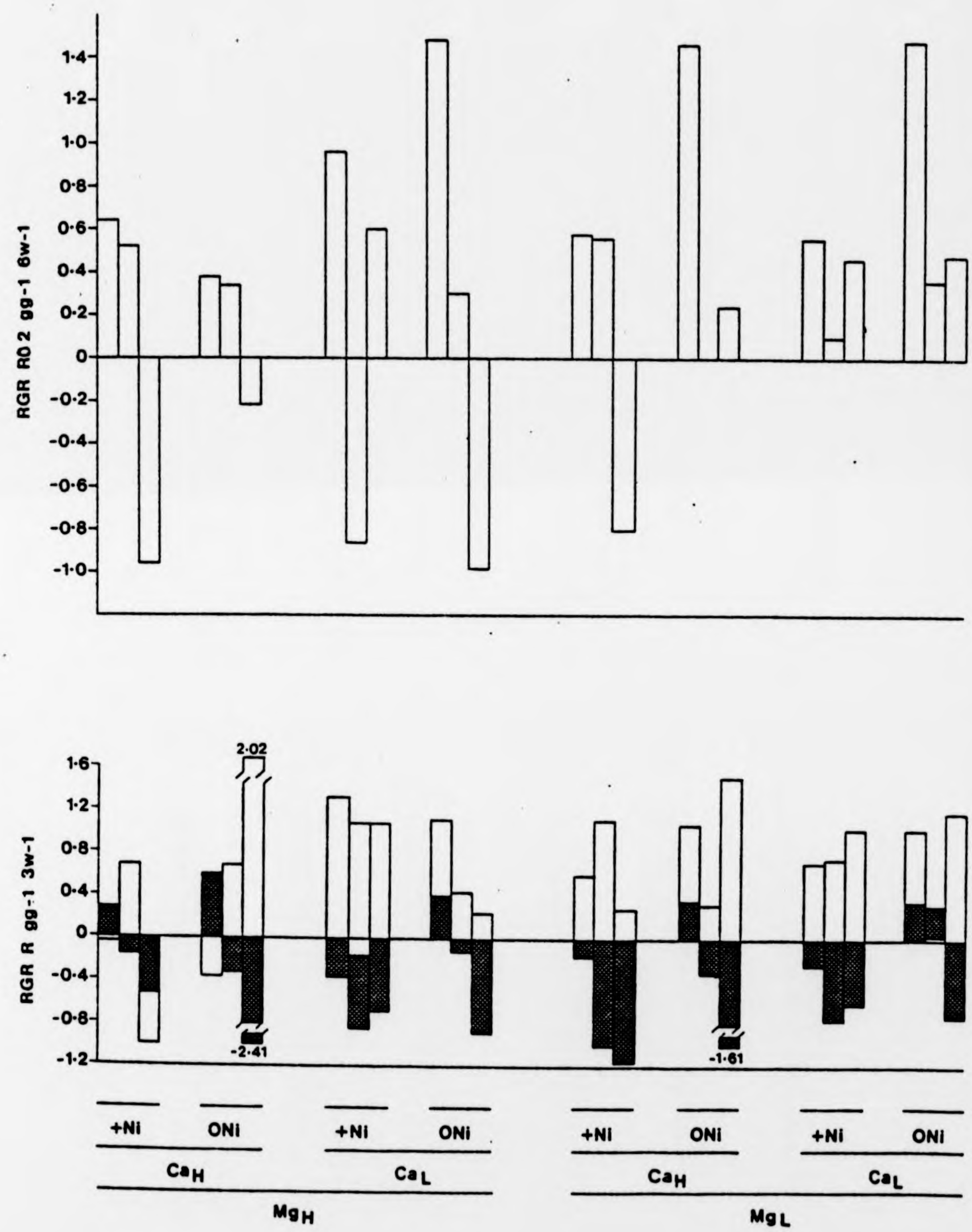
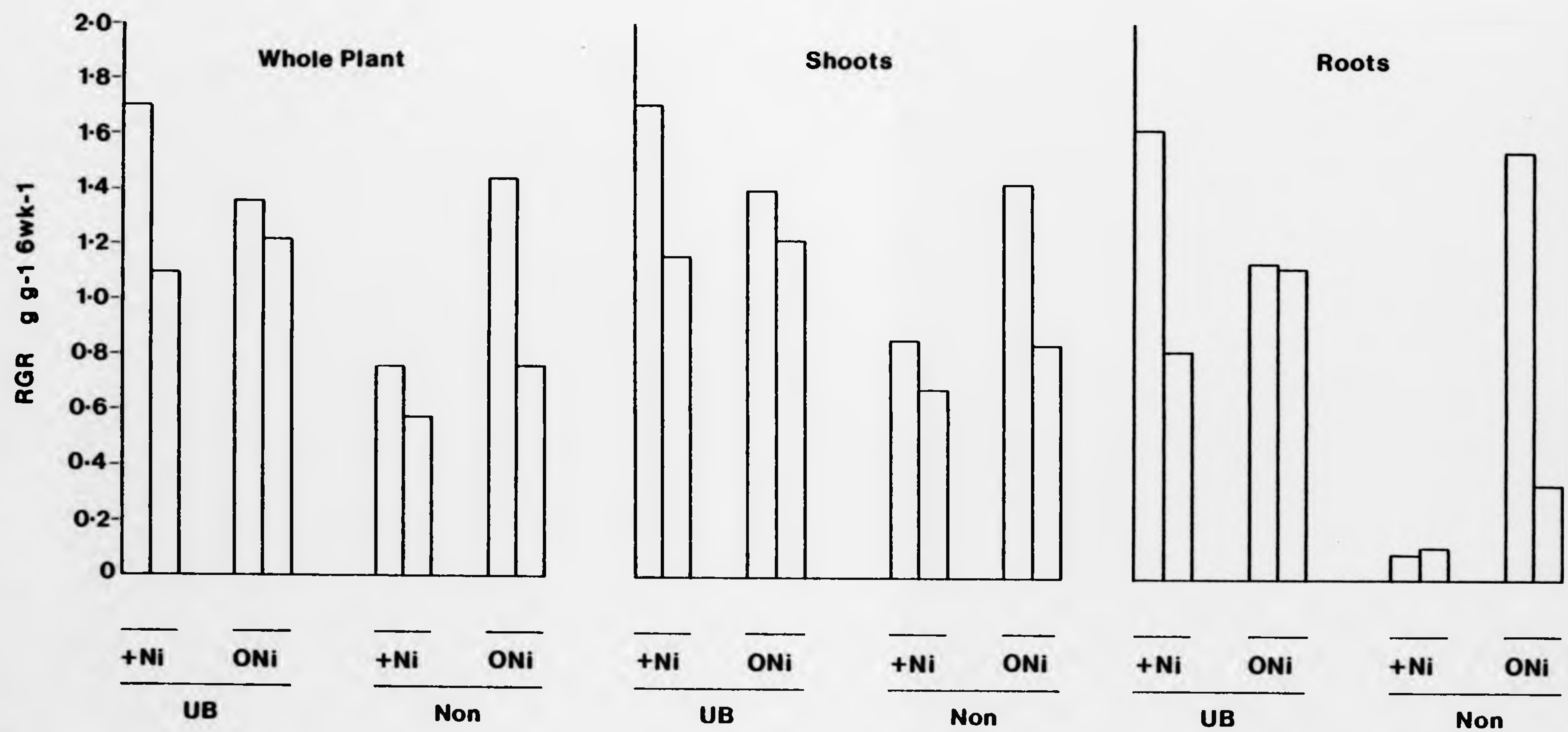

RGR RD2 gg-1 6w-1
1·4
1·2
1·0
0·8
0·6
0·4
0·2
0
-0·2
-0·4
-0·6
-0·8
-1·0
RGR R gg-1 3w-1
1·6
1·2
0·8
0·4
0
-0·4
-0·8
-1·2
2·02
-2·41
-1·61
+Ni
ONi
+Ni
ONi
+Ni
ONi
+Ni
ONi
Ca_H
Ca_L
Ca_H
Ca_L
Mg_H
Mg_L

Fig. 7.3.1:4 The mean RGR's for the different treatments in Experiment 2. In each group of histograms the order for the clone type is NS (non-serpentine from Quadrat 151), and S1 (ultrabasic from Quadrat 61). Abbreviations for RGR's and plant parameters are in Table 7.3.1:1. Plant dry weights are in Appendix VIII.



RGR g g-1 6wk-1
2·0
1·8
1·6
1·4
1·2
1·0
0·8
0·6
0·4
0·2
0
Whole Plant
Shoots
Roots
+Ni
ONi
UB
Non

Table 7.3.1:2 The significant sources of variation of RGR in Experiment 1. (See Fig. 7.3.1:1-3, Tab. 7.3.1:3)

	Mg	Race	Ca Race	Ca Ni	Ni Race	Mg Ca Race	Ca Ni Race
RGR W02	-**	***				**	
RGR W01		***			**		
RGR W12	-***		**			**	
RGR S02	-**	***				*	
RGR S01		***			*		
RGR S12	-***		**			**	
RGR R02		***	*				**
RGR R01		***			**		
RGR R12	-*		**	*			***

* P<0.05 , ** P<0.01 , P<0.001

- for Mg implies that the higher magnesium concentration resulted in a lower RGR.

Table 7.3.1:3 The significant levels of the significant variation (Table 7.3.1:2) in Experiment 1, determined by using Least Significant Differences, see Fig. 7.3.1:1-3 (the variation for the magnesium treatment, considered singularly is not reported in this table, as it can be inferred from Table 7.3.1:2).

RGR	Treatment	Level
RGRW02	Race	NS>S1
		NS>S2
	Mg-Ca-Race	NS, $Mg_{L>H}Ca_H$
		NS, $Mg_H Ca_{L>H}$
		NS>S2, $Mg_H Ca_L$
		NS>S1, $Mg_L Ca_H$
		NS>S2, $Mg_L Ca_H$
		NS>S2, $Mg_L Ca_L$
		S1, $Mg_H Ca_{H>L}$
		S1, $Mg_{L>H}Ca_L$
RGRW01	Race	NS>S1
		NS>S2
		S1>S2
	Ni -Race	NS, ONi>+Ni
		NS>S1,ONi
		NS>S2,ONi
		S1>S2,ONi
RGRW12	Ca-Race	NS, $Ca_{L>H}$
		NS>S1, Ca_L
		NS>S2, Ca_L
		S2>NS, Ca_H
	Mg-Ca-Race	NS, $Mg_H Ca_{L>H}$
		NS, $Mg_{L>H}Ca_H$
		NS>S2, $Mg_H Ca_L$
		S1, $Mg_H Ca_{H>L}$
		S2>NS, $Mg_H Ca_H$
RGRS02	Race	NS>S1
		NS>S2
	Mg-Ca-Race	NS, $Mg_{L>H}Ca_H$
		NS, $Mg_H Ca_{L>H}$
		S1, $Mg_{L>H}Ca_L$

Table 7.3.1:3 (contd.)

RGR	Treatment	Level
RGRSO1	Race	NS>S1
		NS>S2
		S1>S2
	Ni-Race	NS, ONi>+Ni
		NS>S1,ONi
		NS>S2,ONi
		S1>S2,ONi
RGRS12	Ca-Race	NS,$CA_{L>H}$
		NS>S1,Ca_L
		NS>S2,Ca_L
		S2>NS,Ca_H
	Mg-Ca-Race	NS,$Mg_H Ca_{L>H}$
		S1,$Mg_H Ca_{H>L}$
		S1,$Mg_L Ca_{L>H}$
RGRRO2	Race	NS>S1
		NS>S2
	Ca-Race	NS>S1, Ca_L
		NS>S2, Ca_L
		NS>S2,Ca_H
		S1>S2,Ca_H
		S2, $Ca_{L>H}$
	Ca-Ni-Race	NS>S1,Ca_LONi
		NS>S2,Ca_LONi
		NSONi>S2+Ni,Ca_H
		S1ONi>S2+Ni,Ca_H
		S2Ca_HONi>+Ni
		NSONi>S1+NiCa_L
		NSONi>S2+NiCa_L
		S1,$Ca_{H>L}$+Ni
		S2,$Ca_{L>H}$+Ni
		S2,Ca_L+Ni>ONi
RGRRO1	Race	NS>S1
		NS>S2
		S1>S2
	Ni-Race	NS>S2,+Ni
		NS>S2,ONi
		S1>S2,ONi
		S2,+Ni>ONi

Table 7.3.1:3 (cont.)

RGR	Treatment	Level
RGRR12	Ca-Ni	Ca_HONi>+Ni
		Ca_L+Ni>Oni
	Ca-Race	NS>$Ca_{L>H}$
		NS>S1,Ca_L
	Ca-Ni-Race	NS>S1,Ca_L+Ni
		S1>S2,Ca_H+Ni
		S1ONi>S2+Ni,Ca_H
		S2,$Ca_{L>H}$+Ni
		S2,$Ca_{H>L}$ONi
		S2,Ca_HONi>+Ni

Table 7.3.1:4 The significant sources of variation of RGR in Experiment 2. (See Fig. 7.3.1:4)

	Type	Race	Type Ni
RGR W	*	*	
RGR S	*		
RGR R	*	*	*

* P<0.05

The significant levels of the above significant variation determined by using Least Significant Differences.

RGR	Treatments	Level
RGR W	Type	UB>Non
	Race	NS>S1
RGR S	Type	UB>Non
RGR R	Type	UB>Non
	Race	NS>S1
	Type-Ni	UB>Non, +Ni
		Non, 0Ni>+Ni
		UB 0Ni>Non +Ni

Type = Solution type : UB = Ultrabasic , Non = Non-ultrabasic
Ni = Nickel level : 0Ni = 0.0 mg/l Ni , +Ni = 0.2 mg/l Ni
Race = Race of <u>Agrostis</u> <u>canina</u> : NS = Non-serpentine , S1 = Serpentine race 1

involving the initial weights (the three clones' initial weights were not significantly different), means for each tiller were used, and for calculations from Harvest 1 to Harvest 2 (in Experiment 1), means for each treatment for each tiller were used for the Harvest 1 weights. The results for all plant dry weights for both experiments are in Appendix VIII. The means for the different RGR's were calculated for each treatment and are plotted as histograms in Figs. 7.3.1: 1-4. The variance that was significant for these results are given in Tables 7.3.1:2-4.

Experiment 1.

The different results obtained for the RGR for the first and second 3-week intervals and the entire 6-week period are of importance.

The NS clone had its best growth, for the whole plant for the entire 6-week period, in the Mg_H Ca_L ONi or the Mg_L Ca_H ONi solutions (Fig. 7.3.1:1), the growth in both solutions is very similar. The growth on the Mg_H Ca_H ONi solution was significantly lower (Tables 7.3.1: 2 & 3) than both these solutions, however nickel did not have a significant effect for the entire growth period in any solution. (Nickel did have a significant deleterious effect for the first 3-week period on the NS clone in all solutions). It is noteworthy that while calcium often ameliorates magnesium toxicity, in this case Ca_H when combined with Mg_H significantly reduced the NS clone's growth.

The S1 clone grew best (the whole plant for the entire 6-week period) in the Mg_L Ca_H +Ni solution. Again it grew almost as well in other solutions (Mg_H Ca_H +Ni, Mg_L Ca_L ONi, Mg_L Ca_L Oni). It grew significantly better with Ca_H when in Mg_H solutions, while with Ca_L it grew significantly better with Mg_L, indicating interaction between these ions for this clone. Its worst growth was in the Mg_H Ca_L +Ni solution.

For the S2 clone the best growth (whole plant for the entire

6-week period), was in the Mg_L Ca_L + Ni solution. It grew almost as well in other solutions (Mg_H Ca_H+Ni, Mg_L Ca_H +Ni, Mg_L Ca_L ONi). Of considerable interest is the different growth rates for the first and second 3-week periods for this clone (Fig. 7.3.1:1). The lowest RGR for the entire 6-week period was in the Mg_H Ca_L ONi solution.

Experiment 2.

The NS clone grew best (for the whole plant) in the UB + Ni solution and its worst in the NON + Ni solution (Table 7.3.1:4 and Fig. 7.3.1:4). The S1 clone's best growth for the whole plant, was in the UB ONi solution with its worst in the Non +Ni solution.

7.3.2 Concentrations of elements in the shoots.

Of the metal concentrations for the three clones at the beginning of the experiment, only manganese and potassium were slightly but significantly different for the different clones ($p<0.05$) (Table 7.3.2:1). The importance of these differences is not clear, but significant variance statistically does not always imply a significant difference biologically.

The shoots were analysed for their metal concentrations at each harvest. These are reported in Appendix IX, and the means for each treatment for the different metals are plotted as histograms in Figs. 7.3.2: 1-8. The variance of each metal concentration, for the treatments, was determined on $\log_e$ transformed data and then as for the RGR. (Tab.7.3.2:2-4) As found in other work, the concentration of the metal ions in the shoot generally increased with higher solution concentrations.

The contents of all metals (i.e. weights per shoot) for both harvests in Experiment 1 and the single harvest in Experiment 2 increased throughout the experiment compared with the initial content of the shoots (Table 7.3.2:1). The content of the shoots for each metal was compared to the solution quantites available during growth. Although

Table 7.3.2:1 The initial mean metal content (ug plant-1) and concentrations (ug g-1 oven dry weight) of the tillers of <u>Agrostis</u> <u>canina</u> used in Experiments 1 & 2.

Metal	Race					
	NS (n=3)		S1 (n=3)		S2 (n=2)	
	Content	Conc.	Content	Conc.	Content	Conc.
K	180	14000	240	16000	250	18000
Na	8.3	640	5.6	380	11.5	840
Ca	94	7270	75	5090	86	6240
Mg	8.7	670	7.4	500	11.0	830
Fe	4.0	306	3.2	220	2.4	172
Mn	5.7	440	4.0	270	3.2	230
Ni	<0.6	<50	<0.7	<50	<0.7	<50
Zn	1.0	81	0.7	51	0.8	55

Figs. 7.3.2:1-4. The mean shoot element concentrations (per dry weight) (harvest 1 shaded) for the different clones and treatments at each harvest in Experiment 1. Other conventions as Figs. 7.3.1: 1-3. The results for all analyses are in Appendix IX.

Fig. 7.3.2:1

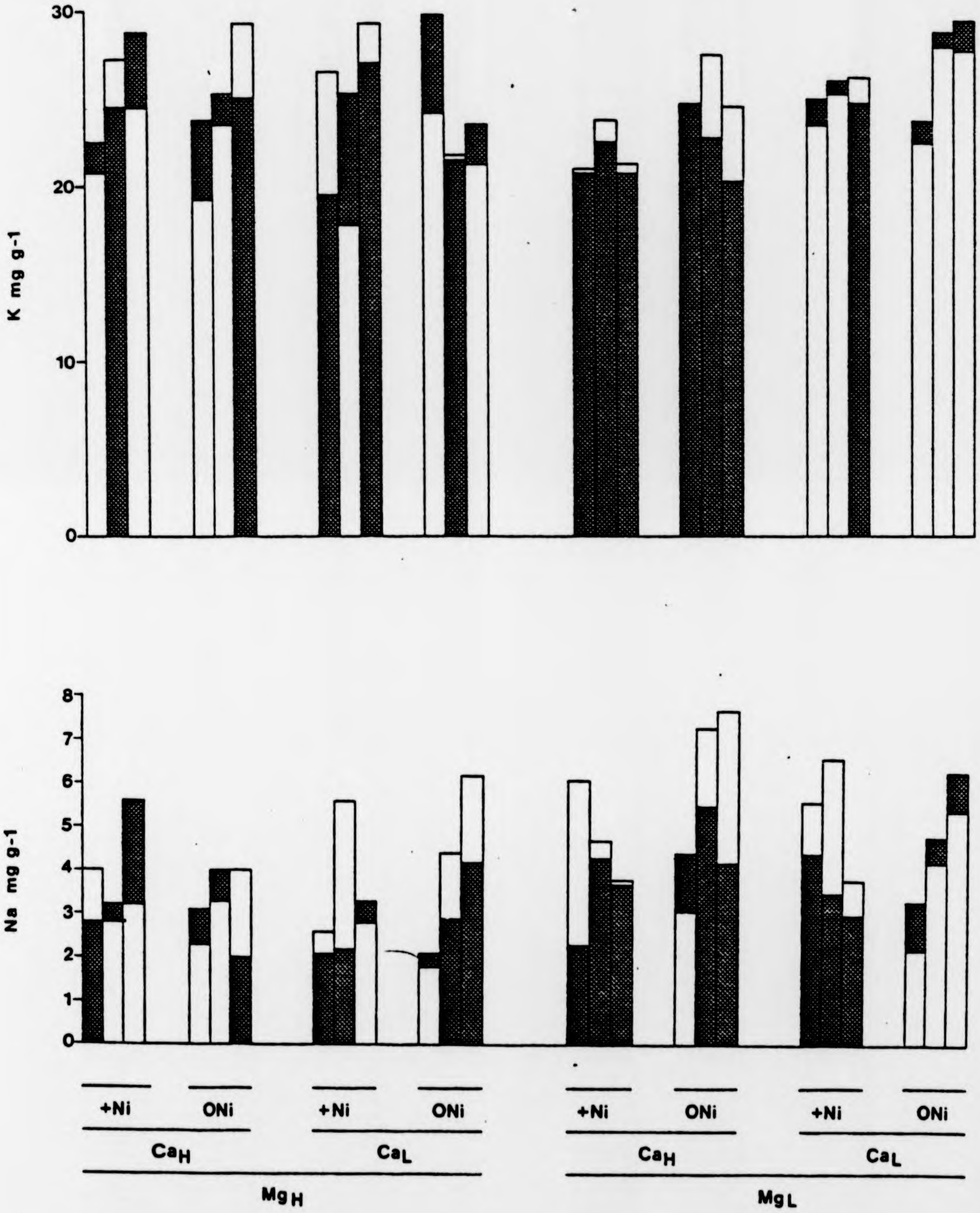

30
20
10
0
K mg g-1
8
7
6
5
4
3
2
1
0
Na mg g-1
+Ni
ONi
+Ni
ONi
+Ni
ONi
+Ni
ONi
Ca_H
Ca_L
Ca_H
Ca_L
Mg_H
Mg_L

Fig. 7.3.2:2

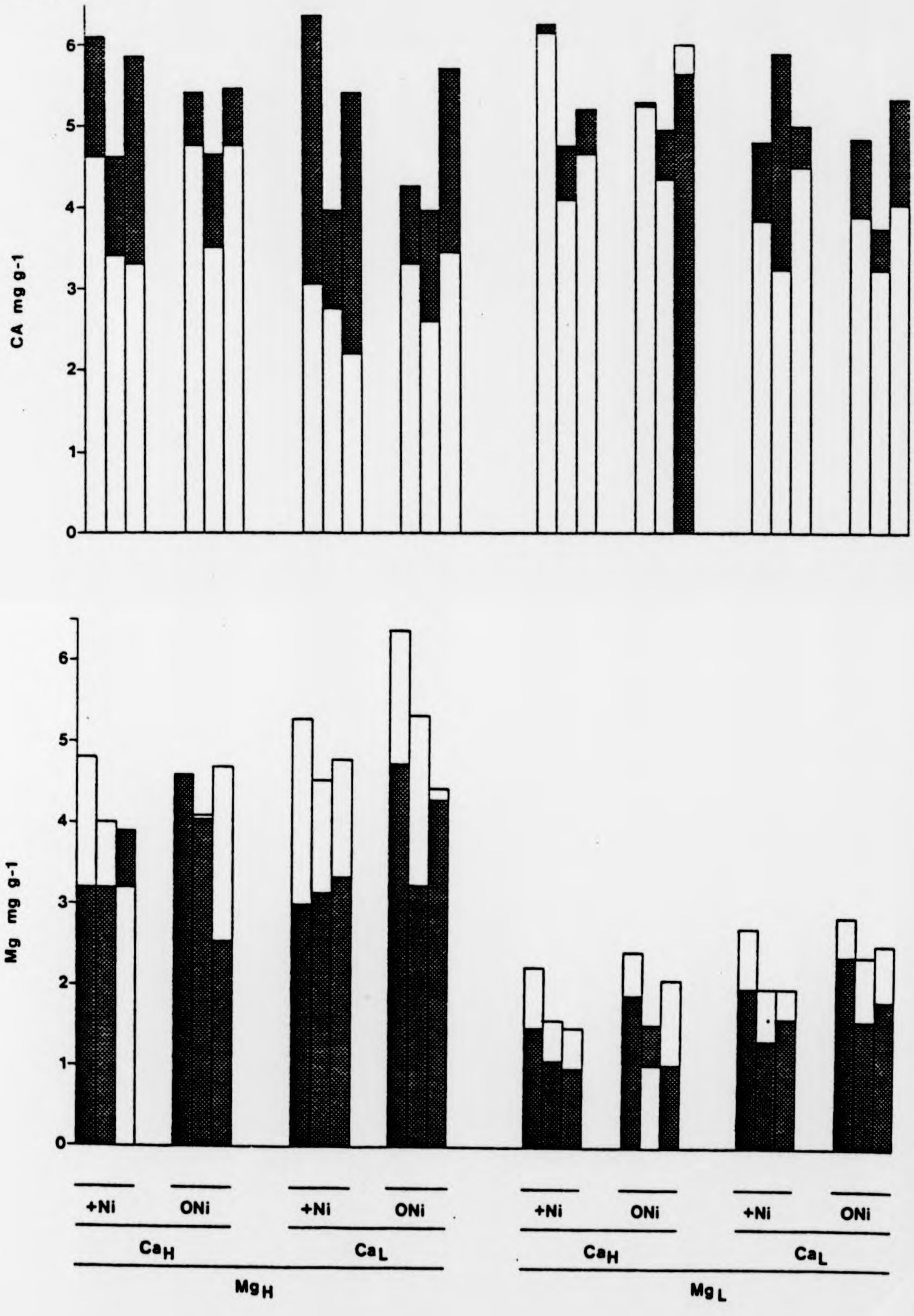
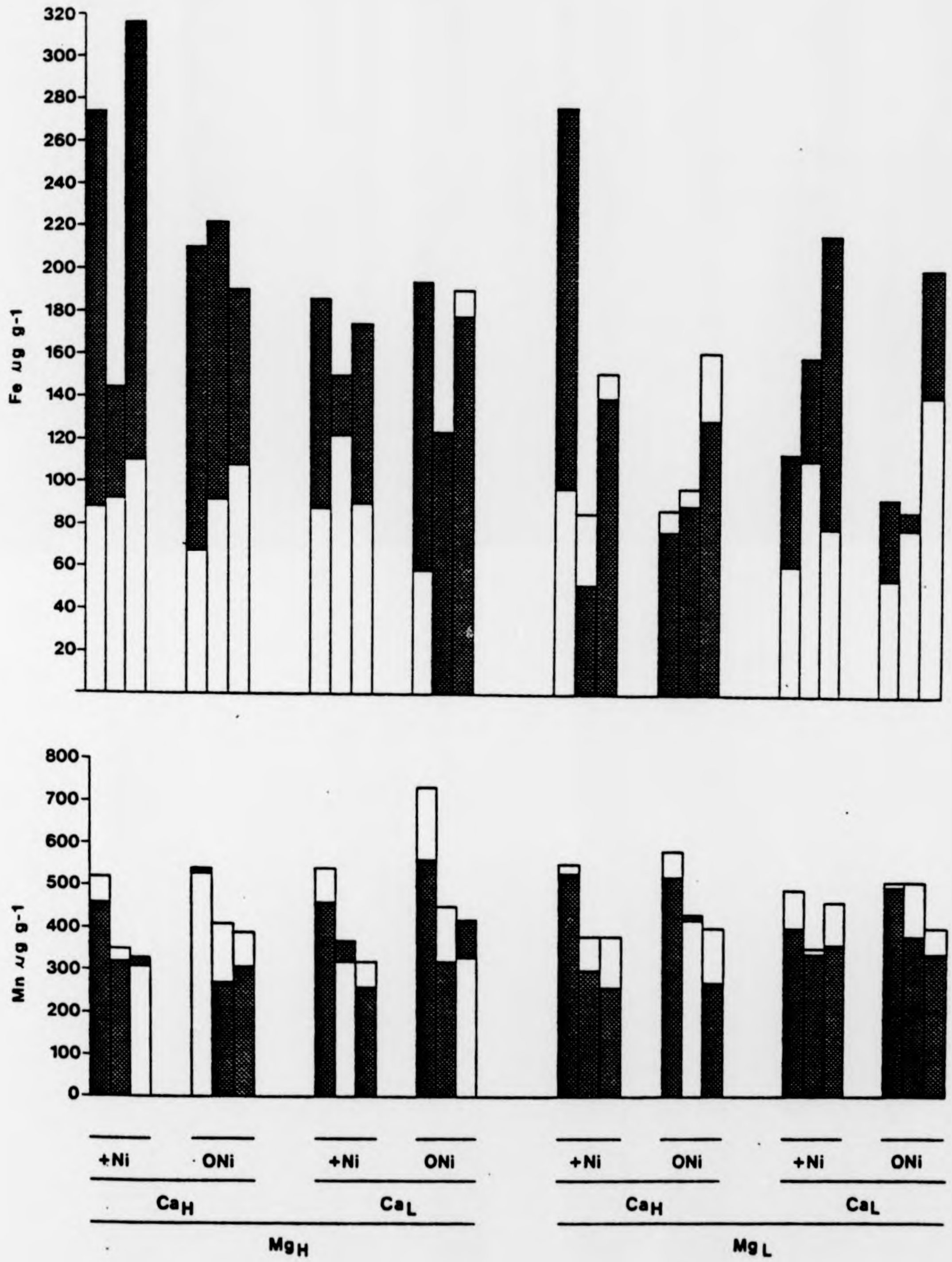
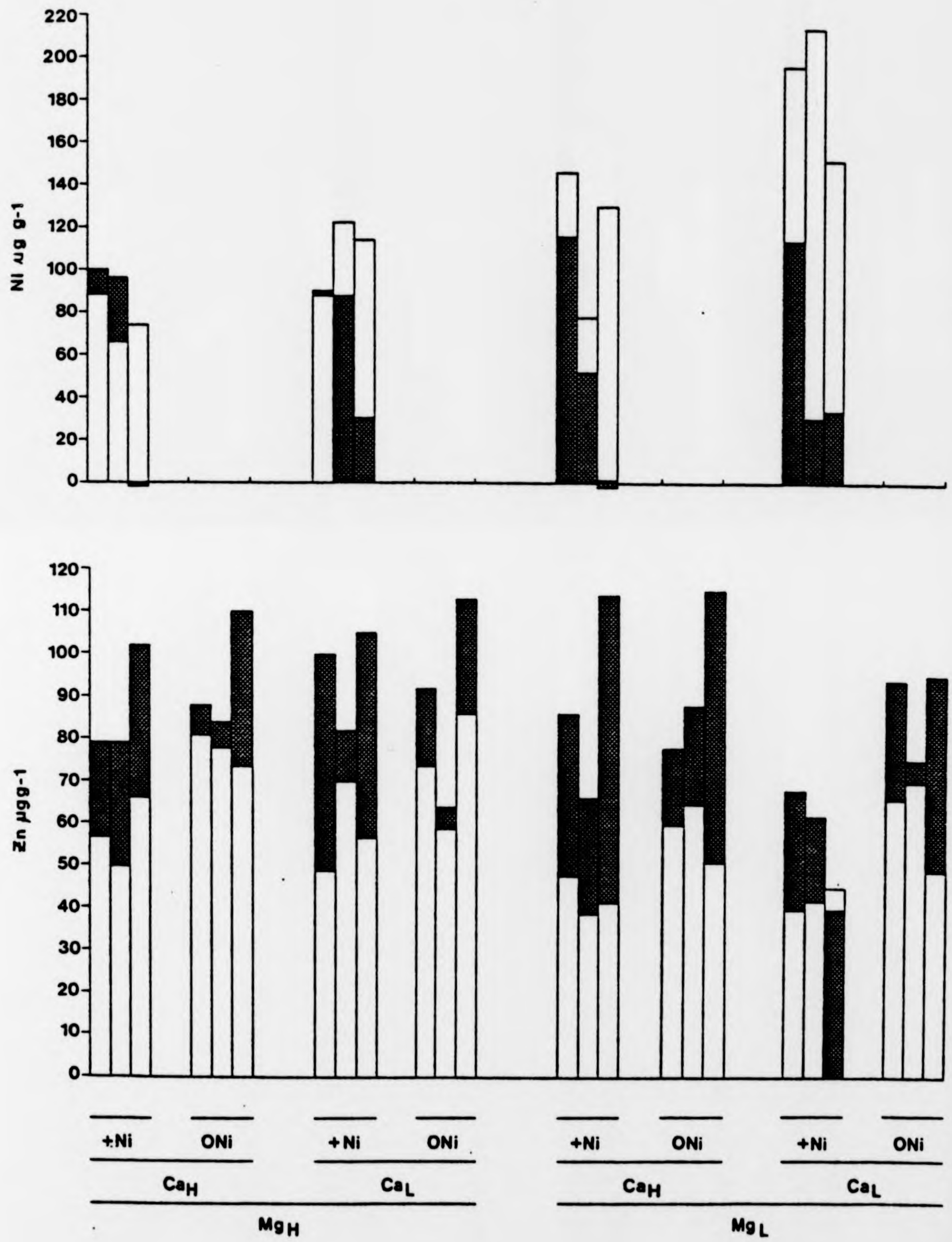

CA mg g-1
0
1
2
3
4
5
6
Mg mg g-1
0
1
2
3
4
5
6
+Ni
ONi
+Ni
ONi
+Ni
ONi
+Ni
ONi
Ca_H
Ca_L
Ca_H
Ca_L
Mg_H
Mg_L

Fig. 7.3.2:3



320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
Fe µg g-1
800
700
600
500
400
300
200
100
0
Mn µg g-1
+Ni
ONi
+Ni
ONi
+Ni
ONi
+Ni
ONi
Ca_H
Ca_L
Ca_H
Ca_L
Mg_H
Mg_L

Fig.7.3.2:4



Ni µg g-1
220
200
180
160
140
120
100
80
60
40
20
0
Zn µgg-1
120
110
100
90
80
70
60
50
40
30
20
10
0
+Ni
ONi
+Ni
ONi
+Ni
ONi
+Ni
ONi
Ca_H
Ca_L
Ca_H
Ca_L
Mg_H
Mg_L

Figs. 7.3.2:5-8. The mean shoot elemental concentrations (per dry weight) for the different clones and treatments in Experiment 2. Other conventions as Fig. 7.3.1:4. The results for all analyses are in Appendix IX.

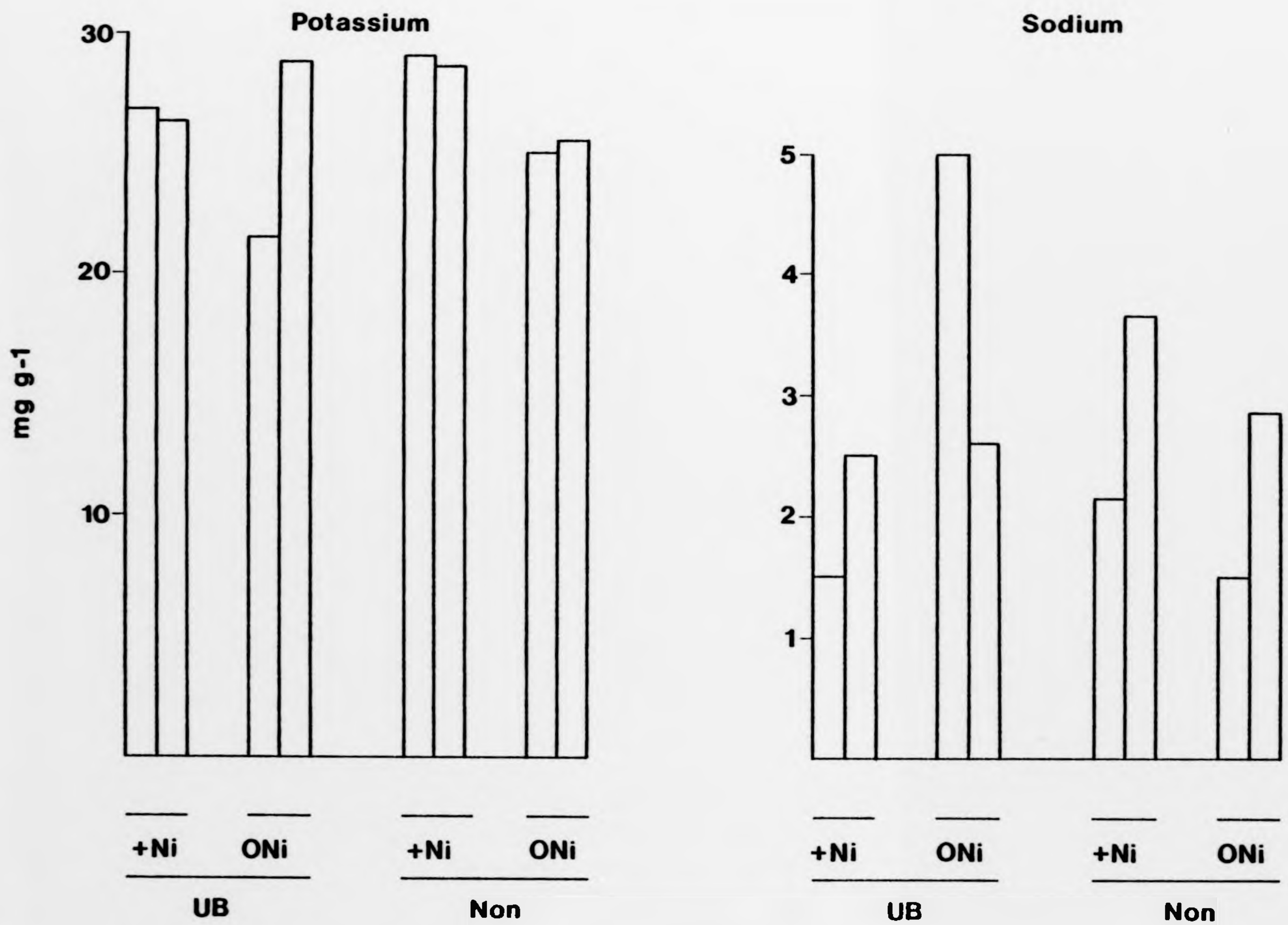
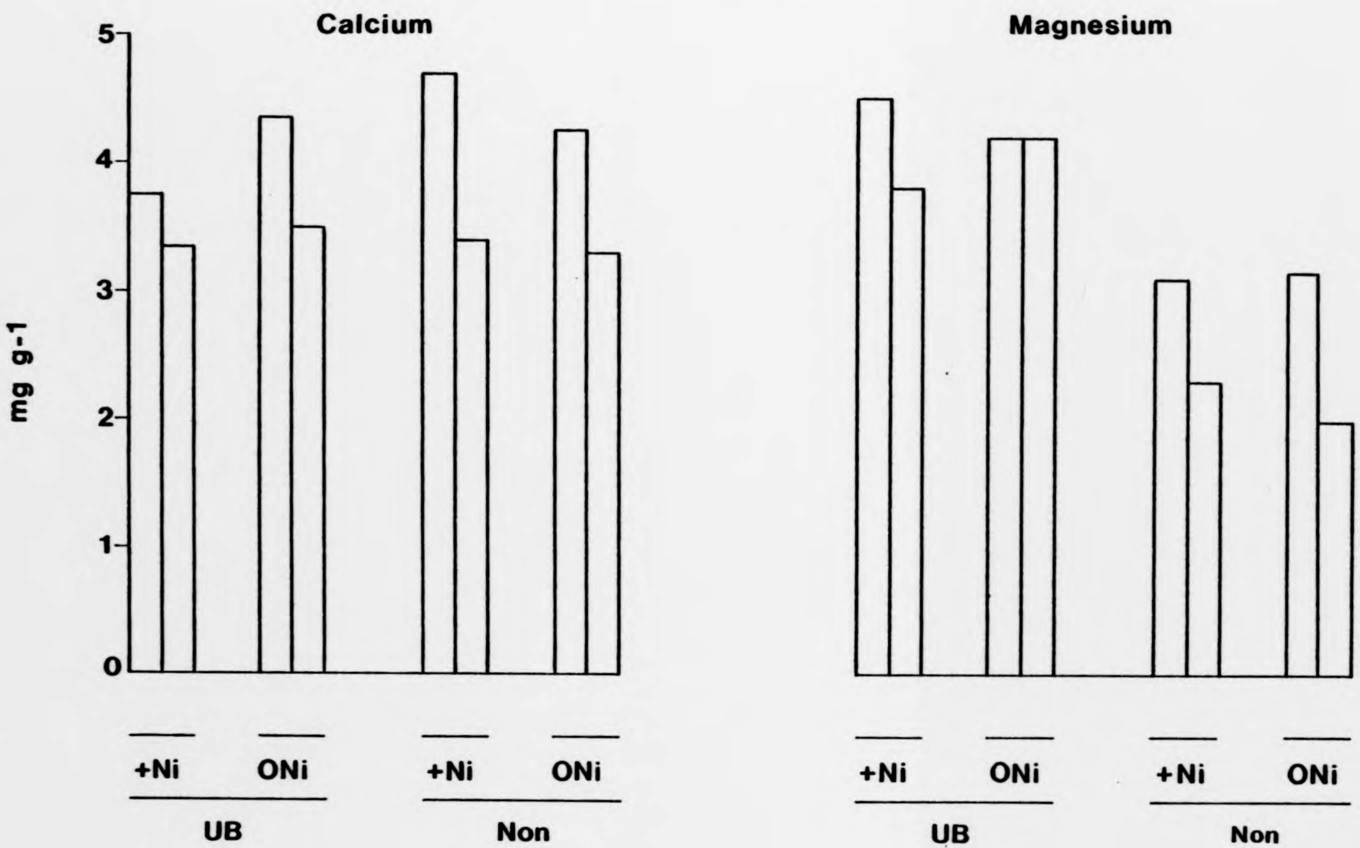

Potassium
Sodium
mg g-1
30
20
10
5
4
3
2
1
+Ni
ONi
+Ni
ONi
UB
Non
+Ni
ONi
+Ni
ONi
UB
Non

Fig. 7.3.2:5



Calcium
Magnesium
mg g-1
5
4
3
2
1
0
+Ni
ONi
+Ni
ONi
UB
Non
+Ni
ONi
+Ni
ONi
UB
Non

Fig. 7.3.2:6

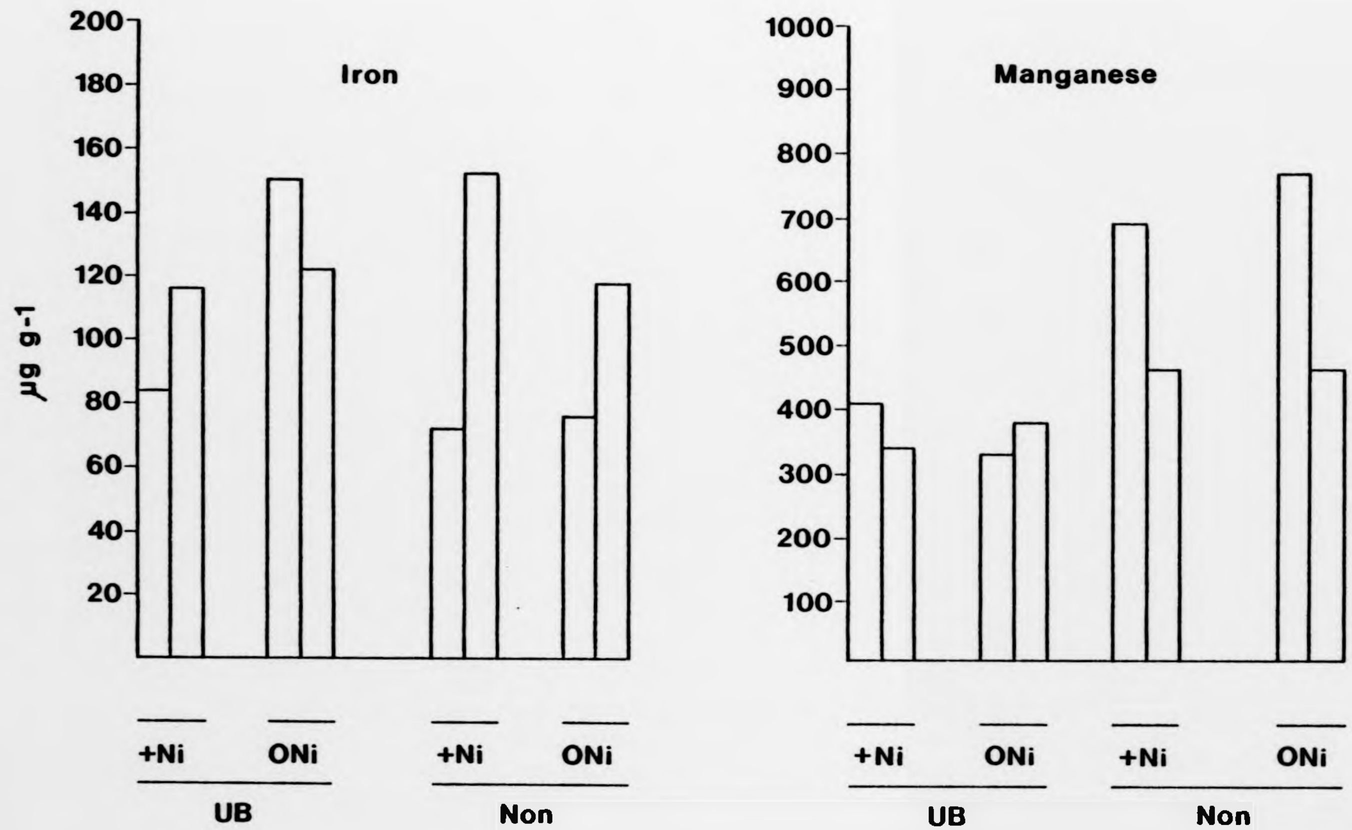
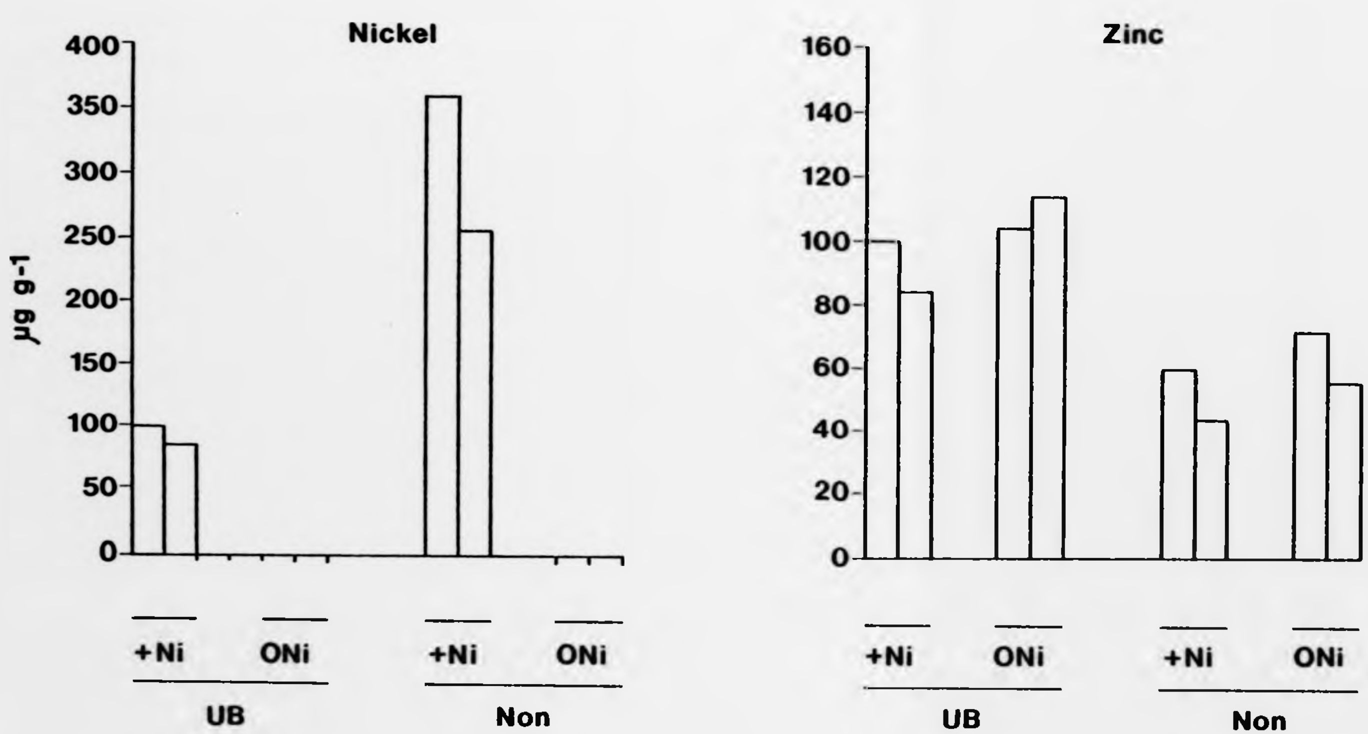

µg g-1
200
180
160
140
120
100
80
60
40
20
Iron
+Ni
ONi
+Ni
ONi
UB
Non
1000
900
800
700
600
500
400
300
200
100
Manganese
+Ni
ONi
+Ni
ONi
UB
Non

Fig. 7.3.2:7



Nickel
400
350
300
250
200
150
100
50
0
μg g-1
+Ni
ONi
UB
+Ni
ONi
Non
Zinc
160
140
120
100
80
60
40
20
0
+Ni
ONi
UB
+Ni
ONi
Non

Fig. 7.3.2:8

Table 7.3.2:2 The significant sources of variation of the concentrations of the different metals analyzed (loge transformed) from Experiment 1. (See Figures 7.3.2:1-4 for the mean concentrations of each metal, and Table 7.3.2:3)

Metal	Harvest	Mg	Ca	Ni	Race	Mg Ca	Ca Race	Ni Race	Mg Ca Ni	Mg Ca Race	Ca Ni Race
K	1					*					
	2									*	
Na	1	-*									
	2	-*						**			
Ca	1				*						
	2	-***	***		**						
Mg	1	***	-*	-*	**						
	2	***	-***	-**	***						
Fe	1	**				*					
	2				***	**		*			*
Mn	1				***						
	2				***						
Ni	1			#	***			#	#		#
	2	-***	-**	#			*	#	#		#
Zn	1	*		-*	*	*			*		
	2	***		-***							

* P<0.05 , ** P<0.01 , *** P<0.001

For Ni these components were not possible in the variance analysis.

- implies that the concentration of the metal was negatively related to the concentration of the treatment.

Table 7.3.2:3 The significant levels of the significant variation (Table 7.3.2:2), in Experiment 1, for the log (base e) transformed concentrations of the different metals analysed, using Least Significant Differences, see Fig. 7.3.2:1-4. (The variation for the Mg, Ca and Ni treatments considered singularly are not reported in this table, as they can be inferred from Table 7.3.2:2.

Metal	Harvest 1		Harvest 2	
	Treatment	Level	Treatment	Level
K	Mg-Ca	$Mg_L Ca_{L>H}$	Mg-Ca-Race	NS,$Mg_H Ca_{L>H}$
				NS>S1,$Mg_H Ca_L$
				S1,$Mg_H Ca_{H>L}$
				S1,$Mg_{L>H} Ca_L$
				S1>NS,$Mg_H Ca_H$
Na			Ni-Race	NS,+Ni>ONi
				S1>NS,ONi
				S2>NS,ONi
				S2,ONi +Ni
Ca	Race	NS>S1	Race	NS>S1
		S2>S1		S2>S1
Mg	Race	NS>S1	Race	NS>S1
		NS>S2		NS>S2
Fe	Mg-Ca	$Mg_{H>L} Ca_H$	Race	S1>NS
		$Mg_H Ca_H > Mg_L Ca_L$	Race	S2>NS
				S2>S1
			Mg-Ca	$Mg_{L>H} Ca_H$
				$Mg_{H>L} Ca_L$
				$Mg_L Ca_{H>L}$
			Ni-Race	S2>S1,ONi
				S2>NS,ONi
				S2,ONi>+Ni
			Ca-Ni-Race	S2>S1,Ca_H+Ni
				S2>NS,Ca_HONi
				S2>S1,Ca_HONi
				S2,$Ca_{H>L}$+Ni
				S2,Ca_LONi>+Ni
Mn	Race	NS>S1	Race	NS>S1
		NS>S2		NS>S2
Ni	Race	NS>S2	Ca-Race	S1,$Ca_{L>H}$ *
		NS>S2		

/cont.

Table 7.3.2:3 (contd.)

Metal	Harvest 1		Harvest 2	
	Treatment	Level	Treatment	Level
Zn	Race	S2>NS		
		S2>S1		
	Mg-Ca:	$Mg_{H>L}Ca_L$		
		$Mg_L Ca_{H>L}$		
		$Mg_H Ca_H > Mg_L Ca_L$		
	Mg-Ca-Ni:	$Mg_{H>L}Ca_L$+Ni	**	
		$Mg_L Ca_{H>L}$+Ni		
		$Mg_L Ca_H$ONi>Ca_L+Ni		
		$Mg_L Ca_L$ONi>+Ni		

Symbols explained in text

* For Ni Harvest 2. Significance was only for unlog-transformed data.

** i.e. With $Mg_L Ca_L$+Ni there is less Zn in the shoot.

Table 7.3.2:4 The significant sources of variation of the concentrations of the different metals analyzed (loge transformed) from Experiment 2. See Figures 7.3.2:5-8 for the mean concentrations of each metal.

Metal	Type	Ni	Race	Type Ni	Type Race	Type Ni Race
K						
Na				*		
Ca			**			
Mg	***		***		**	**
Fe			*			
Mn	***		**		**	
Ni	***					
Zn	***	**	*			

* P<0.05 , ** P<0.01 , *** P<0.001

The significant levels of the above significant, variation determined by using the Least Significant Difference.

Metal	Relationship	Component
Na	Type-Ni	UB,0Ni>+Ni
Ca	Race	NS>S1
Mg	Type	UB>Non
	Race	NS>S1
	Type-Race	NS,UB>Non
		S1,UB>Non
		NS>S1,Non
	Type-Ni-Race	NS,UB>Non +Ni
		NS,UB>Non 0Ni
		NS>S1,UB +Ni
		NS>S1,Non +Ni
		NS>S1,Non 0Ni
		S1,UB>Non +Ni
		S1,UB>Non 0Ni
Fe	Race	S1>NS
Mn	Type	Non>UB
	Race	NS>S1
	Type-Race	NS,Non>UB
		NS>S1,Non
		S1,Non>UB
Ni	Type	Non>UB
Zn	Type	UB>Non
	Ni	0Ni>+Ni
	Race	NS>S1

Type = Solution type : UB = Ultrabasic , Non = Non-ultrabasic
Ni = Nickel level : 0Ni = 0.0 mg/l Ni , +Ni = 0.2 mg/l Ni
Race = Race of <u>Agrostis canina</u> : NS = Non-serpentine , S1 = Serpentine race 1

roots were not analysed it seems unlikely that the culture solutions were seriously depleted. This is including consideration of a high root:shoot ratio for several of the metals particularly nickel (Johnston & Proctor 1981). One further point from this is that there was differential accumulation of the metals in the shoots, indicating that a selective absorption was taking place and implying that the roots were functional.

The metal concentrations of the different clones (in the solution most closely resembling the soil solution at their sites of collection), were compared to the values in field-collected plants (Table 7.3.2:5). The differences, particularly for iron and to a lesser extent, sodium and potassium must be considered in interpreting the results. Iron may be included in interactions with nickel (Khalid & Tinsley 1980), and the higher concentrations of potassium could be important.

7.4 Discussion

7.4.1 Aspects of the design and results of the experiments.

The different results for the two harvests in Experiment 1 has wider implications for work of this kind.

The solution cultures were designed to test the different ions at their concentrations on Rhum. While the nickel concentration of 0.2 mg l^{-1} has not proved to be very toxic to any of the three clones, in the first 3-week period of Experiment 1 there is evidence of a deleterious nickel effect on the NS clone. That this effect is not carried into the second 3-week period is important if puzzling. Either the nickel is not as toxic to older plants, or the toxicity has been ameliorated or tolerated (Fitter & Hay 1981). Dijkshoorn et al. (1979) has shown nickel in grasses to be inhibitory to 50% of test plants when a shoot concentration of 100 µg g^{-1} is reached. This level is reached in the NS and S1 clones in the first 3-week period of Experiment 1 and

Table 7.3.2:5 The mean elemental concentrations in the shoots of the three Rhum clones of *Agrostis canina* grown in culture solutions most resembling the soil solution from their sites of collection, and of *A. canina* from the field at the same locations. Results are for harvest 1 and 2 in Experiment 1: there was a single harvest in Experiment 2. All concentrations ug g-1 oven-dry weight.

Clone Type or Field	Experiment & Harvest	Culture Solution	K	Na	Ca	Mg	Fe	Mn	Ni	Zn
NS	Exp.1 1	Mg Ca 0Ni	23800	3300	4800	2400	94	500	0	94
	2		22500	2200	3800	2900	56	500	0	66
	Exp.2	Non 0Ni	25000	1500	4250	3150	76	770	0	72
Field			6860	210	1190	1910	2050	280	0	100
S1	Exp.1 1	Mg Ca +Ni	24500	3200	4600	3200	144	320	96	79
	2		27300	2800	3400	4000	92	350	64	50
	Exp.2	UB +Ni	26300	2500	3350	3800	116	340	70	84
Field			4520	310	1610	6380	5350	210	86	71
S2	Exp.1 1	Mg Ca +Ni	28800	5600	5850	3800	316	330	0	104
	2		24500	3200	3300	3200	130	310	74	66
Field			6780	440	1120	7310	4400	160	88	63

n=3 for all means. Symbols explained in the text.

is of interest when the RGRW01's for these clones are considered (Fig.7.3.1:1 and 7.32:4), with nickel significantly reducing the RGR for the NS clone, but not for the S1 clone. The S2 clone has a positive but not significant response to nickel in the culture solutions, even though its shoot concentrations are low. (The S2 nickel concentration is significantly lower than the NS concentration at Harvest 1). One other possibility is that by the second 3-week period the NS clone has adapted to the nickel concentrations and that its RGR is even enhanced by nickel. Grime & Hodgson (1969) found low concentrations of toxic ions could increase response, possibly by liberating iron.

Also of importance is the high calcium concentration in the ultrabasic soil solution compared to the non-ultrabasic soil solution on Rhum. The magnesium/calcium quotients for Rhum are below those found on most other serpentine sites (Chapter 6), and Experiment 1 suggests calcium is unimportant in ameliorating nickel toxicity for any of the clones, including NS in the first 3-week period. Turitzin (1982) has also found that calcium is not a universal explanation of serpentine toxicity amelioration. The NS clone actually responds negatively to high calcium, particularly at the Mg_H treatments (Fig. 7.3.1:1-3). Although the NS clone has a significantly better RGR at Mg_L (with Ca_L), at Mg_H (with Ca_L) it has a significantly better RGR than the S2 clone. The S1 clone had a significantly better RGRW at Ca_H, (with Mg_H), but in general, it seems unlikely that magnesium is acutely toxic in these soils. (This supports earlier conclusions of Proctor 1971a). The S1 clone, which was collected from a soil with relatively high soil solution calcium, grew better when the concentrations of magnesium and calcium were both high or low; it may be that a balance of the two ions is better for this race.

Overall, growth was significantly better at Mg_L, suggesting that there may be some slight toxic effect of this element even at the low concentrations in this experiment. (In this case the possibly more important effect is its proportion of the total cations).

The results of Experiment 2 generally support the conclusions of Experiment 1, (for the 6-weeks). Two major points emerge from Experiment 2: (i) after 6-weeks, the NS clone's RGR is not reduced by nickel in the UB solution (as also found in Experiment 1), and (ii) nickel in the Non solution significantly reduces the RGR of both clones. The growth reduction is only significant for roots (possibly because the large mean square for error in Experiment 2). This effect is not present in Experiment 1 where only magnesium and calcium are varied (with sodium inversely), in addition to nickel, but in Experiment 2 there were more differences between the UB and Non solutions (Table 7.2.3:1), with the largest differences being those of phosphate and zinc, these two also the more important physiologically (Clarkson & Hanson 1980).

Zinc and other micronutrients have been considered as possibly important as toxic or ameliorative factors in serpentine toxicity (Proctor & Woodell 1975). In Experiment 2 the nickel concentration in the shoot is significantly higher in the Non solution than in the UB solution. Also the zinc concentrations have several significant interactions with solution type and nickel concentration (Table 7.3.1:4). Zinc may be competing or interfering with nickel through its uptake or translocation (Fig.7.3.2:8). There is significantly less nickel in the shoots grown in the UB solution (with high zinc) than in the shoots grown in the Non solution (with low zinc). Also, there is significantly less zinc in the shoots in either the UB or Non solution, when nickel is included in the culture solution. However, since there is a much larger increase in nickel uptake at low zinc, than there is a zinc uptake at low nickel

(Fig.7.3.2:8), it seems that zinc is affecting the uptake of nickel more than nickel is affecting that of zinc. However, the precise nature of the effect is not known and interpretations are confounded because the solutions differed in other ways beside their concentrations of nickel and zinc.

A comparison with Experiment 1 allows the importance of the effect of magnesium and calcium or nickel uptake to be discounted however, further supporting the zinc effect. The NS clone would be expected to grow better (or as well as) in the Non solution than in the UB solution (from Exp. 1 results, and its collection site), and it does without nickel, but with nickel its RGR is significantly reduced. However, where the NS clone in the UB+Ni solution may have been expected to have a lower RGR than UBONi, in fact in UB+Ni it grows as well as in the NonOni solution (also shown in Exp. 1). Since magnesium and calcium are not affecting nickel uptake or its effect on growth, and zinc (or phosphate) is the next important difference between the solutions, it seems that zinc is responsible for the effect. Phosphate could be having some influence, as it does differ between the solutions, but even at its lower concentration in the Non solution (Table 7.2.3:1) it is still high compared to other soil solutions (Allen 1974, Nye & Tinker 1977).

As there is less manganese in the shoots grown in the UB than the Non solutions (in Experiment 2), there is a possible inhibitive interaction with magnesium or zinc affecting manganese uptake, but the nickel solution concentration did not affect it.

A number of other considerations of the design and results of the experiments must be made. As noted above, the potassium concentration of the shoots in the culture solutions were much higher than the concentrations found in the Rhum plants from the field (Table 7.3.2:5). Fitter & Hay (1981) note that there is an inhibitory effect on potassium uptake by organic ions in soil solution, which are absent from solution cultures changed weekly though they would also be low in skeletal soils. They also note that there is a direct relationship between potassium transport to the shoots and RGR. Since the clones under investigation were grown under favourable light and temperature conditions, it is likely the RGR's exceed those present in the field, and therefore potassium translocation and absorption would be higher. Also the comparison of young plants in solution to older plants in the field must be considered, as they may have different responses and mechanisms, even though by July field-grown plants would be largely new growth, they could have older roots.

In both experiments the NS clone had the highest magnesium concentration. This is possibly evidence of luxury consumption by the NS clone, again possibly related to RGR (Chapin 1980), or non-selective absorption (Johnston & Proctor 1981).

The iron concentrations of shoots grown in solution culture were far below those from the field. This probably resulted from the difficulties of estimating soil solution iron (Nye & Tinker 1977). However even with the low iron the nickel/iron quotients are less than those reported to cause nickel toxicity in Lolium perenne (Khalid & Tinsley 1980). The NS clone always had more manganese than the S1 or S2 clones (in field-grown plants, the initial shoots and shoots from the harvests in Exp. 1 and 2), which suggests a higher affinity for this ion (Clarkson & Hanson 1980).

7.4.2 General implications of the results of these experiments for work on plant metal toxicity.

These experiments have shown the complex nature of ion interactions in solution culture, and their importance in interpreting the results and that time can have an effect. The different results for the two harvests of Experiment 1 have important implications for investigations of metal tolerance in plants. Tolerance index measured over a few days of an adventitious root in a single salt solution (plus $Ca(NO_3)_2$) cannot reveal much concerning the situation for the entire plant growing for long periods in solutions of varying composition.

The soil solutions investigated here are dilute, but probably represent those which pertain to the Rhum soils for most of the year.

The pretreatment for the clones can be quite important. In Experiment 1 the calcium concentrations of the shoots decreased over time, while the shoot calcium content increased slightly. These shoots were exposed to a 0.1mg l^{-1} $Ca(NO_3)_2$ pretreatment solution, which possibly increased their shoot concentrations of calcium; while in other work, pretreatment levels of 0.5-1.0 mg l^{-1} $Ca(NO_3)_2$ are often used with little reference in the discussion. It is also possible that the higher calcium concentrations are due to the growth in John Innes No. 2 compost.

7.4.3 Conclusions.

The results from the two experiments throw some light on the causes of the ultrabasic vegetation and barrenness on Rhum.

The apparent nickel-toxicity for the NS clone in the first 3-week period of Experiment 1 is important. This suggests that this clone was not able to respond quickly to increased nickel concentrations in the solution bathing its roots. While the fact that it was able to adjust in the second 3-week period indicates that 0.2 mg l^{-1} nickel (in simulated soil solutions)is not very toxic. However, it is probable that on Rhum, in spite of the wet climate, drier spells do occur (these do exist), and because of the free draining sandy soils on the ultra-basics, the soil solutions could become much more concentrated. If half the water in the soil solution is removed the concentration of magnesium will roughly double (Nye & Tinker 1977), and nickel will probably respond similarly (being divalent). A temporary increase of nickel concentration in the soil solution could have similar or greater toxic effects on plants than the 0.2 mg l^{-1} nickel did on the NS clone in the first 3-week period of Experiment 1. Also, the NS clone was shown in Experiment 1 to have a significantly lower RGR in the Mg_HCa_H solutions. Higher calcium and magnesium concentrations are a feature of the Rhum solutions on ultrabasic soil, and again with drying out of the soil solution this could have an important effect.

Experiment 2 suggests that a factor (other than magnesium and calcium by comparison to Experiment 1) in the ultrabasic soil solution may ameliorate nickel toxicity for both the NS and S1 clones. This is possibly zinc or perhaps phosphate (or an interaction).

CHAPTER EIGHT

Field Experiments and Observations.

8.1 Introduction

The field experiments were designed to investigate the effects of nutrient addition on the vegetation on the ultrabasic soils on Rhum. Field observations were made and recorded to examine the effects of erosion. Previous work on Rhum had suggested the importance of these factors on the vegetation (Ferreira & Wormell 1971, Nature Conservancy Council 1974, Ragg & Ball 1964, Ball 1974), but many details needed further investigation.

A fertilizer addition experiment on the slopes of Hallival (NM 393964) by Ferreira & Wormell (1971), was started in August 1965, with the addition of nitrogen, phosphorus and potassium fertilizers to a single 10 x 10m plot. By September 1966, they noted an increase in vegetation cover from 5-10% to 15%, which by September 1969 was 60% (Fig. 8.1:1). In April 1967 and April 1968 there were additional applications of fertilizer, which included calcium, making it impossible to distinguish between toxicity amelioration and nutrient deficiency. They expected complete cover to be achieved within four years from 1969. The site was visited by myself in June 1982 and it was noted that it had nearly 100% cover and was still sharply distinct from the surrounding vegetation (Fig. 8.1:1). The site was described in June 1982 by J. Proctor (unpublished), and it seems that the bryophytes Ferreira & Wormell thought might decline, have become established as an important part of the community, which has become more species rich. It is remarkable that the site has persisted since it is in a very wet, highly leached area. It indicates that once a vegetation is established, it can maintain itself for several years at least.

8.2 Major-nutrient addition

8.2.1 Methods

CHAPTER EIGHT

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8.2 Major-nutrient addition

8.2.1 Methods

Fig. 8.1:1. The increased vegetation after fertilization of a site on Hallival (NM 393964). The upper photograph was taken in 1969 by P.Wormell after fertilization in 1965, 1967, 1968; the lower was taken by myself in 1982. There was no fertilization after 1968.

Fig. 8.1:1. The increased vegetation after fertilization of a site on Hallival (NM 393964). The upper photograph was taken in 1969 by P.Wormell after fertilization in 1965, 1967, 1968; the lower was taken by myself in 1982. There was no fertilization after 1968.

[illegible] 5.11. The increased vegetation after fertilisation of a site on [illegible] (NM [illegible]). The upper photograph was taken in [illegible] by P. Normal[illegible] after fertilisation in [illegible], [illegible], [illegible]; the lower was taken by myself in 198[illegible]. There was no fertilisation after [illegible].

An experiment was set up on April 14-16, 1981 in three separate areas of the ultrabasic complex near Transects 7, 9 and 13. The experiments were a factorial randomized-block design for nitrogen, phosphorus and potassium with three replicates at each area. The rates of application were: nitrogen, 10.0g N m^{-2} (as NH_4NO_3); phosphorus, 5.0 g P m^{-2} (as $NaH_2PO_4 .2H_2O$); and potassium, 10.0 g K m^{-2} (as KCl); after Spence & Millar (1963) and Proctor (unpublished). The chemicals were added to each quadrat after dilution with 125ml of water from a nearby stream (with 125ml of water added to the controls).

The 1x1m quadrats were laid out in three rows by eight, with a 1m strip between rows and 1m between each quadrat along a row. Each treatment was randomly located once along each row (which were treated as blocks). One hundred points from a point quadrat were used to record species in each 1x1m quadrat.

Unfortunately, two of the three areas were washed away after starting the experiment. The area near Transect 9 survived, and plant cover was recorded again on May 19, 1981 and July 22, 1981.

8.2.2 Results

The total species cover for each quadrat is given in Table 8.2.2:1. There were insufficient data for analysis of individual species changes and hence the change in total vegetation cover was used to interpret the effect of the fertilizer treatments. Also, because of the importance of the response of grasses to fertilization (Rorison 1971, Jeffrey 1971), these were separately analysed.

The variance of the data were analysed using the percent change for each plot from April to July (May did not show a significant change) using the GENSTAT ANOVA programs. Prior to this the April, May and July data were analysed separately for variance and all were

Table 8.2.2:1 The treatments of the fertilization addition experiment, and the percent cover for all species in each 1x1m quadrat (determined with a point quadrat) for the fourteen-week period investigated.

Treatment							
NK	N	K	-	NP	P	PK	NPK
NP	-	P	PK	N	NPK	K	NK
PK	K	NK	N	NP	-	NPK	P
% Cover April 16, 1981							
31	29	13	30	51	35	60	44
28	18	57	26	10	14	22	29
29	24	32	15	19	21	8	51
% Cover May 19, 1981							
21	27	28	31	44	39	60	50
32	15	71	30	24	19	15	17
26	25	31	22	15	15	10	49
% Cover July 22, 1981							
29	32	22	39	86	46	54	69
44	21	95	39	20	46	17	33
31	20	38	36	32	25	19	57

N = Nitrogen , P = Phosphorus , K = Potassium , - = Control
See Text for chemicals and quantities used.

found to be not significantly different between the treatments. For the period, April to July, only nitrogen separately and the three treatments combined showed a significant response (Table 8.2.2:2). The variation for grass species only, were analysed between treatments using percent change, and was not significant for any treatment. The data for the grasses only was highly variable, probably masking any response, possibly due to the deer grazing.

8.2.3 Discussion

The results of the fertilizer addition experiment, especially when combined with the results of Ferreira & Wormell (1971), show the importance of low nutrients as a limiting factor to the vegetation on the ultrabasic soils on Rhum. The importance of this factor is quite variable on serpentines (Proctor & Woodell 1975). The short-term experiment discussed here has shown a positive response to nitrogen fertilization as well as to total fertilizer with nitrogen, phosphorus and potassium. Combined with the fact that the experimental plot of Ferreira & Wormell (1971) is still distinct after 14 years, since the last treatment, it seems certain that nutrients are a limiting factor for the vegetation on the Rhum ultrabasics.

The apparent grazing on the grasses *Molinia caerulea* and *Nardus stricta* in my experiment is important. Grazing preference differs between species (Harper 1977), the red deer selects younger grasses. The effect of this on the experiment is not known, but the quadrats with most improved growth were grazed.

8.3 Permanent Quadrats

Three permanent quadrats of 1x1m were established near Quadrats 62, 94 and 199 in July 1980. They were mapped in detail on a grid of 20-cm squares and photographed. The quadrats were revisited

Table 8.2.2:2 The significant variation of the percent change in cover due to treatments from April to July, 1981 in the fertilization addition experiment. For the total treatment (NPK), the significant levels were determined using the Least Significant Difference.

Treatment	Level
N *	
NPK *	NPK > control **
	NPK > K **
	NPK > P *
	NPK > PK **
	NPK > NK **

* $P < 0.05$, ** $P < 0.01$

in September 1981 and June 1982 and only very slight changes were noticed (small increases in a few grasses).

A further five permanent quadrats of 1x1m were located on apparently eroding edges of vegetation or fixed edges in more open ground, and were photographed on the Bealach near Ruinsival(near Transects 7 and 28), on September 3, 1980. These were revisited and re-photographed in September 1981 and June 1982. The edges that had appeared to be eroding were in fact doing so at a rate of about 10cm per year. (Fig. 8.3:1), while the edges that had appeared more stable showed no changes during the 2-year period (not shown).

This evidence does indicate some stability, but the eroding edges (Fig. 8.3:1) were on what would be assumed to be fixed closed vegetation. Earlier work on the island supports that erosion could be an important problem (Ragg & Ball 1964, Ball 1965). They found in examining soil profiles on the ultrabasics,that often beneath a surface of immature ranker is a more mature profile, which they suggest could not have formed under the present vegetation. Further evidence they cite are the deposits and partial formations of several A horizons in the Coire nan Grund soils (near Transect 2), suggesting short stable periods between erosion. Beneath these there is a thick peaty podzol which they say could only have formed during long stable periods. They conclude that the erosion now dominant could be the result of climatic change or of overgrazing and burning in the earlier centuries.

8.4 Discussion

It is unfortunate that field experiments are so difficult to establish and monitor on Rhum and that more time was not available. Field experiments on the ultrabasic areas of Rhum are difficult because of the inaccessibility of the sites and the possibility of disturbance by the large population (about 1500 animals) of red deer (*Cervus elaphus*)

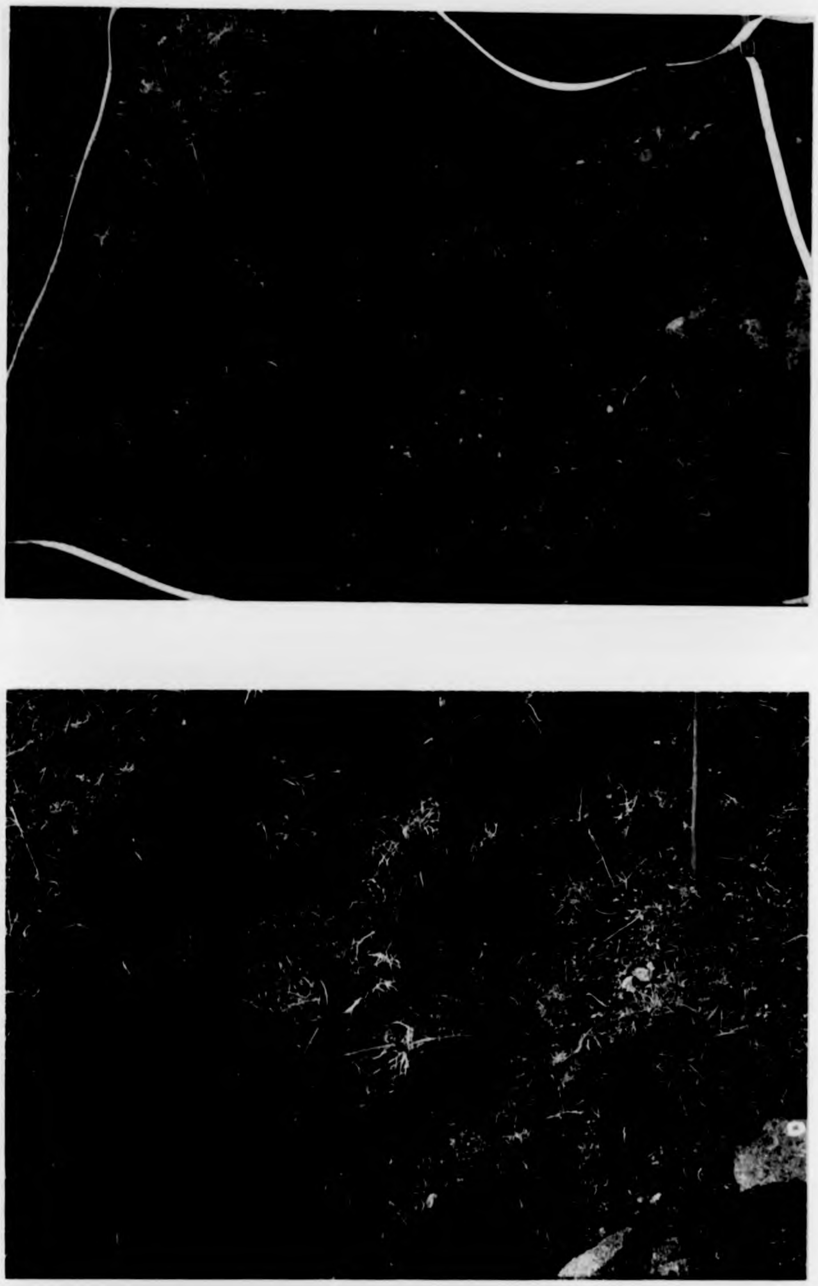

Fig. 8.3:1. Erosion. Upper photograph September 1980, lower photograph September 1981, next page (both photographs) June 1982.

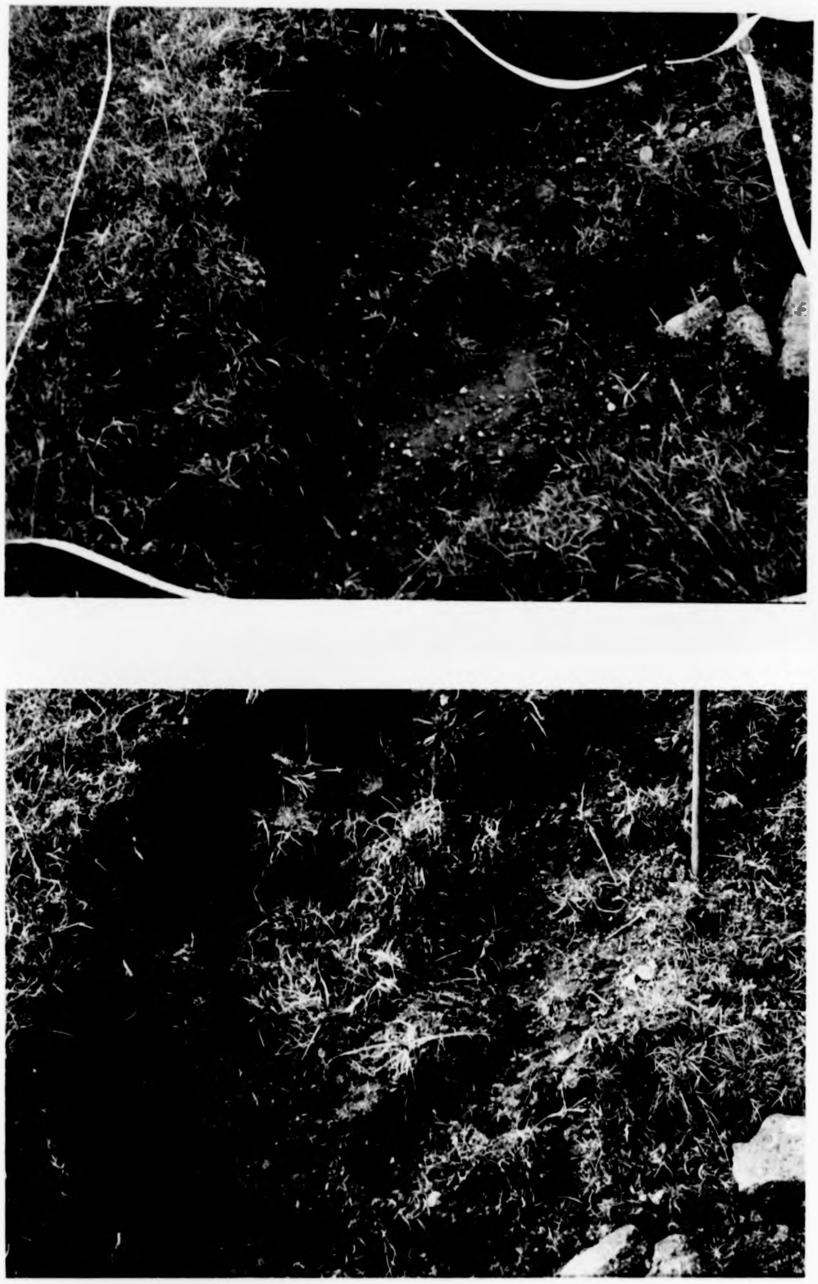

Fig. 8.3:1. Erosion. Upper photograph September 1980, lower photograph September 1981, next page (both photographs) June 1982.

[illegible] Erosion. Upper photograph September 1980, lower photograph September 1981, next page (both photographs) June 1982.

(continued)

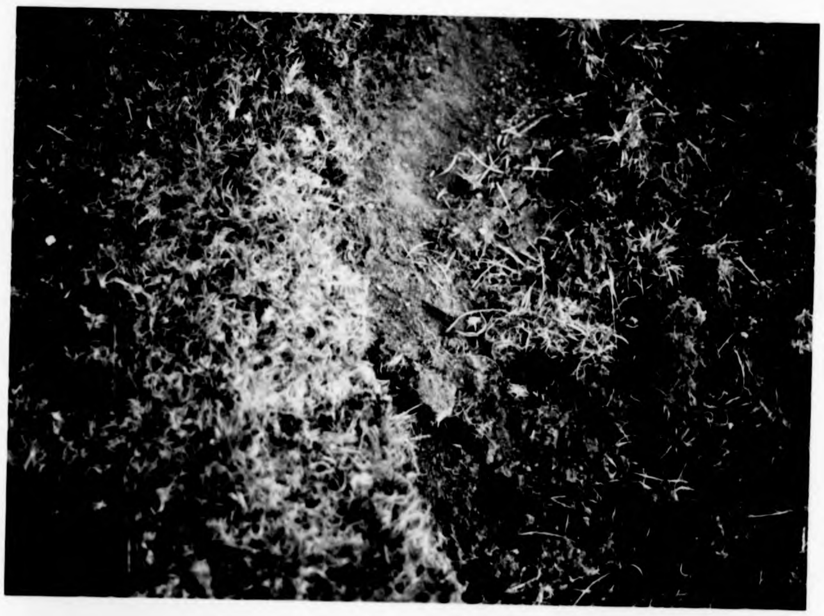

Fig. 8.3:1. (continued)

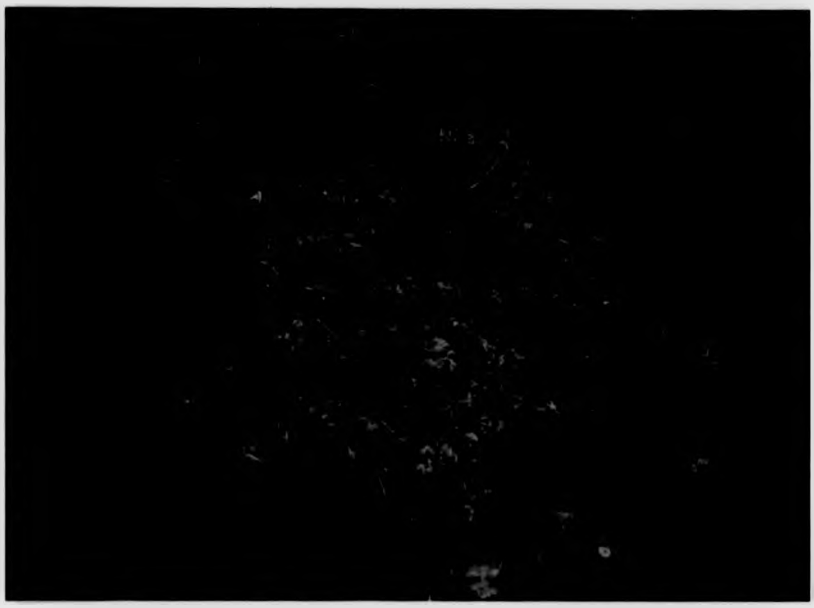

Fig. 8.3:1. (continued)

(Ball 1974). Deer fences would be difficult to transport and would affect the micro-climate at any rate. Measurement of erosion rates from more areas on the island, and more fertilization addition experiments on a wide selection of ultrabasic and non-ultrabasic soils could be important. Additionally, further work examining soil horizons under the vegetated ultrabasic and from different areas of the barren ultrabasic soils would be useful. However, from the field experiments that were carried out, combined with the results from earlier researchers, erosion and nutrient deficiency can be considered important factors influencing the vegetation on the ultrabasics.

The addition of calcium to their fertilization plot on Hallival (Ferreira & Wormell 1971), is probably not as important as it might have been. Calcium was shown not to have an effect on the nickel toxicity of the NS clone, nor were the S1 or S2 clones showing toxicity symptoms in the first 3-week period of Experiment 1 (Chapter 7). Additionally, both this growth Experiment and Proctor (1971a) have shown the soils and plants from this area of Rhum not to be particularly magnesium toxic, another serpentine toxicity factor often ameliorated by calcium. While it is possible calcium made an important difference, the vegetation had previously shown a positive response to fertilization without calcium, which is further substantiated by the fertilization experiment described in this work.

The possible climatic change and burning effect on the erosion on Rhum (mentioned by Ragg & Ball 1964) could be very important and are discussed below.

CHAPTER NINE

Final Discussion

The twelve classes from the vegetation classification are useful in interpreting the vegetation, its relationships to the soil variables, and possible causal factors. The interpretation of these relationships, and the evidence from the other aspects investigated, suggests that the typical serpentine problems of heavy metal toxicity and low nutrients are at least of some importance on Rhum.

Heavy metal toxicity, especially nickel, is related, if not partly causal, to the distinct ultrabasic vegetation and barrenness. Total soil nickel is the best correlated of all soil variables, with the barren classes in both the vegetation and soil ordinations. Exchangeable nickel in contrast, was not significantly correlated with the barren classes, but was significantly higher in the vegetated ultrabasic classes. It may be that exchangeable nickel is high because of the relatively higher cation exchange capacities of vegetated soils and that in this case, total nickel is giving a better indication of a nickel effect. Further, total soil nickel (but not exchangeable), correlated with plant nickel concentrations. Nickel was present(up to 0.2 mg l^{-1}) in some of the ultrabasic soil solutions, and was toxic in solution culture to the NS clone (for the first part of the experiment). The possible physiological mechanisms related to uptake, translocation, enzyme activation, growth and respiration that nickel could affect in the plant are numerous (Clarkson & Hanson 1980). Being similar in size to several divalent micronutrients and magnesium, it could disrupt or enhance physiological activities in the plant and thereby negatively affect it. However, nickel tolerance has been shown to be developed in plants (Chapter 7, S1 and S2 clones; Johnston & Proctor 1981). Also, mechanisms of tolerance are known (Wainwright & Woolhouse 1975) and grasses can be used to reclaim toxic spoils of other heavy metals (Smith & Bradshaw 1979). Slingsby & Brown (1977) found nickel in British serpentines to be relatively high but often relatively unavailable to plants (oats), yet on Rhum it is high and available to native plants. The ultrabasics on Rhum also have some cobalt and chromium, which while not correlated with barrenness in the vegetation ordination do correlate with the vegetated ultrabasics and are in the plant material.

Low nutrients are also a factor as shown by the nutrient addition experiment and that of Ferreira & Wormell (1971). Also, a magnesium, calcium effect is shown on the NS clone in solution culture, as it has a lower RGR in the high magnesium and calcium solutions, but not at a result of a high magnesium/calcium quotient. The ultrabasics on Rhum are often barren (as are other serpentines in Britain, Proctor & Woodell 1975), yet on Rhum the soil is not extraordinary chemically or apparently particularly toxic. It is therefore either an undetermined factor affecting the vegetation, or an interaction of different factors that maintain the barren ultrabasic soils and distinct vegetation.

Grime (1974) suggests that there are three major determinants of vegetation, competition, stress and disturbance; and that each has a different effect, whereby stress and disturbance together prevent the "resolution of competition". He claims

> "At moderate intensities this intervention has the effect of creating spatial or temporal niches; at their most severe both stress and disturbance may so suppress plant development that individual plants scarcely impinge on each other and competition is occluded. The difference between stress and disturbance lies in the fact that whilst both inhibit the development of a longer standing crop, the former does so by restricting primary production, the latter by damage to the vegetation. Whereas stress is usually imposed by the physical environment (shortages of light, water, mineral nutrients, suboptimal temperatures, soil and toxins), disturbance arises from the activities of grazing animals, pathogens, man (trampling, mowing and ploughing) and from physical phenomena such as soil erosion".

It seems probable therefore that an interaction of stress and disturbance on the ultrabasic soils on Rhum are responsible for the barren sites; and the distinct closed vegetation is due to a reduced effect of stress or disturbance or both, combined with general soil differences.

The barren classes (5-8) may be subject to several of the stress factors listed above, particularly nutrient deficiency, and soil toxins. Nutrient deficiency is suggested by the measures of the soil nutrients (Table 4.1:1 and Appendix VI), and the possible response to nutrient addition (Ferreira & Wormell 1971, Section 8.2). Soil toxins are present as nickel (discussed above), with nickel probably at much higher and potentially more toxic concentrations during drier spells, when the soil water volume would decrease. Nickel was shown to reduce growth to native non-serpentine races in solution culture work at dilute concentrations (Chapter 7). The stress effect could be increased by an irregular (or possibly periodic) drying out of the soils. April and May are, on average, the driest months on Rhum (Table 1.1:1), and in May 1980 I was on Rhum during a prolonged dry spell when the ground in the wet flushes was cracked and dried out. During such times, and particularly when new growth is starting in the spring, toxicity could have an important influence on the vegetation.

Disturbance factors include heather burning, grazing, soil erosion and frost heaving, but these factors are difficult to quantify. Heather burning up onto the ridges has been recorded (Nature Conservancy Council 1974) and may have several deleterious effects. These include: soil loss after burning, loss of nutrients from the soil, and on the ultrabasic soils and possible release of soluble chromium (and possibly nickel, see below). The increased soil erosion from burning compounds the normal erosion and losses of topsoil, particularly on leached ridges with high rainfall. Nitrogen and phosphorus are known to be lost to the nutrient cycle after burning (Gimingham 1972), and this would increase the nutrient deficiency. Hafez, Reisenauer & Stout (1979) reported a flush of soluble chromium after heating serpentine soils to 300°C (soil temperatures up to 600°C have been incurred in heather burns, Gimingham 1972), and nickel would probably have a similar response. Therefore, in the regrowth period immediately following a burn, the new vegetation would have to survive increased stress from higher than usual concentrations of chromium and nickel. Additionally, ground frost is frequent in Kinloch in April (on average, Table 1.1:1), and is shown to occur on the Barkeval Bealach (Fig. 1.1:4) as well, with frost-heaving on the barren soils, which I have observed as stone stripes. This could be contributed to by the sandy nature of the soils on the ultrabasics. Finally, grazing has been prevalent on Rhum for the last few centuries, with large herds of sheep previously (up to 6000 animals, Nature Conservancy Council 1974), and red deer.

It is probable therefore, that a combination of the above factors is influencing the vegetation on the ultrabasic soils and producing the barrenness. Where closed vegetation exists on the ultrabasics it is generally in less exposed areas.

REFERENCES

Adams, F., Burmester, C., Hue, N.V. & Long, F.L. (1980). A comparison of column-displacement and centrifugation methods for obtaining soil solution. Soil Science Society of America Journal. 44, 733-735.

Allan, S.E., Grimshaw, H.M., Parkinson, J.A. & Quarmby, C. (1974). Chemical Analysis of Ecological Materials. Blackwell Scientific Publications, Oxford.

Anderson, A.J., Meyer, D.R. & Mayer, F.K. (1973). Heavy metal toxicities: levels of nickel, cobalt and chromium in the soil and plants associated with symptoms and variation in growth of an oat crop. Australian Journal of Agricultural Research, 24, 557-571.

Anderson, A.J., Meyer, D.R., & Mayer, F.K., (1979). Effects of the environment on the symptom pattern of nickel toxicity in the oat plant. Annals of Botany, 43, 271-283.

Antonovics, J., Bradshaw, A.D. & Turner, R.G. (1971). Heavy metal tolerance in plants. Advances in Ecological Research, 7, 1-85.

Austenfeld, F.A. (1979). Phytotoxicity of nickel and cobalt on Phasedus vulgaris cultivar saxa grown in solution culture. Zeitschrift fur Pflanzenerährung und Bodenkunde, 142, 786-791.

Ball, D.F., (1965). Field Meeting, British Society of Soil Science, Island of Rhum, May 17th-22nd, 1965, Nature Conservancy Council Office, Isle of Rhum.

Ball, M.E. (1974). Floristic changes on grasslands and heaths on the Isle of Rhum after a reduction or exclusion of grazing. Journal of Environmental Management, 2, 299-318.

Bannister, P. (1966). The use of subjective estimates of cover-abundance as the basis for ordination. Journal of Ecology, 54, 665-674.

Bartlett, R. & James, B. (1980). Studying dried, stored soil samples - some pitfalls. Soil Science Society of America Journal, 44, 721-724.

Bates, J.H. (1978). The influence of metal availability on the bryophyte and macrolichen vegetation of four rock types on Skye and Rhum. Journal of Ecology, 66, 457-482.

Batten, G.D. (1978). Some factors affecting the extraction of soil available phosphate. Australian Journal of Soil Research, 16, 355-357.

Birks, H.J.B. (1978). Past and Present Vegetation of the Isle of Skye. A Palaeoecological Study. Cambridge University Press, England.

Bohn, H., McNeal, B. , & O'Connor, G. (1979). Soil Chemistry. Wiley, New York.

Briggs, K.G., (1974). Soil sampling and soil uniforming for N, P and K in a small plot area. Canadian Journal of Soil Science, 51, 115-117.

Chapin, F.S. III (1980). The mineral nutrition of wild plants. Annual Review of Ecology and Systematics, 11, 233-260.

Clapham, A.R., Tutin, T.G. & Warburg, E.F. (1962). Flora of the British Isles. Cambridge University Press, England.

Clarkson, D.T. & Hanson, J.B. (1980). The mineral nutrition of higher plants. Annual Review of Plant Physiology, 31, 239-298.

Clymo, R.S. (1962). An experimental approach to part of the calcicole problem. Journal of Ecology, 50, 707-731.

Clymo, R.S. (1980). Preliminary survey of the peat bog Hummell Knowe Moss using various numerical methods. Vegetatio, 42, 129-148.

Cotlove, E. Trantham, H.V., & Bowman, R.L. (1958). An instrument for and method for automatic, rapid, accurate, and sensitive titration of chloride in biological samples. Journal of Laboratory and Clinical Medicine, 5, 461-468.

Cox, R.M. & Hutchinson, T.C. (1980). Multiple metal tolerances in the glass Deschampsia cespitosa (L.) Beauv. from the Sudberg smelting area. New Phytologist, 84, 631-648.

Dijkshoorn, V.W., van Broekhoven L.W. & Lampe, J.E.M. (1979). Phytotoxicity of Zinc, nickel, cadmium, lead, copper and chromium in the pasture plant species supplied with graduated amounts from the soil. Netherlands Journal of Agricultural Science. 27, 241-253.

Emeleus, G.H. & Forster, R.M. (1979). Field Guide to the Tertiary Igneous Rocks of Rhum, Inner Hebrides. Geology and Physiography Section, Nature Conservancy Council, Edinburgh.

Epstein, E. (1972). Mineral Nutrition of Plants: Principles and Perspectives. Wiley, New York.

Etherington, J.R. (1975). Environment and Plant Ecology. Wiley, London.

Ferreira, R.E.C. (1970). A Vegetation Map of the Isle of Rhum. Nature Conservancy Council, Edinburgh.

Ferreira, R.E.C. (1974). Vegetation, vegetation classification. Isle of Rhum National Nature Reserve, 17-20 and Appendix 3, Nature Conservancy Council, Edinburgh.

Ferreira, R.E.C. & Wormell, P. (1971). Fertiliser response of vegetation on ultrabasic terraces on Rhum. Botanical society of Edinburgh Transactions. 41, 149-154.

Fitter, A.H. & Hay, R.K.M. (1981). Environmental Physiology of Plants. Academic Press, London.

Gaile, G.L. & Burt, J.E. (1980). Directional statistics. Concepts and Techniques in Modern Geography, 25, 3-36.

Gauch, H.G.,Jr. (1980). Rapid initial clustering of large data sets. Vegetatio , 42, 103-111.

Gauch, H.G., Jr. (1982). Multivariate Analysis in Community Ecology. Cambridge University Press, England.

Gauch, H.G., Jr. & Whittaker, R.H. (1981). Hierarchical classification of community data. Journal of Ecology, 69, 537-558.

Gauch, H.G., Jr., Whittaker, R.H. and Singer, S.B. (1981). A comparative study of non-metric ordinations. Journal of Ecology, 69, 135-152.

GENSTAT (1977). A general statistical program. Rothamsted Experimental Station, England.

Gimingham, C.H. (1972). Ecology of Heathlands. Chapman and Hall, London.

Greig-Smith, P. (1980). The development of numerical classification and ordination. Vegetatio , 42, 1-9.

Grime, J.P. (1974). Vegetation classification by reference to strategies. Nature, London, 250, 26-31.

Grime, J.P. & Hodgson, J.G. (1969). An investigation of the ecological significance of lime-chlorosis by means of large-scale comparative experiments. Ecological Aspects of the Mineral Nutrition of Plants. (Ed. by I.H. Rorison), pp. 67-100. Blackwell,Oxford.

Grubb, P. J. & Suter, M.B. (1971). The mechanism of acidification of soil by Calluna and Ulex and the significance for conservation. The Scientific Management of Animal and Plant Communities for Conservation, (Ed. by E. Duffey and A.S. Watt), pp. 115-135. Blackwell, Oxford.

Hafez, A.A.R., Reisenaver, H.M. & Stout, P.R. (1979). The solubility and plant uptake of chromium from heated soils. Communications in soil science and Plant Analysis, 10, 1261-1270.

Harper, J.L. (1977). Population Biology of Plants. Academic Press, London.

Harrison, A.F. & Bocock, K.L. (1981). Estimation of soil bulk-density from loss-on-ignition values. Journal of Applied Ecology, 18, 919-927.

Hart, R. (1977). An ecological, morphological and chemical comparison of weeds and natives on serpentine barrens of southeastern Pennsylvania. Ph.D. thesis, University of Pennsylvania.

Hart, R. (1980). The coexistence of weeds and restricted native plants on serpentine barrens in southeastern Pennsylvania. Ecology, 61, 688-701.

Hawksworth, D.L., James, P.W. & Coppins, B.J. (1980). Checklist of British lichen-forming lichenicolons and allied fungi. Lichenologist, 12, 1-115.

Hill, M.O. (1973). Reciprocal averaging: an eigenvector method of ordination. Journal of Ecology, 61, 237-250.

Hill, M.O. (1979a). TWINSPAN - A Fortran Program for Arranging Multivariate Data in an Ordered Two-way Table by Classification of the Individuals and Attributes. Cornell University, Ithaca, New York.

Hill, M.O. (1979b). DECORANA - A Fortran Program for Detrended Correspondence Analysis and Reciprocal Averaging. Cornell University, Ithaca, New York.

Hill, M.O., Bunce, R.G.H. & Shaw, M.W. (1975). Indicator species analysis, a divisive polythetic method of classification, and its application to a survey of native pinewoods in Scotland. Journal of Ecology, 63, 597-613.

Hill, M.O. & Gauch, H.G. Jr. (1980). Detrended correspondence analysis, an improved ordination technique. Vegetatio , 42, 47-58.

Hoagland, D.R. & Arnan, D.I. (1950). The water-culture method for growing plants without soil. Californian Agricultural Station Circular, 347.

Hunt, R. (1978). Plant Growth Analysis. Arnold, London.

Hunter, J.G. & Vergnano, O. (1953). Trace-element toxicities in oat plants. Annals of Applied Biology, 40, 761-777.

Jeffrey, D.W. (1970). A note on the use of ignition loss as a means for the approximate estimation of soil bulk density. Journal of Ecology, 58, 297-299.

Jeffrey, D.W. (1971). The experimental alteration of a Kobresia-rich sward in Upper Teesdale. The Scientific Management of Animal and Plant Communities for Conservation. (Ed. by E.Duffey & A.S. Watt), pp. 79-89. Blackwell, Oxford.

Johnston, W.R. (1974). Mineral uptake by plants of serpentine and lead mine soils. B.A. (Hons.) thesis, University of Stirling.

Johnston, W.R. (1976). Studies in the plant ecology of two Scottish serpentine areas. M.Sc. thesis, University of Stirling.

Johnston, W.R. & Proctor, J. (1977). Metal concentrations in plants and soils from two British serpentine sites. Plant and Soil, 46, 275-278.

Johnston, W.R. & Proctor, J. (1979). Ecological studies on the lime hill serpentine, Scotland. Botanical Society of Edinburgh Transactions, 43, 145-150.

Johnston, W.R. & Proctor, J. (1980). Ecological studies on Meikle Kilrannoch serpentine. Botanical Society of Edinburgh Transactions, 43, 207-215.

Johnston, W.R. & Proctor, J. (1981). Growth of serpentine and non-serpentine races of Festuca rubra in solutions simulating the chemical conditions in a toxic serpentine soil. Journal of Ecology, 69, 855-869.

Kershaw, K.A. (1973). Quantitative and Dynamic Plant Ecology. Arnold, London.

Khalid, B.Y. & Tinsley, J. (1980). Some effects of nickel toxicity on rye grass. Plant and Soil, 55, 139-144.

Lyon, G.L., Peterson, P.J., Brooks, R.R. & Butler, G.W. (1971). Calcium, magnesium and trace elements in a New Zealand serpentine flora. Journal of Ecology, 59, 421-429.

McKay, M.M. (1980). Rev.Dr. John Walker's Report on the Hebrides of 1764 and 1771. John Donald, Edinburgh.

McLean, D. (1796). The Statistical Account of Scotland. Edinburgh.

MacLean, D. (1845). The New Statistical Account of Scotland. Edinburgh.

McVean, D.N. & Ratcliffe, D.A. (1962). Plant Communities of the Scottish Highlands. Her Majesty's Stationery Office, London.

Madhok, O.P. & Walker, R.B. (1969). Magnesium nutrition of two species of sunflower. Plant Physiology, Lancaster, 44, 1016-1022.

Main, J.L. (1974). Differential responses to magnesium and calcium by native populations of Agropyron spicatum. American Journal of Botany, 61, 931-937.

Marrs, R.H. (1977). Ecological aspects of the mineral nutrition of several members of the Ericaceae. Ph.D. Thesis, University of Stirling.

Marrs, R.H. & Proctor, J. (1976). The response of serpentine and non-serpentine Agrostis stolonifera L. to magnesium and calcium. Journal of Ecology, 64, 953-964.

Marrs, R.H. & Proctor, J. (1978). Chemical and ecological studies of heath plants and soils of the Lizard peninsula, Cornwall. Journal of Ecology, 66, 417-432.

Molloy, M.G. & Lockman, R.B., (1979). Soil analysis as affected by drying temperature. Communications in Soil Science and Plant Analysis, 10, 545-550.

Moore, J.J. (1962). The Braun-Blanquet system: A reassessment. Journal of Ecology, 50, 761-769.

Mueller-Dombois, D. & Ellenberg, H. (1974). Aims and Methods of Vegetation Ecology. Wiley, New York.

Munro, R.W. (1961). Munro's Western Isles of Scotland & Geneologies of the Clans 1549. Oliver & Boyd, Edinburgh.

Nature Conservancy Council. (1974). Isle of Rhum National Nature Reserve. Nature Conservancy Council, Edinburgh.

Nye, P.H. & Tinker, P.B. (1977). Solute Movement in the Soil Root System. Blackwell, Oxford.

O'Neill, J.V. & Webb, R.A. (1970). Simultaneous determination of nitrogen, phosphorus and potassium in plant material by automatic methods. Journal of the Science of Food and Agriculture, 21, 217-219.

Perkin Elmer, (1976) Analytical Methods for Atomic Absorption Spectrophotometry. Norwalk, Connecticut.

Pomeroy, D.E. (1974). Biological studies on a peaty podzol I. The physical environment. Pedobiologia, 14, 419-428.

Poore, M.E.D. (1955). The use of phytosociological methods in ecological investigation. The Braun-Blanquet system. Journal of Ecology, 43, 226-244.

Poore, M.E.D. (1956). The use of phytosociological methods in ecological investigations. General discussion of phytosociological problems. Journal of Ecology, 44, 28-50.

Prentice, I.C. (1977). Non-metric ordinations in ecology. Journal of Ecology, 65, 85-94.

Proctor, J. (1969). Studies in serpentine plant ecology. D.Phil. thesis, University of Oxford.

Proctor, J. (1971a). The plant ecology of serpentine. II. Plant response to serpentine soils. Journal of Ecology, 59, 397-410.

Proctor, J. (1971b). The plant ecology of serpentine. III. The influence of a high Mg/Ca ratio and high nickel and chromium levels in some British and Swedish serpentine soils. Journal of Ecology, 59, 827-842.

Proctor, J., Burrow, J. & Craig, G.C. (1980). Plant and soil chemical analyses from a range of Zimbabwean serpentine sites. Kirkia, 12, 127-139.

Proctor, J., Johnston, W.R., Cottam, D.A. & Wilson, A.B. (1981). Field-capacity water extracts from serpentine soils. Nature, London, 294, 245-246.

Proctor, J. & McGowan, I.D. (1976). Influence of magnesium on nickel toxicity. Nature, London, 260,134.

Proctor, J. & Woodell, S.R.J. (1971). The plant ecology of serpentine I. Serpentine vegetation of England and Scotland. Journal of Ecology, 59, 375-395.

Proctor, J. & Woodell, S.R.J. (1975). The ecology of serpentine soils. Advances in Ecological Research, 9, 255-366.

Ragg, J.M. & Ball, D.F. (1964). Soils of the ultrabasic rocks of the island of Rhum. Journal of Soil Science, 15, 124-133.

Rorison, I.H. (1969). Ecological inferences from laboratory experiments on mineral nutrition. Ecological Aspects of the Mineral Nutrition of Plants. (Ed. by I.H. Rorison), pp.155-175. Blackwell, Oxford.

Rorison, I.H. (1971). The use of nutrients in the control of the floristic composition of grassland. The Scientific Management of Animal & Plant Communities for Conservation. (Ed. by E. Duffey and A.S. Watt), pp. 65-77. Blackwell, Oxford.

Russell, E.W. (1973). Soil Conditions and Plant Growth. Longman, London.

Shewry, P.R. & Peterson, P.J. (1975). Calcium and magnesium in plants and soil from a serpentine area on Unst, Shetland. The Journal of Applied Ecology, 12, 381-391.

Shewry, P.R. & Peterson, P.J. (1976). Distribution of chromium and nickel in plants and soils from serpentine and other sites. Journal of Ecology, 64, 195-212.

Slingsby, D.R. & Brown, D.H. (1977). Nickel in British serpentine soils. Journal of Ecology, 65, 597-615.

Smith, R.A.H. & Bradshaw, A.D. (1979). The use of metal tolerant plant populations for the reclamation of metalliferous wastes. Journal of Applied Ecology, 16, 595-612.

Spence, D.H.N. (1970). Scottish serpentine vegetation. Oikos, 21,22-31.

Spence, D.H.N. & Millar, E.A. (1963). An experimental study of the infertility of Shetland serpentine soil. Journal of Ecology, 51, 333-343.

Turitzin, S.N. (1982). Nutrient limitations to plant growth in a California serpentine grassland. The American Midland Naturalist, 107, 95-99.

Wainwright, S.J. & Woolhouse, H.W. (1975). Physiological mechanisms of heavy metal tolerance in plants. The Ecology of Resource Degradation and Renewal. (Ed. by M.J. Chadwick and G.T. Goodman) pp.231-257. Blackwell, Oxford.

Walsh, L.M. (1971). Instrumental Methods for Analysis of Soils and Plant Tissue. Soil Science Society of America Incorporated, Madison, Wisconsin.

Watson, E.V. (1968). British Mosses and Liverworts. Cambridge University Press, England.

Webster, R. (1977). Quantitative and Numerical Methods in Soil Classification and Survey Monographs on Soil Survey. Clarendon Press, Oxford.

Wilkins, D.A. (1957). A technique for the measurement of lead tolerance in plants. Nature, London, 180, 37-38.

Wong, M.H. & Bradshaw, A.P. (1982). A comparison of the toxicity of metals, using root elongation of rye grass, Lolium perenne. New Phytologist, 91, 255-261.

Slingsby, D.R. & Brown, D.H. (1977). Nickel in British serpentine soils. Journal of Ecology, 65, 597-615.

Smith, R.A.H. & Bradshaw, A.D. (1979). The use of metal tolerant plant populations for the reclamation of metalliferous wastes. Journal of Applied Ecology, 16, 595-612.

Spence, D.H.N. (1970). Scottish serpentine vegetation. Oikos, 21,22-31.

Spence, D.H.N. & Millar, E.A. (1963). An experimental study of the infertility of Shetland serpentine soil. Journal of Ecology, 51, 333-343.

Turitzin, S.N. (1982). Nutrient limitations to plant growth in a California serpentine grassland. The American Midland Naturalist, 107, 95-99.

Wainwright, S.J. & Woolhouse, H.W. (1975). Physiological mechanisms of heavy metal tolerance in plants. The Ecology of Resource Degradation and Renewal. (Ed. by M.J. Chadwick and G.T. Goodman) pp.231-257. Blackwell, Oxford.

Walsh, L.M. (1971). Instrumental Methods for Analysis of Soils and Plant Tissue. Soil Science Society of America Incorporated, Madison, Wisconsin.

Watson, E.V. (1968). British Mosses and Liverworts. Cambridge University Press, England.

Webster, R. (1977). Quantitative and Numerical Methods in Soil Classification and Survey Monographs on Soil Survey. Clarendon Press, Oxford.

Wilkins, D.A. (1957). A technique for the measurement of lead tolerance in plants. Nature, London, 180, 37-38.

Wong, M.H. & Bradshaw, A.P. (1982). A comparison of the toxicity of metals, using root elongation of rye grass, Lolium perenne. New Phytologist, 91, 255-261.

Appendix I

Vegetation Classification Data

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Quadrat  Then 8 couplets per line of species no. and transformed Domin
                 no. (See Appendix II for species names and no.s)
----------------------------------------------------------------------

   2    12 0.40 31 0.90 47 2.60 50 0.40 53 0.90 54 0.90 57 0.40 58 2.60
   2    61 3.00 65 0.20 68 0.90 80 0.20 87 0.20 95 0.20100 0.20102 0.90
   2   115 0.40117 5.90118 0.40129 0.20
   3     2 0.90 28 0.90 31 2.60 47 0.90 54 2.60 57 0.90 58 0.90 61 0.90
   3    65 0.90 79 3.00 80 0.90114 0.20115 0.20117 2.60
   4     1 0.20  2 0.90  7 3.00 31 2.60 47 3.00 53 0.20 54 2.60 57 0.40
   4    58 2.60 61 2.60 65 0.90 68 0.40 80 0.04 94 0.04 95 0.04 97 0.04
   4   102 0.20105 0.20108 0.04111 0.04114 0.20117 3.00119 0.04128 0.04
   4   129 0.40130 0.20
   5    28 0.40 31 0.90 47 0.90 53 0.20 54 2.60 58 0.90 61 0.20 65 0.90
   5    79 0.90 80 0.40 94 0.04117 3.00132 0.20
   6     2 2.60  7 4.60 23 0.20 31 0.90 47 2.60 54 2.60 57 0.90 58 0.90
   6    65 0.40 94 0.90 95 0.20 97 0.04102 0.40108 0.04111 0.04117 2.60
   6   129 0.40134 0.20
   7     7 0.90 12 0.20 23 0.20 31 0.40 47 0.40 50 0.90 53 0.20 54 2.60
   7    55 0.90 58 2.60 61 5.90 65 2.60 68 2.60 70 0.90100 0.20102 3.00
   7   108 0.20117 0.90119 0.40
   8     2 0.40  7 4.60 12 0.40 15 0.20 28 0.20 31 0.90 47 2.60 53 0.90
   8    54 0.40 58 0.40 61 4.60 65 0.40 68 2.60 79 0.40 80 0.40 94 0.20
   8   102 0.40117 2.60129 0.20
   9     7 0.40 31 0.90 47 3.00 53 0.90 54 2.60 55 0.40 57 0.40 58 2.60
   9    61 3.00 65 0.90 68 2.60 80 0.40 87 0.20 94 0.20102 0.40115 0.20
   9   117 3.00
  10     1 0.40  2 0.90 15 0.20 28 0.20 31 0.90 41 0.04 47 3.00 50 2.60
  10    53 0.40 54 2.60 58 2.60 61 3.00 65 0.20 68 2.60 80 0.40 94 0.20
  10   102 0.20115 0.40117 5.90119 0.20129 0.20
  11     2 0.20  5 0.90  7 0.04 28 2.60 31 0.04 41 0.20 47 0.90 53 0.20
  11    54 0.90 58 0.40 61 2.60 62 0.40 65 2.60 68 2.60 79 2.60 80 0.04
  11    97 0.04115 0.90116 0.20117 2.60
  12     7 0.40 20 0.04 28 0.90 31 0.40 41 0.20 47 0.90 53 0.20 54 2.60
  12    58 2.60 60 0.20 65 2.60 68 2.60 79 0.40 80 0.04 81 0.04117 0.20
  12   137 0.04
  13     7 2.60 17 0.40 24 0.40 28 0.40 31 0.40 43 0.04 47 0.90 53 0.20
  13    54 0.40 58 0.90 60 0.40 65 0.40 68 0.90 70 2.60 79 0.40 80 0.04
  13    87 0.20102 0.04
  14     2 0.20 17 0.04 28 0.20 47 0.20 54 0.04 57 0.20 58 0.90 60 0.20
  14    65 0.40 68 0.40117 0.20
  15     7 0.40 28 0.40 41 0.04 47 0.20 54 0.04 58 0.90 60 0.90 65 0.40
  15    70 0.20 87 0.04 95 0.04102 0.20!17 2.60120 0.04
  16     7 0.90 13 0.40 14 0.40 18 0.90 24 2.60 26 0.20 43 0.04 47 0.40
  16    54 0.40 60 0.90 65 0.40 79 0.40 80 0.04 95 0.04102 0.04117 3.00
  17     7 3.00 15 0.04 24 0.04 58 0.04 61 0.04 62 0.04 70 0.04 99 0.04
  17   142 0.04
  18     2 0.20  7 3.00 13 2.60 24 2.60 28 0.20 31 0.40 41 0.20 47 0.90
  18    53 0.20 54 0.40 58 0.40 60 0.90 62 0.40 65 0.04117 0.90
  19     2 0.40  7 3.00 15 0.20 24 2.60 28 0.20 30 0.04 31 0.20 41 0.20
  19    47 0.40 53 0.20 54 0.20 58 0.20 60 0.40 62 0.20 65 0.40 87 0.04
  19   117 2.60
  20     2 0.20  7 3.00 10 0.20 13 2.60 15 0.20 17 0.20 24 0.90 28 0.20
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20   30 0.20 31 0.40 41 0.20 43 0.04 47 2.60 53 0.40 54 0.40 58 0.40
20   60 0.40 62 0.40 87 0.04 95 0.20117 2.60
21    2 0.90  7 3.90 12 2.60 15 0.40 17 0.20 23 0.04 29 0.20 31 0.40
21   41 2.60 44 0.20 46 0.40 47 4.60 53 0.90 54 0.90 57 0.40 58 2.60
21   62 0.04 65 0.90 70 2.60 83 0.20 94 0.20100 0.40102 2.60108 0.40
21  110 0.40117 0.90129 0.40
22    2 2.60  7 5.90 12 2.60 15 0.20 29 0.20 30 0.20 31 2.60 41 0.90
22   46 0.40 47 4.60 53 0.40 54 2.60 57 2.60 58 3.00 65 0.40 68 0.90
22   70 0.20 87 0.20 95 0.20102 2.60111 0.04117 0.90121 0.04126 0.20
22  129 0.90
23    2 0.40  7 5.90 28 0.20 31 2.60 41 0.20 46 2.60 47 0.90 53 0.20
23   54 3.00 55 0.20 58 2.60 61 2.60 65 0.90 70 0.90 83 0.20 94 0.20
23   95 0.04100 0.90102 0.90108 0.04117 3.00121 0.20129 0.20
24    7 5.90 24 2.60 31 2.60 44 0.20 46 0.90 47 0.90 53 0.40 54 0.90
24   55 0.20 61 3.90 65 0.90 68 2.60 74 0.40 79 3.90 83 0.20 94 0.90
24   95 0.40102 2.60117 0.90
25    7 2.60 15 0.04 24 0.20 28 3.00 31 0.40 41 0.90 43 0.20 44 0.20
25   47 0.40 53 0.20 54 0.90 58 0.90 61 2.60 65 0.90 68 0.90 70 0.90
25   80 0.04102 0.90117 2.60
26    2 0.20 28 3.00 31 0.20 41 0.90 47 2.60 54 3.00 58 2.60 61 0.90
26   65 0.20 68 4.60 70 2.60 80 0.20 81 0.04 83 0.20 95 0.90 97 0.90
26  102 0.90117 0.90
27    2 2.60  7 2.60 15 0.20 31 2.60 41 0.90 43 0.40 47 2.60 53 0.40
27   54 2.60 57 0.90 58 2.60 61 2.60 65 0.40 68 0.40 80 0.20 83 0.90
27   94 0.20 97 0.20100 0.20102 0.90117 4.60129 0.40
28   94 0.20
30    7 3.00 28 2.60 31 0.40 41 0.40 47 0.90 53 0.20 54 2.60 57 0.90
30   58 2.60 87 0.20114 0.04115 0.40117 3.00129 0.40134 2.60
31   28 2.60 31 0.40 47 0.90 54 0.90 57 0.40 58 0.90117 0.04119 0.04
32    7 3.00 28 2.60 31 0.20 47 2.60 53 0.04 54 2.60 57 2.60 58 0.40
32   62 0.20 87 0.40 95 0.20117 0.04
33    7 0.40 28 0.40 47 0.40 54 0.90 57 0.90 58 0.40 95 0.04117 0.04
34    7 2.60 54 0.90 57 0.90 58 0.90 87 0.20117 0.04
35    7 2.60 28 0.90 47 0.40 54 0.40 57 0.90 58 0.90 87 0.90117 0.20
36   28 0.20 31 0.04 47 0.40 53 0.04 54 0.40 57 0.40 58 0.90117 0.04
37    7 0.20 28 0.90 47 0.20 54 0.90 57 0.40 58 0.40117 0.04
38    7 0.90 28 0.90 31 0.04 47 0.20 54 0.40 58 0.40117 0.40
39    7 3.00 28 2.60 47 0.90 54 2.60 57 2.60 58 0.40 87 0.20117 0.40
39  128 0.40129 0.40
40    7 3.00 28 0.20 47 0.90 53 0.20 54 0.40 57 0.40 58 0.40 87 0.20
40  117 0.90
41    7 0.90 28 0.90 47 2.60 54 2.60 58 2.60114 0.04117 0.40
42   28 2.60 47 2.60 54 2.60 58 0.90117 0.04
43    7 2.60 28 0.90 47 2.60 54 0.90 58 0.90117 0.04
44   28 2.60 47 2.60 53 0.04 54 0.40 58 0.40117 0.20
45    7 0.04 20 0.04 28 2.60 47 3.00 54 0.90 58 2.60117 2.60129 0.04
46    7 2.60 28 0.90 31 0.40 43 0.04 47 0.90 54 0.40 58 2.60 87 0.04
46  117 0.04
47   28 2.60 47 0.90 54 0.40 58 2.60 80 0.04
48   28 0.40 47 2.60 54 0.40 58 2.60117 0.40
49   28 2.60 31 0.90 47 0.90 54 0.40 58 0.40117 0.20
50   28 0.90 50 0.90 54 0.20 58 0.90117 0.90
51    7 3.00 17 0.40 24 0.90 26 0.04 28 0.90 31 2.60 41 0.90 43 0.40
51   44 0.20 47 0.90 53 0.20 54 0.90 58 2.60 60 3.90 61 0.40 65 0.90
51   68 0.40 79 3.00 81 0.20102 0.20117 3.00
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52    7 4.60 24 0.90 29 0.40 31 2.60 41 0.40 44 0.90 46 0.40 47 0.90
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52   79 3.00 83 0.20 95 2.60100 0.90102 0.90122 4.60129 0.20
53    2 0.20  7 4.60 13 0.90 17 0.40 23 0.20 24 2.60 25 0.40 29 0.90
53   31 3.00 41 0.40 44 2.60 46 2.60 47 0.90 53 0.90 55 0.20 60 5.90
53   61 3.90 68 3.00 70 0.40 79 2.60 83 0.20 95 2.60102 2.60117 2.60
53  122 3.90129 0.20
54    7 3.00 13 3.00 15 0.20 24 3.00 25 0.40 26 0.20 28 0.40 31 2.60
54   41 0.20 44 0.40 53 0.40 54 0.90 55 0.90 57 0.40 58 0.40 60 3.90
54   61 3.00 65 0.40 68 2.60 70 0.90 79 2.60 83 0.40 88 0.90 95 3.00
54  107 0.40115 0.40117 3.90122 0.20125 0.20
55    2 0.40  7 2.60 17 0.40 24 0.90 26 0.20 28 0.40 31 0.90 41 0.20
55   43 0.90 44 0.20 47 0.90 53 0.20 54 2.60 57 0.40 58 0.40 60 0.90
55   65 0.40102 0.20117 0.40
56    2 0.90  7 2.60 13 2.60 14 0.40 17 0.20 23 0.04 24 2.60 30 0.20
56   31 2.60 41 0.20 43 0.90 44 0.20 47 2.60 53 0.40 54 0.40 57 0.40
56   58 0.40 60 2.60 95 0.20107 0.40117 3.00129 0.04
57    2 0.90  7 3.00 15 0.20 17 0.20 24 2.60 26 0.20 28 2.60 31 2.60
57   41 0.20 43 0.40 44 0.40 47 2.60 53 0.90 54 0.90 55 0.20 57 0.40
57   58 0.90 60 3.00 61 0.90 62 0.20 68 0.90 70 2.60 79 2.60 80 0.20
57   95 0.40107 4.60117 3.90129 0.04
58    7 3.00 24 0.40 28 2.60 31 0.20 47 0.90 53 0.20 54 0.20 57 2.60
58   58 0.20 80 0.40 87 0.40104 0.20107 0.40117 0.20
59    2 0.90  7 3.00 13 0.40 17 0.40 23 0.20 24 3.00 28 0.40 31 2.60
59   41 0.20 44 0.90 47 2.60 53 0.90 54 0.40 55 0.20 57 0.40 58 2.60
59   60 2.60 68 0.90 70 0.90 79 2.60 80 0.20 95 0.20100 0.20102 0.04
59  107 0.90117 3.90122 0.40129 0.20
60    2 0.40  7 5.90 10 0.04 13 2.60 17 0.40 23 0.40 24 0.90 29 0.40
60   31 2.60 41 0.20 44 2.60 47 0.90 53 2.60 54 0.90 55 0.90 57 0.90
60   58 2.60 60 3.00 68 2.60 70 0.90 95 0.40102 0.40117 3.00119 0.04
60  129 0.20
61    2 0.40  5 2.60  7 2.60 15 0.20 28 0.90 41 0.20 47 0.40 54 0.40
61   58 0.20 60 0.90 62 0.40 65 0.90 68 0.90 79 0.90116 0.04117 0.40
62    4 0.20  5 2.60  7 0.90 28 0.40 41 0.20 46 0.20 47 0.20 54 0.20
62   58 0.90 65 0.20 79 0.20 80 0.04102 0.20117 0.20
63    2 0.40  5 0.20  7 0.40 26 0.90 28 0.04 31 0.20 41 0.40 43 0.90
63   44 0.20 47 0.20 48 0.20 53 0.04 54 0.40 55 0.40 58 0.90 60 2.60
63   61 0.90 62 0.20 65 0.20 68 2.60 79 3.00 81 0.04117 2.60129 0.04
64    4 0.04  5 0.04 46 0.20 53 0.04 54 0.90 58 0.20 65 0.40 75 0.20
65    4 0.04  5 2.60  7 0.40 26 0.20 28 2.60 39 0.20 41 0.20 43 0.40
65   46 0.04 47 0.40 53 0.20 54 2.60 55 0.40 58 0.40 60 0.40 65 0.90
65   68 2.60 81 0.20111 0.20117 2.60
66    4 0.04  5 0.04 28 2.60 41 0.04 42 0.04 46 0.20 54 0.40 58 0.40
66   65 0.90100 0.04117 0.04
67    7 0.40 31 3.00 41 0.40 44 0.90 46 3.90 47 0.90 53 0.90 54 3.00
67   55 2.60 58 2.60 60 2.60 61 4.60 65 0.20 68 3.90 79 0.90 94 0.40
67  100 0.90102 3.90117 0.90118 0.90
68    4 0.20  5 0.90 20 0.04 28 0.40 47 0.40 54 0.90 58 0.90 65 2.60
68   68 0.20117 0.04
69    4 0.20 47 0.20 54 0.40 58 0.40 65 0.20 83 0.04
70    4 0.20  7 2.60 28 0.90 41 0.20 47 0.90 53 0.40 54 0.40 58 0.90
70   65 0.40 68 0.90117 0.40
71    5 0.90 19 0.90 28 2.60 41 0.20 54 0.90 65 0.90 66 0.90 68 3.90
71   79 3.90 80 0.40 95 0.04110 0.40114 0.40117 0.40
72    2 0.04  4 0.04  5 0.90  7 2.60 15 0.20 19 0.40 23 0.20 28 0.90
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72    31 0.20 41 0.40 43 0.20 47 0.90 54 0.40 58 0.90 65 0.90 68 3.00
72    79 2.60 80 0.90114 0.90117 2.60129 0.20
73     4 0.04  5 0.20  7 0.04  8 0.20 15 0.20 26 0.04 28 2.60 41 0.40
73    47 0.40 54 0.20 58 0.40 65 0.90 68 0.40 79 0.20 80 0.40 87 0.20
73   115 0.90117 0.20
74     7 0.20 31 2.60 46 0.90 47 0.40 53 0.90 54 2.60 55 0.90 58 2.60
74    60 2.60 61 5.90 68 3.00 70 2.60100 2.60102 4.60117 4.60
75     2 0.20  5 0.20  7 2.60 15 0.20 28 2.60 31 0.90 41 0.20 43 0.90
75    47 0.90 53 0.90 54 0.90 58 0.90 60 0.90 61 2.60 62 0.20 65 2.60
75    68 2.60 70 0.20100 0.04102 0.40117 0.90129 0.20
76     2 0.20  7 2.60 15 0.20 20 0.04 23 0.04 28 2.60 31 2.60 41 0.90
76    43 0.20 44 0.20 46 0.20 47 0.90 53 0.90 54 0.90 57 0.40 58 0.40
76    60 2.60 62 0.40 68 3.90 70 3.00102 0.40117 0.90129 0.20
77     2 2.60  5 0.40  7 3.00 15 0.20 23 0.90 26 0.20 28 0.90 31 2.60
77    41 0.20 44 0.90 47 0.90 53 0.40 54 0.90 58 0.90 60 0.40 62 0.90
77    65 0.20 68 3.90 70 0.40 79 4.60114 0.40117 3.90129 0.20
78     2 0.90  5 0.40  7 3.00 15 0.20 20 0.04 23 0.40 26 0.20 28 2.60
78    31 2.60 43 0.40 44 0.40 47 0.90 53 0.40 54 0.40 58 0.40 60 0.90
78    62 0.20 68 3.00 79 3.00 80 0.20117 0.90129 0.04
79     2 0.90  7 3.00 15 0.20 28 2.60 31 0.90 41 0.40 43 0.40 44 0.40
79    47 2.60 53 0.40 54 0.90 58 2.60 62 0.40 65 0.20 68 0.90 79 2.60
79    80 0.40117 2.60129 0.40
80     2 0.90  3 0.40  7 2.60 15 0.20 20 0.20 28 0.90 31 0.40 41 0.40
80    43 0.40 44 0.20 47 0.90 53 0.40 54 0.90 58 2.60 62 0.40 65 0.90
80    68 2.60 79 3.00 80 0.20117 2.60129 0.20
81     7 3.00 10 0.40 13 3.90 14 3.00 17 0.40 24 2.60 25 0.40 28 0.20
81    31 2.60 44 0.90 46 0.40 52 0.20 53 0.40 57 0.40 58 0.40 60 7.40
81    68 0.20 70 0.90 79 0.90 83 0.40 95 0.40102 3.00117 0.90
82     7 3.00 13 2.60 14 2.60 24 2.60 25 0.40 28 0.20 31 2.60 44 0.40
82    46 2.60 52 0.20 55 0.90 60 8.40 68 0.40 70 2.60 78 2.60 79 0.20
82    83 0.90102 3.00117 2.60
83     7 2.60 10 0.04 13 2.60 14 2.60 15 0.20 24 0.40 25 0.40 31 2.60
83    44 0.20 53 0.40 58 0.20 60 7.40 68 2.60 70 0.90 79 3.00100 0.90
83   102 3.00117 0.40
84     7 3.90 10 0.40 13 0.90 14 0.90 17 0.04 23 0.20 24 2.60 25 0.40
84    29 0.20 31 2.60 44 0.40 47 0.20 52 0.20 53 0.40 60 7.40 68 2.60
84    70 0.40 79 0.90 83 0.40100 0.40102 2.60107 2.60117 2.60129 0.04
85     7 0.40 28 0.90 54 0.20 57 0.20 60 0.20 65 0.40 68 3.00 80 0.20
85    96 0.40133 0.40
86     2 0.04  7 0.40 28 0.90 31 0.20 41 0.20 47 0.20 54 0.20 58 0.20
86    60 0.40 65 0.20 68 0.90 78 0.40 79 0.40 87 0.20117 0.40
87     2 0.40  7 3.00 13 2.60 14 0.20 17 0.40 24 3.00 25 0.04 28 0.40
87    29 0.40 31 2.60 44 0.90 47 2.60 52 0.40 53 0.40 54 0.40 60 4.60
87    65 0.20 68 0.40 70 0.20 79 0.90117 3.00129 0.20
88     2 0.90  7 3.00 13 0.40 14 0.40 24 0.20 28 0.40 31 0.20 43 0.40
88    47 0.40 53 0.40 54 0.40 58 0.20 60 0.40 65 0.40 68 0.40 79 0.90
88   114 0.20117 0.90
89     2 0.90  7 2.60 13 2.60 14 0.90 24 2.60 31 0.40 41 0.20 43 0.40
89    47 0.40 53 0.20 60 3.00 65 0.40 68 0.90 78 2.60 79 0.90114 0.40
89   117 3.90129 0.20
90     2 0.04  7 3.00 10 0.04 13 2.60 17 0.20 28 0.90 29 0.04 44 0.04
90    47 0.40 53 0.20 54 0.40 58 0.40 60 0.40 79 0.20114 0.20117 0.40
90   129 0.20
91     2 0.04  5 0.04  7 2.60 14 2.60 15 0.20 20 0.04 26 0.20 28 0.04
91    31 0.40 41 0.90 43 0.20 47 0.40 53 0.20 60 2.60 70 0.20 78 5.90
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 91    95 0.04117 3.00
 92     2 0.20   3 0.04   7 0.90 13 0.40 14 0.20 24 0.20 25 0.20 26 0.04
 92    30 0.04 41 0.20 47 0.90 54 0.20 60 0.40 65 0.40 78 2.60 80 0.04
 92    81 0.40117 0.40
 93     2 0.20   3 0.04   7 0.40 13 2.60 14 0.90 15 0.04 24 0.90 26 0.04
 93    30 0.04 41 0.20 47 0.40 53 0.40 60 0.40 78 3.00 87 0.40117 2.60
 94     2 0.40   3 0.04   7 0.90 13 0.40 14 0.20 24 0.40 28 0.40 47 0.40
 94    58 0.40 60 0.40 62 0.40 65 0.20 80 0.20117 0.20
 95     3 0.40   7 0.40 13 0.20 24 0.04 28 0.40 47 0.40 54 0.40 58 0.20
 95    60 0.20 65 0.20117 0.20
 96     2 0.20   3 0.40   7 3.00 13 2.60 14 0.90 28 0.40 47 0.40 53 0.20
 96    54 2.60 58 0.20 60 0.90 65 0.20 78 0.90 81 0.20 87 0.20117 0.40
 97     2 0.40   3 0.40   5 0.04   7 0.90 13 2.60 14 2.60 15 0.20 17 0.20
 97    24 0.90 28 0.40 41 0.40 43 0.20 47 0.40 58 0.20 60 2.60 62 0.04
 97   117 2.60118 0.20
 98     2 0.40   7 0.90 13 2.60 14 0.40 41 0.40 43 0.40 47 0.90 53 0.20
 98    58 0.20 60 2.60 61 0.04 65 0.40 78 0.90 81 0.20 97 0.20102 0.20
 98   117 2.60
 99     2 0.40   3 0.40   7 2.60 13 0.90 15 0.20 23 0.20 41 0.20 47 0.40
 99    53 0.20 54 0.20 58 0.04 60 0.40 62 0.04117 0.90
100     2 0.40   3 0.20   7 2.60 13 0.40 15 0.20 28 0.20 41 0.20 47 0.90
100    58 0.20 60 0.90 65 0.20117 0.90
101    14 2.60 25 0.40 27 0.90 31 0.90 34 0.20 44 0.40 53 2.60 54 5.90
101    55 2.60 58 2.60 59 3.00 60 5.90 61 0.90 67 0.40 68 0.90 70 0.40
101    71 0.20 83 0.90 94 0.90100 0.90102 2.60119 0.90
102    14 0.40 25 0.90 31 2.60 34 0.90 44 0.40 53 0.04 54 0.20 55 2.60
102    59 2.60 60 7.40 61 0.90 67 0.40 68 2.60 70 0.90 71 0.90100 0.90
102   102 0.90119 2.60
103     7 0.20 14 0.40 30 0.04 31 2.60 34 0.90 41 0.04 44 0.40 53 0.20
103    55 0.40 59 2.60 60 7.40 68 2.60 70 0.90 71 0.90 73 0.40100 0.90
103   102 0.90119 0.90
104     7 2.60 13 2.60 15 0.90 17 0.04 21 0.20 25 0.40 27 0.90 31 2.60
104    33 0.04 44 0.40 47 2.60 49 0.20 53 0.40 54 0.40 55 0.90 58 0.90
104    60 5.90 68 2.60 70 0.90100 0.90102 0.90119 0.90
105     7 0.90 13 2.60 14 0.40 17 0.04 24 0.90 27 2.60 29 0.20 31 0.90
105    34 0.20 44 0.90 47 0.90 53 0.40 55 2.60 58 0.40 59 2.60 60 5.90
105    61 3.00 68 2.60 70 0.40 71 0.90 95 0.04100 0.40102 0.90119 0.40
106     7 0.40 14 0.90 21 2.60 25 0.40 27 0.40 31 0.90 44 0.40 47 0.40
106    49 0.90 53 0.90 54 0.90 55 2.60 56 0.40 59 2.60 60 5.90 61 4.60
106    68 2.60 70 0.90 94 0.90 95 0.04100 0.90102 0.90108 0.90
107     7 0.90 25 0.20 27 0.40 28 0.20 29 0.04 30 0.90 31 0.90 34 0.90
107    44 0.40 47 2.60 54 0.20 55 0.90 58 0.40 60 5.90 61 2.60 68 0.90
107    70 0.90100 0.40102 0.90112 0.40119 0.20
108     7 0.90 14 2.60 25 0.40 27 0.20 31 0.90 32 0.40 44 0.20 49 0.90
108    53 0.40 54 0.40 55 3.00 58 0.20 59 3.00 60 4.60 61 2.60 68 0.90
108    70 0.40 71 0.90 73 2.60 94 0.40100 0.90102 0.90119 0.40
109    24 2.60 25 0.40 31 2.60 44 0.90 53 0.40 54 0.40 55 0.40 59 0.40
109    60 7.40 61 2.60 68 0.90 70 0.40 71 0.90 73 0.90 78 0.90100 2.60
109   102 0.90119 0.40
110     7 0.20 25 0.40 27 0.40 31 0.90 32 0.90 33 0.40 34 0.40 44 0.40
110    47 0.90 53 0.20 54 0.40 55 0.20 57 2.60 58 0.40 59 0.90 60 7.40
110    68 2.60 70 0.40 73 0.40 78 0.90 94 0.40100 0.90102 0.90112 0.20
110   119 0.90
111     7 4.60 15 0.20 17 0.20 19 0.20 27 0.40 28 0.40 30 0.20 31 3.00
111    32 0.40 33 0.04 43 0.90 47 0.40 52 0.20 53 2.60 54 2.60 55 0.90
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111	58	2.60	60	3.00	61	2.60	68	0.40	70	2.60	82	3.00	83	0.40	100	3.90
111	102	3.00	112	0.04	129	0.04										
112	2	0.20	7	2.60	9	0.04	15	0.40	19	0.40	20	0.20	27	0.40	28	2.60
112	30	0.04	31	2.60	32	0.40	41	0.04	43	0.40	44	0.40	47	0.90	52	0.20
112	53	0.40	54	0.40	55	0.90	58	0.90	60	4.60	65	0.04	68	3.00	70	0.90
112	79	2.60	83	0.40	95	0.04	102	0.40	112	0.04	117	2.60	118	0.40	129	0.04
113	7	3.00	9	0.04	13	0.20	15	0.20	17	0.04	20	0.20	27	0.90	30	0.20
113	31	3.00	32	0.90	43	0.90	44	0.40	47	2.60	53	0.90	54	3.00	55	0.90
113	57	0.40	58	0.90	60	5.90	64	0.40	65	0.20	68	2.60	70	3.00	83	0.90
113	100	0.90	102	0.90	112	0.20	117	2.60								
114	7	0.90	9	0.20	15	0.20	19	0.90	24	0.20	27	0.20	31	3.00	32	0.40
114	43	0.90	47	0.40	52	0.20	53	0.90	54	3.00	55	0.90	58	0.90	60	7.40
114	64	0.90	68	2.60	70	3.00	79	0.90	86	0.40	94	0.40	100	0.40	102	0.90
114	112	3.00	118	0.40												
115	2	0.04	7	5.90	9	0.20	15	0.04	17	0.40	19	0.20	27	2.60	29	0.40
115	31	2.60	32	0.20	43	0.40	44	0.90	47	0.90	52	0.20	53	0.90	54	0.90
115	55	2.60	58	2.60	60	4.60	61	0.90	65	0.20	68	0.90	70	2.60	83	0.40
115	94	0.40	95	0.20	100	0.90	102	0.90	117	0.40	118	0.90				
116	2	0.20	7	3.90	9	0.20	13	2.60	15	0.40	17	0.04	19	2.60	27	2.60
116	28	0.04	29	0.20	31	2.60	33	0.40	41	0.40	44	0.40	47	0.90	53	0.90
116	54	0.90	55	2.60	57	0.20	60	3.00	61	0.40	65	0.90	68	2.60	70	3.90
116	80	0.40	82	0.40	83	0.20	100	0.40	102	0.40	112	0.20	115	0.40	117	0.90
117	2	0.40	7	3.00	9	0.20	13	2.60	15	0.40	19	0.40	25	0.20	27	0.20
117	31	2.60	32	0.90	41	0.40	43	0.40	44	0.40	47	0.90	52	0.20	53	0.90
117	54	0.40	55	0.90	57	3.90	58	0.20	60	3.90	61	2.60	68	2.60	70	2.60
117	79	0.40	100	0.20	101	0.40	102	0.40	112	0.20	115	0.20	117	2.60		
118	7	3.90	13	2.60	17	0.40	31	3.00	32	0.90	43	0.90	44	0.20	47	0.20
118	53	0.40	54	0.90	55	0.40	58	0.20	60	3.90	61	0.90	64	0.20	70	2.60
118	79	0.40	94	0.40	95	0.20	100	0.40	101	0.20	102	0.40	118	0.40	123	0.20
118	129	0.20														
119	7	3.00	9	0.04	15	0.40	17	0.90	28	2.60	30	0.20	31	3.00	32	0.90
119	41	0.40	43	0.20	44	0.90	45	0.20	47	0.90	53	0.40	54	2.60	55	2.60
119	58	2.60	60	3.90	61	2.60	62	0.40	64	0.40	68	0.40	70	3.00	83	0.90
119	100	0.90	102	0.40	112	0.40	117	0.20								
120	7	5.90	20	0.40	27	0.40	28	0.40	30	0.20	31	3.00	41	0.20	44	0.20
120	47	0.90	52	0.20	53	0.90	54	0.40	55	2.60	58	0.90	60	3.90	61	0.90
120	64	0.40	68	0.90	70	2.60	80	0.20	83	0.40	100	0.40	102	0.90	115	0.40
120	117	0.20														
121	7	0.90	24	0.40	28	0.40	31	0.04	47	0.40	58	0.40	60	0.40	65	0.40
121	66	0.40	88	0.20	98	0.40	117	0.04								
122	5	0.90	7	2.60	14	0.04	24	0.90	26	0.20	41	0.40	47	0.40	54	0.40
122	58	0.40	60	3.00	65	0.90	66	0.40	68	0.90	79	0.20	117	0.04		
123	5	0.90	7	2.60	24	0.90	26	0.04	28	0.20	31	0.04	41	0.20	54	0.40
123	58	0.40	60	2.60	65	0.40	66	0.40	117	0.90						
124	2	0.40	7	3.00	14	2.60	15	0.90	17	0.04	19	0.20	24	0.40	25	0.40
124	26	0.20	31	0.90	41	0.40	44	0.20	47	0.90	53	0.40	54	0.40	58	2.60
124	60	3.00	61	0.90	65	0.90	66	0.20	68	0.90	73	0.40	79	3.00	81	0.04
124	117	2.60														
125	5	0.04	7	0.04	24	0.04	28	2.60	54	0.40	58	2.60	60	0.90	65	0.40
125	66	2.60	81	0.40												
126	7	0.20	24	0.40	28	0.40	47	0.04	58	0.20	60	0.20	81	0.04	117	0.04
127	7	0.40	26	0.04	28	0.40	47	0.04	54	0.40	58	0.40	60	0.20	65	0.40
127	66	0.40	81	0.20	117	0.04										
128	5	0.20	7	2.60	11	0.90	13	0.90	14	2.60	24	2.60	25	0.40	26	0.20
128	28	0.20	31	0.90	41	0.40	44	0.90	47	0.40	58	0.40	60	3.00	61	0.90

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128    65 0.90 66 0.40 68 0.90 79 0.90 81 0.40 97 0.04117 3.00
129     5 0.20  7 2.60 19 0.20 24 0.90 28 0.20 31 0.04 41 0.20 43 0.04
129    47 0.20 58 0.40 60 2.60 61 0.90 65 0.90 66 0.40 79 0.20117 0.20
130     5 0.20  7 2.60 24 0.40 26 0.04 28 0.40 47 0.90 58 0.40 60 0.40
130   114 0.40117 0.20
131     7 2.60 13 2.60 25 0.20 29 0.04 31 3.90 54 0.20 55 0.40 58 0.90
131    60 3.00 61 3.00 64 0.40 68 2.60 74 2.60 79 4.60 95 0.20102 3.90
131   117 3.00118 2.60
132    25 0.20 29 0.40 30 0.20 31 2.60 44 0.20 54 0.40 55 0.40 60 3.90
132    61 3.00 62 0.40 64 0.90 68 2.60 79 4.60 83 0.40 87 0.40 91 0.04
132    95 0.20102 0.20117 0.90122 3.00
133     7 2.60 13 0.90 25 0.20 29 0.40 31 2.60 41 0.04 44 2.60 54 2.60
133    55 0.20 58 0.40 60 3.00 61 4.60 64 0.90 65 0.20 68 2.60 79 3.00
133    87 2.60 95 0.40102 0.90107 0.40117 4.60122 0.40
134     7 3.00 13 0.90 14 0.90 24 3.90 29 0.20 31 2.60 44 0.20 54 0.90
134    58 0.40 60 2.60 61 2.60 64 0.40 68 0.90 79 3.90 83 0.20 88 0.40
134    95 0.40107 0.20117 4.60129 0.90
135     7 2.60 10 0.90 13 0.20 24 0.40 25 0.90 29 0.40 31 3.00 44 0.90
135    50 0.90 53 0.04 54 0.40 58 0.40 60 3.90 61 2.60 63 0.40 68 3.00
135    79 4.60 83 0.90 94 0.90100 0.40102 0.90117 3.00
136     7 2.60 19 0.40 24 4.60 25 0.04 29 0.40 31 2.60 41 0.40 44 0.20
136    54 0.20 60 2.60 61 2.60 64 0.40 65 0.90 67 0.20 68 0.90 74 3.90
136    79 2.60 88 0.90102 0.90107 0.20117 4.60118 0.20122 5.90
137     6 0.90  7 4.60 10 0.04 13 0.40 17 0.20 29 0.20 31 2.60 44 0.90
137    54 3.00 57 0.90 58 2.60 60 3.90 61 2.60 64 0.90 68 0.90 79 2.60
137    80 0.90 95 0.40102 2.60103 2.60117 3.00135 2.60
138     7 3.90 10 0.40 24 3.90 25 0.40 31 2.60 44 0.90 54 0.90 58 0.20
138    60 2.60 61 4.60 68 0.20 79 3.00102 2.60117 3.90
139     7 4.60 25 0.40 26 0.40 31 3.00 44 0.40 50 0.90 53 0.90 54 2.60
139    58 2.60 60 3.00 61 3.90 65 0.90 67 0.20 68 0.90 72 0.20 79 3.00
139    83 2.60 93 0.40102 3.00122 2.60
140     7 4.60 19 0.04 25 0.90 31 2.60 44 2.60 53 0.90 54 3.00 55 0.40
140    58 2.60 60 3.90 61 2.60 64 0.20 68 2.60 70 0.40 79 3.00 95 0.90
140   100 0.40102 0.90106 0.20117 2.60118 2.60
141     2 0.90  7 2.60 13 3.00 24 0.04 28 0.20 31 0.40 44 0.20 47 0.90
141    54 0.40 57 0.20 60 0.90 65 0.20 68 0.04 79 0.90 87 0.20116 0.20
141   117 0.90
142     7 5.90 10 0.40 13 3.90 24 2.60 29 0.40 31 2.60 44 0.04 47 2.60
142    53 0.40 54 0.40 60 3.90 68 2.60 79 3.00102 0.20116 0.20117 3.00
143     7 4.60 13 4.60 24 0.40 29 0.20 31 2.60 44 0.90 47 0.40 53 0.90
143    54 0.40 58 0.90 60 3.00 61 0.90 68 2.60 79 3.90102 0.20117 4.60
144     2 2.60  7 4.60 13 4.60 24 0.04 28 3.00 31 2.60 44 0.04 47 0.40
144    54 0.90 58 0.90 60 0.90 61 0.40 68 0.90 79 3.00 80 0.20 95 0.04
144   102 0.90117 3.90129 2.60
145     7 2.60 10 0.20 13 3.00 14 0.90 24 0.20 25 0.20 29 0.90 31 2.60
145    44 0.20 47 0.20 53 0.40 54 0.90 58 2.60 60 4.60 61 3.00 62 0.40
145    65 0.90 79 2.60 94 0.90 95 0.20102 2.60117 0.40
146     7 3.90 13 0.40 14 2.60 23 0.04 25 0.90 29 0.90 31 2.60 44 0.40
146    53 0.40 60 3.00 61 2.60 68 0.90 79 7.40117 7.40
147     7 4.60 13 2.60 14 2.60 24 2.60 29 0.90 31 2.60 44 0.40 54 0.04
147    60 4.60 68 0.90 79 4.60117 4.60
148     2 0.20  7 3.90 10 0.40 13 3.00 14 2.60 18 2.60 24 3.00 25 0.20
148    29 0.40 31 2.60 44 0.40 47 0.04 53 0.90 58 0.20 60 3.00 61 0.90
148    65 0.20 68 0.40 79 5.90 80 0.20117 3.90129 0.90
149     7 3.00 13 3.00 14 0.40 17 0.04 28 0.90 29 0.04 31 0.40 44 0.40
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149    47 0.40 53 0.20 54 0.40 58 0.40 60 2.60 65 0.40 68 0.20 79 2.60
149    87 0.40117 3.00
150     7 3.90 13 3.90 14 3.00 25 0.90 29 0.90 31 2.60 44 0.90 53 0.90
150    60 3.90 61 3.00 68 0.20 79 4.60102 0.04117 5.90
151     7 4.60 28 0.90 31 0.90 47 3.00 53 0.40 54 3.00 57 2.60 58 0.40
151    87 2.60 95 0.40102 0.90115 0.40117 3.00
152     1 2.60  2 0.40  7 5.90 28 0.90 31 2.60 47 3.90 51 0.90 53 3.00
152    54 4.60 57 2.60 58 3.90 69 0.90 98 0.40102 0.90111 0.40115 0.20
152   117 5.90
153     1 2.60  7 7.40 21 0.40 28 0.04 29 0.20 31 3.90 41 0.20 47 3.00
153    50 2.60 51 2.60 53 2.60 54 3.00 55 0.20 57 3.00 58 4.60 69 0.20
153   102 0.90117 5.90129 0.04
154     1 2.60  2 2.60  7 3.00 28 2.60 31 3.00 38 3.00 41 0.90 43 0.20
154    47 3.00 50 0.90 51 0.90 53 2.60 54 3.00 55 0.20 57 2.60 58 3.90
154    66 0.90 69 3.00102 3.90111 0.04117 7.40129 0.40
155     1 0.90  2 3.00  7 5.90 28 2.60 31 3.00 38 2.60 47 3.90 53 0.20
155    54 0.90 55 0.04 57 2.60 58 0.90 69 0.20 80 0.90111 0.20115 0.90
155   117 3.90129 0.04
156     1 0.40  2 2.60  7 4.60 19 0.04 31 3.90 38 2.60 41 0.20 43 0.20
156    47 3.00 50 0.40 51 0.90 53 2.60 54 4.60 55 0.40 57 3.00 58 3.00
156    61 2.60 68 0.04 69 3.00102 2.60117 5.90119 0.04129 0.20
157     2 2.60  7 4.60 29 0.40 31 3.00 38 2.60 41 0.40 44 0.04 47 3.00
157    50 2.60 51 0.90 53 0.90 54 3.90 57 2.60 58 3.00 69 3.00102 0.20
157   117 4.60129 0.04
158     1 0.20  2 2.60  7 5.90 29 0.20 31 2.60 43 0.20 44 0.04 47 4.60
158    53 0.04 54 4.60 55 0.20 57 3.90 58 3.00 61 0.40 69 3.00102 0.40
158   117 5.90129 0.40
159     1 0.04  2 2.60  7 3.90 31 3.00 38 2.60 41 0.04 43 0.20 44 0.20
159    47 3.90 50 3.00 51 0.90 53 0.40 54 4.60 55 0.20 57 3.00 58 3.90
159    69 2.60 87 0.20 95 0.04102 0.40110 0.20117 3.90129 0.20
160     1 2.60 31 2.60 47 3.00 50 3.00 51 2.60 53 0.40 54 4.60 57 2.60
160    58 3.00 69 0.04 80 0.20102 0.40111 0.40115 2.60117 5.90129 0.20
161    16 2.60 31 2.60 50 2.60 54 4.60 55 0.20 58 3.00 63 3.00 76 0.40
161   102 5.90111 3.00117 8.40118 0.20124 0.20129 0.40
162    16 0.90 31 2.60 50 0.40 54 3.90 57 0.20 58 3.00 63 3.00 68 2.60
162    76 0.20102 2.60111 0.90117 8.40
163    16 3.00 31 0.90 50 0.90 54 5.90 58 5.90 63 3.00 68 0.40 69 0.90
163    76 0.40102 3.90117 8.40129 0.90
164     1 0.90 16 2.60 31 0.90 43 0.40 47 0.90 50 0.90 53 0.20 54 4.60
164    57 0.90 58 3.00 63 0.20 69 0.90 89 0.40111 0.90117 5.90129 0.90
165    16 3.00 31 3.00 50 3.00 52 0.90 54 7.40 58 3.00 63 3.00 69 0.40
165    76 0.90 94 0.90102 3.90111 3.00117 7.40129 0.40
166     1 2.60 16 2.60 23 0.40 43 0.90 44 0.20 47 3.00 54 3.90 57 0.20
166    58 3.00 63 0.90 76 0.90 80 0.40111 0.90117 4.60129 0.90
167    16 0.90 31 0.90 47 0.20 50 0.90 54 4.60 57 0.40 58 3.00 63 0.90
167    69 0.90 80 0.20 89 0.20111 2.60117 4.60129 0.40
168     1 3.90 16 0.40 47 0.90 51 0.90 54 2.60 57 0.20 58 3.00 63 0.20
168    80 0.40111 0.90116 0.40117 3.00129 0.40
169     1 2.60 16 2.60 43 0.40 44 0.04 47 0.90 50 2.60 51 2.60 53 0.04
169    54 0.90 57 2.60 58 0.40 69 0.40 80 0.40 87 0.40111 0.90116 0.20
169   117 7.40129 0.20
170     1 0.90 16 0.90 43 0.04 44 0.20 50 3.00 51 0.90 54 4.60 57 0.90
170    58 2.60 69 0.40 80 0.20 87 0.04 95 0.20115 0.04117 4.60129 0.20
171    16 3.00 19 0.04 23 2.60 31 3.90 35 0.04 40 0.04 50 2.60 52 2.60
171    54 3.00 61 5.90 63 0.40 68 2.60 74 7.40 87 0.90 95 0.40100 0.40
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171   102 3.00105 0.20106 2.60116 3.90117 3.90119 2.60140 0.40
172    16 0.90 31 3.00 50 2.60 51 2.60 54 2.60 58 3.00 61 3.00 63 2.60
172    68 2.60 69 0.20 74 3.90 77 0.20 95 0.04102 0.40110 3.00117 7.40
172   119 0.20129.0.20
173    16 2.60 31 3.00 50 2.60 54 3.00 57 0.40 58 0.40 61 5.90 63 0.40
173    74 2.60 77 3.00 95 0.20102 2.60108 0.20110 2.60117 0.90
174    16 2.60 19 0.20 31 3.00 50 2.60 52 0.20 54 0.90 61 5.90 63 2.60
174    74 7.40 95 0.40102 0.40106 0.04110 3.00117 3.00121 0.04122 0.20
174   129 0.04
175    12 3.00 16 0.90 31 3.00 43 0.20 50 2.60 51 0.90 54 2.60 61 5.90
175    63 2.60 68 2.60 74 2.60 79 3.00 95 0.20100 0.20102 0.40110 0.40
175   117 3.00119 0.20129 0.20
176    16 2.60 31 2.60 50 3.00 51 0.40 54 3.00 56 2.60 58 3.00 61 3.90
176    63 3.00 68 0.90 69 0.20 74 0.90 77 0.90 94 0.20 95 0.20102 0.40
176   110 0.90117 2.60119 0.40
177    16 3.00 22 0.90 31 3.00 38 0.20 44 0.04 50 2.60 51 2.60 52 0.20
177    54 3.00 57 0.40 58 3.90 63 0.90 68 0.90 69 0.20 74 3.00 76 0.20
177    77 0.90 94 0.20 95 0.20102 0.90108 0.20110 0.90117 2.60118 0.20
177   124 0.20129 0.20
178    16 2.60 31 2.60 50 2.60 51 0.90 54 2.60 57 0.40 58 5.90 63 0.90
178    68 0.90 69 0.40102 0.20110 0.90114 0.40117 7.40124 0.40129 0.20
179    16 3.00 31 2.60 47 3.00 50 0.90 51 3.00 54 0.40 57 0.40 58 4.60
179    63 0.20 68 0.90 77 0.20102 3.90110 0.40117 7.40129 0.40
180    16 3.00 22 4.60 31 3.00 50 3.00 51 2.60 54 2.60 58 5.90 63 3.00
180    68 0.40 69 0.40 77 0.40102 2.60110 0.20117 3.90129 0.40
181     7 4.60 13 2.60 24 2.60 29 0.40 31 2.60 54 0.90 60 3.90 61 2.60
181    68 2.60 79 3.90 80 0.20 94 0.40102 0.40117 2.60
182     7 3.00 24 3.00 29 0.20 31 0.90 54 0.90 57 0.90 60 2.60 61 3.00
182    68 2.60 69 2.60 74 0.40 79 2.60 94 0.90117 2.60122 0.20129 2.60
183     7 2.60 22 0.90 24 2.60 29 0.20 31 2.60 44 0.40 54 0.90 60 0.40
183    61 4.60 68 2.60 69 2.60 74 0.40 79 3.00102 2.60117 2.60
184     7 3.90 13 0.20 16 0.40 31 2.60 50 0.90 54 2.60 57 0.90 58 2.60
184    60 2.60 65 0.90 68 2.60 79 0.90 80 0.20 95 0.20102 0.90110 2.60
184   117 2.60129 0.40
185     7 2.60 13 0.90 31 2.60 44 0.40 60 0.90 61 2.60 62 0.20 68 2.60
185    79 4.60117 2.60129 0.20
186     7 5.90 13 2.60 15 0.20 29 0.20 31 2.60 50 0.90 54 2.60 57 0.90
186    58 0.20 61 0.90 64 0.90 68 2.60 79 2.60 80 0.40102 2.60117 0.90
187     7 2.60 13 2.60 29 0.20 50 0.40 54 0.90 60 0.40 61 2.60 68 0.90
187    79 5.90 88 0.40102 0.40117 0.90122 2.60
188     7 0.90 24 2.60 31 2.60 44 0.20 54 0.90 60 2.60 61 2.60 62 0.40
188    65 0.40 68 2.60 79 3.00102 0.40117 2.60129 0.90
189     7 0.90 31 0.40 44 0.40 54 0.90 57 0.20 60 0.90 61 0.90 65 0.40
189    68 0.90 79 0.90 80 2.60 88 2.60117 0.90
190     7 3.90 16 0.40 29 0.40 31 2.60 44 0.40 54 2.60 57 0.40 58 2.60
190    60 0.40 61 2.60 64 2.60 68 2.60 79 0.90102 0.40117 2.60129 0.40
191     7 2.60 18 0.90 37 0.90 47 2.60 53 0.20 57 2.60 58 0.40 62 0.90
191    80 0.20 87 0.40117 0.90129 0.20
192     7 2.60 47 0.90 53 0.40 54 0.90 57 2.60 58 0.90 62 0.04 80 0.04
192    94 0.04102 0.20117 0.90119 0.04129 0.20
193     7 2.60 37 0.40 47 0.90 53 0.20 57 2.60 58 0.40 80 0.04117 0.20
194     7 0.90 47 0.40 57 0.40 58 0.40 80 0.04117 0.04
195     7 3.00 37 0.90 47 2.60 53 0.40 54 0.90 57 2.60 58 0.20 62 2.60
195    80 0.20 87 0.04102 0.20117 2.60129 0.04
196     7 2.60 37 0.90 47 0.90 53 0.40 54 0.40 57 2.60 58 0.40 80 0.40
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196    81 0.40117 2.60
197     7 2.60 47 0.90 53 0.04 57 0.90 58 0.20 80 0.04 87 0.40117 0.40
197   129 0.04
198     7 2.60 23 0.20 38 0.20 47 2.60 50 0.40 53 0.90 54 2.60 57 2.60
196    58 2.60 62 0.04 80 0.20 87 2.60 95 0.20102 0.40117 3.00
199     7 2.60 38 0.40 47 0.90 53 0.40 54 0.90 57 0.90 58 0.90 95 0.20
199   117 0.90138 0.40
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200    95 0.20102 0.04105 0.20117 0.90129 0.04
201     7 3.90 18 2.60 28 0.90 29 0.40 37 0.90 47 3.00 53 0.90 54 3.90
201    57 0.40 58 2.60 62 0.40 80 0.20 83 0.40 94 0.40100 0.04102 0.90
201   115 0.40117 2.60129 0.40131 0.04
202     7 2.60 18 0.20 23 0.04 37 0.90 47 2.60 53 0.90 54 2.60 57 2.60
202    58 0.40 80 0.20 94 0.04 97 0.90115 0.40117 2.60
203     7 0.40 37 2.60 47 0.90 53 0.20 57 2.60 58 0.20 80 0.20 87 0.40
203   117 0.40
204     7 3.00 15 0.04 37 0.90 47 2.60 53 0.90 54 0.90 57 0.90 58 0.90
204    62 0.20 80 0.20 87 0.40115 0.20117 3.00119 0.04129 0.20
205     7 2.60 30 0.20 37 0.90 47 0.90 53 0.40 54 0.40 57 0.90 58 0.40
205    62 0.40 80 0.20 87 0.20117 0.90
211     2 0.40  7 5.90 15 0.20 28 2.60 31 2.60 41 0.20 47 4.60 50 0.20
211    52 0.20 53 0.90 54 3.00 57 2.60 58 2.60 69 0.40 88 0.04111 0.20
211   117 0.90129 0.04
212     2 0.40  7 5.90 28 2.60 31 2.60 47 2.60 53 0.90 54 3.00 57 2.60
212    58 2.60 69 0.40102 0.90111 0.40115 0.40117 2.60
213     1 0.90  2 2.60  7 5.90 15 0.20 28 0.20 31 2.60 44 0.40 47 3.00
213    50 0.40 53 0.90 54 3.00 57 2.60 58 3.00 61 0.40 62 0.90 68 0.20
213    69 2.60 80 0.40 87 0.40 94 0.20102 0.90117 3.00129 0.20
214     1 2.60  7 2.60 28 0.20 31 2.60 47 3.90 50 2.60 53 2.60 54 3.00
214    57 3.00 58 2:60 69 0.40 80 0.20111 0.40115 0.90117 3.00
215     7 2.60 47 2.60 53 0.20 57 0.90 58 0.20 80 0.20117 0.20
221    16 3.00 31 2.60 50 3.00 54 4.60 57 0.40 58 2.60 61 5.90 63 3.00
221    69 0.20102 3.00110 0.40117 2.60118 0.90
222    16 0.90 22 0.20 31 3.00 50 2.60 51 0.20 54 0.90 55 0.20 58 2.60
222    61 5.90 63 3.90 69 0.20 77 0.90 94 0.40102 0.90117 0.20118 0.90
223    16 2.60 22 0.40 31 2.60 50 2.60 51 0.20 54 0.90 55 0.40 58 0.90
223    61 4.60 63 2.60 69 0.40 77 0.20 79 2.60 92 0.90117 0.90118 0.20
224    16 2.60 22 0.40 31 2.60 50 0.90 54 0.90 55 0.90 58 0.90 61 5.90
224    63 3.90 69 0.20 77 0.20 94 0.20100 0.20108 0.20112 0.04117 0.04
224   118 0.20
225    16 3.00 22 0.20 31 2.60 50 2.60 51 0.20 54 0.40 55 0.90 57 0.40
225    58 2.60 61 4.60 63 3.00 69 0.20 77 2.60 94 0.20102 0.40108 0.20
225   117 0.04118 0.40
231     7 0.20 24 0.20 47 0.04 57 0.20 80 0.04116 0.20117 0.20
232     2 0.90  7 3.90 10 0.04 13 3.00 14 0.90 17 0.40 24 0.40 28 2.60
232    29 0.20 34 2.60 41 0.20 44 0.90 47 3.90 53 2.60 54 3.00 55 0.20
232    57 2.60 58 0.90 60 0.20 61 0.40 62 0.20 80 0.04 95 0.40102 0.20
232   117 2.60129 0.40
233     2 0.90  7 3.90 13 2.60 15 0.40 17 0.40 24 2.60 25 0.04 28 0.90
233    29 0.40 31 2.60 41 0.40 44 0.20 47 2.60 53 0.90 54 3.00 55 2.60
233    58 0.90 60 3.00 65 0.04 79 2.60 87 0.20 95 0.20115 0.20117 3.00
233   129 0.04
234     2 0.40  7 3.90 28 0.90 29 0.20 41 0.20 47 0.90 53 0.40 54 0.90
234    57 2.60 58 0.40 61 0.40 80 0.20 87 0.90 95 0.40117 2.60
235     2 0.40  7 3.00 13 2.60 17 0.20 28 2.60 29 0.40 31 0.90 41 0.20
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235   43 0.40 44 0.04 46 0.04 47 2.60 53 0.90 54 0.90 57 2.60 58 2.60
235   60 2.60 61 0.90 83 0.04 87 0.40 90 0.20 95 0.40117 2.60129 0.40
236    7 2.60 13 2.60 28 2.60 44 0.20 47 0.90 53 0.20 54 3.00 57 0.90
236   58 0.40 80 0.20 87 0.40 90 0.20 95 0.20117 0.40
237    7 3.00 13 2.60 17 0.20 28 2.60 31 0.90 41 0.20 44 0.40 47 2.60
237   53 0.40 54 3.00 57 2.60 58 0.90 60 0.40 61 0.90 87 0.20 90 0.20
237   95 0.40102 0.90115 0.40117 0.90
238    5 3.00  7 3.00 15 0.40 19 2.60 20 0.40 24 0.90 25 0.90 26 0.04
238   29 0.04 31 0.90 41 0.40 43 0.40 44 0.40 47 0.40 48 0.20 53 0.90
238   54 3.00 55 0.40 58 0.90 60 2.60 61 3.00 65 0.90 66 0.40 68 0.90
238   74 0.40 83 0.20 85 0.40 95 0.40102 2.60139 0.40
239    5 4.60  7 0.40 15 0.40 17 0.20 19 0.40 20 0.20 24 0.90 26 0.40
239   28 2.60 31 0.20 41 0.40 47 0.90 48 0.40 53 0.40 54 3.00 57 0.90
239   58 2.60 60 0.40 62 0.90 65 2.60 66 0.90 68 0.90 79 2.60 83 0.40
239   84 0.20 86 0.90114 0.40
240    5 2.60  7 2.60 20 0.04 24 0.40 26 0.04 28 0.90 31 0.90 41 0.40
240   47 0.40 48 0.40 53 0.40 54 0.90 57 0.90 60 0.90 65 0.40 66 2.60
240   80 0.20 81 0.90
241    2 0.04  4 0.40  7 3.90 13 2.60 23 0.90 31 2.60 44 0.40 60 2.60
241   61 2.60 65 0.40 68 0.90 79 3.90 87 0.20 95 0.20102 0.20107 0.40
241  115 0.20117 3.90129 0.40
242    7 3.00 23 0.90 28 2.60 31 0.90 44 0.40 54 0.90 58 0.40 60 0.90
242   61 0.90 65 0.90 68 2.60 79 3.00 80 0.04 87 0.40102 0.90107 0.90
242  117 3.90129 0.04
243    7 4.60 10 0.04 23 2.60 24 2.60 31 3.90 44 0.20 60 4.60 61 4.60
243   79 5.90 88 0.20 94 0.20 95 3.00102 0.20107 3.90117 3.00122 0.40
243  129 0.20
244   24 4.60 31 2.60 44 0.20 60 3.90 61 4.60 65 0.04 74 2.60 79 0.90
244   87 5.90107 0.90117 2.60122 4.60
245    7 3.90 10 0.04 13 0.04 23 2.60 24 0.90 31 3.00 44 0.90 54 0.20
245   60 2.60 61 4.60 68 2.60 69 0.20 79 5.90 95 0.20102 0.40107 0.40
245  112 0.20117 3.00129 0.20
246    7 4.60 10 0.20 13 2.60 23 2.60 24 2.60 31 3.00 44 0.20 54 0.20
246   60 3.00 61 3.90 68 2.60 79 5.90 91 0.40 95 2.60102 0.90117 3.90
246  122 0.40129 0.20
247    7 3.00 13 0.20 23 0.20 31 3.00 44 0.40 55 0.20 58 0.90 60 3.90
247   61 3.00 79 3.00 94 0.40 95 0.40102 2.60112 0.20117 5.90
248    2 0.40  7 3.00 23 0.20 28 0.04 31 0.90 44 0.90 54 2.60 58 0.90
248   60 2.60 65 0.40 68 0.90 69 0.20 79 2.60 80 0.20 95 0.20102 0.40
248  111 0.20116 0.20117 3.00
249    7 5.90 10 0.90 13 0.40 23 0.20 31 3.00 43 0.40 54 0.90 58 0.40
249   60 3.00 61 3.00 65 0.40 79 2.60 95 3.00102 2.60117 3.90122 2.60
250    7 3.00 13 0.20 23 0.90 31 2.60 44 0.90 54 0.90 57 0.20 58 0.20
250   60 0.40 61 3.00 65 0.40 68 0.40 79 3.00 80 0.40 95 0.40117 3.00
250  122 2.60129 0.20
251   28 2.60 43 0.40 47 0.90 54 0.40 58 0.40 60 0.40 68 0.90117 0.04
251  119 0.20
252    2 0.04  3 0.40 20 0.04 43 0.20 47 0.90 54 0.20 58 0.20 60 0.40
252   65 0.04 68 0.20
253   28 0.40 43 0.04 47 0.90 58 0.40 60 0.40141 0.20
254   43 0.40 47 2.60 53 0.20 54 0.40 58 0.40 60 2.60 65 0.90 68 0.40
254  115 0.20117 0.04
255    7 0.40 43 0.04 47 0.90 53 0.20 58 0.40 60 0.90 65 0.40 68 0.40
255  117 0.20
256   28 0.20 43 0.20 47 2.60 54 0.20 58 0.40 60 0.20 65 0.20 68 0.90
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257     2 0.40   4 0.04   7 0.20 28 2.60 31 0.40 43 0.40 47 2.60 58 0.90
257    60 0.90 65 0.40 68 0.90 81 0.04117 0.90
258     8 0.40 28 0.04 47 0.40 54 0.40 59 0.90 60 0.90 65 0.40 68 0.90
259     2 0.20   8 0.90 39 0.40 41 0.04 43 0.20 54 0.90 58 0.90 60 0.90
259    65 0.40 68 0.90117 0.20
260     2 0.40   3 0.90   7 2.60 28 0.20 39 0.20 41 0.40 47 0.90 54 0.90
260    58 0.90 60 0.90 65 0.40 68 2.60114 0.04117 0.40
261     7 0.40   8 0.40 15 0.04 26 0.04 28 0.20 41 0.40 43 0.04 47 0.40
261    54 0.40 58 0.40 60 2.60 65 0.20 68 0.90 81 0.40 97 0.04117 0.20
262     7 0.90   8 0.90 25 0.04 28 0.20 41 0.20 43 0.40 47 0.90 53 0.40
262    54 0.40 58 0.40 60 0.40 65 0.40 68 0.40 79 2.60 81 0.20117 0.20
263     3 0.40   7 2.60   8 0.20 26 0.20 28 0.40 31 0.90 41 0.40 43 0.40
263    47 2.60 54 0.40 58 0.90 60 3.90 65 0.40 68 0.40 79 0.90 81 0.20
263   117 0.40
264     7 2.60 28 0.90 29 0.04 41 0.40 43 0.40 47 2.60 54 0.90 58 0.40
264    60 0.90 65 0.20 68 0.40117 0.20
265     8 0.20 28 0.40 43 0.20 47 0.40 54 0.40 58 0.20 60 0.90 65 0.04
271     5 0.04 54 0.20 58 0.04
272     2 0.04   7 0.40   8 0.04 28 0.04 41 0.04 47 2.60 53 0.04 58 0.40
272    60 0.40 65 0.20 81 0.04100 0.04117 0.20
273     4 0.20   5 0.04   8 0.20 28 0.20 43 0.04 47 0.40 58 0.40 60 0.20
273    65 0.04 81 0.04
274    58 0.04
275     5 0.20 53 0.04 54 0.04 58 0.20 65 0.20
276     7 0.20 28 0.40 43 0.04 47 0.90 58 0.40 60 0.20117 0.90
277     2 0.04   7 0.40   8 0.40 28 2.60 41 0.20 47 0.20 54 0.90 58 0.20
277    60 0.90114 0.04117 0.90129 0.04
278     2 0.40   7 2.60   8 0.20 12 2.60 14 0.04 28 2.60 31 0.20 41 0.04
278    43 0.04 47 0.90 54 0.40 58 0.40 60 0.90 65 0.20
279     7 7.40 28 0.04 41 0.04 47 0.20 53 0.04 58 0.20
280     4 0.40   5 0.40   8 0.40 47 0.04 54 0.90 58 0.40 60 0.40 65 0.04
280    81 0.04 83 0.04112 0.04
281     2 0.40   7 4.60 13 2.60 15 0.04 17 0.90 21 2.60 27 0.40 28 0.90
281    30 0.90 31 2.60 41 0.20 43 0.20 44 0.90 47 3.90 53 0.90 54 0.90
281    55 0.90 58 0.90 60 3.00 61 0.90 62 0.90 68 0.90 70 0.20 80 0.20
281    83 0.40 94 0.40100 0.40102 2.60117 3.00
282     2 0.20   7 3.90 10 0.04 13 4.60 17 0.90 21 0.40 24 0.20 27 0.20
282    28 0.40 30 0.40 31 2.60 43 0.04 44 0.20 47 2.60 53 0.90 54 0.40
282    55 2.60 57 0.90 58 0.40 60 3.00 61 2.60 68 0.90 70 0.40 94 0.40
282   100 0.20102 0.90117 3.00127 0.20
283     7 2.60 13 2.60 14 2.60 24 2.60 31 2.60 44 0.90 47 0.40 53 0.40
283    55 0.40 60 7.40 61 0.90 68 0.90 79 3.00102 0.90117 0.90
284     7 3.00 10 0.04 13 3.00 20 0.04 29 0.20 31 2.60 44 0.40 53 0.90
284    54 0.40 55 0.90 60 7.40 61 2.60 68 0.90 79 2.60100 0.04102 0.90
284   117 0.20
285     7 0.90 14 2.60 20 0.04 31 0.90 32 0.20 43 0.20 44 0.90 46 0.40
285    53 2.60 55 0.40 57 0.20 60 7.40 68 0.90 70 0.90102 0.90119 0.04
291     2 0.20   7 3.00 13 3.00 15 0.20 17 0.90 20 0.20 27 0.20 28 2.60
291    30 0.40 31 2.60 44 0.04 47 3.90 49 0.04 53 0.90 54 0.90 55 2.60
291    58 0.90 60 3.00 61 2.60 62 2.60 68 3.90 70 2.60 97 0.40100 0.20
291   102 0.90117 0.20
292     7 2.60 17 0.20 24 0.40 27 0.90 31 3.00 41 0.20 44 0.90 47 0.90
292    53 2.60 54 2.60 55 2.60 58 2.60 60 5.90 62 2.60 68 3.90 70 0.20
292    83 2.60100 2.60102 2.60
293     2 0.20   7 3.90 13 2.60 17 0.90 20 0.20 21 0.90 27 0.20 28 0.90
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293    30 0.40 31 2.60 44 0.40 47 2.60 53 0.90 54 0.40 55 0.90 60 2.60
293    62 0.40 68 3.00 70 0.40 81 0.40 97 0.90102 0.90117 0.20
294     2 0.90  7 3.00 13 2.60 15 0.20 17 0.40 27 0.40 28 0.90 31 0.90
294    36 0.20 47 2.60 53 0.90 54 0.40 55 0.40 56 0.40 60 2.60 61 0.40
294    62 0.40 68 0.90 70 0.40 81 0.20 97 2.60100 0.20102 0.20107 0.40
294   117 0.40129 0.40
295     7 3.00 16 0.40 17 0.20 24 0.40 25 0.90 31 0.40 44 0.20 53 0.20
295    54 0.20 55 2.60 58 0.40 59 0.40 60 7.40 62 0.40 70 0.90 83 0.90
295    94 0.90100 0.90117 0.90
301    14 0.20 24 0.90 47 0.20 54 0.90 58 0.90 60 2.60 65 0.90110 0.04
301   113 0.04117 0.20
302     2 0.40  7 3.00 13 2.60 14 2.60 15 0.40 24 0.90 26 0.20 31 0.90
302    41 0.40 43 0.20 44 0.40 47 0.40 54 0.40 60 2.60 65 0.90 79 2.60
302    80 0.20117 2.60
303     7 0.40  5 0.04 13 0.20 14 0.40 15 0.20 24 3.00 31 0.20 43 0.04
303    47 0.04 60 0.40 65 0.40 79 0.90 87 0.20 94 0.20117 2.60119 0.04
304     2 0.20  7 2.60 13 0.90 14 2.60 24 2.60 31 0.04 47 0.04 60 0.40
304    79 2.60 80 0.20 87 0.90117 2.60
305     2 0.90  7 2.60 13 0.90 14 2.60 15 0.40 28 0.40 31 0.40 41 0.40
305    43 0.20 44 0.90 47 0.90 53 0.04 54 0.90 57 0.20 60 2.60 65 0.90
305    79 2.60114 0.40117 0.90
306     2 0.20 13 2.60 14 3.00 15 0.04 24 0.40 26 0.04 31 0.20 41 0.20
306    47 0.40 54 0.40 57 0.04 60 2.60 61 0.04 79 2.60117 2.60
307     2 0.90  7 3.00 14 2.60 15 0.20 24 0.90 26 0.40 28 0.20 31 0.40
307    41 0.40 47 0.20 54 0.20 60 0.40 65 0.20 78 3.00 79 0.40 87 0.20
307   102 0.40117 0.90
308     2 0.04  7 0.40 43 0.40 60 0.90 87 0.40117 0.90136 0.20
309     2 0.20  7 2.60 13 0.40 14 0.90 23 0.04 24 0.40 31 0.90 43 0.04
309    80 0.04 87 0.20117 0.40
310     2 0.90  7 3.90 13 0.90 14 3.00 15 0.20 31 0.90 41 0.40 43 0.20
310    44 2.60 53 0.40 54 0.40 60 2.60 62 0.04 65 0.20117 4.60
311     1 0.90 15 2.60 16 2.60 31 0.90 41 0.20 46 0.40 47 3.90 50 0.90
311    53 2.60 54 0.40 55 2.60 56 0.40 58 2.60 61 3.00 62 0.90 65 2.60
311    68 2.60100 0.40102 2.60111 0.40117 2.60118 0.90
312     1 0.90 15 0.20 31 2.60 43 0.20 47 2.60 50 0.90 53 0.90 54 3.00
312    55 0.90 56 0.90 58 3.90 65 0.90 68 2.60 80 0.04102 2.60108 0.20
312   111 0.90117 2.60129 0.20
313     1 0.90 15 0.40 31 2.60 44 0.90 47 2.60 46 0.04 50 2.60 53 0.40
313    54 4.60 55 2.60 56 0.90 58 2.60 64 0.20 65 2.60  9 2.60 88 0.04
313   100 0.20102 3.90111 0.90117 3.00118 0.20
314     1 0.90 15 0.40 16 0.90 31 2.60 38 0.04 47 2.60 50 0.90 52 0.20
314    53 0.40 54 3.90 55 0.90 56 0.90 58 3.90 68 2.60 69 0.90 76 0.40
314    94 0.90102 2.60109 0.90117 3.00
315     1 2.60 15 0.90 16 0.90 29 0.40 31 2.60 41 0.90 47 3.00 50 0.90
315    53 0.90 54 3.90 55 2.60 56 2.60 58 3.00 68 2.60 69 2.60102 3.90
315   111 0.90117 2.60
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APPENDIX II

Species Recorded in Quadrats and Species Number

1 Alchemilla alpina
2 Antennaria dioica
3 Anthyllis vulneraria
4 Arenaria norvegica ssp. norvegica
5 Armeria maritima
6 Blechnum spicant
7 Calluna vulgaris
8 Cherleria sedoides
9 Cochlearia spp.
10 Dactylorhiza maculata var.ericetorum
11 Drosera rotundifolia
12 Empetrum spp.
13 Erica cinerea
14 E. tetralix
15 Euphrasia spp.
16 Galium saxatile
17 Hypericum pulchrum
18 Juniperus communis ssp. nana
19 Leontodon autumnalis
20 Linum catharticum
21 Lotus corniculatus
22 Lycopodium alpinum
23 L. selago
24 Narthecium ossifragum
25 Pedicularis sylvatica
26 Pinguicula vulgaris
27 Plantago lanceolata
28 P. maritima
29 Polygala serpyllifolia
30 P. vulgaris
31 Potentilla erecta
32 Primula vulgaris
33 Prunella vulgaris
34 Ranunculus acris
35 Ranunculus flammula ssp. flammula
36 Rhinanthus minor
37 Rubus fruticosus agg.
38 Salix herbacea
39 Saxifraga oppositifolia
40 S. stellaris
41 Selaginella selaginoides
42 Silene acaulis
43 Solidago virgaurea
44 Succisa pratensis
45 Taraxacum spp.
46 Thalictrum alpinum
47 Thymus drucei
48 Tofieldia pusilla
49 Trifolium repens
50 Vaccinium myrtillus
51 V. vitis-idaea
52 Viola palustris
53 V. riviniana
54 Agrostis spp.

APPENDIX II (cont)

55 *Anthoxanthum odoratum*
56 *Deschampsia cespitosa*
57 *D. flexuosa*
58 *Festuca spp.*
59 *Holcus lanatus*
60 *Molinia caerulea*
61 *Nardus stricta*
62 *Sieglingia decumbens*

63 *Carex bigelowii*
64 *C. binervis*
65 *C. demissa*
66 *C. dioica*
67 *C. echinata*
68 *C. flacca/panicea*
69 *C. pilulifera*
70 *C. pulicaris*
71 *Eriophorum angustifolium*
72 *E. vaginatum*
73 *Juncus acutiflorus*
74 *J. squarrosus*
75 *J. triglumis*
76 *Luzula campestris/multiflora*
77 *L. sylvatica*
78 *Schoenus nigricans*
79 *Trichophorum cespitosum*

80 *Andreaea spp.*
81 *Blindia acuta*
82 *Brachythecium rivulare*
83 *Breutelia chrysocoma*
84 *Bryum pallens*
85 *B. pseudotriquetrum*
86 *Campylium stellatum*
87 *Campylopus atrovirens*
88 *C. flexuosus*
89 *C. pyriformis*
90 *Cephaloziella sp.*
91 *Ctenidium molluscum*
92 *Dicranella heteromalla*
93 *Dicranum majus*
94 *D. scoparium*
95 *Diplophyllum albicans*
96 *Drepanocladus revolvens*
97 *Frullania tamarisci*
98 *Grimmia apocarpa*
99 *G. trichophylla*
100 *Hylocomium splendens*
101 *Hyocomium flagellare*
102 *Hypnum cupressiforme*
103 *Isothecium myosuroides*
104 *Nardia compressa*
105 *N. scalaris*
106 *Plagiothecium denticulatum*
107 *Pleurozia purpurea*
108 *Pleurozium schreberi*
109 *Polytrichum alpinum*
110 *P. commune*
111 *P. piliferum*

APPENDIX II (cont)

112 Pseudoscleropodium purum
113 Rhacomitrium aciculare
114 R. ellipticum
115 R. fasciculare
116 R. heterostichum
117 R. lanuginosum
118 Rhytidiadelphus loreus
119 R. squarrosus
120 Riccardia pinguis
121 Scapania ornithopodioides
122 Sphagnum spp.
123 Ulota hutchinsiae

124 Cetraria islandica
125 Cladonia arbuscula
126 C. crispata var. cetrariiformis
127 C. portentosa
128 C. subcervicornis
129 C. uncialis ssp. biuncialis
130 Coelocaulon aculeatum
131 Peltigera praetextata
132 Stereocaulon vesuvianum

133 Eleocharis sp.
134 Anthelia julacea
135 Herberta adunca
136 Marsupella sp.
137 Pohlia wahlenbergii
138 Oligotrichum hercynicum
139 Scapania undulata
140 Splachnum sphaericum
141 Tortella tortuosa
142 Rhacomitrium canescens

Higher plant names are after Clapham et al.(1962); bryophytes after Watson (1968); and lichens after Hawksworth et al. (1980).

APPENDIX II (cont)

112 Pseudoscleropodium purum
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120 Riccardia pinguis
121 Scapania ornithopodioides
122 Sphagnum spp.
123 Ulota hutchinsiae

124 Cetraria islandica
125 Cladonia arbuscula
126 C. crispata var. cetrariiformis
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130 Coelocaulon aculeatum
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133 Eleocharis sp.
134 Anthelia julacea
135 Herberta adunca
136 Marsupella sp.
137 Pohlia wahlenbergii
138 Oligotrichum hercynicum
139 Scapania undulata
140 Splachnum sphaericum
141 Tortella tortuosa
142 Rhacomitrium canescens

Higher plant names are after Clapham et al.(1962); bryophytes after Watson (1968); and lichens after Hawksworth et al. (1980).

APPENDIX III

RESULTS OF SOIL ANALYSES , ASPECT AND SLOPE FOR ALL QUADRATS+

QUAD No.	pH	% LOSS ON IGNITION	TOTAL N *	TOTAL P *	EXCH K *	EXCH Na *	EXCH Ca *	EXCH Mg *	TOTAL Co *	TOTAL Cr *	EXCH Fe *	TOTAL Ni *	EXCH Ni *	EXCH Zn *	ASPECT (degrees) **	SLOPE (degrees)
1	4.5	9.4	3320	374	60.5	25.6	126.1	9.3	42	42	2.1	374	0.2	-	-	-
2	4.6	22.7	6506	805	97.6	23.7	79.3	76.5	73	49	2.4	566	0.2	-	135	5.
3	4.9	13.7	3016	354	45.0	4.6	32.6	30.3	62	42	6.2	686	0.4	-	180	4.
4	4.8	14.9	3090	494	61.0	11.1	41.5	30.0	41	41	6.2	433	0.2	-	180	1.
5	5.0	11.0	2756	374	49.9	10.4	32.6	25.6	62	42	6.2	603	0.6	-	180	1.
6	5.0	11.9	2677	203	70.0	17.0	54.3	49.0	20	40	4.0	203	0.6	-	180	2.
7	5.1	22.2	7232	814	122.0	35.7	154.4	303.7	60	45	6.0	542	1.0	-	315	4.
8	5.2	15.7	3366	530	100.0	20.4	105.1	190.0	82	61	4.1	653	1.6	-	225	4.
9	5.2	22.0	4045	592	110.3	30.0	66.3	191.9	82	41	4.1	734	0.6	-	160	4.
10	5.3	15.4	3535	506	74.7	16.6	74.7	100.6	81	40	2.0	949	0.0	-	180	4.
11	5.9	5.0	4223	1051	20.6	12.0	103.0	150.0	144	62	4.1	2472	2.5	-	315	2.
12	5.6	16.2	4029	1110	40.0	34.2	300.9	340.1	155	89	0.9	1776	2.7	-	315	2.
13	5.7	7.1	2560	642	36.4	10.0	210.1	220.5	150	107	2.1	2140	2.4	-	315	2.
14	6.1	10.1	2573	609	31.5	23.7	402.2	374.3	160	105	4.2	1600	3.2	-	0	1.
15	6.2	10.1	2907	494	55.6	35.0	565.3	507.6	124	82	2.1	2060	2.9	-	0	1.
16	5.3	2.9	1313	323	4.0	1.0	20.4	15.0	141	81	.0.0	2424	0.0	-	0	5.
17	5.5	1.0	1111	242	6.1	1.0	11.3	11.3	121	61	0.0	2424	1.0	-	315	1.
18	5.6	2.0	1162	283	0.1	6.9	10.1	10.1	121	81	2.0	2424	0.4	-	315	4.

* µg g-1 dry weight ** EAST=0 NORTH=90 WEST=180 SOUTH=270 - Not Determined

+EXCH Cr AND EXCH Co WERE BELOW THE DETECTION LIMIT FOR ALL QUADRATS

QUAD No.	pH	% LOSS ON IGNITION	TOTAL N *	TOTAL P *	EXCH K *	EXCH Na *	EXCH Ca *	EXCH Mg *	TOTAL Co *	TOTAL Cr *	EXCH Fe *	TOTAL Ni *	EXCH Ni *	EXCH Zn *	ASPECT (degrees) **	SLOPE (degrees)
19	6.0	2.6	1364	343	22.2	4.2	52.0	45.3	121	61	2.0	2424	1.0	-	315	6.
20	5.2	3.2	1414	283	10.2	11.3	10.1	11.3	121	61	4.0	2424	1.0	-	315	4.
21	5.3	18.7	5069	654	126.4	37.9	402.9	512.7	109	87	4.4	1199	1.7	-	90	2.
22	5.4	8.7	1640	280	88.6	16.1	113.1	110.8	103	82	2.1	1092	0.6	-	315	3.
23	5.7	5.6	1442	280	10.5	0.9	57.7	46.1	103	103	0.0	2060	0.4	-	0	0.
24	5.5	24.3	6606	700	103.8	36.3	167.7	449.3	94	94	7.1	802	2.0	-	0	4.
25	5.6	21.6	5466	777	111.3	39.5	237.6	329.3	126	105	6.3	840	0.0	-	0	3.
26	6.2	11.0	5720	499	47.6	26.0	260.9	279.6	125	83	4.2	1144	0.6	-	0	2.
27	6.0	5.1	1414	263	20.2	0.5	72.4	61.1	101	81	2.0	2020	0.4	-	45	10.
28	6.2	5.5	1377	347	10.4	13.3	155.4	139.4	102	61	2.0	2040	1.6	-	0	2.
29	5.7	8.8	2091	326	22.4	14.1	75.4	66.3	82	82	2.0	938	0.2	-	-	-
30	5.0	7.8	2040	490	14.3	4.1	13.7	9.1	82	82	2.0	877	0.2	-	180	2.
31	5.5	2.4	859	242	14.1	7.7	10.1	10.1	121	61	2.0	2020	0.6	-	45	2.
32	5.1	3.0	2424	1353	22.2	.8.9	11.3	13.6	101	61	0.0	2020	0.2	-	315	3.
33	4.9	5.1	1313	303	10.1	3.2	4.5	6.0	101	61	2.0	2020	0.0	-	0	3
34	5.2	2.4	808	263	20.2	7.9	13.6	10.1	101	40	2.0	2020	0.6	-	315	3.
35	4.9	1.4	650	200	10.0	2.0	4.5	11.2	120	80	0.0	2400	0.4	-	0	3.
36	4.8	1.6	750	200	2.0	2.6	4.5	6.7	120	60	0.0	2400	0.0	-	90	1.
37	4.9	2.2	1650	940	10.0	9.0	4.5	9.0	100	60	0.0	1600	0.0	-	45	1.
38	5.2	3.4	1111	404	20.2	6.9	11.3	10.1	121	61	2.0	2020	1.2	-	135	2.
39	4.9	2.0	2050	1100	10.0	3.4	4.5	9.0	100	40	0.0	2400	1.4	-	45	3.
40	5.1	2.6	1950	900	12.0	3.2	17.9	13.4	120	40	2.0	2000	0.6	-	135	2.
41	5.5	4.0	1244	104	13.5	0.0	6.1	9.4	102	82	2.0	2040	0.0	0.0	0	2.
42	5.4	4.0	1040	104	7.0	0.0	6.1	7.1	122	61	0.0	2440	0.0	0.0	0	1.
43	5.0	3.7	900	102	10.1	3.2	6.1	9.7	121	. 61	2.0	2424	0.0	0.0	45	1.
44	5.1	4.0	1030	202	17.2	4.7	12.1	16.0	121	61	2.0	2424	0.0	0.0	0	2.
45	4.7	4.0	900	141	9.7	4.2	8.1	12.9	121	61	2.0	2020	0.0	0.0	0	3.
46	4.8	3.7	1397	143	19.2	10.0	10.2	12.4	102	82	2.0	2040	0.0	0.0	0	2.

QUAD No.	pH	% LOSS ON IGNITION	TOTAL N *	TOTAL P *	EXCH K *	EXCH Na *	EXCH Ca *	EXCH Mg *	TOTAL Co *	TOTAL Cr *	EXCH Fe *	TOTAL Ni *	EXCH Ni *	EXCH Zn *	ASPECT (degrees) **	SLOPE (degrees)
47	4.7	4.8	1142	104	11.6	6.7	8.2	11.2	102	61	0.0	2040	0.0	0.0	0	1.
48	4.8	3.5	930	104	10.2	7.1	12.2	10.0	102	61	0.0	2040	0.0	0.0	0	1.
49	4.7	4.9	1193	163	14.1	6.3	6.2	12.2	122	61	2.0	2440	0.0	0.0	45	2.
50	4.8	3.0	776	102	9.1	7.9	6.1	9.5	101	81	0.0	2020	0.0	0.0	90	2.
51	5.4	3.1	836	104	21.2	25.9	297.8	163.2	102	61	0.0	2040	8.2	0.0	90	15.
52	5.5	10.3	5051	424	90.6	60.7	415.5	453.7	106	85	2.1	1696	8.5	0.2	45	9.
53	5.7	2.1	929	102	11.9	10.7	137.4	103.0	101	61	0.0	2020	4.0	0.0	45	10.
54	5.8	2.4	770	222	3.8	4.7	52.5	53.9	101	61	0.0	2020	2.0	0.0	135	10.
55	5.5	3.7	929	102	26.1	11.7	109.1	90.1	101	40	2.0	2424	0.0	0.0	90	6.
56	5.2	5.8	1652	265	29.2	8.4	36.7	31.8	102	41	2.0	2040	0.0	0.0	45	4.
57	5.2	29.3	2544	227	42.2	30.5	193.6	119.5	103	62	2.1	2060	2.1	0.2	90	8.
58	5.2	6.1	1397	224	26.1	9.2	30.6	22.0	102	41	2.0	2040	0.0	0.0	90	16.
59	5.4	12.3	3557	107	51.6	43.3	282.9	149.8	104	62	2.1	1664	2.1	0.2	90	15.
60	5.3	8.2	2596	105	48.2	41.0	140.1	88.6	103	41	2.1	2060	2.1	0.2	90	20.
61	6.5	3.2	1040	102	25.3	32.4	204.0	126.5	122	82	0.0	2040	0.0	0.0	225	7.
62	6.3	4.2	1051	105	33.0	43.7	329.6	265.7	144	124	0.0	2060	2.1	0.0	315	1.
63	6.1	6.0	1772	105	37.7	47.0	379.0	251.3	124	82	0.0	2060	2.1	0.0	315	16.
64	6.6	3.2	836	265	26.5	28.4	257.0	283.6	122	102	0.0	2040	2.0	0.0	45	2.
65	6.2	5.4	1154	165	45.7	49.4	494.4	436.7	103	144	0.0	1640	4.1	0.0	315	3.
66	6.4	5.3	1154	260	34.0	40.0	354.3	290.5	82	103	0.0	1071	2.1	0.0	45	4.
67	5.4	16.8	5061	525	121.8	201.4	382.2	451.5	105	105	4.2	798	6.3	0.0	315	5.
68	5.7	6.0	1075	309	37.5	42.6	300.8	199.0	103	103	0.0	1092	2.1	0.0	45	2.
69	5.9	3.2	938	306	28.6	24.5	232.6	177.5	143	82	0.0	1081	0.0	0.0	0	4.
70	6.0	4.0	999	433	35.0	33.6	288.4	203.9	124	103	0.0	1092	0.0	0.0	315	2.
71	5.7	23.3	6405	1420	92.4	266.7	537.6	655.2	126	315	2.1	1600	8.4	0.0	180	2.
72	5.8	8.6	4017	1401	51.5	41.6	317.2	438.5	144	227	0.0	2060	12.4	0.0	315	4.
73	6.1	8.5	3011	1524	44.1	39.6	350.2	401.7	105	105	0.0	2472	10.3	0.0	135	2.
74	6.0	24.8	7290	1040	159.6	367.5	508.2	646.0	168	109	6.3	1600	10.5	0.4	270	3.

QUAD No.	pH	% LOSS ON IGNITION	TOTAL N *	TOTAL P *	EXCH K *	EXCH Na *	EXCH Ca *	EXCH Mg *	TOTAL Co *	TOTAL Cr *	EXCH Fe *	TOTAL Ni *	EXCH Ni *	EXCH Zn *	ASPECT (degrees) **	SLOPE (degrees)
75	5.5	8.3	2550	816	57.3	51.6	336.5	261.1	143	61	2.0	2440	6.1	0.0	270	6.
76	5.3	8.4	2652	836	51.0	38.4	159.1	102.0	122	82	4.1	2440	2.0	0.0	135	8.
77	5.5	36.8	5564	1664	61.2	61.4	416.0	434.7	146	166	2.1	2000	6.3	0.0	270	3.
78	5.1	15.4	4275	940	93.7	72.9	337.8	267.8	144	103	6.2	2060	2.1	0.4	315	2.
79	5.2	10.5	3060	890	46.1	44.5	216.2	140.9	143	102	2.0	2440	6.1	0.0	315	4.
80	5.2	14.0	4120	940	86.9	74.2	370.8	304.9	144	103	4.1	2472	6.2	0.2	0	5.
81	4.8	37.2	8507	1204	301.7	410.9	600.5	419.4	107	214	0.6	535	0.6	1.5	45	8.
82	5.2	45.3	9612	1339	414.7	430.5	1244.2	924.5	100	151	6.5	410	2.2	1.3	45	4.
83	4.7	41.2	10000	1663	241.9	365.0	510.4	321.0	100	194	15.1	324	4.3	1.1	45	12.
84	4.4	46.6	9612	1642	373.7	306.0	546.0	162.0	100	194	30.2	302	4.3	0.9	90	2.
85	5.5	18.6	5250	1470	42.6	266.0	831.6	367.5	105	336	0.0	861	6.3	0.0	45	1.
86	5.4	23.7	7579	1950	55.5	311.6	780.2	430.4	85	551	2.1	700	4.2	0.0	90	2.
87	5.0	19.7	5304	936	70.1	82.0	357.0	145.6	83	146	4.2	686	2.1	0.4	90	2.
88	5.1	11.7	3605	865	20.0	40.2	193.6	72.1	103	124	2.1	909	0.0	0.2	90	2.
89	5.4	5.9	2071	747	16.6	10.0	111.1	62.6	121	101	0.0	1616	2.0	0.4	90	1.
90	5.0	0.6	2601	890	24.5	10.4	34.7	30.6	122	82	2.0	1632	0.0	0.2	45	4.
91	6.7	7.4	2936	1277	24.9	20.2	251.3	276.0	144	62	2.1	2060	6.2	0.0	180	2.
92	6.0	4.6	2397	1224	9.2	14.5	79.6	69.4	163	82	0.0	2440	4.1	0.2	180	2.
93	6.2	3.2	1970	1050	11.5	6.1	22.2	22.4	162	40	4.0	2424	0.0	0.0	135	7.
94	6.6	2.2	1566	929	6.5	5.9	54.5	58.0	102	61	0.0	2424	2.0	0.0	90	1.
95	6.2	1.9	1616	970	7.3	6.3	50.5	67.5	102	61	0.0	3232	4.0	0.0	90	2.
96	6.0	1.8	1364	820	6.5	9.5	36.4	45.5	141	40	0.0	2020	2.0	0.0	135	3.
97	6.0	21.0	950	660	5.4	5.4	20.0	51.2	160	60	0.0	4000	2.0	0.0	90	5.
98	5.9	2.0	1465	889	14.0	9.5	56.6	95.6	162	40	0.0	2424	4.0	0.0	45	5.
99	5.0	1.0	1350	900	6.0	4.0	26.0	44.0	180	40	0.0	2000	2.0	0.2	135	3.
100	5.0	0.8	1050	760	7.6	12.2	50.0	72.0	140	40	0.0	3200	4.0	0.0	135	5.
101	6.6	49.6	12010	1613	425.1	444.7	1386.5	2405.2	131	44	2.2	2100	26.2	0.2	270	10.
102	6.3	86.1	17000	1926	710.1	540.0	1666.6	3091.2	90	22	2.2	2240	47.0	0.2	270	8.

QUAD No.	pH	% LOSS ON IGNITION	TOTAL N *	TOTAL P *	EXCH K *	EXCH Na *	EXCH Ca *	EXCH Mg *	TOTAL Cu *	TOTAL Cr *	EXCH Fe *	TOTAL Mn *	EXCH Mn *	EXCH Zn *	ASPECT (degrees) **	SLOPE (degrees)
103	6.2	80.1	14403	1407	912.4	515.0	1900.3	2175.6	133	0	15.5	644	24.4	4.9	315	6.
104	5.0	32.0	9222	1900	231.1	347.7	1221.1	1462.0	233	233	2.1	1696	27.6	0.6	270	6.
105	6.0	34.9	8031	1549	279.0	349.0	1174.5	1717.2	127	140	2.1	1696	17.0	0.6	270	4.
106	6.1	69.2	14170	1760	506.0	400.4	1716.0	2604.0	66	44	2.2	1056	19.0	1.5	270	3.
107	6.2	10.6	4021	1367	85.9	69.0	457.0	767.0	204	102	0.0	2056	12.2	0.0	270	25.
108	6.2	76.9	13404	977	359.6	499.5	1629.5	2397.6	22	22	2.2	866	24.4	0.7	315	5.
109	6.1	64.7	12263	1417	449.1	440.4	1334.2	2267.2	131	153	4.4	1744	21.0	1.3	270	15.
110	6.1	37.2	9630	1626	203.3	342.4	950.7	1647.0	150	214	2.1	1204	15.0	0.6	270	20.
111	6.2	20.9	4550	1336	152.6	239.6	695.4	901.0	140	.106	2.1	2120	17.0	0.4	90	9.
112	6.3	30.4	9156	1786	209.3	303.0	1022.5	1656.0	109	174	4.4	690	2.2	1.1	90	3.
113	6.1	32.0	9002	2635	153.4	209.4	1110.9	1121.0	216	151	2.2	1720	13.0	0.2	90	5.
114	6.0	36.0	11170	2354	196.6	330.5	1032.5	1149.1	216	151	4.3	1000	17.3	0.7	90	4.
115	6.0	32.1	8056	2130	211.7	317.5	695.5	842.4	173	130	4.3	1050	0.6	0.0	90	3.
116	5.0	32.0	9570	2554	171.0	346.0	1146.1	907.6	101	113	4.5	1062	11.3	0.7	90	2.
117	5.6	57.4	8056	1605	211.7	302.4	902.9	892.1	151	86	6.5	972	0.6	1.9	90	12.
118	5.0	23.3	6367	1519	103.6	239.7	663.4	610.5	150	107	4.3	1712	6.4	0.4	90	10.
119	6.0	10.9	4565	1430	60.3	57.2	343.2	201.6	154	110	0.0	2200	4.4	0.0	135	15.
120	5.9	10.4	3796	1144	72.2	775.0	520.0	416.0	146	83	2.1	2496	4.2	0.4	90	0.
121	5.7	1.5	1263	505	6.5	0.1	50.5	35.0	81	81	0.0	949	0.0	0.0	180	2.
122	5.7	3.5	1530	469	9.6	10.0	100.0	70.0	61	82	0.0	632	2.0	0.0	225	5.
123	5.0	3.0	1326	300	11.6	23.3	200.1	69.4	41	224	0.0	490	2.0	0.0	225	2.
124	5.0	10.2	2701	536	50.9	32.6	105.4	107.1	41	227	4.1	350	2.1	0.0	225	5.
125	6.2	4.0	1414	800	9.5	14.0	145.4	64.6	40	102	0.0	566	4.0	0.0	225	2.
126	6.3	3.4	1414	465	6.7	9.9	64.6	42.2	61	101	0.0	820	2.0	0.0	225	1.
127	6.4	2.4	1326	420	12.2	15.9	151.0	69.4	82	122	0.0	890	2.0	0.0	225	2.
128	6.0	8.7	2627	639	54.4	27.6	105.1	110.4	62	144	4.1	659	2.1	0.0	315	2.
129	6.5	2.0	1717	606	14.1	10.0	105.0	80.9	101	81	0.0	2020	2.0	0.0	225	4.
130	6.2	4.5	1734	551	34.9	25.9	195.0	89.0	102	82	0.0	1632	2.0	0.0	270	2.

QUAD No.	pH	% LOSS ON IGNITION	TOTAL N *	TOTAL P *	EXCH K *	EXCH Na *	EXCH Ca *	EXCH Mg *	TOTAL Cu *	TOTAL Cr *	EXCH Fe *	TOTAL Ni *	EXCH Al *	EXCH Zn *	ASPECT (degrees) **	SLOPE (degrees)
131	5.4	67.0	13614	1100	307.2	400.4	290.4	176.0	0	44	0.0	22	0.0	0.0	135	12.
132	4.8	42.7	9300	1246	210.4	270.4	124.6	66.6	21	62	12.5	62	0.0	0.0	180	10.
133	4.9	35.3	6501	1049	113.4	56.3	141.2	93.5	21	107	6.4	21	0.0	0.0	135	5.
134	4.7	43.2	8910	1000	144.7	70.4	77.0	59.2	0	65	10.0	0	0.0	0.0	135	12.
135	4.0	57.5	16950	1695	194.4	275.7	149.2	110.5	23	45	11.3	23	0.0	0.0	135	5.
136	5.0	83.7	13767	752	364.0	456.0	223.4	102.6	23	0	4.6	23	0.0	0.0	135	10.
137	4.7	46.2	8453	1006	115.5	47.0	100.0	64.1	42	42	6.3	21	0.0	0.0	90	15.
138	4.7	34.0	10326	1134	101.9	73.0	104.9	63.3	21	43	0.6	21	0.0	0.0	90	4.
139	4.5	64.1	13904	1421	315.2	452.9	1136.6	339.7	22	22	6.7	0	0.0	0.0	45	7.
140	4.8	16.7	6136	832	143.5	58.5	200.0	72.0	21	62	4.2	21	0.0	0.0	90	10.
141	5.2	10.0	2295	612	15.9	10.0	32.6	14.5	61	102	2.0	612	0.0	0.0	225	2.
142	5.6	50.6	10734	1081	-271.4	310.0	250.6	154.0	42	64	10.6	191	0.0	1.1	180	5.
143	5.2	53.6	10335	1145	303.2	206.2	207.0	144.2	42	64	12.7	191	0.0	1.3	225	4.
144	5.1	33.5	6240	811	199.7	339.0	257.9	147.7	42	62	0.3	374	0.0	1.3	180	4.
145	4.4	57.4	14310	1569	354.0	-309.5	250.2	156.9	0	85	21.2	85	0.0	1.3	135	2.
146	4.6	49.6	11925	1081	210.4	265.0	139.9	100.1	0	85	19.1	127	0.0	0.4	180	3.
147	5.0	33.2	6440	996	112.3	50.0	100.2	77.0	21	104	10.4	200	0.0	0.2	270	12.
148	4.9	41.9	7455	945	163.0	264.6	100.6	105.0	21	105	0.4	231	0.0	0.0	270	2.
149	5.0	47.1	7065	1070	224.7	270.2	363.0	237.5	43	86	6.4	257	2.1	1.3	270	1.
150	4.0	51.2	11834	1091	226.0	200.3	150.4	137.0	21	64	10.7	150	0.0	0.6	270	3.
151	5.5	6.8	1926	642	17.1	9.0	10.7	5.1	64	64	2.1	963	0.0	0.0	0	10.
152	4.3	0.4	2679	752	29.2	0.4	20.5	14.6	46	68	4.6	547	0.0	0.0	225	3.
153	5.2	0.1	2373	670	47.2	13.6	36.2	30.1	68	68	4.5	723	0.0	0.2	315	7.
154	5.2	19.0	4040	960	101.2	30.9	70.4	75.0	44	66	4.4	462	0.0	0.2	270	4.
155	5.1	16.2	3317	899	30.0	9.2	15.0	9.6	43	43	2.1	449	0.0	0.0	315	4.
156	5.3	16.0	4662	955	100.0	37.1	102.1	102.6	44	67	4.4	333	0.0	0.7	270	6.
157	5.2	37.6	3371	720	113.4	40.4	115.6	92.5	43	64	4.3	270	0.0	1.3	270	2.
158	5.2	15.5	3075	750	70.3	35.3	85.0	80.3	50	75	5.0	300	0.0	0.5	90	2.

QUAD No.	pH	% LOSS ON IGNITION	TOTAL N *	TOTAL P *	EXCH K *	EXCH Na *	EXCH Ca *	EXCH Mg *	TOTAL Co *	TOTAL Cr *	EXCH Fe *	TOTAL Ni *	EXCH Ni *	EXCH Zn *	ASPECT (degrees) **	SLOPE (degrees)
159	5.2	10.0	4770	912	112.4	36.9	110.2	114.1	42	64	4.2	316	0.0	0.6	270	1.
160	5.0	13.2	3441	799	82.6	23.5	71.0	58.6	44	67	2.2	222	0.0	0.4	0	10.
161	4.2	14.0	3914	906	177.2	44.5	63.9	77.0	0	0	6.2	0	0.0	0.2	225	15.
162	4.7	27.2	4399	1039	186.6	63.6	78.4	86.8	0	0	6.4	21	0.0	0.6	225	14.
163	4.6	29.6	5085	1220	280.9	306.0	120.4	85.6	0	0	8.6	0	0.0	0.4	225	14.
164	4.6	22.9	4836	853	210.1	68.9	110.2	116.3	0	0	6.2	21	0.0	0.4	225	16.
165	4.5	11.2	3399	845	164.8	52.7	76.2	76.8	0	0	4.1	0	0.0	0.2	225	12.
166	4.4	16.4	4004	1040	110.2	26.5	29.1	40.8	21	0	6.2	21	0.0	0.0	225	6.
167	4.4	14.2	3245	721	142.1	34.0	59.7	77.9	21	0	8.2	0	0.0	0.2	225	10.
168	4.7	13.3	3516	1050	36.3	13.0	12.6	98.7	21	21	2.1	21	0.0	0.0	225	5.
169	4.5	13.5	2964	832	64.3	23.7	22.9	27.0	0	0	6.2	0	0.0	0.2	225	10.
170	4.4	17.2	3952	874	126.9	43.5	56.2	62.2	0	0	8.3	0	0.0	0.4	225	20.
171	4.1	40.3	7452	1050	306.9	209.4	276.5	144.7	0	0	4.3	0	0.0	0.7	225	6.
172	4.5	15.5	3952	1082	90.9	38.5	106.1	81.5	0	21	10.7	0	0.0	0.4	225	5.
173	4.3	47.2	12102	2150	353.2	305.2	130.0	95.9	0	0	8.7	0	0.0	0.7	225	4.
174	4.4	44.3	12394	2102	306.7	291.6	129.6	79.9	0	0	6.5	0	0.0	0.4	225	4.
175	4.2	26.3	6720	1197	210.0	60.9	102.9	109.6	0	0	8.4	0	0.0	0.4	225	5.
176	4.4	33.2	7632	1505	265.0	60.2	114.5	70.0	0	0	8.5	0	0.0	0.6	225	5.
177	4.4	43.3	5400	1176	172.2	40.5	100.0	96.0	0	21	10.5	0	0.0	0.0	225	3.
178	4.0	31.2	9523	1391	173.3	61.0	70.6	85.0	0	21	12.8	0	0.0	0.4	225	12.
179	4.2	30.7	8321	1336	294.7	260.0	170.1	93.3	21	0	8.5	0	0.0	0.9	225	2.
180	4.3	7.6	2295	245	67.5	23.1	36.7	40.4	0	20	6.1	0	0.0	0.0	225	1.
181	4.1	49.0	12207	903	336.0	306.6	264.6	147.0	0	21	6.3	21	0.0	0.0	225	10.
182	4.4	51.4	11370	1102	282.0	335.0	203.5	125.1	0	21	6.4	21	2.1	1.1	225	10.
183	4.6	71.0	15795	1264	230.7	285.5	74.9	99.0	0	23	11.7	23	2.3	0.7	225	10.
184	4.5	24.0	4120	639	127.7	39.4	61.0	82.4	0	21	12.4	21	2.1	0.2	225	10.
185	4.3	32.0	7950	636	106.6	61.1	70.0	103.5	0	21	10.6	21	0.0	0.2	225	10.
186	4.3	34.3	5511	792	246.1	273.9	179.0	98.4	0	21	10.7	21	2.1	0.6	225	10.

QUAD No.	pH	% LOSS ON IGNITION	TOTAL N *	TOTAL P *	EXCH K *	EXCH Na *	EXCH Ca *	EXCH Mg *	TOTAL Co *	TOTAL Cr *	EXCH Fe *	TOTAL Ni *	EXCH Ni *	EXCH Zn *	ASPECT (degrees) **	SLOPE (degrees)
187	4.6	60.5	10260	1199	206.5	64.4	53.3	77.0	0	22	4.4	22	0.0	0.7	225	10.
188	4.6	20.1	5145	567	174.3	53.1	71.4	85.9	0	21	6.3	21	2.1	0.2	225	10.
189	4.5	61.7	9791	813	325.3	276.1	111.3	66.3	0	21	6.4	21	0.0	0.6	225	10.
190	4.6	41.5	8232	1210	210.6	71.5	90.6	67.2	0	67	11.2	45	0.0	0.5	225	10.
191	5.3	3.3	1212	323	9.5	2.6	8.1	8.9	141	61	2.0	3232	2.0	0.0	270	12.
192	5.6	3.4	1010	283	8.1	0.0	6.1	10.7	141	61	0.0	2828	0.0	0.0	135	2.
193	5.3	2.9	1010	283	10.9	0.0	6.1	9.7	141	61	2.0	2424	2.0	0.0	225	0.
194	5.5	3.4	909	304	7.1	2.6	6.1	9.7	162	81	0.0	2826	2.0	0.0	135	4.
195	5.4	2.3	960	364	8.9	0.0	6.1	12.3	162	61	0.0	2828	2.0	0.0	135	5.
196	5.0	2.2	960	303	8.7	0.0	4.0	10.7	162	40	2.0	2424	2.0	0.0	180	3.
197	5.3	22.0	850	320	7.8	3.0	4.0	8.4	160	60	0.0	2800	2.0	0.0	180	2.
198	5.3	2.5	758	222	9.1	2.0	10.1	11.5	141	61	2.0	2424	2.0	0.0	135	2.
199	5.1	1.9	850	240	4.2	0.0	4.0	5.6	140	60	2.0	2000	0.0	0.0	90	2.
200	5.4	1.0	500	220	3.6	1.4	8.0	8.0	120	60	0.0	2400	0.0	0.0	135	3.
201	5.8	2.3	1030	343	9.1	5.9	6.1	12.3	121	81	2.0	2424	0.0	0.0	135	10.
202	5.7	3.4	1081	242	16.0	5.1	8.1	13.1	141	101	2.0	2424	0.0	0.0	180	6.
203	5.7	2.2	820	242	4.9	5.7	4.0	6.9	141	101	0.0	2424	0.0	0.0	180	2.
204	5.4	4.8	1030	242	16.4	7.9	10.1	15.6	121	121	2.0	2424	0.0	0.0	225	15.
205	5.2	3.2	820	222	5.3	5.9	6.1	5.7	162	101	0.0	2828	0.0	0.0	225	3.
211	5.5	6.4	2100	525	25.0	7.1	23.1	17.4	84	147	2.1	525	0.0	0.0	180	10.
212	5.4	11.3	2987	600	63.0	25.1	70.0	64.5	82	124	2.1	536	0.0	0.0	180	15.
213	5.1	10.9	3033	525	140.7	59.4	239.4	117.6	63	84	4.2	294	0.0	1.1	225	20.
214	5.0	8.2	2472	453	40.2	13.2	35.0	26.4	62	82	2.1	309	0.0	0.0	225	16.
215	5.1	3.5	1020	306	5.5	0.0	6.1	3.9	61	82	0.0	245	0.0	0.0	180	6.
221	4.0	39.6	5400	1040	172.6	34.1	64.5	94.2	21	21	31.2	0	0.0	0.0	270	3.
222	4.1	17.3	5150	1030	160.9	43.3	70.0	94.0	21	21	14.4	0	0.0	0.2	315	2.
223	4.1	39.2	7579	1272	419.0	79.7	140.4	101.0	21	21	6.4	0	0.0	0.4	225	2.
224	3.9	27.4	6195	1050	209.0	65.1	130.2	92.4	21	21	8.4	0	0.0	0.4	270	5.

QUAD No.	pH	% LOSS ON IGNITION	TOTAL N *	TOTAL P *	EXCH K *	EXCH Na *	EXCH Ca *	EXCH Mg *	TOTAL Co *	TOTAL Cr *	EXCH Fe *	TOTAL Ni *	EXCH Ni *	EXCH Zn *	ASPECT (degrees) **	SLOPE (degrees)
225	4.1	22.0	5170	1199	244.2	49.9	89.4	117.3	22	22	15.3	0	0.0	0.2	270	0.
231	5.0	5.0	1420	300	7.6	0.0	12.2	7.6	102	82	2.0	1632	0.0	0.0	180	2.
232	5.0	5.6	2009	453	16.1	0.0	16.5	8.7	144	62	2.1	2472	0.0	0.0	45	1.
233	5.1	10.2	2499	300	6.9	20.0	220.3	100.0	143	61	4.1	2440	2.0	1.4	45	6.
234	5.1	4.6	3570	400	10.2	0.0	14.3	9.4	143	82	2.0	2440	0.0	0.0	45	0.
235	5.1	11.0	2524	412	41.2	14.2	60.0	55.0	124	82	4.1	2472	2.1	0.2	90	3.
236	5.1	5.0	1007	449	22.6	0.0	36.7	31.6	143	61	4.1	2440	0.0	0.0	0	2.
237	5.0	2.2	1111	323	5.1	0.0	24.2	24.9	141	81	0.0	2424	0.0	0.0	90	5.
238	5.6	2.7	1111	323	14.1	4.4	103.0	96.2	121	81	0.0	2424	2.0	0.0	90	3.
239	5.0	5.1	1957	330	19.4	10.1	251.3	107.1	124	82	2.1	2060	4.1	0.0	180	5.
240	6.0	2.2	1162	545	10.3	3.4	105.0	92.1	121	101	0.0	1616	0.0	0.0	45	5.
241	4.6	44.0	5350	706	363.6	204.6	175.5	94.2	0	21	17.1	21	0.0	1.9	315	4.
242	4.8	35.1	7330	642	177.6	48.2	87.7	66.3	0	43	6.6	64	0.0	0.2	96	2.
243	4.8	45.6	6966	1037	315.4	76.5	84.2	75.6	0	43	15.1	43	0.0	0.4	90	0.
244	4.7	75.1	9053	1109	505.0	410.6	254.9	177.0	0	24	14.2	47	2.4	1.4	135	3.
245	4.9	50.2	7021	960	323.3	321.0	136.9	110.9	0	47	23.6	165	0.0	0.7	90	3.
246	4.5	45.2	5777	654	289.9	260.1	261.6	143.9	0	22	17.4	44	0.0	2.0	135	0.
247	4.9	66.4	7044	1243	479.5	352.2	201.3	136.2	0	30	8.9	59	0.0	0.9	135	6.
248	5.2	34.0	6039	701	253.0	51.5	83.0	116.9	0	24	7.3	49	0.0	0.2	135	10.
249	4.9	52.1	6922	894	340.1	318.3	91.6	70.5	0	22	0.7	22	0.0	0.9	135	8.
250	4.9	12.7	3966	610	37.3	6.8	20.6	22.5	0	41	4.1	62	2.1	0.0	135	0.
251	5.3	3.0	2695	924	93.5	376.2	2226.4	2332.0	190	110	0.0	3000	0.0	0.0	270	10.
252	6.2	4.3	2369	824	7.0	255.4	795.2	1155.7	124	144	0.0	2472	0.2	0.0	270	12.
253	6.2	4.4	3640	1002	74.5	268.3	1055.4	1435.2	125	104	0.0	2496	6.2	0.0	270	20.
254	6.3	7.0	2670	845	71.1	56.4	576.0	669.5	144	144	0.0	2084	6.2	0.0	270	10.
255	6.3	4.2	2004	803	45.3	50.7	510.9	803.7	105	144	0.0	3296	0.2	0.0	270	12.
256	6.6	3.2	2005	979	50.6	49.6	424.3	846.6	163	143	0.0	2056	0.2	0.0	270	10.
257	6.4	3.0	3519	1306	34.5	37.1	293.0	622.2	104	143	0.0	2056	6.1	0.0	270	10.

QUAD No.	pH	% LOSS ON IGNITION	TOTAL N *	TOTAL P *	EXCH K *	EXCH Na *	EXCH Ca *	EXCH Mg *	TOTAL Co *	TOTAL Cr *	EXCH Fe *	TOTAL Ni *	EXCH Ni *	EXCH Zn *	ASPECT (degrees) **	SLOPE (degrees)
258	6.4	2.3	2879	1172	21.6	15.0	141.4	309.1	162	121	0.0	2026	6.1	0.0	270	4.
259	6.4	3.7	1970	820	34.7	41.2	266.6	476.7	121	101	0.0	2424	6.1	0.0	270	3.
260	6.0	9.2	3672	734	92.6	54.1	571.2	561.0	102	82	0.0	2040	4.1	0.0	225	8.
261	6.3	1.4	960	343	19.2	23.0	121.2	202.0	141	81	2.0	3232	8.1	0.0	180	25.
262	6.2	3.0	1364	505	24.4	23.8	165.6	181.6	141	81	2.0	2020	4.0	0.0	180	25.
263	5.9	3.6	606	606	26.9	25.3	153.5	193.9	141	81	2.0	2020	4.0	0.0	180	25.
264	6.0	2.3	1010	404	17.4	22.4	125.2	153.5	141	101	2.0	2020	4.0	0.0	180	25.
265	6.3	1.6	1061	405	11.1	20.0	117.2	155.5	141	81	2.0	3232	2.0	0.0	180	25.
271	6.4	1.9	909	525	15.6	14.6	70.7	90.2	121	81	0.0	2020	0.0	0.0	315	2.
272	6.0	2.4	1061	444	14.5	15.4	97.0	105.7	141	61	2.0	2020	0.0	0.0	270	10.
273	6.0	2.0	1162	505	14.1	14.1	82.8	91.5	141	61	0.0	2424	0.0	0.0	270	2.
274	6.0	1.0	1414	606	10.0	16.8	74.7	96.6	121	81	2.0	2424	0.0	0.0	315	2.
275	6.2	2.0	1364	667	12.3	13.1	60.7	76.6	141	81	2.0	2020	0.0	0.0	315	3.
276	5.9	2.5	1414	747	17.6	17.6	97.0	62.6	121	61	0.0	2020	0.0	0.0	315	3.
277	5.8	21.6	1970	869	11.5	11.9	60.6	85.2	141	81	0.0	2020	0.0	0.0	315	3.
278	6.0	2.0	1313	646	13.5	15.8	72.7	64.6	162	81	2.0	2424	0.0	0.0	315	5.
279	5.8	2.5	1313	606	16.4	13.7	52.5	65.0	141	81	0.0	2020	0.0	0.0	315	5.
280	5.9	2.1	1111	606	15.8	15.0	113.1	76.8	141	81	0.0	2020	0.0	0.0	315	4.
281	5.1	33.7	6604	624	299.5	266.2	624.0	582.4	83	104	0.3	811	2.1	1.3	90	2.
282	5.0	48.6	5717	610	175.1	98.1	618.0	519.1	103	103	14.4	960	2.1	1.4	0	7.
283	4.9	54.6	9240	1092	382.2	260.4	361.2	249.9	63	147	23.1	147	2.1	1.3	225	10.
284	4.5	58.5	10257	954	568.2	273.5	907.4	600.0	85	85	19.1	297	2.1	4.7	270	4.
285	5.2	56.6	12800	1534	423.4	391.0	1334.9	1192.3	130	173	6.5	432	0.6	2.4	180	8.
291	5.6	25.0	8498	1195	173.0	226.6	580.9	760.1	144	41	6.2	1640	2.1	0.8	315	5.
292	5.5	42.8	10475	2142	247.0	243.6	915.6	932.4	231	189	8.4	693	4.2	0.6	270	10.
293	5.4	26.0	6798	803	191.6	179.2	894.0	764.3	144	82	18.3	2060	2.1	1.2	315	2.
294	5.7	24.0	5923	1071	177.2	232.8	667.4	984.3	144	62	6.2	2060	2.1	0.8	225	4.
295	5.4	36.6	11370	2247	285.6	152.6	500.3	557.6	254	297	12.7	572	0.5	0.4	180	5.

QUAD No.	pH	% LOSS ON IGNITION	TOTAL N *	TOTAL P *	EXCH K *	EXCH Na *	EXCH Ca *	EXCH Mg *	TOTAL Co *	TOTAL Cr *	EXCH Fe *	TOTAL Ni *	EXCH Ni *	EXCH Zn *	ASPECT (degrees) **	SLOPE (degree
301	5.5	6.4	2020	586	13.1	6.1	32.3	20.2	101	61	2.0	1616	0.0	0.0	270	2.
302	5.5	11.0	3009	673	50.6	18.6	110.2	96.1	102	61	2.0	1632	0.0	0.2	135	10.
303	5.5	4.5	1566	424	15.6	8.3	34.3	21.8	121	81	2.0	2020	0.0	0.0	180	15.
304	5.1	5.5	2172	808	9.7	2.6	6.1	3.6	121	61	2.0	2020	0.0	0.0	135	15.
305	5.3	12.7	3264	796	47.5	18.8	103.6	71.4	102	61	2.0	1632	0.0	0.4	135	5.
306	5.7	3.9	2273	840	7.3	5.5	46.5	29.7	121	61	0.0	1616	0.0	0.2	135	5.
307	5.3	9.8	3264	877	24.1	11.0	65.3	44.1	122	61	2.0	1632	0.0	0.2	180	4.
308	4.5	11.3	3519	938	36.1	14.9	28.6	36.7	102	82	6.1	1632	0.0	0.0	180	3.
309	5.0	2.8	1970	700	6.7	4.0	8.1	9.5	141	61	2.0	2020	0.0	0.0	180	5.
310	5.3	4.3	1869	626	11.7	10.7	74.7	51.7	141	61	2.0	2020	0.0	0.2	135	5.
311	4.9	15.4	3700	703	154.5	44.9	144.2	156.8	21	62	6.2	62	0.0	0.0	180	3.
312	5.2	18.0	4197	020	143.9	67.6	104.6	113.1	22	65	6.5	22	0.0	0.0	180	20.
313	5.1	14.6	3090	630	92.2	40.1	77.7	74.6	21	63	6.3	21	0.0	0.0	180	20.
314	5.0	13.7	3726	821	93.7	27.0	60.5	63.1	22	43	6.5.	22	0.0	0.0	180	15.
315	5.0	14.0	3490	700	90.4	31.6	67.0	70.0	21	64	6.4	21	0.0	0.0	180	20.

QUAD No.	pH	% LOSS ON IGNITION	TOTAL N *	TOTAL P *	EXCH K *	EXCH Na *	EXCH Ca *	EXCH Mg *	TOTAL Co *	TOTAL Cr *	EXCH Fe *	TOTAL Ni *	EXCH Ni *	EXCH Zn *	ASPECT (degrees) **	SLOPE (degree
301	5.5	6.4	2020	586	13.1	6.1	32.3	20.2	101	61	2.0	1616	0.0	0.0	270	2.
302	5.5	11.0	3009	673	50.6	10.6	110.2	96.1	102	61	2.0	1632	0.0	0.2	135	10.
303	5.5	4.5	1566	424	15.6	8.3	34.3	21.8	121	81	2.0	2020	0.0	0.0	180	15.
304	5.1	5.5	2172	808	9.7	2.6	6.1	3.6	121	61	2.0	2020	0.0	0.0	135	15.
305	5.3	12.7	3264	796	47.5	10.0	103.6	71.4	102	61	2.0	1632	0.0	0.4	135	5.
306	5.7	3.9	2273	840	7.3	5.5	46.5	29.7	121	61	0.0	1616	0.0	0.2	135	5.
307	5.3	9.8	3264	877	24.1	11.0	65.3	44.1	122	61	2.0	1632	0.0	0.2	180	4.
308	4.5	11.3	3519	930	36.1	14.9	28.6	36.7	102	82	6.1	1632	0.0	0.0	180	3.
309	5.0	2.8	1970	700	6.7	4.0	8.1	9.5	141	61	2.0	2020	0.0	0.0	180	5.
310	5.3	4.3	1869	626	11.7	10.7	74.7	51.7	141	61	2.0	2020	0.0	0.2	135	5.
311	4.9	15.4	3700	703	154.5	44.9	144.2	156.8	21	62	6.2	62	0.0	0.0	180	3.
312	5.2	18.0	4197	820	143.9	67.6	104.6	113.1	22	65	6.5	22	0.0	0.0	180	20.
313	5.1	14.6	3090	630	92.2	40.1	77.7	74.6	21	63	6.3	21	0.0	0.0	180	20.
314	5.0	13.7	3726	821	93.7	27.0	60.5	63.1	22	43	6.5.	22	0.0	0.0	180	15.
315	5.0	14.0	3490	700	90.4	31.6	67.0	70.0	21	64	6.4	21	0.0	0.0	180	20.

Appendix IV

Ordination scores for all 283 quadrats included in the DECORANA and TWINSPAN vegetation analyses for Axes I - III, and the TWINSPAN classification group number. (Quadrats 1 and 29 omitted.)

Quad rat	Axis I	Axis II	Axis III	TWINSPAN Group No.
2	197	155	153	2
3	158	186	182	7
4	176	181	155	5
5	184	203	161	6
6	155	207	164	5
7	170	116	110	2
8	137	146	163	12
9	176	169	125	10
10	206	169	146	2
11	124	207	140	7
12	149	232	87	7
13	70	164	96	8
14	157	240	93	7
15	149	194	155	8
16	75	179	248	8
17	51	206	210	5
18	53	186	211	8
19	87	190	218	8
20	90	199	186	8
21	137	184	104	10
22	161	195	137	5
23	138	143	142	10
24	100	105	186	12
25	132	188	136	11
26	129	191	74	7
27	164	180	153	10
28	119	0	0	3
30	186	254	129	5
31	168	285	69	6
32	156	255	127	5
33	197	258	117	6
34	154	222	167	5
35	138	227	170	6
36	223	260	84	6
37	189	277	87	6
38	144	257	125	6
39	166	260	135	6
40	128	220	176	5
41	198	256	88	6
42	181	285	64	6
43	139	257	116	6
44	146	306	63	6
45	187	266	103	6
46	156	241	116	6
47	184	299	50	6
48	207	267	75	6
49	146	273	77	6
50	240	227	126	6
51	98	170	161	11
52	69	86	139	10
53	65	74	187	12
54	70	111	194	12
55	115	207	139	8
56	78	172	189	11
57	77	148	173	11
58	124	250	161	5
59	92	151	177	11
60	87	145	148	11
61	64	260	120	7
62	89	313	86	7
63	81	159	160	11
64	191	248	68	7
65	119	259	90	7
66	119	318	57	7
67	125	81	100	10
68	127	318	71	7
69	191	276	61	7
70	115	237	119	7
71	73	222	134	7
72	99	215	162	7
73	125	303	87	7
74	139	84	102	10
75	114	196	111	10
76	82	163	89	10
77	100	166	178	7
78	85	178	152	7
79	128	218	150	7
80	117	203	153	7
81	34	122	175	12
82	26	125	166	12
83	34	111	151	12
84	49	104	172	12
85	74	213	52	7
86	80	214	153	7
87	65	150	186	11
88	79	206	186	8
89	35	197	239	11
90	62	212	187	8
91	0	252	267	8
92	2	286	261	8
93	18	233	291	11
94	75	230	165	8
95	107	259	126	8
96	64	226	199	8
97	36	194	208	8
98	52	205	196	11
99	74	206	196	8
100	80	217	170	8

Appendix IV

Ordination scores for all 283 quadrats included in the DECORANA and TWINSPAN vegetation analyses for Axes I - III, and the TWINSPAN classification group number. (Quadrats 1 and 29 omitted.)

Quad rat	Axis I	Axis II	Axis III	TWINSPAN Group No.
2	197	155	153	2
3	158	186	182	7
4	176	181	155	5
5	184	203	161	6
6	155	207	164	5
7	170	116	110	2
8	137	146	163	12
9	176	169	125	10
10	206	169	146	2
11	124	207	140	7
12	149	232	87	7
13	70	164	96	8
14	157	240	93	7
15	149	194	155	8
16	75	179	248	8
17	51	206	210	5
18	53	186	211	8
19	87	190	218	8
20	90	199	186	8
21	137	184	104	10
22	161	195	137	5
23	138	143	142	10
24	100	105	186	12
25	132	188	136	11
26	129	191	74	7
27	164	180	153	10
28	119	0	0	3
30	186	254	129	5
31	168	285	69	6
32	156	255	127	5
33	197	258	117	6
34	154	222	167	5
35	138	227	170	6
36	223	260	84	6
37	189	277	87	6
38	144	257	125	6
39	166	260	135	6
40	128	220	176	5
41	198	256	88	6
42	181	285	64	6
43	139	257	116	6
44	146	306	63	6
45	187	266	103	6

Quad rat	Axis I	Axis II	Axis III	TWINSPAN Group No.
46	156	241	116	6
47	184	299	50	6
48	207	267	75	6
49	146	273	77	6
50	240	227	126	6
51	98	170	161	11
52	69	86	139	10
53	65	74	187	12
54	70	111	194	12
55	115	207	139	8
56	78	172	189	11
57	77	148	173	11
58	124	250	161	5
59	92	151	177	11
60	87	145	148	11
61	64	260	120	7
62	89	313	86	7
63	81	159	160	11
64	191	248	68	7
65	119	259	90	7
66	119	318	57	7
67	125	81	100	10
68	127	318	71	7
69	191	276	61	7
70	115	237	119	7
71	73	222	134	7
72	99	215	162	7
73	125	303	87	7
74	139	84	102	10
75	114	196	111	10
76	82	163	89	10
77	100	166	178	7
78	85	178	152	7
79	128	218	150	7
80	117	203	153	7
81	34	122	175	12
82	26	125	166	12
83	34	111	151	12
84	49	104	172	12
85	74	213	52	7
86	80	214	153	7
87	65	150	186	11
88	79	206	186	8
89	35	197	239	11
90	62	212	187	8
91	0	252	267	8
92	2	286	261	8
93	18	233	291	11
94	75	230	165	8
95	107	259	126	8
96	64	226	199	8
97	36	194	208	8
98	52	205	196	11
99	74	206	196	8
100	80	217	170	8

Quad rat	Axis I	Axis II	Axis III	TWINSPAN Group No.
101	78	84	44	9
102	23	17	21	9
103	9	30	24	9
104	54	114	85	9
105	26	52	63	9
106	52	32	36	9
107	62	89	68	9
108	7	16	29	9
109	27	49	98	9
110	43	95	57	9
111	92	94	51	10
112	78	144	111	10
113	82	127	77	10
114	63	103	52	10
115	73	103	71	10
116	48	130	66	10
117	91	134	124	10
118	53	110	113	10
119	87	124	68	10
120	70	116	91	10
121	78	256	159	8
122	40	208	137	8
123	52	209	152	8
124	75	172	172	11
125	105	331	88	7
126	68	223	154	8
127	105	299	119	7
128	42	178	210	11
129	50	183	156	7
130	78	237	166	8
131	129	74	181	12
132	67	48	191	12
133	108	94	195	12
134	84	118	229	12
135	90	88	169	12
136	103	60	249	12
137	119	90	188	12
138	101	97	209	12
139	110	95	152	12
140	112	102	142	10
141	66	190	211	8
142	59	150	197	12
143	75	138	198	12
144	106	183	199	11
145	89	119	165	12
146	77	121	230	12
147	43	139	231	12
148	51	145	244	11
149	63	168	204	11
150	62	126	223	12
151	161	198	175	5
152	193	215	136	1
153	201	199	143	1
154	203	200	146	1
155	166	230	169	1
156	198	176	160	1
157	210	197	172	1
158	188	206	168	1
159	217	199	163	1
160	256	221	132	1
161	273	151	137	4
162	240	153	144	4
163	269	163	140	4
164	266	201	144	1
165	278	154	136	4
166	261	220	123	1
167	277	202	137	4
168	279	248	114	1
169	283	212	167	1
170	276	198	150	1
171	257	17	219	3
172	275	105	189	3
173	292	51	182	3
174	297	28	235	3
175	230	81	182	3
176	288	99	145	3
177	301	131	153	3
178	268	171	158	4
179	250	170	142	4
180	309	167	115	4
181	69	117	203	12
182	125	117	204	12
183	146	96	198	12
184	170	145	162	3
185	90	106	210	12
186	117	137	181	12
187	69	86	252	12
188	95	109	193	12
189	100	137	220	12
190	147	122	164	12
191	147	244	178	5
192	173	227	157	5
193	156	247	177	5
194	148	243	154	5
195	151	239	152	5
196	167	239	198	5
197	125	220	193	5
198	185	199	170	1
199	165	217	165	5
200	164	241	172	5
201	158	218	151	5
202	172	237	151	5
203	201	264	213	5
204	163	223	170	5
205	142	228	175	5
211	161	228	131	1
212	167	219	138	1
213	177	199	157	1
214	215	213	127	1
215	128	246	151	5

Quad rat	Axis I	Axis II	Axis III	TWINSPAN Group No.
221	270	102	148	3
222	276	74	142	3
223	259	82	173	3
224	270	62	142	3
225	296	80	134	3
231	149	230	234	5
232	107	200	134	11
233	86	159	164	11
234	149	209	192	5
235	123	204	150	11
236	120	236	155	5
237	138	212	145	10
238	93	185	98	10
239	90	287	97	7
240	60	309	135	7
241	86	121	218	12
242	106	154	183	12
243	69	73	245	12
244	103	37	269	12
245	90	84	218	12
246	76	91	234	12
247	119	100	186	12
248	115	154	175	11
249	98	89	213	12
250	109	86	235	12
251	113	260	47	7
252	101	247	77	8
253	127	267	47	8
254	90	211	72	7
255	94	201	94	7
256	134	246	67	7
257	122	253	88	7
258	113	210	55	7
259	115	235	48	7
260	94	214	117	7
261	55	195	91	7
262	71	207	148	7
263	73	197	126	7
264	107	240	114	7
265	94	227	54	7
271	226	256	72	6
272	131	254	96	7
273	122	297	42	7
274	268	254	48	6
275	127	325	58	7
276	159	241	130	6
277	118	266	90	7
278	129	229	104	8
279	58	211	207	5
280	128	279	39	7
281	87	140	106	10
282	85	132	137	10
283	27	120	192	12
284	50	97	158	12
285	17	112	105	9

Quad rat	Axis I	Axis II	Axis III	TWINSPAN Group No.
291	77	151	84	10
292	78	111	55	10
293	59	156	103	10
294	62	188	110	10
295	30	85	67	9
301	77	177	122	8
302	42	178	222	11
303	67	154	258	11
304	40	164	281	11
305	45	190	196	11
306	31	166	240	11
307	12	243	274	11
308	82	158	187	8
309	54	179	244	11
310	62	170	205	11
311	171	152	88	2
312	202	172	91	2
313	205	151	86	2
314	218	156	98	2
315	214	156	93	2

APPENDIX V

The means and F-ratios for the soil data from each transect. All total and exchangeable values in µg g-1; these values and those for % loss-on-ignition are expressed for soil oven dried at 105°C. The type of mean given depends on the normality of the data. Arithmetic means are given with a single value in parenthesis for standard error. Geometric means arising from $\log_e$ and square root transformations (the latter indicated by +) are given with values in parentheses for the transformed mean followed by the transformed standard deviation. n = 10 except for transects 21-23, 27, 29, 30 and 32 where n = 5.

APPENDIX V

The means and F-ratios for the soil data from each transect. All total and exchangeable values in μg g^{-1}; these values and those for % loss-on-ignition are expressed for soil oven dried at $105^{\circ}C$. The type of mean given depends on the normality of the data. Arithmetic means are given with a single value in parenthesis for standard error. Geometric means arising from $\log_e$ and square root transformations (the latter indicated by +) are given with values in parentheses for the transformed mean followed by the transformed standard deviation.

$n = 10$ except for transects 21-23, 27, 29, 30 and 32 where $n = 5$.

Transect No.	pH	% Loss on Ignition	Total N	Total P	Exch K	Exch Na	Exch Ca	Exch Mg
1	5.0	15.2	3800	490	76.7	19.6	67.5	63.3
	(0.1)	(2.7,0.3)	(8.2,0.4)	(6.2,0.4)	(4.3,0.3)	(3.0)	(4.2,0.5)	(4.1,1.1)
2	5.7	4.4	2050	470	22.0+	12.1+	75.6	119.6+
	(0.1)	(1.5,0.9)	(7.6,0.5)	(6.1,0.6)	(4.7,1.9)	(3.5,1.8)	(4.3,1.5)	(10.9,7.5)
3	5.7	10.0	2700	430	41.1	16.3	136.7+	160.8+
	(0.1)	(2.3,0.6)	(7.9,0.7)	(6.1,0.4)	(3.7,0.9)	(2.8,0.8)	(11.7,4.8)	(12.7,6.6)
4	5.1	2.6	1230	460	13.1	4.9	9.5	11.6
	(0.1)	(1.0,0.4)	(7.1,0.5)	(6.1,0.8)	(2.0)	(1.6,0.5)	(1.8)	(2.5,0.4)
5	5.0	4.2	1070	180	11.8	5.0	8.0	10.8
	(0.1)	(0.3)	(60)	(10)	(2.5,0.3)	(1.0)	(2.1,0.3)	(2.4,0.2)
6	5.4	6.4	1680	220	31.6+	18.3	146.9+	91.5
	(0.1)	(1.9,0.9)	(7.4,0.7)	(5.4,0.3)	(5.6,2.2)	(2.9,0.9)	(12.1,5.0)	(4.5,0.9)
7	6.1	5.1	1340	250	38.0	45.3	312.4	251.0
	(0.1)	(1.6,0.5)	(7.2,0.5)	(5.5,0.5)	(3.6,0.4)	(3.8,0.7)	(5.7,0.3)	(5.5,0.4)
8	5.5	13.8	4130	1230	68.4	73.7	354.4	342.1
	(0.1)	(2.6,0.5)	(8.3,0.4)	(120)	(4.2,0.4)	(4.3,0.8)	(36.7)	(18.5,5.1)
9	5.1	23.6+	6490	1280	85.9	235.1	455.4+	195.4
	(0.1)	(4.9,1.6)	(1000)	(130)	(4.5,1.2)	(55.0)	(21.3,9.1)	(5.3,1.0)
10	6.2	2.8	1580	930	8.9	8.7	48.2	64.4
	(0.1)	(1.0,1.0)	(7.4,0.3)	(6.8,0.2)	(2.2,0.5)	(2.2,0.5)	(3.9,0.7)	(4.2,0.6)
11	6.2	54.4	11700	1570	382.5+	404.6	1344.4	2069.6
	(0.1)	(7.8)	(1200)	(90)	(19.6,6.1)	(43.9)	(134.1)	(213.8)
12	6.0	29.5	7670	1790	154.3	298.7+	812.2	843.7+
	(0.1)	(4.4)	(830)	(7.5,0.3)	(18.2)	(17.3,4.9)	(6.7,0.5)	(29.0,6.9)
13	6.1	3.9	1650	530	15.4	17.9+	139.2	74.7
	(0.1)	(1.4,0.6)	(7.4,0.3)	(6.3,0.2)	(2.7,0.8)	(4.2,1.0)	(17.8)	(7.8)
14	4.8	49.2	10260	1110	198.2	147.8	178.7	100.0
	(0.1)	(6.0)	(9.2,0.3)	(7.0,0.3)	(5.3,0.5)	(5.0,1.0)	(5.2,0.8)	(4.6,0.5)
15	5.0	42.8	8940	1030+	209.0	240.9	195.8	128.3
	(0.1)	(4.5)	(1120)	(32.1,3.8)	(30.4)	(35.4)	(29.5)	(18.5)
16	5.1	14.2	3520	800	70.5	26.0	63.7	58.2
	(0.1)	(2.7,0.5)	(320)	(6.7,0.1)	(11.7)	(4.7)	(12.8)	(12.9)
17	4.5	17.1	3940	930	150.7	45.8	58.3+	75.1
	(0.1)	(2.8,0.3)	(8.3,0.2)	(6.8,0.2)	(23.0)	(3.8,0.8)	(7.6,2.5)	(8.3)

Transect No.	pH	% Loss on Ignition	Total N	Total P	Exch K	Exch Na	Exch Ca	Exch Mg
18	4.3	32.8	7590	1410	224.2	95.7	117.6+	89.7
	(0.1)	(4.3)	(1030)	(180)	(30.7)	(4.6,1.0)	(10.8,2.8)	(8.5)
19	4.5	43.6	9040	880	229.0+	129.3	102.7	92.3
	(0.1)	(3.8,0.4)	(1140)	(6.8,0.3)	(15.1,2.2)	(4.9,0.9)	(4.6,0.6)	(4.5,0.3)
20	5.3	3.0	900	290	7.8	1.2	6.1+	9.6
	(0.1)	(1.1,0.8)	(60)	(20)	(0.7)	(0.4)	(2.5,0.4)	(0.6)
21	5.6	3.1	960	260	9.0	6.0	6.7+	10.7
	(0.1)	(1.1,0.3)	(50)	(5.5,0.2)	(2.2,0.6)	(1.8,0.2)	(2.6,0.4)	(1.9)
22	5.2	8.3	2480	500	46.5+	14.5+	38.4	36.4+
	(0.1)	(2.1,0.6)	(470)	(60)	(6.8,3.5)	(3.8,2.9)	(3.6,1.4)	(6.0,3.5)
23	4.0	27.9	5840	1120	244.1	52.1	95.2	99.7
	(0.0)	(3.3,0.4)	(8.7,0.2)	(50)	(5.5,0.4)	(4.0,0.3)	(4.6,0.4)	(4.6,0.1)
24	5.3	4.8	1790	400	12.8	28.1+	50.3	44.3+
	(0.1)	(1.6,0.6)	(7.5,0.4)	(6.0,0.2)	(2.5,0.6)	(1.5,1.8)	(3.9,1.1)	(6.7,3.2)
25	4.8	46.1	6710	840	308.6	213.8	127.8+	102.2
	(0.1)	(5.4)	(500)	(6.7,0.3)	(43.0)	(47.4)	(11.3,3.6)	(14.0)
26	6.2	4.3	2910	940	52.6	73.4	551.4	794.0
	(0.1)	(1.5,0.4)	(180)	(6.8,0.2)	(9.3)	(4.3,1.0)	(6.3,0.8)	(6.7,0.6)
27	6.1	2.2	1000	470	19.8	23.2	135.2	117.4
	(0.1)	(0.8,0.4)	(120)	(40)	(2.8)	(0.8)	(4.9,0.2)	(22.1)
28	6.0	2.7	1280	610	14.9	14.8	77.1	82.3
	(0.1)	(1.0,0.7)	(7.2,0.2)	(6.4,0.2)	(0.7)	(0.5)	(4.3,0.2)	(4.9)
29	4.9	50.4	8940	910	369.7	257.8	700.5	557.9
	(0.1)	(4.0)	(1290)	(6.8,0.4)	(65.3)	(46.5)	(6.6,0.5)	(6.3,0.6)
30	5.5	30.4	8610	1380	197.3	207.0	692.1	783.7
	(0.0)	(3.4,0.2)	(1040)	(7.2,0.5)	(5.3,0.1)	(17.5)	(6.5,0.3)	(66.6)
31	5.3	6.4	2410	740	17.3	9.5+	48.7+	33.5+
	(0.1)	(1.9,0.5)	(7.8,0.3)	(50)	(2.8,0.8)	(3.1,0.9)	(7.0,3.4)	(5.8,2.4)
32	5.0	15.1	3650	750	113.6	41.6	86.4	89.8
	(0.0)	(2.7,0.1)	(180)	(40)	(4.7,0.3)	(3.7,0.4)	(4.5,0.4)	(4.5,0.4)
F ratio	40.38	23.29	23.90	22.09	18.32	13.65	19.28	36.19
	***	***	***	***	***	***	***	***

*** P<0.001

Transect No.	Total Co	Total Cr	Exch Fe	Total Ni	Exch. Ni	Exch. Zn	Mg/Ca
1	60	40	4.4	580	0.5	-	1.12*
	(7)	(3.8,0.1)	(0.6)	(60)	(-0.6,0.8)		(1.06,0.39)
2	140	80	2.2+	2220	1.6+	-	0.95
	(6)	(6)	(1.5,0.9)	(90)	(1.3,0.4)		(-0.05,0.22)
3	100	90	3.2	1220	0.7	-	1.05
	(5)	(4)	(0.7)	(7.1,0.4)	(-0.4,0.9)		(0.05,0.36)
4	110	60	1.0	2170	0.7	-	1.50+
	(3)	(4)	(0.3)	(110)	(0.1)		(1.22,0.21)
5	110	70	1.2	2190	0	0	1.37
	(3)	(3)	(0.3)	(70)	(0)	(0)	(0.08)
6	100	50	2.1	2010	1.8+	0.1	0.74
	(4,6,1.6)	(4.0,0.3)	(0.7,0.0)	(70)	(1.4,1.1)	(0.0)	(-0.30, 0.25)
7	120	100	0.4	14.0	2.1	0	0.80
	(6)	(4.6,0.2)	(0.4)	(7.3,0.4)	(0.6)	(0)	(-0.22,0.22)
8	150	140	2.9	2180	7.3	0+	0.95
	(5.0,0.1)	(4.9,0.5)	(0.7)	(100)	(1.1)	(0.2,0.3)	(-0.06,0.27)
9	110	180	4.5+	690	3.4	0.4+	0.54
	(4)	(5.2,0.6)	(2.1,1.7)	(6.5,0.6)	(0.9)	(0.7,0.4)	(-0.62,0.38)
10	160	50	0.1+	2740	3.0	0	1.34
	(5)	(3.9,0.3)	(0.3,0.7)	(7.9,0.2)	(0.5)	(0.0)	(0.29,0.31)
11	130	80+	2.7+	1560+	22.0	0.8+	1.56
	(19)	(8.7,5.0)	(1.6,1.0)	(39.5,8.7)	(3.1,0.4)	(0.9,1.4)	(0.08)
12	160	120	3.5	1400	8.6+	0.4+	0.98
	(5.1,0.2)	(4.8,0.2)	(0.6)	(7.2,0.4)	(2.9,0.9)	(0.6,0.4)	(-0.02,0.16)
13	70+	120	0.8	790	2.0	0	0.56
	(8.1,1.4)	(4.8,0.4)	(0.5)	(6.7,0.5)	(0.3)	(0)	(-0.58,0.33)
14	20	50	7.8+	20+	0	0	0.59
	(4)	(9)	(2.8,0.5)	(4.1,2.4)	(0)	(0)	(0.05)
15	30	80	10.3+	210	0	0.8	0.65
	(6)	(6)	(3.2,0.9)	(5.4,0.6)	(0)	(0.2)	(0.04)
16	50	70	3.8	420	0	0.3+	0.83
	(3.9,0.2)	(3)	(0.3)	(6.0,0.5)	(0)	(0.5,0.4)	(0.06)
17	0	0	6.3	0	0	0.3	1.34
	(0)	(0)	(0.6)	(0)	(0)	(0.1)	(0.29,0.65)

- = not determined

Transect No.	Total Co.	Total Cr	Exch Fe	Total Ni	Exch Ni	Exch Zn	Mg/Ca
18	0	0	8.6	0	0	0.4	0.78
	(0)	(0)	(2.2,0.4)	(0)	(0)	(0.1)	(-0.25,0.31)
19	0	20	8.6	0	0	0.6	0.98
	(0)	(3.2,0.4)	(0.9)	(0)	(0)	(0.1)	(0.13)
20	150	60	1.0	2620	1.4	0	1.58
	(4)	(3)	(0.3)	(110)	(0.3)	(0)	(0.46,0.30)
21	140	100	1.2	2500	0	0	1.57
	(8)	(6)	(0.5)	(80)	(0)	(0)	(0.18)
22	70	100	2.1	360	0	0.2	0.71
	(4.2,0.2)	(4.6,0.3)	(0.7)	(5.9,0.4)	(0)	(0.2)	(0.07)
23	0	20	13.0	0	0	0.3	1.10
	(0)	(3.0,0.0)	(2.6,0.6)	(0)	(0)	(0.1)	(0.17)
24	130	80	2.0	2240	1.0	0+	0.72
	(5)	(4)	(0.5)	(110)	(0.5)	(0.2,0.4)	(0.07)
25	0	30	11.8+	50	0	0.7+	0.79
	(0)	(3.4,0.3)	(3.4,0.9)	(3.9,0.6)	(0)	(0.8,0.4)	(-0.23,0.30)
26	150	120	0	2720	6.8	0	1.52
	(10)	(7)	(0)	(120)	(0.5)	(0)	(0.16)
27	140	90	2.0	2990	4.0	0	1.30
	(0)	(4)	(0)	(100)	(1.4,0.5)	(0)	(0.26,0.15)
28	140	80	0.8	2140	0	0	1.08
	(4)	(3)	(0.3)	(60)	(0)	(0)	(0.09)
29	90	120	14.3	480+	2.8	1.9	0.80
	(4.5,0.3)	(4.8,0.3)	(3.1)	(21.9,7.9)	(1.0,0.6)	(0.6,0.6)	(0.05)
30	180	100	8.6+	1410	3.2	0.8+	1.13
	(24)	(4.6,0.8)	(2.9,0.5)	(330)	(1.0,0.6)	(0.8,0.2)	(0.09)
31	120	60	1.9+	1830	0	0.1	0.72
	(4.8,0.1)	(4.2,0.1)	(1.4,0.6)	(7.5,0.2)	(0)	(0.1)	(-0.33,0.35)
32	0	60+	6.4	0	0	0	1.04
	(0)	(7.7,0.6)	(0.0)	(0)	(0)	(0)	(0.02)
F ratio	63.89	10.59	12.34	67.87	31.46	8.37	4.12
	***	***	***	***	***	***	***

*** $P<0.001$

APPENDIX VI

The means for the soil data for the 12 TWINSPAN vegetation classification groups in $\mu g\ g^{-1}$; these values and those for % loss-on-ignition are expressed for soil oven dried at 105°C. The type of mean given depends on the normality of the data. Arithmetic means are given with a single value in parenthesis for standard error. Geometric means arising from $\log_e$ and square root transformations (the latter indicated by +) are given with values in parentheses for the transformed mean followed by the transformed standard deviation.

Class	pH	% LOI	Total N	Total P	Exch K	Exch Na	Exch Ca	Exch Mg
1	5.0	14.0+	3410	760	72.4+	25.0+	46.3	54.2+
	(0.4)	(3.75,0.97)	(1060)	(210)	(8.51,2.84)	(5.00,1.85)	(3.84,0.88)	(7.36,2.69)
2	5.1	16.7	4250	750	106.7	33.9	90.2	105.0
	(0.2)	(2.81,0.20)	(8.35,0.31)	(9)	(4.67,0.25)	(3.52,0.44)	(4.50,0.35)	(4.65,0.53)
3	4.3	31.1	6150+	1210+	224.9	66.8	111.2	98.0
	(1.47,0.11)	(13.2)	(78.43,18.80)	(34.84,7.54)	(110)	(4.20,0.91)	(4.71,0.39)	(4.58,0.21)
4	4.4	18.5	4610	960	186.9	69.9	77.9	78.2
	(0.2)	(2.92,0.54)	(8.44,0.49)	(380)	(75)	(4.25,0.92)	(4.36,0.48)	(16.4)
5	5.3	3.8	1280	350	12.4	3.2+	11.5	12.9
	(1.67,0.05)	(1.34,0.71)	(7.15,0.46)	(5.86,0.44)	(2.51,0.82)	(1.77,1.35)	(2.44,0.88)	(2.56,0.76)
6	5.1	3.3	1150	280	12.3	6.9	11.0	14.9
	(1.63,0.09)	(1.20,0.49)	(7.05,0.34)	(5.64,0.65)	(2.51,0.58)	(4.9)	(2.40,0.98)	(2.70,0.80)
7	6.0	5.4	2080	690+	31.1	32.1	238.3	231.8
	(0.4)	(1.68,0.83)	(7.64,0.66)	(26,17,8.00)	(3.44,0.66)	(3.47,0.97)	(5.47,0.78)	(5.45,0.85)
8	5.8	3.9	1760	640+	13.9	13.7	77.2	67.7
	(0.5)	(1.37,0.78)	(7.47,0.41)	(25.37,5.78)	(2.63,0.78)	(2.62,1.13)	(4.35,1.19)	(4.21,1.18)
9	6.0	53.1	11800	1620	369.0+	382.4	1273.3	1870.5
	(0.4)	(23.0)	(3460)	(320)	(19.21,5.75)	(145)	(454)	(780)
10	5.6	20.7+	5900	950	133.6	150.4+	488.8+	493.3+
	(0.4)	(4.55,1.58)	(2940)	(6.85,0.70)	(76)	(12.26,6.66)	(22.11,9.20)	(22.21,9.50)
11	5.4	9.3	2740	630	33.8	32.8+	122.6+	84.0+
	(1.68,0.06)	(2.22,0.87)	(7.92,0.53)	(290)	(3.52,1.06)	(5.73,4.47)	(11.07,5.07)	(9.16,3.97)
12	4.8	45.7	8940	1010	257.2	224.3	168.4	125.0
	(1.57,0.08)	(17.8)	(3550)	(340)	(130)	(147)	(5.13,0.84)	(4.83,0.70)

Class	Total Co	Total Cr	Exch Fe	Total Ni	Exch Ni	Exch Zn	Mg/Ca
1	50	60	3.9+	290+	0.0	0.17+	1.01
	(34)	(40)	(1.97,0.46)	(16.93,11.40)	(0)	(0.41,0.40)	(0.0079,0.554)
2	40	50	6.4	90	0.0	0.00	1.16
	(28)	(3.97,0.20)	(0.2)	(4.49,1.72)	(0)	(0)	(0.15,0.25)
3	10+	10+	9.2	0	0.0	0.33	0.88
	(2.36,3.15)	(3.18,2.60)	(2.22,0.66)	(0)	(0)	(0.23)	(-0.13,0.34)
4	0	0	7.5	0	0.0	0.37	1.02
	(0)	(0)	(1.98,0.34)	(0)	(0.0)	(0.27)	(0.28)
5	120	70+	1.5	2040	0.1	0.00	1.13
	(37)	(8.18,1.28)	(1.5)	(812)	(-1.67,1.26)	(0)	(0.12,0.44)
6	110	60	0.6+	2130	0.0	0.00	1.39+
	(15)	(12)	(0.80,0.81)	(441)	(0)	(0)	(1.18,0.18)
7	130	110	0.6+	2040	3.8	0.00	0.97
	(32)	(4.70,0.47)	(0.74,0.93)	(749)	(3.3)	(-11.06,2.14)	(-0.03,0.42)
8	120	80	1.4+	2060	2.2+	0.00	0.88
	(38)	(4.33,0.40)	(0.72,0.82)	(866)	(1.10,0.92)	(0)	(-0.13,0.46)
9	140	100+	3.5+	1340+	18.8	0.83+	1.47
	(66)	(9.80,5.22)	(1.87,1.06)	(36.65,10.30)	(2.94,0.50)	(0.91,0.57)	(0.31)
10	140	90	4.4	1550	3.7+	0.24+	0.99
	(45)	(4.55,0.39)	(3.3)	(693)	(1.92,1.23)	(0.49,0.47)	(-0.13,0.34)
11	100	70	3.1	1590	0.6+	0.14+	0.71
	(42)	(4.23,0.45)	(2.5)	(819)	(0.74,0.85)	(0.37,0.39)	(-0.35,0.37)
12	10+	50+	10.8	60	0.4+	0.41+	0.74
	(3.59,4.09)	(7.33,3.01)	(6.3)	(4.06,1.95)	(0.62,0.85)	(0.64.0.53)	(-0.30,0.40)

Appendix VII

The elemental concentrations of the plant species analyzed.
Replicates listed one on each line for each quadrat,
and are for the same subsample except for nitrogen.
All values ug g-1 dry weight.

Agrostis canina

Quad rat	N	K	Na	Ca	Mg	Co	Cr	Fe	Mn	Ni	Zn
2	12700	5500	211	1070	1050	0.0	0.0	760	170	0.0	134.7
	13200	7770	260	1010	2470	0.0	0.0	1570	148	0.0	150.9
	13200	7520	377	950	1230	0.0	0.0	610	144	0.0	81.9
11	-	6010	293	1160	1090	0.0	0.0	590	77	0.0	66.8
	-	5640	362	1070	990	0.0	0.0	190	82	0.0	77.0
	-	7240	346	870	940	0.0	0.0	250	91	0.0	59.4
31	12600	6150	367	1170	8800	16.7	16.7	5780	145	100.0	63.3
	13400	7010	458	1010	6830	16.3	16.3	4040	163	81.7	68.6
	13400	7170	507	1180	6310	16.3	16.3	3380	157	81.7	55.6
61	10800	4140	349	1630	7180	16.6	16.6	5930	191	99.7	81.4
	9900	4780	279	1410	2660	15.5	15.5	1810	206	31.0	69.7
	9600	4650	289	1800	9290	16.1	16.1	8310	227	128.6	62.7
151	11000	5610	233	1100	2000	16.7	16.7	2280	347	0.0	110.0
	12500	7920	210	1380	1660	15.0	0.0	1450	235	0.0	82.3
	11700	7060	197	1100	2060	16.5	16.5	2420	257	0.0	108.6
211	10300	7780	245	1220	1330	15.3	15.3	1060	131	0.0	125.4
	10600	6230	381	1520	2070	15.2	15.2	1970	204	0.0	118.9
	11500	6440	226	1690	1900	16.1	16.1	1270	211	0.0	133.9
311	12000	7170	287	1180	1470	16.0	16.0	6370	217	0.0	123.0
	11600	7840	418	1040	920	0.0	0.0	3160	209	0.0	143.8
	11300	7680	246	1030	890	0.0	15.4	1520	221	0.0	106.1

- not determined

Arenaria norvegica ssp *norvegica* Collected from Q73

Part	N	K	Na	Ca	Mg	Co	Cr	Fe	Mn	Ni	Zn
Shoot	-	14200	975	375	10800	25	50	6500	100	250	68
	-	11470	686	343	8726	25	49	5880	98	196	44
	-	13950	950	350	9200	25	50	5500	185	200	38
Flower	-	6180	1765	1030	8530	147	0	2940	118	147	59

- not determined

Calluna vulgaris

Quadrat	N	K	Na	Ca	Mg	Co	Cr	Fe	Mn	Ni	Zn
2	13900	5890	667	2050	1410	0.0	0.0	420	468	0.0	34.8
	13900	5700	637	2340	1670	0.0	0.0	460	374	0.0	32.7
	13800	5910	576	2350	1660	0.0	0.0	460	373	0.0	29.6
11	11300	4300	482	2560	2110	0.0	0.0	630	149	0.0	16.6
	11600	3660	798	3070	2200	0.0	0.0	450	343	16.0	28.7
	12200	3250	817	2610	2040	0.0	0.0	290	332	0.0	24.5
31	13200	4980	583	2930	5950	0.0	16.7	3470	245	66.7	38.3
	12900	4970	654	3020	4890	0.0	15.6	1990	260	46.7	23.4
	13200	5060	730	2860	3970	0.0	15.9	2030	221	31.7	76.2
61	13000	4150	1000	2730	3250	0.0	0.0	1630	142	16.7	51.7
	12100	3740	828	3080	2640	0.0	0.0	750	88	15.6	34.4
	13900	4170	1194	2780	2790	0.0	0.0	1170	203	14.9	29.9
151	12600	6000	759	2560	2780	15.8	15.8	2820	443	0.0	44.3
	12900	6090	775	2820	2660	16.5	16.5	1950	419	0.0	56.1
	12000	6280	712	2620	2650	16.6	16.6	2290	436	0.0	31.5
211	13400	6290	473	3150	1780	0.0	0.0	920	341	0.0	33.1
	12600	6070	493	3240	2140	0.0	0.0	1780	345	0.0	34.6
	12900	6890	674	3240	2010	0.0	0.0	1120	411	0.0	36.2

Festuca vivipara

Quad rat	N	K	Na	Ca	Mg	Co	Cr	Fe	Mn	Ni	Zn
2	11200	3170	182	850	940	0.0	0.0	680	109	0.0	87.9
	9800	3610	205	730	1020	0.0	0.0	550	125	0.0	39.4
	10200	4150	167	780	880	0.0	0.0	520	107	0.0	115.0
11	8800	5040	193	730	970	0.0	0.0	450	48	0.0	55.1
	7800	7130	171	950	1820	0.0	0.0	1230	65	0.0	35.7
	7500	4630	180	990	1650	0.0	0.0	1030	72	0.0	28.4
31	10800	3210	306	1660	15320	16.1	32.3	8370	200	161.3	41.9
	10700	3370	371	1080	8240	16.1	0.0	3690	134	64.5	27.4
	10800	4650	317	1350	8050	16.7	16.7	3820	142	66.7	33.3
61	7300	3320	242	1580	5790	15.1	15.1	4380	123	60.6	34.8
	10300	2790	234	1010	3610	15.6	0.0	3260	123	31.2	32.7
	9900	2970	233	800	1860	16.1	0.0	1810	91	16.6	26.6
151	-	6780	272	850	1800	15.1	15.1	1800	97	0.0	48.4
	-	5790	258	840	2000	0.0	0.0	1760	113	0.0	56.5
	-	4720	310	950	1720	0.0	16.3	1620	114	0.0	45.8
171	-	5810	291	710	470	0.0	0.0	130	113	0.0	103.6
	-	2800	182	800	480	0.0	0.0	150	126	0.0	34.8
211	8200	6310	237	1060	1270	0.0	0.0	1090	89	0.0	57.0
	10400	7130	276	930	1100	0.0	0.0	800	94	0.0	43.8
	10300	6130	307	990	840	0.0	0.0	630	76	0.0	34.0
311	8700	5910	296	950	480	0.0	0.0	210	133	0.0	36.2
	7400	4360	234	970	550	0.0	0.0	280	150	0.0	56.3
	10500	5990	317	920	520	0.0	0.0	220	135	0.0	85.0

\- not determined

Plantago maritima

Quadrat	N	K	Na	Ca	Mg	Co	Cr	Fe	Mn	Ni	Zn
2	11700	5390	2450	3370	6880	10.0	10.0	4370	135	60.0	124.0
	10600	4855	2579	3065	10490	19.5	19.5	8240	165	97.3	115.8
	11400	5524	3673	2910	12190	9.5	19.1	6650	136	95.4	93.5
11	11600	6284	1870	4779	13020	28.6	18.2	8090	193	191.5	35.6
	11500	5286	1626	4859	16420	27.4	18.6	11680	247	306.6	59.5
	10300	6228	2005	4357	9870	27.9	8.9	6030	243	231.7	43.7
31	10900	5337	5569	4464	30630	17.8	26.7	11820	193	276.2	58.8
	12100	7428	3492	4145	35080	27.2	27.2	12670	203	281.2	50.8
	9900	6849	6411	4046	19560	19.9	19.9	6830	142	159.0	54.7
61	8200	4512	1972	5204	14890	19.2	28.9	6990	150	198.8	83.7
	9000	3224	1033	4418	43620	35.9	44.9	22420	344	475.9	68.2
	9700	4490	1650	5270	29280	30.0	40.0	15970	288	390.0	72.0
151	11000	8306	4306	3376	6710	9.9	19.8	4430	147	29.7	101.0
	8100	7460	3835	3187	4960	10.0	19.9	3260	156	29.9	149.4
	13800	12834	5385	3043	4820	9.9	9.9	2340	124	19.8	142.3
211	10900	5565	4450	4068	16800	19.6	48.9	13570	197	117.4	91.9
	13800	6412	2287	3318	5720	9.8	19.5	4350	123	38.9	144.0
	12800	3821	3258	4350	14120	18.2	54.7	12650	157	91.2	93.0
311	13400	9496	4165	4479	5270	9.8	19.6	2520	83	19.6	82.3
	14800	10167	4594	4229	4820	9.9	19.8	3630	121	19.8	89.9
	8200	9351	4005	4371	4840	0.0	0.0	840	62	96.0	118.7

Rhacomitrium lanuginosum

Quadrat	N	K	Na	Ca	Mg	Co	Cr	Fe	Mn	Ni	Zn
2	6100	663	253	1657	12180	9.7	9.7	8290	93	117.0	33.1
	7000	774	347	2361	5350	9.9	9.9	5650	58	49.6	24.8
	6500	978	190	1228	3880	10.0	18.0	5990	57	29.9	34.5
	-	1192	186	1331	3180	9.3	0.0	3170	39	18.6	27.0
11	7500	860	313	1260	2430	9.8	0.0	2150	31	19.5	23.4
	5500	1153	215	1133	2480	9.8	9.8	2150	39	19.5	37.1
	6300	864	216	1218	12170	19.6	19.6	12770	167	127.7	30.4
	-	750	164	856	2810	9.6	0.0	1830	28	19.2	17.3
31	7300	843	287	1456	22220	19.2	19.2	14370	132	229.9	44.1
	7200	1153	313	1426	17770	19.5	19.5	10550	117	195.4	25.4
	7000	858	292	1628	32160	19.5	19.5	21450	167	302.2	25.3
	-	672	257	1541	26270	19.8	19.8	15610	143	256.9	26.7
61	6600	568	274	3126	11550	9.8	19.6	9210	115	147.0	42.1
	6000	452	285	3592	15640	19.7	19.7	12990	173	196.8	47.2
	6300	580	230	2610	10090	10.0	20.0	9500	102	130.0	43.0
	-	775	298	2097	11520	19.9	19.9	11330	108	149.1	27.8
151	8000	1235	299	1496	10510	19.3	28.9	15340	164	106.1	28.9
	7100	768	482	2490	26750	29.5	49.2	29420	275	226.3	49.2
	7900	754	474	2543	28230	29.0	38.7	28910	278	222.4	44.5
	-	980	250	1290	8490	10.0	30.0	15900	147	90.0	47.0
171	6300	1067	207	543	610	9.9	0.0	1280	27	0.0	46.4
	6500	1477	529	798	770	10.0	0.0	690	51	0.0	46.9
	5900	1254	343	568	680	9.8	0.0	580	43	0.0	23.5
	-	966	187	730	620	9.9	0.0	680	35	0.0	25.6
211	8100	1275	299	1384	3330	10.0	19.9	7570	78	29.9	30.9
	9000	1173	288	1153	4710	9.9	19.9	7950	71	39.8	33.8
	8600	1163	286	1282	4180	9.9	19.7	8090	71	29.6	28.6
	-	1168	198	1406	4900	9.9	19.8	8710	94	39.6	31.7
311	7600	968	79	613	820	0.0	9.9	2960	25	0.0	21.7
	8200	974	89	656	870	9.9	9.9	2880	24	0.0	21.9
	7500	974	99	795	1050	9.9	9.9	3480	32	0.0	23.9
	-	778	100	748	910	10.0	10.0	2600	27	0.0	20.0

- not determined

Appendix VIII The initial dry weights (g) of *Agrostis canina* used in experiments 1 & 2.

Race	Experiment 1 Whole Plant	Experiment 1 Shoot	Experiment 2 Whole Plant	Experiment 2 Shoot
1	0.0136	0.0111	0.0263	0.0205
	0.0126	0.0109	0.0117	0.0102
	0.0152	0.0105	0.0169	0.0145
	0.0109	*		
	0.0180	*		
	0.0232	*		
2	0.0175	0.0110	0.0213	0.0167
	0.0139	0.0097	0.0216	0.0188
	0.0247	0.0195	0.0380	0.0306
	0.0166	0.0124		
	0.0175	0.0140		
	0.0308	0.0245		
3	0.0089	0.0078		
	0.0168	0.0142		
	0.0190	0.0122		
	0.0110	0.0092		
	0.0195	0.0148		
	0.0349	0.0242		

* not determined : Mean for six replicates = 0.0124

Appendix VIII The initial dry weights (g) of *Agrostis canina* used in experiments 1 & 2.

Race	Experiment 1		Experiment 2	
	Whole Plant	Shoot	Whole Plant	Shoot
1	0.0136	0.0111	0.0263	0.0205
	0.0126	0.0109	0.0117	0.0102
	0.0152	0.0105	0.0169	0.0145
	0.0109	*		
	0.0180	*		
	0.0232	*		
2	0.0175	0.0110	0.0213	0.0167
	0.0139	0.0097	0.0216	0.0188
	0.0247	0.0195	0.0380	0.0306
	0.0166	0.0124		
	0.0175	0.0140		
	0.0308	0.0245		
3	0.0089	0.0078		
	0.0168	0.0142		
	0.0190	0.0122		
	0.0110	0.0092		
	0.0195	0.0148		
	0.0349	0.0242		

* not determined : Mean for six replicates = 0.0124

Dry weights (g) of <u>Agrostis</u> <u>canina</u> from Growth Experiments 1

See Chapter 7 for levels of Mg , Ca , Ni and races of <u>A</u>. <u>canina</u>

Experiment 1 Level Mg	Level Ca	Level Ni	Whole plant harvest 1: Replicate / Race	1	2	3	Whole plant harvest 2: Replicate / Race	1	2	3
1	1	1	1	0.0344	0.0582	0.0163	1	0.0586	0.0830	0.0285
			2	0.0213	0.0361	0.0432	2	0.0889	0.0505	0.0672
			3	0.0193	0.0312	0.0213	3	0.0353	0.0663	0.0399
		2	1	0.0766	0.0282	0.0350	1	0.0274	0.0557	0.0520
			2	0.0375	0.0264	-	2	0.0611	0.0320	0.0654
			3	0.0166	0.0116	-	3	0.0721	0.0251	0.0214
	2	1	1	0.0185	0.0206	0.0216	1	0.0701	0.0654	0.0063
			2	0.0315	0.0262	0.0400	2	0.0267	0.0393	0.0219
			3	0.0265	0.0329	0.0190	3	0.0572	0.0665	0.0405
		2	1	0.0377	0.0317	0.0341	1	0.1481	0.0593	0.1132
			2	0.0309	0.0321	0.0366	2	0.0431	0.0576	0.0469
			3	0.0129	0.0145	0.0274	3	0.0406	0.0259	0.0210
2	1	1	1	0.0142	0.0397	0.0179	1	0.0766	0.0712	0.0309
			2	0.0139	0.0348	0.0372	2	0.0939	0.0865	0.0553
			3	0.0144	0.0143	0.0133	3	0.0406	0.0356	0.0508
		2	1	0.0300	0.0369	0.0472	1	0.0654	0.0876	0.1761
			2	0.0343	0.0195	0.0302	2	0.0360	0.0466	0.0627
			3	0.0174	0.0233	0.0131	3	0.0482	0.0482	0.0590
	2	1	1	0.0328	0.0231	0.0213	1	0.0341	0.0764	0.0037
			2	0.0189	0.0181	0.0321	2	0.0892	0.0570	0.0612
			3	0.0248	0.0265	0.0244	3	0.0559	0.0384	0.0926
		2	1	0.0504	0.0277	0.0253	1	0.2029	0.0643	0.0610
			2	0.0288	0.0395	0.0405	2	0.0558	0.0810	0.0412
			3	0.0200	0.0213	-	3	0.0460	0.0829	0.0372

- replicate died

Experiment 1

Level Mg	Level Ca	Level Ni	Race	Shoot harvest 1, Replicate 1	Shoot harvest 1, Replicate 2	Shoot harvest 1, Replicate 3	Race	Shoot harvest 2, Replicate 1	Shoot harvest 2, Replicate 2	Shoot harvest 2, Replicate 3
1	1	1	1	0.0283	0.0468	0.0152	1	0.0520	0.0711	0.0256
			2	0.0177	0.0307	0.0391	2	0.0741	0.0448	0.0600
			3	0.0169	0.0195	0.0205	3	0.0302	0.0647	0.0392
		2	1	0.0653	0.0238	0.0309	1	0.0246	0.0489	0.0473
			2	0.0343	0.0223	-	2	0.0515	0.0294	0.0545
			3	0.0157	0.0114	-	3	0.0616	0.0229	0.0191
	2	1	1	0.0166	0.0187	0.0183	1	0.0624	0.0569	0.0773
			2	0.0310	0.0226	0.0347	2	0.0235	0.0375	0.0202
			3	0.0245	0.0279	0.0182	3	0.0484	0.0533	0.0351
		2	1	0.0332	0.0268	0.0295	1	0.1227	0.0511	0.1000
			2	0.0265	0.0279	0.0319	2	0.0353	0.0499	0.0417
			3	0.0121	0.0111	0.0246	3	0.0341	0.0238	0.0206
2	1	1	1	0.0123	0.0340	0.0159	1	0.0687	0.0635	0.0359
			2	0.0135	0.0305	0.0335	2	0.0835	0.0769	0.0486
			3	0.0133	0.0116	0.0123	3	0.0365	0.0351	0.0462
		2	1	0.0269	0.0323	0.0408	1	0.0571	0.0752	0.1512
			2	0.0267	0.0177	0.0345	2	0.0327	0.0409	0.0510
			3	0.0164	0.0205	0.0120	3	0.0419	0.0437	0.0514
	2	1	1	0.0305	0.0192	0.0194	1	0.0312	0.0690	0.0756
			2	0.0164	0.0168	0.0281	2	0.0825	0.0545	0.0535
			3	0.0220	0.0246	0.0212	3	0.0476	0.0341	0.0813
		2	1	0.0434	0.0249	0.0204	1	0.1604	0.0551	0.0541
			2	0.0232	0.0321	0.0326	2	0.0498	0.0747	0.0713
			3	0.0174	0.0193	-	3	0.0384	0.0707	0.0324

- replicate died

Experiment 2

Solution Type	Level Ni	Replicate Race	Whole plant weight 1	2	3	Replicate Race	Shoot weight 1	2	3
1	1	1	0.1568	0.1336	0.0460	1	0.1288	0.1079	0.0403
		2	0.0552	0.0775	0.1242	2	0.0485	0.0681	0.1016
	2	1	0.0458	0.0435	0.1834	1	0.0399	0.0375	0.1557
		2	0.1188	0.0739	0.0832	2	0.0977	0.0617	0.0695
2	1	1	0.0316	0.0484	-	1	0.0293	0.0431	-
		2	0.0512	0.0575	0.0385	2	0.0447	0.0522	0.0354
	2	1	0.0936	0.0578	0.0846	1	0.0759	0.0471	0.0673
		2	0.0598	0.0630	0.0504	2	0.0525	0.0555	0.0441

- replicate died

Appendix IX The initial metal concentrations (ug g-1) of the tillers of Agrostis canina used in experiments 1 & 2. See Chapter 7 for races of A. canina.

Race	Exp.No.	K	Na	Ca	Mg	Fe	Mn	Ni	Zn
1	1	13700	984	8400	643	322	505	<50	92
	1	15100	483	6910	808	263	449	<50	90
	2	13300	445	6520	574	334	367	<50	61
2	1	16600	364	5770	504	146	250	<50	52
	1	16500	355	4620	510	166	332	<50	47
	2	15400	424	4890	485	347	235	<50	54
3	1	16600	1221	6940	1070	180	289	<50	45
	1	18600	466	5540	600	163	163	<50	64

Metal concentrations (ug g-1) in <u>Agrostis</u> <u>canina</u> from Growth Experiments 1.

See Chapter 7 for levels of Mg , Ca , Ni and races of <u>A.</u> <u>canina</u>

Experiment 1			Potassium concentration harvest 1				Potassium concentration harvest 2			
			Replicate	1	2	3	Replicate	1	2	3
Mg	Ca	Ni	Race				Race			
1	1	1	1	15800	26700	24700	1	20700	21800	19500
			2	24000	26000	22400	2	29000	28500	24200
			3	34000	25600	26800	3	26500	28100	26800
		2	1	27900	17900	25100	1	16300	18400	22700
			2	22600	28000	-	2	21300	18700	30300
			3	23900	26300	-	3	25600	31700	30100
	2	1	1	18100	17400	23200	1	29300	24600	25200
			2	21000	29900	25200	2	17000	21300	14900
			3	30600	25100	25200	3	31000	32400	24200
		2	1	29400	32700	27100	1	29800	20000	23000
			2	20700	21500	22000	2	14900	26600	24000
			3	22700	22500	25400	3	14700	27300	21900
2	1	1	1	18300	22100	22000	1	18900	22500	21400
			2	22200	25400	20100	2	26600	23100	21600
			3	20700	15100	26400	3	23300	18500	22200
		2	1	23400	27900	23300	1	25400	19900	28900
			2	29000	19800	19600	2	24500	25700	31900
			3	18300	14600	27600	3	23300	21700	28200
	2	1	1	29500	23400	21900	1	19200	25700	25800
			2	24400	20800	32900	2	30000	21600	23800
			3	29500	22400	22400	3	22600	27100	29300
		2	1	27100	29100	14700	1	25400	20900	21300
			2	27000	27300	28400	2	26100	32200	25300
			3	31600	27200	-	3	34500	26200	22400

- replicate died

Experiment 1

Mg	Ca	Ni	Race	Sodium concentration harvest 1, Replicate 1	Replicate 2	Replicate 3	Sodium concentrations harvest 2, Replicate 1	Replicate 2	Replicate 3
1	1	1	1	4082	1282	2961	1028	5200	4999
			2	4942	1302	3387	2595	3237	2627
			3	5620	9359	1030	3229	4323	2105
		2	1	2102	3152	4045	2642	2146	2010
			2	2770	5269	-	2764	5270	1744
			3	2070	1974	-	2801	5678	3534
	2	1	1	3464	1738	1093	1724	2810	3295
			2	2337	2876	1440	1596	5870	9285
			3	2142	6003	1721	2843	3517	1922
		2	1	2108	933	3219	979	2592	1950
			2	5564	1702	1411	6018	2806	4260
			3	3099	6080	3454	10115	3255	5220
2	1	1	1	4269	1617	943	3276	3625	11404
			2	6112	3198	3581	5711	4257	4266
			3	1316	6096	2846	1370	7547	2543
		2	1	2902	4644	5640	3898	2324	3160
			2	5242	6072	5075	9256	9715	3038
			3	1676	6100	4607	4716	8637	9720
	2	1	1	3772	3776	5672	8410	5140	3310
			2	3048	3571	4005	2606	10373	6725
			3	2613	3454	2830	2152	6963	2341
		2	1	2938	2811	4287	2719	1044	2911
			2	3234	2259	8997	6225	4254	2071
			3	3449	9194	-	4231	2797	9264

- replicate died

Experiment 1

Mg	Ca	Ni	Race	Calcium concentration harvest 1, Replicate 1	2	3	Race	Calcium concentration harvest 2, Replicate 1	2	3
1	1	1	1	6622	4993	6662	1	4473	3837	5471
			2	5577	4192	4058	2	3875	2902	3419
			3	6286	9166	2135	3	4554	2741	2616
		2	1	4145	6667	5461	1	5283	4395	4549
			2	3681	5549	-	2	2861	3995	3580
			3	4696	6250	-	3	3167	6443	4581
	2	1	1	6702	6752	5669	1	2847	2985	3359
			2	4231	3926	3636	2	2341	3135	2724
			3	6477	5062	4700	3	2275	1680	2634
		2	1	4706	4060	4023	1	3040	3619	3250
			2	3253	4256	4273	2	2124	2254	3300
			3	6921	5292	4928	3	4251	4410	1700
2	1	1	1	8437	5549	4795	1	5187	6521	6716
			2	4723	4961	4513	2	4679	3819	3829
			3	6862	4418	4371	3	5309	3026	5708
		2	1	5756	5147	4935	1	6504	4499	4744
			2	4727	5295	4821	2	5011	4613	3405
			3	4191	7747	4980	3	6716	5405	5905
	2	1	1	3977	5664	4705	1	4365	3747	3492
			2	5410	6919	5384	2	3106	3374	3199
			3	4828	5029	5129	3	5329	4655	3557
		2	1	4464	4066	6064	1	3824	4245	3627
			2	3827	3622	3807	2	3188	3802	2685
			3	5101	5633	-	3	3222	4478	4439

- replicate died

Experiment 1

Mg	Ca	Ni	Race	Mg conc. harvest 1, Replicate 1	Replicate 2	Replicate 3	Race	Mg conc. harvest 2, Replicate 1	Replicate 2	Replicate 3
1	1	1	1	3415	3524	2632	1	4521	3802	6057
			2	4377	2198	2939	2	4752	3906	3378
			3	4437	5641	1586	3	3892	3435	2297
		2	1	4737	3780	5258	1	4166	4803	4867
			2	2770	5269	-	2	3880	4505	3856
			3	3025	1974	-	3	3898	5569	4712
	2	1	1	3464	2005	3552	1	4652	4961	6234
			2	2660	4203	2520	2	3405	4336	5942
			3	2856	4749	2383	3	5273	5253	3845
		2	1	4669	4105	5506	1	5957	6504	6700
			2	4809	2778	2195	2	5098	5260	5700
			3	3306	6080	3454	3	6011	3675	3642
2	1	1	1	1830	1470	1415	1	1729	2423	2610
			2	926	1230	1194	2	1659	1641	1516
			3	940	1077	1016	3	1815	961	1758
		2	1	1778	2554	1349	1	2913	1743	2648
			2	1685	1836	1160	2	1874	2108	1935
			3	914	1220	976	3	2179	1916	2211
	2	1	1	2050	2213	1805	1	2924	2878	2499
			2	1524	1042	1424	2	2379	1538	2031
			3	1363	1727	1768	3	2021	1796	2110
		2	1	2765	2510	1837	1	2934	3382	2379
			2	1617	1324	1846	2	2083	2831	2264
			3	2155	1554	-	3	2441	2566	2663

- replicate died

Experiment 1

Mg	Ca	Ni	Race	Iron concentration harvest 1, Replicate 1	Replicate 2	Replicate 3	Race	Iron concentration harvest 2, Replicate 1	Replicate 2	Replicate 3
1	1	1	1	167	160	493	1	96	70	98
			2	141	162	128	2	135	56	83
			3	444	256	244	3	83	116	128
		2	1	153	315	162	1	102	51	53
			2	219	224	-	2	97	85	92
			3	159	219	-	3	81	109	131
	2	1	1	151	134	273	1	80	88	97
			2	161	221	72	2	106	133	124
			3	204	179	137	3	103	94	71
		2	1	151	93	339	1	61	49	75
			2	189	90	70	2	142	100	120
			3	207	225	102	3	220	105	243
2	1	1	1	607	220	0	1	73	79	139
			2	0	82	75	2	60	97	103
			3	0	215	203	3	205	142	100
		2	1	94	77	61	1	131	66	66
			2	94	71	72	2	76	122	98
			3	76	122	195	3	179	114	194
	2	1	1	82	130	129	1	80	72	33
			2	152	149	178	2	61	183	93
			3	227	305	118	3	105	73	62
		2	1	58	100	122	1	79	45	46
			2	108	78	77	2	100	67	70
			3	144	259	-	3	130	142	154

- replicate died

Experiment 1

Mg	Ca	Ni	Race	Manganese concentration harvest 1, Replicate 1	2	3	Race	Manganese concentration harvest 2, Replicate 1	2	3
1	1	1	1	425	539	427	1	592	451	528
			2	353	350	243	2	418	318	313
			3	444	320	232	3	414	243	281
		2	1	634	357	639	1	345	521	709
			2	241	303	-	2	378	382	464
			3	255	373	-	3	284	404	484
	2	1	1	512	495	382	1	469	531	614
			2	379	332	389	2	404	253	297
			3	286	224	278	3	331	249	370
		2	1	512	532	644	1	622	778	797
			2	273	340	361	2	382	506	474
			3	496	405	345	3	308	462	219
2	1	1	1	610	456	519	1	510	575	571
			2	352	320	216	2	326	390	432
			3	169	194	427	3	493	221	411
		2	1	468	735	356	1	907	438	404
			2	384	438	478	2	375	477	392
			3	229	390	195	3	472	366	374
	2	1	1	353	352	477	1	489	510	457
			2	305	387	320	2	391	248	411
			3	432	345	307	3	577	447	367
		2	1	685	412	380	1	301	772	453
			2	399	351	392	2	361	710	453
			3	388	285	-	3	319	450	432

-replicate died

Experiment 1

Mg	Ca	Ni	Race	Nickel concentration harvest 1, Replicate 1	Harvest 1, Replicate 2	Harvest 1, Replicate 3	Nickel concentration harvest 2, Replicate 1	Harvest 2, Replicate 2	Harvest 2, Replicate 3
1	1	1	1	83	53	164	96	70	98
			2	141	81	64	101	56	42
			3	0	0	0	83	77	64
		2	1	0	0	0	0	0	0
			2	0	0	-	0	0	0
			3	0	0	-	0	0	0
	2	1	1	0	134	137	80	88	97
			2	81	111	72	106	133	124
			3	0	90	0	103	94	142
		2	1	0	0	0	0	0	0
			2	0	0	0	0	0	0
			3	0	0	0	0	0	0
2	1	1	1	203	147	0	109	118	209
			2	0	82	75	120	65	51
			3	0	0	0	137	142	108
		2	1	0	0	0	0	0	0
			2	0	0	0	0	0	0
			3	0	0	0	0	0	0
	2	1	1	82	130	129	240	181	165
			2	0	0	89	364	92	107
			3	0	102	0	157	147	154
		2	1	0	0	0	0	0	0
			2	0	0	0	0	0	0
			3	0	0	-	0	0	0

- replicate died

Experiment 1

Mg	Ca	Ni	Race	Zinc concentration harvest 1, Replicate 1	2	3	Race	Zinc concentration harvest 2, Replicate 1	2	3
1	1	1	1	83	53	99	1	40	46	70
			2	85	73	77	2	54	45	50
			3	104	128	73	3	83	58	57
		2	1	73	105	81	1	112	61	69
			2	66	101	-	2	68	102	64
			3	111	110	-	3	53	76	92
	2	1	1	136	80	82	1	52	44	52
			2	81	100	65	2	74	73	62
			3	112	125	79	3	47	52	71
		2	1	98	84	93	1	71	78	72
			2	66	63	63	2	50	60	66
			3	83	113	142	3	66	94	97
2	1	1	1	122	73	63	1	40	55	49
			2	74	57	67	2	39	42	36
			3	132	108	102	3	34	50	43
		2	1	103	77	55	1	70	60	49
			2	122	85	58	2	69	67	59
			3	167	61	117	3	54	51	49
	2	1	1	49	78	77	1	48	36	36
			2	46	60	80	2	33	46	47
			3	45	41	35	3	42	51	43
		2	1	81	90	110	1	64	68	65
			2	86	62	77	2	75	74	60
			3	72	117	-	3	52	42	54

- replicate died

Experiment 2 The metal concentrations in <u>Agrostis canina</u> (ug g-1).

See Chapter 7 for the levels of the variables and the races of <u>A. canina</u>.

Solution Type	Ni Level	Race	Replicate	K	Na	Ca	Mg	Fe	Mn	Ni	Zn
1	1	1	1	30700	1340	3170	5330	58	371	78	114
			2	31000	924	3470	4560	69	506	92	111
			3	18600	2230	4770	3630	124	353	124	74
		2	1	22100	3240	2940	3840	103	273	103	72
			2	24600	2310	3080	3650	147	360	73	81
			3	32200	1920	4080	3850	98	374	74	98
	2	1	1	23200	1250	3510	3470	188	294	0	88
			2	16000	4340	5600	4570	200	267	0	100
			3	25400	9340	3960	4500	64	443	0	126
		2	1	31700	2280	3710	4370	102	397	0	128
			2	30000	2750	3440	4400	121	401	0	121
			3	24800	2770	3280	3800	144	331	0	90
2	1	1	1	30700	2640	4440	3110	85	623	256	51
			2	27300	1680	4990	3100	58	754	464	70
			3	-	-	-	-	-	-	-	-
		2	1	28500	3020	3300	2320	168	430	224	45
			2	30200	3690	4120	2420	144	493	335	43
			3	26800	4310	2820	2220	141	445	212	42
	2	1	1	26000	1280	4310	3040	99	651	0	63
			2	23300	1590	4610	3100	53	949	0	85
			3	25600	1560	3780	3320	74	720	0	70
		2	1	21400	2900	3710	1790	95	433	0	57
			2	29700	2660	3290	2050	90	477	0	54
			3	25600	2960	2900	1850	171	472	0	57

- replicate died

APPENDIX X.

The TWINSPAN species x stands vegetation classification table (which includes the 100 most common species) is in the back pocket of the thesis. The species names are abbreviations of those in Appendix II.

APPENDIX XI

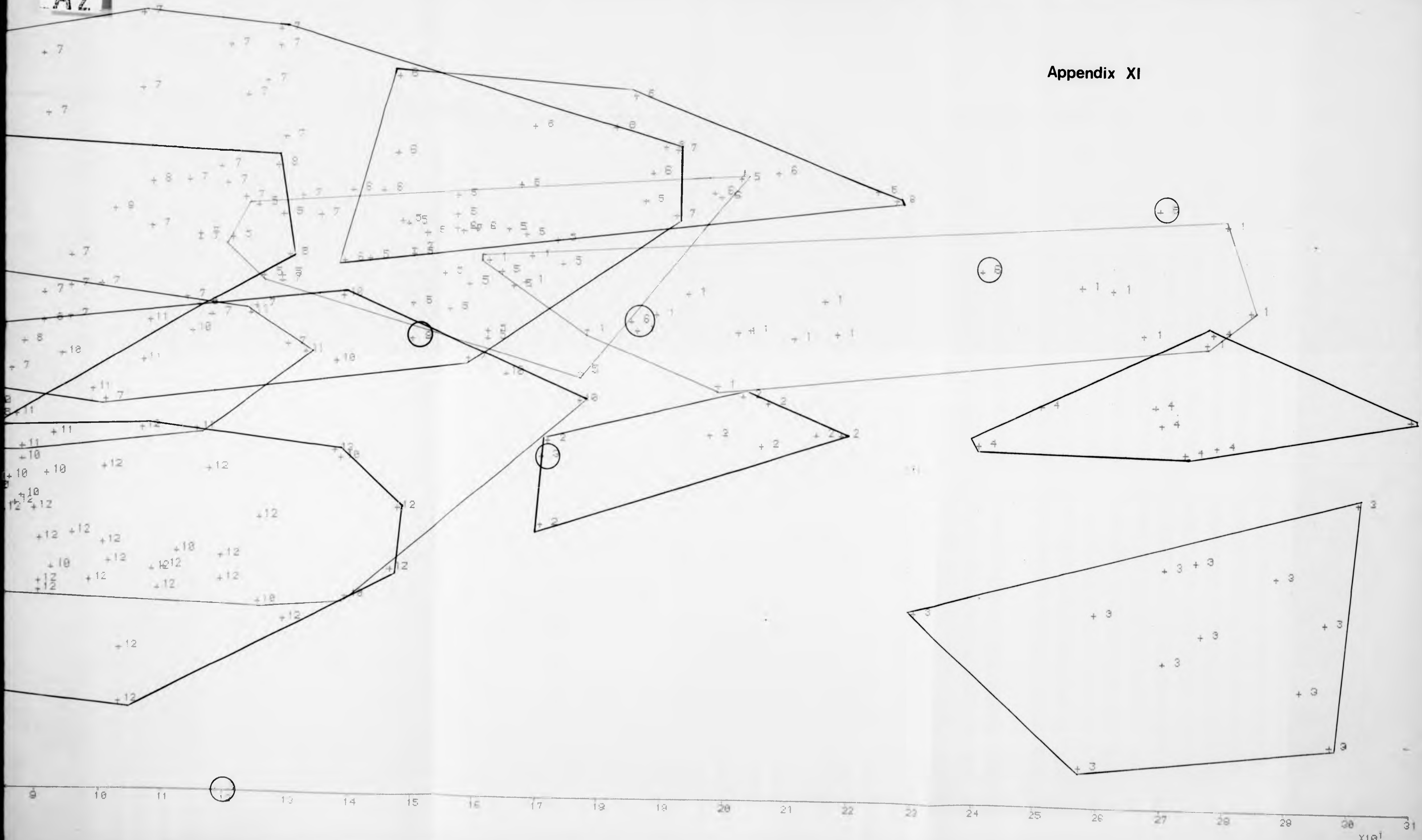
The plot of the quadrats (n=283) on the first two axes of the DECORANA vegetation ordination, by their class numbers, is in the back pocket of the thesis. Axis I is the horizontal axis, Axis II the vertical.

The vegetation classes are outlined to help show their location (with a few outlying points in some classes not included in the outlines, but individually ringed). See Chapter 2.

A1

A2

Appendix XI



Appendix X

Class:	5	6	7	8	9	10	11	12
	2 111111112222222 122	222	22 1112222222222222222 22 2	11 21113 11223	211111211111	12 1111111121122222 2	3333 13333 1222 111	1111111 11111111112 11222222211122
	173345999999999000001333503	2333333434444444444777 5	666781772225555556666677766783 4 112667777886	11523 5222011289999990457019	9000000800001	5432671111111129118899 9 22773	9000089200015556843332562444	23333333 44888888889455334444444544458888
	7924081234567902345516011446	2356789611234578914650	4695040357914567891234523728159031261527890 6	035560 31231890804567901288612	51236854579 0	2083741234589026712134917567	3347998825606790782355134490	841245789 35123567890734361234569026703412
30 POLY VULG	1 1			11 1	1 3	111 11 3222	1 1	1
27 PLAN LANC					3 21 342 2	22314 234121112		
32 PRIM VULG					21 3	2232133 3		
33 PRUN VULG					1 2	1 2		
34 RANU ACRI					133 13 2		4	
49 TRIF REPE					33 1	1		
59 HOLC LANA					254445 4 23			
67 CARE ECHI					22	3		1 1
70 CARE PULI	1 1		4 2	41 1	32333233232	22 3 44355445415412422 4 15	4331 3	23 34
71 ERIO ANGU					133 3 3 3	3		
73 JUNC ACUT					2 4 32		2	
82 BRAC RIVU						5 2		
25 PEDI SYLV			1		1323 22 2 122	33 1	2 11 1 2	11 3 22 1 2211 3 3 22
64 CARE BINE						1 23 122		232 3 3 4 32
83 BREU CHRY	2		1 1 2 1		33	1 11 223 2 3241 2 13	1	1 213 4 12 23
10 DACT MACU				1 1		1	1 21	312 1 1 113 2 12
103 ISOT MYOS								4
107 PLEU PURP	2					2	253	1 22123532
122 SPHA SPP						5	2	5 4 1 4 5125 25 244
21 LOTU CORN					4 1	42 3		
44 SUCC PRAT	1		3221	1 1 1	122221323232	342 3 22 31313223112 1 12	323 412343231111111123	1 113332 31 22 1222424 1221131 312233232
100 HYLO SPLE	1		1 1		333333 3224	32 3345 323232421211 1 211	1	2 1
112 PSEU PURU			1		2 1	1115 2 11		1 1
13 ERIC CINE	4			4 4242144325 2 2	44	1 4 4445544	4413 244343434 2445544 55	4 312 554 344 1353 4 142152454554
14 ERIC TETR				1 1 2 1 34 1 241	422344 2		3244332444552 143 4 2	3 3 4454 54
24 NART OSSI	1 2 1		1 3 32	2 322 23334431 21 3 1 4 1	2 3 4	3 3 1 2 1	354324 43 2 44535524 13 21	4 52 5 21454 4 45 5 4534 4 4 4 44
26 PING VULG			1 1 1 1 21 1 11	1 1 11 111		1	1 2 11 1 1 131	2 1
78 SCHO NIGR			2	3 54	33		5 5 43	4
79 TRIC CESP		3	1 1 43 1 5 4 542 3 455452	2 1 31 3 2		55 3 4 3 2 2	342 3 3444 44 35 4 555544	255555455 5454554553354454555355455555431
17 HYPE PULC			1 1	2 2 1 1 1	1 11	1 1 223 11 33332 1 1	11222 221 2 1 1	1 2 2
60 MOLI CAER		1	21 314243133342533213 123 1 32 23 23	23312 2254432222134233233342	55555555555	554 4455555555555555544 342	2222 5454444454555154 545344	5545545 555423 24325555443554552 5555555
20 LINU CATH		1	1 11 1 1 1	1 1	1	2 11 2 11 1		1
97 FRUL TAMA	3 11		1 1 3			234 1	11	
3 ANTH VULN			2 2 3	122221 2	1		1	
4 AREN NORV			111 2 11 1 1 11 11					2
5 ARME MARI		1	11 12 11 1 1 433 54 3 44322	1 33 1 1		5 1	1 1 1	
8 CHER SEDO			2 1 23231 1112	1				
39 SAXI OPPO			2 1 1					
48 TOFI PUSI			22			1	1	
66 CARE DIOI			422 3 34	222		2	2 1	
86 CAMP STEL			3			2		
81 BLIN ACUT	2		1 21 1 211 11 3 11 1	1 1 2		21	12 111	
18 JUNI COMM	3 1 4			3			4	
37 RUBU SAXA	3 2 33 33433 3							
134 ANTH JULA	4 1							
23 LYCO SELA	1 1		132	1		1 1	1 1 12	11 334 4410 1
29 POLY SERP	21 1		1	1	11	2 1 2 1 1	222122 1	12121 13211 11 2 3 22 2333 1
95 DIPL ALBI	1 11 1 2 2111 1		1 3	1 1 11	1 1	4321 1 11 2	1212 212 1 1	2112 2 1 2452 1 5 1452 2
19 LEON AUTU			1 3 2 2			14 12 31 42	1	2
46 THAL ALPI	2		11 1 1		2	2 453 2 1	1	3 4 2
68 CARE FLAC	2 3		232 32233333222 1553 4453455534343	3 2 11	34443344334	43 5525443 23544335534 245	3 3 33422 3243313	444435313 4 444443434 544334 44 243313312
7 CALL VULG	555455444354444425441455555555	24 1354 3 4 1 1	41124 2 1 2344 2 23 224 12 424555424	2414 344 555553253444 42343	5 1233433 1	5555215453555545555555254445	2245443454 545555555545255555	554 54555 545544543355554455 55555555455
41 SELA SELA	1 2 1 3		1 12 1 12122 1 11 1 22 1131121 2212	11 21 111 211 1 31	1	2 212 1 211221 43131	1 2 12222121111 1213322	2112
43 SOLI VIRG		1 1	122112 112221 1 21 222	1 3 1 12 1 11211	1	2 3233231 211 231	1 122 11 132 2123	2
88 CAMP FLEX				1				

Appendix X

Class:	5	6	7	8	9	10	11	12
	2 1111111122222222 122	222	22 1112222222222222222 22	2 11 21113 11223	211111211111	12 111111111211222222 2	3333 13333 1222 111	1111111 11111111112 1122222222111122
	17334599999999000001333503	23333333434444444444777	5666781772225555556666677766 7834 112667777886	11523 52220112899999904570199	9000008000001	543267111111291188999 22773	9000089200015556843332562444	23333333 44888888889455334444445444588888
	79240812345679023455160114462	35678961123457891465	04695040357914567891234523728159031261527890602	35560 312318908045679012886125	12368545796	20837412345890267121349175673	3347998825606790782355134490	841245789 35123567890734361234569026703412
30 POLY VULG	1 1			11	1 1 3	111 11 3222	1 1	1
27 PLAN LANC					3 21 342 2	22314 234121112		
32 PRIM VULG					21 3	2232133 3		
33 PRUN VULG					1 2	1 2		
34 RANU ACRI					133 13 2		4	
49 TRIF REPE					33 1	1		
59 HOLC LANA					254445 4 23			
67 CARE ECHI					22	3		
70 CARE PULI	1 1		4 2	41 1	32333233232	22 3 44355445415412422 4 15	4331 3	1 1 23 34
71 ERIO ANGU					133 3 3 3	3		
73 JUNC ACUT					2 4 32		2	
82 BRAC RIVU						5 2		
25 PEDI SYLV			1		1323 22 2 122	33 1	2 11 1 2	11 3 22 1 2211 3 3 22
64 CARE BINE						1 23 122		232 3 3 4 32
83 BREU CHRY	2		1 1 2 1		33	1 11 223 2 3241 2 13	1	1 213 4 12 23
10 DACT MACU				1 1		1	1 21	312 1 1 113 2 12
103 ISOT MYOS								4
107 PLEU PURP	2					2	253	1 22123532
122 SPHA SPP						5	2	5 4 1 4 5125 25 244
21 LOTU CORN					4 1	42 3		
44 SUCC PRAT	1		3221	1 1 1	122221323232	342 3 22 31313223112 1 12	323 41234323111111123	1 113332 31 22 12224241221131 312233232
100 HYLO SPLE	1		1 1		333333 3224	32 3345 323232421211 1 211	1	2 1
112 PSEU PURU			1		2 1	1115 2 11		1 1
13 ERIC CINE	4			4 4242144325 2 2	44	1 4 4445544 4	413 244343434 2445544 55	4 312 554 344 1353 4 142152454554
14 ERIC TETR				1 1 2 1 34 1 241	422344 2		3244332444552 143 4 2	3 3 4454 54
24 NART OSSI	1 2 1		1 3 32	2 322 23334431 21 3 1 4 1	2 3 4	3 3 1 2 1	354324 43 2 44535524 13 21	4 52 5 21454 4 45 5 4534 4 4 4 44
26 PING VULG			1 1 1 1 21 1 11	1 1 11 111		1	1 2 11 1 1 131	2 1
78 SCHO NIGR			2	3 54	33		5 5 43	4
79 TRIC CESP		3	1 1 43 1 5 4 542 3 455452	2 1 31 3 2		55 3 4 3 2 2	342 3 3444 44 35 4 555544	255555455 54545545533544545553554555555431
17 HYPE PULC			1 1	2 2 1 1 1	1 11	1 1 223 11 33332 1 1	11222 221 2 1 1	1 2 2
60 MOLI CAER		1	21 314243133342533213 123 1 32 23 23	23312 2254432222134233233342	555555555555	554 445555555555555544 342	2222 5454444454555154 545344	5545545 555423 24325555443554552555555555
20 LINU CATH		1	1 11 1 1 1	. 1 1	1	2 11 2 11 1		1
97 FRUL TAMA	3 11		1 1 3			234 1	11	
3 ANTH VULN			2 2 3	122221 2 1			1	
4 AREN NORV			111 2 11 1 1 11 11					2
5 ARME MARI		1	11 12 11 1 1 1 433 54 3 44322	1 33 1 1		5 1	1 1 1	
8 CHER SEDO			2 1 23231 1112	1				
39 SAXI OPPO			2 1 1					
48 TOFI PUSI			22			1	1	
66 CARE DIOI			422 3 34	222		2	2 1	
86 CAMP STEL			3			2		
81 BLIN ACUT	2		1 21 1 211 11 3 11 1	1 1 2		21	12 111	
18 JUNI COMM	3 1 4			3			4	
37 RUBU SAXA	3 2 33 33433 3							
134 ANTH JULA	4 1							
23 LYCO SELA	1 1		132	1		1 1	1 1 12 1	11 234 4418 1
29 POLY SERP	21 1		1	. 1	11	2 1 2 1 1	222122 1	12121 13211 11 2 3 22 2333 1
95 DIPL ALBI	1 11 1 2 2111 1		1 3	1 1 11	1 1	4321 1 11 2	1212 212 1 1	2112 2 1 2452 1 5 1452 2
19 LEON AUTU			1 3 2 2			14 12 31 42	1	2
46 THAL ALPI	2		11 1 1		2	2 453 2 1	1	3 4 24
68 CARE FLAC	2 3		232 32233333222 1553 44534555343 43	3 2 11	34443344334	43 5525443 23544335534 245	3 3 33422 3243313	444435313 4 444443434 544334 44 243313312
7 CALL VULG	5554554443544444254414555555524	1354 3 4 1 1	41124 2 1 2344 2 23 224 12 4245554244	2414 344 555553253444 42343	5 1233433 1	5555215453555545555555254445	2245443454 545555555545255555	554 54555 545544543355554455 555555554555
41 SELA SELA	1 2 1 3		1 12 1 12122 1 11 1 22 1131121 2212	11 21 111 211 1 31	1	2 212 1 211221 43131	1 2 12222121111 1213322	2112
43 SOLI VIRG		1 1	122112 112221 1 21 222	1 3 1 12 1 11211	1	2 3233231 211 231	1 122 11 132 2123	2
88 CAMP FLEX				1				[illegible]

A2

7 8 9 10 11 12 1 2 3 4

2 111222222222222222 22 2 11 21113 11223 211111211111 12 111111121122222 2 3333 13333 1222 111 1111111 11111111112 1122222222111122 11111111122211112 33333 1111111122222 11111111
3177222555555666667776678 34 11266777788 11523 522201128999999457019900000000000 1543267111111291188999 22773900008920001555684333256244 23333333 448888888889455334444445444588888 8666795556111555551 11111 777877772222227 7866666
0403579145678912345237281590312615278906035560 31231890804567901288612512368545790208374123458902671213491756733479988256067907823551344908412457 89 35123567890734361234569026703412346489082350124467983 2702451314542367123458 89023715

11 1 1 3 111 11 3222 1 1 1 000000
3 21 342 2 22314 234121112 000001
21 3 2232133 3 000001
1 2 1 2 000001
133 13 2 4 000001
33 1 1 000001
254445 4 23 000001
22 3 1 1 000001
4 2 41 1 32333233232222 3 44355445415412422 4 15 4331 3 23 3432 3 000001
133 3 3 3 3 000001
2 4 32 2 000001
5 2 000001
1 1323 22 2 122 33 1 2 11 1 2 11 3 22 1 2211 3 3 2222 000010
1 23 122 232 3 3 4 32 1 000010
2 1 33 1 11 223 2 3241 2 13 1 1 213 4 12 23 2 000010
1 1 1 1 21 312 1 1 113 2 12 12 000011
4 000011
2 253 1 22123532 4 000011
5 2 5 4 1 4 5125 25 244 1 000011
4 1 42 3 2 0001
3221 1 1 1 122221323232342 3 22 31313223112 1 12 323 4123432311111112 1 113332 31 22 1222424122 1131 31223323212 11 1112 3 1 0001
1 333333 3224332 3345 323232421211 1 211 1 2 1 32 11 212 1 1 0001
2 1 1115 2 11 1 1 1 0001
4 4242144325 2 2 44 1 4 4445544 4413 244343434 2445544 55 4 312 554 344 1353 4 14215245455443 1 001000
1 1 2 1 34 1 241 422344 2 3244332444552 143 4 2 3 3 4454 5443 001000
1 3 32 2 322 23334431 21 3 1 4 12 3 4 3 3 1 2 1 354324 43 2 44535524 13 21 4 52 5 21454 4 45 5 4534 4 4 4 4424 001001
1 1 1 1 21 1 11 1 1 11 111 1 1 2 11 1 1 131 2 1 001001
2 3 54 33 5 5 43 4 001001
1 1 43 1 5 4 542 3 455452 2 1 31 3 2 55 3 4 3 2 2 342 3 3444 44 35 4 5555442555555455 5454545533544545555355455555543153 53 4 001001
1 1 2 2 1 1 1 1 11 1 1 223 11 33332 1 1 11222 221 2 1 1 1 2 2 1 001010
1 314243133342533213 123 1 32 23 2323312 2254432222213423323334255555555555554 4455555555555555544 3422222 5454444454555154 545344 5545545 555423 2432555544355455255555555 4 001010
1 11 1 1 1 1 1 1 2 11 2 11 1 1 001011
1 1 3 234 1 11 001011
2 2 3 122221 2 1 1 001100
11 1 1 11 11 001100
11 1 1 433 54 3 44322 1 33 1 1 5 1 1 1 1 2 001100
1 23231 1112 1 001100
2 1 1 001100
22 1 1 001100
422 3 34 222 2 2 1 001100
3 2 001100
21 1 211 11 3 11 1 1 1 2 21 12 111 001101
3 4 001110
001111
001111
132 1 1 1 1 1 12 1 11 334 4413 1 12 1 1 4 010000
1 1 11 2 1 2 1 1 222122 1 12121 13211 11 2 3 22 2333 1 1 1 2 1 2 010000
1 3 1 1 11 1 1 4321 1 11 2 1212 212 1 1 2112 2 1 2452 1 5 1452 2 11 1 1 22111111 010000
1 3 2 2 14 12 31 42 1 2 1 11 010001
1 1 2 2 453 2 1 1 3 4 24 21 010001
232 32233333222 1553 4453455534343 3 2 11 34443344334 43 5525443 23544335534 245 3 3 33422 3243313444435313 4 444443434 544334 44 24331331244 31 13444444 4 444 33 33242 010001
41124 2 1 2344 2 23 224 12 42455542412414 344 555553253444 423435 1233433 15555215453555545555555254445224544345 4 545555555545255555 4 54555 5455454 33555544555 55555555455545 4555 554555555 3 5 01001
12 1 12122 1 11 1 22 1131121 2212 11 21 111 211 1 31 1 2 212 1 211221 43131 1 2 12222121111 1213322 2112 1 1 3121 1 31 01001
122112 112221 1 21 222 1 3 1 12 1 11211 1 2 3233231 211 231 1 122 11 132 2123 2 32 21 11 11 1 1 01001
1 2 2 4 3 3 1 1 1 01001

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48 TOFI PUSI			22					
66 CARE DIOI			422 3 34	222		2	2 1	
86 CAMP STEL			3			2		
81 BLIN ACUT	2		1 21 1 211 11 3 11 1	1 1 2		21	12 111	
18 JUNI COMM	3 1 4			3			4	
37 RUBU SAXA	3 2 33 33433 3							
134 ANTH JULA	4 1							
23 LYCO SELA	1 1		132	1		1 1	1 1 12	11 334 4413 1
29 POLY SERP	21 1		1	1 11		2 1 2 1 1	222122 1	12121 13211 11 2 3 22 2333 1
95 DIPL ALBI	1 11 1 2 2111	1	1 3	1 1 11	1 1	4321 1 11 2	1212 212 1 1	2112 2 1 2452 1 5 1452
19 LEON AUTU			1 3 2 2			14 12 31 42	1	2
46 THAL ALPI	2		1 1 1		2	2 453 2 1	1	3 4
68 CARE FLAC	2 3		232 32233333222 1553 4453455534343	3 2 11	34443344334	43 5525443 23544335534 245	3 3 33422 3243313	444435313 4 444443434 544334 44 2433133
7 CALL VULG	55545544435444442544145555555	24 1354 3 4 1 1	41124 2 1 2344 2 23 224 12 424555424	42414 344 555553253444 42343	5 1233433 1	5555215453555545555555254445	2245443454 545555555545255555	54 54555 5455445433555544555 5555555545
41 SELA SELA	1 2 1 3		1 12 1 12122 1 11 1 22 1131121 2212	11 21 111 211 1 31	1	2 212 1 211221 43131	1 2 12222121111 1213322	2112
43 SOLI VIRG		1 1	122112 112221 1 21 222	1 3 1 12 1 11211	1	2 3233231 211 231	1 122 11 132 2123	2
88 CAMP FLEX				1				2 2 4 3 3 1
61 NARD STRI	1 24	1	3 34 3		33 54 544	454554 3343 24344 25 44 3	13 1 3 32 342332	555544455 3545543443455554435555555 4 534
94 DICR SCOP	1 1 2 13	1			33 32 2	12 222 22 111	1	13 3 323 2 1
9 COCH SPP						1111 1 11		
15 EUPH SPP	1 1		1 1 2 1 11111	11 111 1	3	2 12111 2 221 1 1 2111	11 1 2211 1 2 1 3	1 1 1
53 VIOL RIVI	11 11121 2212131321 112321 2	1 1 1	1 1 2 11 2 1 22 11 1 2222	1 1 11221 1 1 1	141132422 21	4331334233322343333333323322	11 1 22334234331112 1	32 1 3 32 32 22 3232
55 ANTH ODOR			2		444245234321	4221433333424444334322	113 14 2	122 1131 23
28 PLAN MARI	14 14 44333	2313343434344424 223	4 1344214 141 11232114224343343534334433 1	22222 22 1 111232222 11 4 1	1	1 24 42 1 32433 444	1 1 2 42 2 434531 5311	2 4
65 CARE DEMI	322	3	23111223223 3212221221111 14324234413331 1312	222 232312 2 111 1111 2 2		331 11 1 3 3324	2 1 22333 1 11 1 3313 22	23 3 3 22 21323 1 22
87 CAMP ATRO	21122 1 2 221 214 3 1	3 11	1 1	11 11 1 1 2		1 1	21311 12 2	2 4 12 5
114 RHAC ELLI	1 1	1	1 2 2 1 32 1	2 11			2 2	
2 ANTE DIOI	2344		1 2 1 1 1 31 12 1433312	2 121312 12223121 11		2 1 1 1221113 3411	1 13132 2313333221332 224 2	2 1 1
47 THYM DRUC	14 3343324333443434133553545	2221133344445343 33	1 1132 11343442 2344242112 323334223334313	31313 322 13242222223333 223	2 434 3	3 2332234231333354544554334	2111 232232 444341544231322	43 21 3 4 2
62 SIEG DECU	1 1 31 4 1 12 2		3 2 2 3122	212 2 11	2	2 4 3 422 1 12	1 1 1 1	2 2 1 2
80 ANDR SPP	21111121 1111111 111	1 2	2 1 21 13111 3 121	1 1 1		1 2 1 2 1	1 1 1 11 11 1 1 1	2 3 1 2 4 1 2
52 VIOL PALU						11 11 1 1	2	1
108 PLEU SCHR	11				3	1 2		
118 RHYT LORE				1		4 3 2 232		4 1
119 RHYT SQUA	1 1 1	1	1		343 2132123		1 1	
31 POTE EREC	1 1 23 434	1 1 22 3 3	1 2 3 134121 144321	2 3 1 1 2121 2 1 2	2344333433434	4345454554555544444443324343	11232 33213444444 43241342	345445445 4443444 4245544443545554444444
102 HYPN CUPR	1 1 1 33 124		1 3	111 1	43333333333	3343555233322342243331243223	2 1 12 1 31 3 2	2451 3445 142 4 422 244 33131 234 1 1335
74 JUNC SQUA						2		24 22 5 4
129 CLAD UNCI	11 1 1 1 1 2 2 223	2 1	1 11121	1		1 1 11 1 2 2211	1 111113212 1 4	1 3 4 1 3 2 1 211 11 1
117 RHAC LANU	1131331144233425311255445443	1111221121114 21 353	1 121 11111 3 11121 1 3112 4413244534422	4211 1131344321124333 3552	3	4 535 44 2 11 345511253533	3444325454345555555454454455	543535555 5244443343454555555455555555313
54 AGRO SPP	4321 3 32 314 32 5455344	4 32232423443232221 4	13221312122 22 1 2322232 31331534345242323313	214 22321222 24 1 212 2 1	151 32 2 12	25555442553342432323224343 35	1 232223232 5533322324	231232534 23333 43334 341 3 11332 1 2
58 FEST SPP	11232123221213221321 24242435	2332224343324442112 33	1221233242222233322321 22133 4 3244123324413	33212 222232121221111 12	24 21 322 2	443444433341434 1323 2444323	12 2344 1334343432	32 3 22414 34 1 43 22 2 21 2
12 EMPE SPP	4			4		4		2
115 RHAC FASC	2 1 222		3 1 13			2 21 1 2	1	2 1
116 RHAC HETE	1		1 1	1			1	1
57 DESC FLEX	4324444244334443331334242343	322 4 2	1 1333	2 1	1 4	2 15 3 223 24	11 2223 4 4	3 3 3 12 2 1 2
98 GRIM APOC				2				
16 GALI SAXA					2			2
50 VACC MYRT		3						3 3 32
76 LUZU CAMP								
63 CARE BIGE								2
77 LUZU SYLV								
106 PLAG DENT						1		
110 POLY COMM			2	1		2		
124 CETR ISLA								
22 LYCO ALPI								3
51 VACC VITI								
56 DESC CESP								
69 CARE PILU							1	44 1
111 POLY PILI	111		1				1	
1 ALCH ALPI	1						1	
30 SALI HERB	2							
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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48	TOFI PUSI			22			1	1		
66	CARE DIOI			422 3 34	222		2	2 1		
86	CAMP STEL			3			2			
81	BLIN ACUT	2		1 21 1 211 11 3 11 1	1 1 2		21	12 111		
18	JUNI COMM	3 1 4			3			4		
37	RUBU SAXA	3 2 33 33433 3								
134	ANTH JULA	4 1								
23	LYCO SELA	1 1		132	1		1 1	1 1 12 1		11 334 4413 1
29	POLY SERP	21 1		1	1	11	2 1 2 1 1	222122 1	12121	13211 11 2 3 22 2333
95	DIPL ALBI	1 11 1 2 21111		1 3	1 1 11	1 1	4321 1 11 2	1212 212 1 1	2112 2	1 2452 1 5 1452
19	LEON AUTU			1 3 2 2			14 12 31 42	1		2
46	THAL ALPI	2		11 1 1		2	2 453 2 1	1	3	4
68	CARE FLAC	2 3		232 32233333222 1553 445345553434	3 3 2 11	34443344334	43 5525443 23544335534 245	3 3 33422 3243313	444435313	4 444443434 544334 44 243313
7	CALL VULG	55545544435444442544145555555	24 1354 3 4 1 1	41124 2 1 2344 2 23 224 12 424555424	42414 344 555553253444 42343	5 1233433	1555521545355554555555525444 5	2245443454 545555555545255555	554 54555	545544543355554455 555555554
41	SELA SELA	1 2 1 3		1 12 1 12122 1 11 1 22 1131121 2212	11 21 111 211 1 31	1	2 212 1 211221 43131	1 2 12222121111 1213322		2112
43	SOLI VIRG		1 1	122112 112221 1 21 222	1 3 1 12 1 11211	1	2 3233231 211 231	1 122 11 132 2123		2
88	CAMP FLEX				1				2	2 4 3 3 1
61	NARD STRI	1 24	1	3 34 3		33 54 544	454554 3343 24344 25 44 3	13 1 3 32 342332	555544455	35455434434555544355555 4 53
94	DICR SCOP	1 1 2 13	1			33 32 2	12 222 22 111	1	13 3	323 2 1
9	COCH SPP						1111 1 11			
15	EUPH SPP	1 1 1		1 1 2 1 11111	11 111 1	3	2 12111 2 221 1 1 2111	11 1 2211 1 2 1 3	1	1 1
53	VIOL RIVI	11 11121 2212131321 112321 2	1 1 1	1 1 2 11 2 1 22 11 1 2222	1 1 11221 1 1 1	141132422 21	43313342333223433333333323332	2 11 1 22334234331112 1	32 1 3	32 32 22 32
55	ANTH ODOR			2		44424523432 1	42214333334244443344322	113 14 2	122	1131 2
28	PLAN MARI	14 14 44333	2313343434344424 223	4 1344214 141 112321142243433435343344331	22222 22 1 111232222 11 4 1	1	1 24 42 1 32433 444	1 1 2 42 2 434531 531	1	2 4
65	CARE DEMI	322	3	23111223223 3212221221111 14324234413331 1312	222 232312 2 111 1111 2 2		331 11 1 3 3324	2 1 22333 1 11 1 3313 22	23 3 3	22 21323 1 22
87	CAMP ATRO	21122 1 2 221 214 3 1	3 11	1 1	11 11 1 1 2		1 1	21311 12 2	2	4 12 5
114	RHAC ELLI	1 1	1	1 2 2 1 32 1	2 11			2 2		
2	ANTE DIOI	2344		1 2 1 1 1 31 12 1433312	2 121312 12223121 11		2 1 1 1221113 3411	1 13132 2313333221332 224 2	2	1 1
47	THYM DRUC	14 3343324333443434133553545	2221133344445343 33	1 1132 11343442 2344242112 32333422333431 3	31313 322 132422222223333 223	2 434 3	3 2332234231333335454455433 4	2111 232232 444341544231322	43	21 3 4 2
62	SIEG DECU	1 1 31 4 1 12 2		3 2 2 3122	212 2 11	2	2 4 3 422 1 12	1 1 1 1	2	2 1 2
80	ANDR SPP	21111121 1111111 111	1 2	2 1 21 13111 3 121	1 1 1 1		1 2 1 2 1	1 1 1 11 11 1 1 1	2 3	1 2 4 1 2
52	VIOL PALU						11 11 1 1	2		
108	PLEU SCHR	11				3	1 2			
118	RHYT LORE				1		4 3 2 232		4	1
119	RHYT SQUA	1 1 1	1	1		343 2132123		1 1		
31	POTE EREC	1 1 23 434	1 1 22 3 3	1 2 3 134121 144321	2 3 1 1 2121 2 1 2	234433334334	4434545455455554444443324343	11232 33213444444 432413423	345445445	4443444 4245544443545554444444
102	HYPN CUPR	1 1 1 33 124		1 3	111 1	4333333333 3	3343555233322342243331243223	2 1 12 1 31 3 2	2451 3445	142 4 422 244 33131 234 1 133
74	JUNC SQUA						2		24	22 5 4
129	CLAD UNCI	11 1 1 1 1 2 2 223	2 1	1 11121	1		1 1 11 1 2 2211	1 111113212 1 4	1 3	4 1 3 2 1 211 11 1
117	RHAC LANU	113133114423342531125544543	1111221121114 21 353	1 121 11111 3 11121 1 3112 4413244534422	4211 1131344321124333 3552	3	4 535 44 2 11 3455112535333	444325454345555555454454455 5	43535555	52444433434545555555455555555531
54	AGRO SPP	4321 3 32 314 32 54553444	3223242344323 2221 41	3221312122 22 1 2322232 31331534345242323313	214 22321222 24 1 212 2 1	151 32 2 122	5555544255334243232322434335	1 232223232 5533322324	231232534	23333 43334 341 3 11332 1 2
58	FEST SPP	11232123221213221321 24242435	2332224343324442112 33	1221233242222233322321 22133 4 32441233244133	33212 2222321212211111 12	24 21 322 2	443444433341434 1323 2444323	12 2344 13343434323	2 3 22414	34 1 43 22 2 21
12	EMPE SPP	4			4		4		2	
115	RHAC FASC	2 1 222		3 1 13			2 21 1 2	1		2 1
116	RHAC HETE	1		1 1	1			1		1
57	DESC FLEX	432444424433444333133424234	3322 4 2	1 1333	2 1	1 4	2 15 3 223 24	11 2223 4 4	3	3 3 12 2 1
98	GRIM APOC				2					
16	GALI SAXA					2				2
50	VACC MYRT		3						3 3	32
76	LUZU CAMP									
63	CARE BIGE								2	
77	LUZU SYLV									
106	PLAG DENT						1			
110	POLY COMM			2	1		2			
124	CETR ISLA									
22	LYCO ALPI									3
51	VACC VITI									
56	DESC CESP									
69	CARE PILU							1		44 1
111	POLY PILI	111		1				1		
1	ALCH ALPI	1								
38	SALI HERB	2								
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		00000000000000000000000000000	000000000000000000000	000000000000000000000000000000000000000000000	0000 000000000000000000000000	111111111111	1111111111111111111111111111	1111111111111111111111111111	111111111	1111111111111111111111111111111111
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		00000000000000000000000000000	111111111111111111111	000000000000000000000000000000000000000000000	1111 111111111111111111111111	000000000000	1111111111111111111111111111	0000000000000000000000000000	111111111	1111111111111111111111111111111111
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                    22                                                                      1                                               1                                                                                             001100
22              3 34            222                 2                        2                   1                                                                                                                                 001100
                3                                                   2                                                                                                                                                                  001100
1    1  211  11     3  11 1      1          1      2                          21          12               111                                                                                                                         001101
                                                3                                                        4                                                                                                                             001110
                                                                                                                                                                                                                                       001111
                                                                                                                                                                                                                                       001111
                          132                               1                1  1    1        1 12                  1          11  334 4413 1          12   1              1            4                                                   010000
        1                               1                   11  2 1      2     1     1              222122    1   12121   13211 11  2 3 22        2333 1  1      1         2 1        2                                                   010000
           1      3      1         1           11   1  1   4321  1  11                 2       1212  212   1 1  2112 2   1         2452 1 5 1452       2          11             1  1  22111111                                          010000
1          3 2      2                                       14   12 31     42                                  1                         2                                         1     11                                            010001
          1         1                                 2    2  453                     2  1                1          3                   4                       24                            21                                              010001
32233333222      1553  445345553434 3   3     2      11    34443344334  43 5525443 23544335534 245   3 3    33422   3243313 444435313 4 444443434 544334  44 24331331244             31   13444444 4 444 33     33242                    010001
24  2 1  2344 2 23  224 12 424555424 2414  344 555553253444 42343 5  1233433  155552154535555455555552544452245443454  5455555555452555 554 54555  545544543355554455 55555555455545        4555 554555555 3        5                                   01001
1     12122 1 11 1 22 1131121 2212 11    21 111       211  1  31   1        2 212  1     211221       43131 1  2 12222121111   1213322                    2112                                   1  1  3121    1  31                                        01001
122112 112221 1             21 222  1 3    1      12    1  11211      1      2    3233231    211      231  1  122 11 132        2123                                         2        32 21          11 11     1       1                              01001
                                          1                                                                                   2             2 4   3 3   1                          1            1                                          01001
3                  34 3                                  33 54   544  454554    3343 24344 25 44 3       13  1  3    32 342332  555544455 35455434434555544355555 4 534                     4  22555   5 555 555 55555                         01010
                                                         33  32    2   12    222       22   111    1                            13   3    323          2        1                                1  1 3            11 2 111        3          01010
                                                                              1111 1   11                                                                                                             4                                        01011
       1            2    1 11111           11       111     1        3       2   12111 2   221 1 1 2111 11 1      2211 1      2 1  3   1                1      1                 1               1      1  112342                                     01011
   11       2   1     22 11  1 2222  1 1     11221  1 1     1  141132422 21 4331334233322343333333332332 2    11   1 22334234331112 1 32   1  3 32          32               22 3232 22  1 1 3541233444321331232342                                 01011
                     2                                      444245234321 4221433333424444334 4322                       113  14    2      122                 1131                     23 3       11     12 11   3 33444          1233        1     01011
14  141 11232114224343343534334433122222 22 1 111232222 11 4  1      1    1  24      42 1 32433     444    1    1 2     42 2 434531 531                       2  4                   11        314 4414       1   1                                   0110
3 3212221221111 143242344133331 1312 222  232312 2 111  1111 2 2          331  11 1      3           3324    2 1 22333 1     11 1 3313 22 23       3  3      22    21323 1   22                                 1413  44     3                    0110
                                  1  11     11     1    1   2                                    1      121311                12      2     2                4 12 5                          214          1 21        3                      0110
          1  2 2 1      32   1     2        11                                                                2    2                                                                                                         2                   0110
   2 1       1 1     31 12 1433312  2      121312 12223121 11      2    1   1       1221113 3411  1 13132 2313333221332  224 2 2                    1      1                       2 5 22 444444    3                                         0111
1343442 2344242112  3233342233343133 1313 322 132422222223333 223   2   434  33 2332234231333354544554334 2111 232232 4443415442313 22 43           21        3             4    2     15333 45555545555555 42544554                  5    1     0111
                  3  2  2   3122                 212   2   11       2                 2 4   3 422 1 12                          1 1       1     1             2          2   1  2                        1                 3       3                           0111
              1 21 13111  3 121     1                1            1 1            1 2 1     2 1     1 1    1      11   11   1   1 12      3    1   2 4       1      2        2 2211   31  1        2 1 21          1                1          0111
                                                                         11 11   1  1                        2                                                11 1                 1           1      41     1                  3            1000
                                                    3           1                  2                                                                                                                   1 1       1 1    11                     1000
                                     1               4  3   2 232                                                           4                         1                                        2     31      133112        1              1000
1                                               343 2132123                              1          1                                                                                 1        21         4 1 1 2                             1000
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           1      3                       111                               1  4333333333333345552333223422433312432 23    2  1         12  1   31  3 2 2451 3445 142 4 422 244 33131 234 1  1335554   233 2 3 541223351445455223242353   2  15445 55    1001
                                                                               2                                                          24           22           5   4                                                554 5435                    101
        1                 11121              1                                1  1 11    1              2 2211         1         111113212  1 4  1   3         4 1  3 2 1    211 11 1              133211   1111   211121 1 11      1121  1    122 3222   101
111 3 11121 1 3112    4413244534422 4211   1131344321124333  3552 3    4 535 44 2 11 3455112535333 44325454345555554544544555 43535555 524444334345455555545555555313424 5555555555534555555 535454455554534441311 55555555   1100
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                                                  4                                            4                                                                                                              21     5                               110101
   1              13                                                                   2 21      1    2                1                        2         2 1                                                     1 1 34 23   2 2                            110101
                 1  1                               1                                                         1                                                       1                                    21                                      110101
              1333          2                       1              1   4     2        15 3    223 24        11 2223    4 4         3           3   3   12  2         1      2     1314344544445454554 2       3 2 22     2 22 1 2                   11011
                                2                                                                                                                                                                        2                                      11011
                                                         2                                                                                                            2                         44243                 334 5432344553445 45535345    11100
                                                                                                                                     3 3         32                                              3 452 4 51 43245 223433334 4443445454434 43523345    11100
                                                                                                                                                                                                3                     2         1        12 23      11100
                                                                                                                                     2                                                          311                        244 425355455 31555355     111010
                                                                                                                                                                                                                            1533 3114   12          111010
                                                                             1                                                                                                                                         41                               111010
               2                                   1                                   2                                                                                                              1          552454332      321                 111010
                                                                                                                                                                                                                            1       2      1         111010
                                                                                                                         3                                                                                                 3 1221     5           111011
                                                                                                                                                                                                  343 34 4    3333       3 4 24 11 1  354             11110
                                                                                                                                                                                                                  33423      4                            11110
                         1                                                                                  1          44                        1                                            3 22 3111222555454   34      1 1111211  2 2 33 2     11110
                                                                                                                                                                                                 3333   2 121221       3 323             3 455         111110
                                                                                                                                                                                                 43543 4434    442 113  233433                           111111
                                                                                                                                                                                                     1  4      5444      1           1                   111111

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