A study of selected cations in a mixed mire ecosystem

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A STUDY OF SELECTED CATIONS
IN A MIXED MIRE ECOSYSTEM

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A dissertation submitted in part
fulfilment of the requirement for
the degree of Master of Science
(Advanced course in Ecology)

SEPTEMBER 1975

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SECTION 1 INTRODUCTION

Tarn Moor and its surrounding area, enclosing Sunbiggin Tarn, are situated in the parish of Orton in central Cumbria (National Grid Reference: 670075). Such an area is of moderate elevation, roughly at an altitude of 250m, linking the hills of the North Pennines to those of the south-eastern part of the Lake District (map 1).

The vegetation of the area has been described by Holdgate (1955a) (1955b), its most outstanding features being :

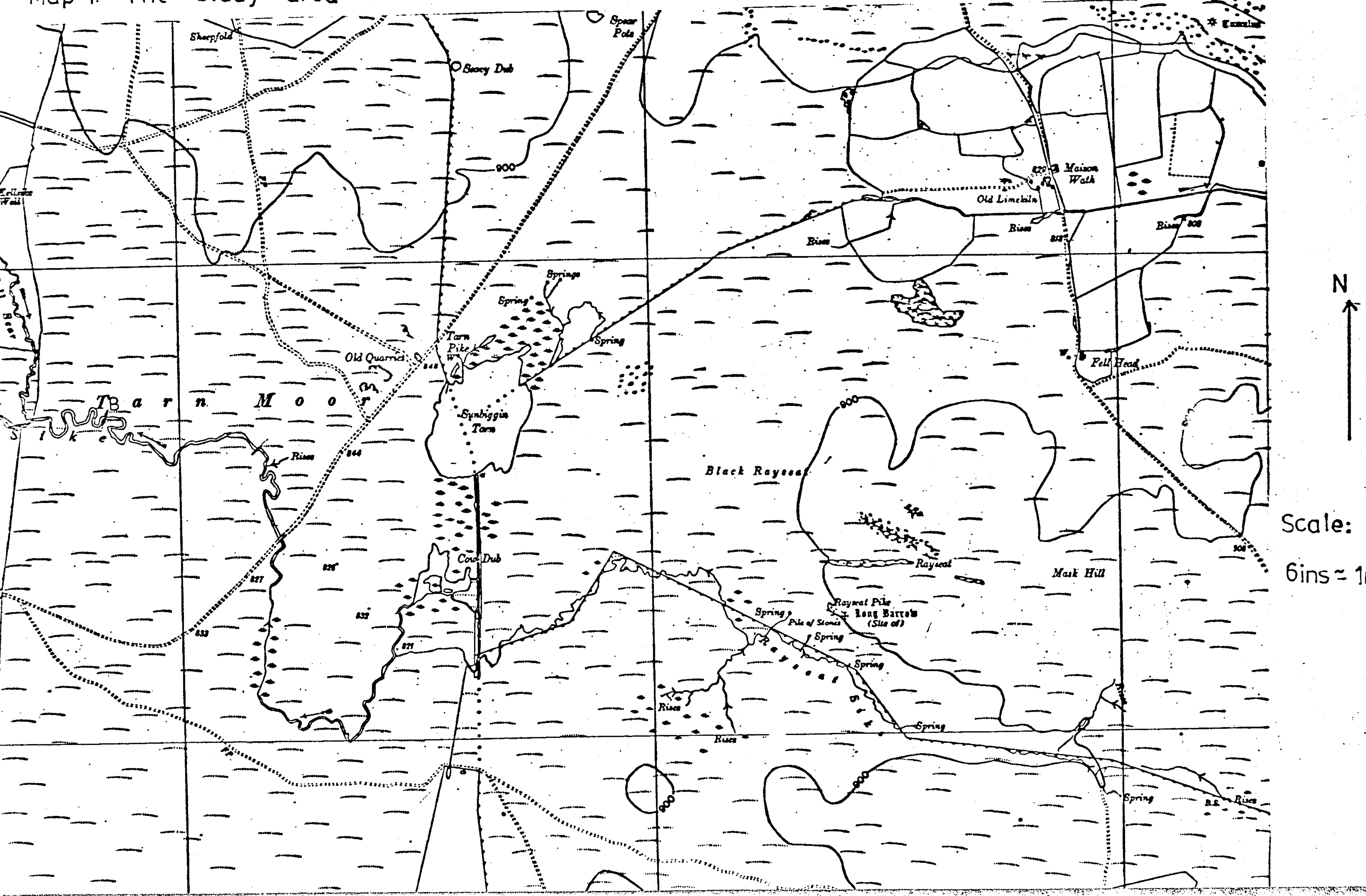
1. The close juxtaposition of a series of mire type ranging from extreme rich fen to acid bog, sensu Du Rietz (1949).
2. The presence of a series of large 'tufa' springs, the water from which inundates the flat terrace which flanks Tarn Syke.
3. The fact that on one of these terraces there is an area of mixed mire sensu Du Rietz, a type of vegetation which is rare in the British Isles, being more typical of sub-arctic and sub-alpine regions.

Mixed mire is perhaps one of the most extreme examples of mosaic vegetation, in which the hydrological conditions typical of rich fen is invaded by species usually considered to be characteristic of acid bog communities.

Mixed mires, not only provide unique areas for the study of the edaphic relationships of mire ecosystems, but also pose the following fundamental questions concerning the early stages of mire succession (Verlandung) of Weber (1908):

1. How do the acidophilous species gain a foothold in the rich fen water?
2. What are the mechanism by which the acid 'bog' conditions are maintained within the developing hummock?

Map 1: The study area



Scale:

6ins ≃ 1mile

The mixed mire at Tarn Moor was the subject of a preliminary investigation by Bellamy and Rieley (1967) in which they showed that each hummock could be regarded both floristically and edaphically as a 'miniature bog', the profile of which showed abrupt changes both in floristic content and peat chemistry. Perhaps their most surprising finding was the lack of any evidence of transport of mineral rich ground water through the hummock profile by capillary action.

The aim of the present work was to extend our knowledge of the mixed mire ecosystem by a study of a series of hummocks of increasing size, each of which could be regarded as a stage in the development of an ombrotrophic mire.

To this end, the following work was planned and carried out :

1. Ten hummocks were selected covering the range of size from 15cm to 72cm in height.
2. The vegetation of each hummock was described using the field methods of the Zurich-Montpelier School of Phytosociology.
3. Cores were removed from each hummock and the profiles were analysed for their floristic content to allow an assessment of the developmental history in phytosociological terms.
4. Selection of the species shown by 3. above to be pioneers in the process of hummock formation for geochemical analysis.
5. Geochemical analysis of the ground water and hummock profiles to ascertain the increasing 'effect' of hummock development with size.
6. Studies of the geochemistry of the hummock species growing around the base of the hummock in direct contact with the flowing ground water.

In view of the limited time available, geochemical studies were limited to the following elements: calcium and magnesium, both of which are major components of the ground water and hence should be supplied to the hummock from below, sodium and potassium, the former being the most abundant ion supplied in the precipitation and potassium as an important plant nutrient supplied in the main from the ground water. In the light of the recent interest shown in the use of Sphagnum sp. to monitor atmospheric lead pollution, it was decided to include the ion in the study, Tarn Moor being far removed from any major roadway or obvious source of airborne lead.

SECTION 2 MATERIALS AND METHODS

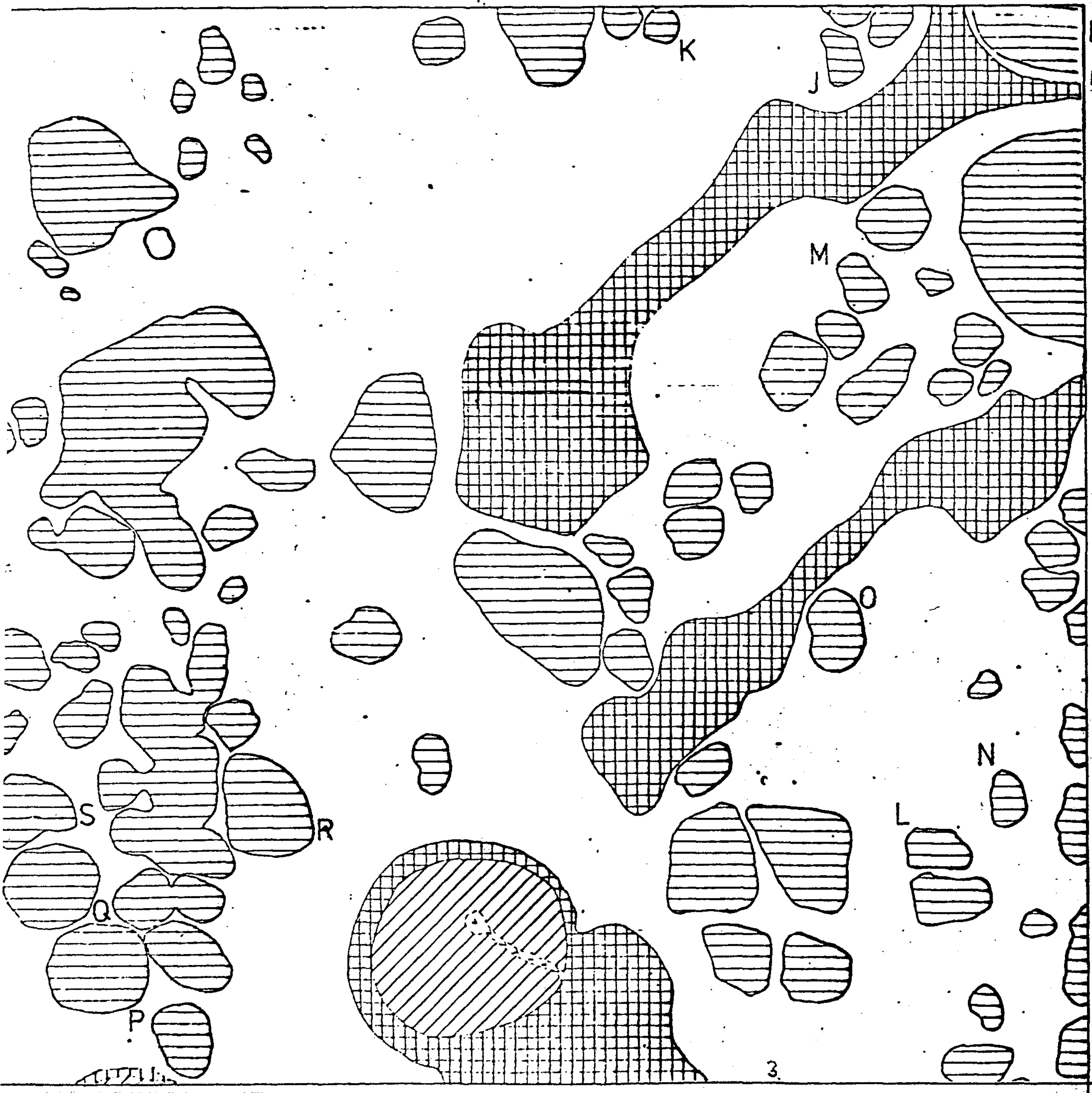
The study area comprised of a randomly chosen 25m square of mixed mire vegetation (Du Rietz 1949) at Tarn Moor, Cumbria (see map 2). Contained in the area were a series of hummocks, variously dominated by different species of Sphagna. The larger hummocks of the study area resembling the nearby moor in that the tops of such hummocks are largely dominated by Calluna Vulgaris (plate 1).

A series of ten hummocks were subjectively chosen to represent as wide a variety as possible in hummock height within the study area. In order to obtain information on the contemporary sociology of plant species growing on the hummock series, values of cover-abundance and sociability were noted in each case.

1. COLLECTION OF PEAT AND WATER SAMPLES

To minimise disturbance, a series of four samples were taken from the ground water at the base of each hummock chosen. A water sample was taken roughly in the middle of the side of each hummock which was correspondingly nearest to an edge comprising the main study area. Sample one would correspond to water taken from the base of a hummock whose side is closest to edge one of the main study area (see map 2) and so on for each of the four edges. Thus, the samples were collected clockwise around each of the hummocks studied, sample one comprising the upslope sample, sample three comprising the downslope sample, whilst samples two and four would be roughly complementary as concerns aspect.

On returning to the laboratory, the pH of the water samples was determined, firstly on the unfiltered samples and secondly on the same samples having been filtered twice using Whatman No.42 filter paper. After the addition of a small amount of chloroform (Spearling 1972) the samples were stored in a cold room at 5°C. The water samples were then analysed for potassium, sodium, calcium, magnesium and lead using a Perkin



Map 2: Part of the area of mixed mire at Tarn Moor.

▤ Sphagnum hummocks.

▦ Areas of standing water.

▨ Tufa mound.

▨ Tufa mound with active spring.

☐ Areas of rheophilous mire.

J–S Sphagnum hummocks examined. (see text).

N ←

Scale. 1:125

0 1 2 3 4 metres.

PLATE I

GENERAL VIEW OF STUDY AREA (taken in July 1975)

A

B

Elmer Model 403 atomic absorption spectro photometer.

From each of the ten hummocks chosen (see map 2) a sample of peat was taken from the top, middle and bottom of each hummock respectively. On returning to the laboratory, the pH of each fresh peat sample was made, using the method of Allen (1974). Also, a small portion of each peat sample was removed and microscopically analysed to ascertain all identifiable plant material contained in each sub-sample.

A mixed acid digestion was then performed on a portion of peat collected in each sample. The method employed was based on that of Adrian (1973). Bearing in mind the disadvantages of a mixed acid digestion procedure when used on plant materials as cited by Allen (1974), 0.25g of the dried peat sample was used in each case. Due to the difficulty of obtaining a complete digestion of the peat material using the quantities of nitric and perchloric acid used by Adrian (1973), the quantity of acid used was raised to that of 25ml. concentrated nitric acid (Malmer and Sjors 1955) and 12.5ml.of concentrated perchloric acid respectively. Any insoluble residue remaining in the solutions of the peat digests were regarded as insoluble silica (Malmer 1962a). All the samples were then analysed for the same elements as the water samples, using atomic absorption spectro photometry.

2. COLLECTION AND ANALYSIS OF BRYOPHYTE SAMPLES

A series of six separate species of Bryophyte, which vary quite markedly with habitat, were collected from the study area (*Campylium stellatum*, *Cratoneuron falcatum*, *Scorpidium scorpioides*, *Sphagnum fuscum*, *Sphagnum palustre* and *Sphagnum plumulosum* were chosen). A small sub-sample of each of the species of moss was firstly weighed when freshly collected and again when dried to constant weight in order to ascertain the percentage water saturation.

Three separate treatments were carried out to each species collected. The first comprised of drying the samples to constant weight and performing the above acid digestion procedure to five replicated samples.

The second procedure consisted of washing thoroughly a ground 3g dry weight sample of each species studied with a molar ammonium acetate solution buffered at pH7. The solution was prepared by the method given by Black (1965). Such a washing was achieved by stirring 50mls of the solution with the moss sample for five minutes before filtering the resultant mixture under reduced pressure using Whatman No.42 filter paper. Such a procedure was repeated four times to each species of moss sampled. The resulting tissue was again oven dried to constant weight and the mixed acid digestion procedure performed on five replicated samples.

The last procedure adopted differed from that given above only in the fact that the eluting solution was distilled water.

Samples from each of the separate treatments were analysed using atomic absorption spectrophotometry for potassium, sodium, calcium, magnesium and lead.

3. DETERMINATION OF THE CATION EXCHANGE CAPACITY OF THE PEAT SAMPLES

Numerous methods are cited in the literature in order to obtain the cation exchange capacity of peat samples e.g. Schollenberger and Simon (1945), Piper (1950), Thun, Herrmann and Knickman (1955), Puustjarvi (1956, 1957) and Thorpe (1973). Many, if not all, of the methods quoted by the above authors involve a time consuming process. However, quicker and relatively simpler methods do exist (Brown 1943, Woodruff 1948).

For the purposes of the present study, Brown's method was employed to obtain separately the levels of exchangeable bases and exchangeable hydrogen within each peat sample analysed. The neutral molar ammonium acetate solution required in the estimation of exchangeable bases contained in the peat samples was prepared by the method given by Black (1965).

4. DETAILED SAMPLING OF A PARTICULAR HUMMOCK IN THE STUDY AREA

A more detailed collecting procedure was adopted for one particular hummock chosen in the study area (hummock O on map 2) (see plate 2). Five water samples were taken from each of the four sides of the hummock using the same sampling procedure as before. The vegetation

PLATE 2

HUMMOCK O IN THE STUDY AREA
(taken in July 1975)

A

B

Hummock O in foreground

comprising mainly of Sphagnum sp., of each of the four sides of the hummock was also sampled. The plants were divided into two samples, the aerial component of the plant and the below ground component. At the same time, the hummock profile was also resampled.

On returning to the laboratory, the water samples were treated exactly in the same manner as those collected during the initial survey. The peat samples were again dried to constant weight and analysed for the major cations selected previously.

SECTION 3 RESULTS AND DISCUSSION

1. CONTEMPORARY SOCIOLOGY AND RECENT HISTORY OF THE SELECTED HUMMOCKS

The results of the vegetational analysis are presented in Table 1, the lists being arranged in order of increasing height of the hummock.

On the basis of such a small subjective sample it is impossible to draw any meaningful conclusions, however, the trends discussed below were borne out by subsequent study of the full range of hummocks present in the area.

Sphagnum rubellum, Sphagnum plumulosum and Sphagnum capillaceum appear to act as the pioneer species, Sphagnum fuscum only being found dominating hummocks greater than 33cm in height. The presence of Carex dioica, Equisetum fluviatile and Succisa pratensis, all of which are typical of rheophilous and transition mires, on these hummocks indicates that up to this size the total hummock may well be subject to the effect of flowing ground water.

The presence of both Phragmites australis and Carex rostrata on the Sphagnum fuscum hummocks can readily be explained by the fact that although all the plants were deporate, they were all shown to be rooted through the hummock into the rheotrophic peat beneath.

It would therefore appear that by the time a hummock has reached about 30cm in height, all meaningful effect of the ground water has effectively been shut off and that the communities of the hummock surface are growing under edaphic conditions which approximate to those of an ombrotrophic mire situation.

The results of the floristic analysis of the hummock profiles are presented in Tables 2 to 4.

The study backs up the conclusion drawn above that the main pioneer species is Sphagnum plumulosum. The other species indentifiable in the bottom layers are Cratoneuron falcatum, Drepanocladus intermedius, Philonotis

TABLE 1

AN ASSOCIATION TABLE OF SPECIES PRESENT FOR A SERIES OF HUMMOCKS SAMPLED AT TARN MOOR, CUMBRIA, 250m SOUTH-WEST ASPECT

SPECIES	HUMMOCK HEIGHT (cm)									
	15	23	25	27	28	33	50	60	67	72
Aulacomnium palustre								+,2		
Calluna vulgaris	+.1	1.2	3.2	1.1	1.2	2.2		2.3	3.2	4.3
Carex dioica	+.2	+.1	+.2	+.1	+.2	+.1				
Carex panicea	1.1	1.1	+.1	+.1		+.1	1.1	+.1		1.2
Carex rostrata							1.2			
Cladonia impexa				1.2		2.2				
Dicranum scoparium				+.2						
Drosera rotundifolia	+.2			+.2	+.2		+.1	1.2		+.1
Empetrum nigrum									+.2	
Equisetum fluviatile		+.1		+.1		+.2				
Erica tetralix	1.1	+.1	1.1		2.2	1.1		1.1	+.1	1.1
Eriophorum angustifolium			1.2							1.2
Eriophorum vaginatum	+.1						1.1		+.2	
Festuca ovina		1.2			1.1	+.1				
Molinia caerulea	2.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	2.1	1.1
Odontoschisma sphagni				2.3			2.2	+.1	+.1	+.2
Oxycoccus palustris			1.1	+.1		+.1				+.1
Phragmites australis			+.1	+.2	+.1	+.2	2.2	+.2	1.1	+.2
Pleurozium schreberi			1.2						1.2	
Polytrichum strictum									+.2	2.2
Potentilla erecta	+.1	1.1	+.1		+.1		+.1	+.1		1.1
Selaginella selaginoides		+.2								
Sphagnum capillaceum			4.5	3.2	2.5	4.5				
Sphagnum fuscum							4.4	5.3	4.4	4.4
Sphagnum plumulosum	2.2	5.5		3.2	3.5					
Sphagnum rubellum	3.2									
Succisa pratensis	+.2	+.2				+.2				

NOTE

The first figure in each column represents an estimate of cover-abundance of each species noted using the five point index used by Braun-Blanquet, the second figure represents the sociability of each species concerned.

TABLE 2

IDENTIFIABLE PLANT SPECIES CONTAINED IN THE BOTTOM PEAT SAMPLES

Hummock height (cm)	Identifiable material in peat samples
15	Cratoneuron falcatum Drepanocladus intermedius Schoenus nigricans (f) Schoenus nigricans (1.b)
23	Odontoschisma sphagni Sphagnum plumulosum
25	Carex rostrata (f) Drepanocladus intermedius Philonotis calcaria
27	Scorpidium scorpioides Sphagnum plumulosum
28	Oxycoccus palustris Sphagnum plumulosum
33	Acrocladium cuspidatum Erica tetralix (l) Erica tetralix (s) Molinia caerulea (l) Sphagnum palustre
50	Acrocladium cuspidatum Drepanocladus intermedius Carex rostrata (b)
60	Cratoneuron falcatum Sedge (r) Sphagnum palustre
67	Calluna vulgaris (s) Cratoneuron falcatum Drepanocladus intermedius Sphagnum palustre
72	Molinia caerulea Sphagnum palustre

TABLE 3

IDENTIFIABLE PLANT SPECIES CONTAINED IN THE MIDDLE PEAT SAMPLES

Hummock height (cm)	Identifiable material in peat samples
15	Molinia caerulea (l) Odontoschisma sphagni Oxycoccus palustris (l) Oxycoccus palustris (s) Sphagnum plumulosum
23	Sphagnum fuscum
25	Acrocladium cuspidatum Drepanocladus revolvens Oxycoccus palustris Sphagnum capillaceum
27	Scorpidium scorpioides Sphagnum plumulosum
28	Cratoneuron falcatum Sphagnum plumulosum
33	Aulacomnium palustre Erica tetralix Molinia caerulea (1.b) Polytrichum strictum Sphagnum capillaceum
50	Calluna vulgaris (s) Oxycoccus palustris (l) Sphagnum fuscum
60	Sphagnum fuscum
67	Aulacomnium palustre Polytrichum strictum Sphagnum fuscum
72	Aulacomnium palustre Molinia caerulea (l) Sphagnum fuscum

TABLE 4

IDENTIFIABLE PLANT SPECIES CONTAINED IN TOP PEAT SAMPLES

Hummock height (cm)	Identifiable material in peat samples
15	Molinia caerulea (1,b) Sphagnum plumulosum Sphagnum tenellum
23	Erica tetralix (l) Odontoschisma sphagni Sphagnum plumulosum
25	Aulacomnium palustre Oxycoccus palustris (l) Polytrichum strictum Sphagnum capillaceum
27	Eriophorum angustifolium (l.t.) Sphagnum plumulosum
28	Sphagnum plumulosum Sphagnum tenellum
33	Empetrum nigrum (l) Sphagnum capillaceum
50	Acrocladium stramineum Odontoschisma sphagni Sphagnum fuscum
60	Odontoschisma sphagni Pohlia nutans Sphagnum fuscum
67	Calluna vulgaris (b.let) Odontoschisma sphagni Sphagnum fuscum
72	Calluna vulgaris (b.let) Molinia caerulea (l) Polytrichum strictum Sphagnum fuscum

Key to tables 2 to 4

b = base

b.let. = branchlet

f = fruit

l = leaves

l.b. = leaf base

l.t. = leaf tip

r = root

s = stem

calcaria, Scorpidium scorpioides and Sphagnum palustre. The latter is a hummock former (Watson 1955) the former four, although species typical of rich fen communities, all can grow in swelling tufts which could act to deflect the flow of water at that particular position, thus helping to provide a niche for the ecesis of the more acidophilous species.

The presence of Schoenus nigricans and Molinia caerulea in the bottom of the profiles is also worthy of note. Both species tend to grow in tight clumps, within the shelter of which acid conditions could develop.

2. GEOCHEMISTRY OF THE PIONEER SPECIES

Samples of the following species: Campylium stellatum, Cratoneuron falcatum, Scorpidium scorpioides, Sphagnum fuscum, Sphagnum palustre and Sphagnum plumulosum, all of which are shown above to be important species in the process of hummock development at the site, were collected from other parts of the mixed mire system, and subsamples were analysed for percentage water content and for total levels of the cations selected above (see table 5).

Puustjarvi (1956) suggested that mosses typical of aquatic environments would be able to replenish their water supply virtually continuously and hence would be typified by a lower water retaining capacity than those normally found growing in conditions where water stress would be likely.

On the basis of the percentage water saturation data, the results suggest that the mosses shown fall into the following series: Campylium stellatum, Scorpidium scorpioides, Cratoneuron falcatum, Sphagnum palustre, Sphagnum plumulosum and Sphagnum fuscum.

The results of the cation analysis show conclusively that the six mosses studied are best considered in two groups:

Group 1 - Campylium stellatum, Cratoneuron falcatum, Scorpidium scorpioides as the initiators in that all appear to be growing with the influence of the ground water.

Group 2 - Consisting of all three species of Sphagnum, all of which appear to grow above the influence of the ground water.

TABLE 5

TOTAL LEVELS OF SELECTED CATIONS DETERMINED IN A SERIES OF BRYOPHYTE SPECIES

		Per gram dry weight				
Species	Percentage water saturation	Total Potassium mgm	Total Sodium mgm	Total Calcium mgm	Total Magnesium mgm	Total Lead µgm
Campylium stellatum	85.7	0.88± 0.05	0.16± 0.02	99.2± 4.32	2.86± 0.05	46.80± 3.38
Scorpidium scorpioides	86.8	0.64± 0.06	0.11± 0.01	103.20± 3.87	2.79± 0.03	38.60± 4.12
Cratoneuron falcatum	88.6	1.39± 0.17	0.12± 0.01	100.80± 9.69	3.09± 0.11	33.80± 0.80
Sphagnum palustre	89.7	3.24± 0.42	0.91± 0.14	3.42± 0.24	1.00± 0.01	19.00± 3.03
Sphagnum plumulosum	91.1	1.26± 0.10	0.71± 0.03	1.13± 0.06	0.67± 0.00	41.80± 3.30
Sphagnum fuscum	92.2	2.11± 0.06	1.38± 0.01	1.42± 0.02	0.52± 0.03	35.50± 2.22

Mean ± standard error.

n = 5. n = sample size

The main differences between the cations analysed of the two groups are as follows :

1. Group 1 mosses are significantly richer in calcium and magnesium than those in Group 2, and
2. In contrast, group 2 mosses are significantly richer in sodium and potassium than the former.

It has been shown since the early part of the century that species of Sphagna must exert some degree of selectivity in the ions they absorb (Skene 1915). However, as was demonstrated by Puustjarvi (1955), the various groups of the genus Sphagna differ markedly in their capacity to utilize bases in their substratum. Such a process of cation exchange has also been demonstrated by Williams and Thompson (1936), Ramaut (1954) and Anschutz and Gessner (1954) showed that other cations are exchanged for hydrogen ions. Thus, once the presence of Sphagnum species has become established, the conditions of the surrounding area, via the alteration of pH, would be greatly affected, a fact borne out by the entry of acidophilous species on the larger hummocks in the middle and top peat samples (Tables 3 and 4).

A list of plausible explanations of the continuing acidity of such Sphagnum dominated areas was considered by Clymo (1967). He concluded that the most likely explanation for such a phenomenon could be due to the cation exchange properties of the plants themselves. Based on the input of various physical data, Clymo (op.cit) produced a model which predicted the eventual pH around the plants, assuming that a Donnan equilibrium operates in such a system.

Tables 6 and 7 show the levels of non-exchangeable cations recorded when the moss species analysed were subjected to different extraction liquids i.e. molar ammonium acetate at pH 7 and distilled water. Treated with either solution, the total potassium level found for each species considered seems to be stored in almost a completely exchangeable form. Whereas in contrast, for three species of Bryophyte studied all of the total lead recorded seems to be stored in a non-exchangeable form. In the case of using ammonium

TABLE 6

NON-EXCHANGEABLE LEVELS OF SELECTED CATIONS DETERMINED IN A SERIES OF BRYOPHYTE SPECIES USING AMMONIUM ACETATE TREATMENT

	Per gram dry weight				
Species	Potassium mgm	Sodium mgm	Calcium mgm	Magnesium mgm	Lead μgm
Campylium stellatum	0.00 ± 0.00	0.04 ± 0.01	22.80 ± 0.58	0.36 ± 0.00	44.00 ± 2.76
Scorpidium scorpioides	0.00 ± 0.00	0.02 ± 0.00	104.80 ± 1.99	1.32 ± 0.04	50.80 ± 1.96
Cratoneuron falcatum	0.00 ± 0.00	0.03 ± 0.00	36.84 ± 2.06	0.59 ± 0.02	43.60 ± 3.12
Sphagnum palustre	0.00 ± 0.00	0.01 ± 0.00	0.09 ± 0.00	0.02 ± 0.00	20.00 ± 1.55
Sphagnum plumulosum	0.00 ± 0.00	0.04 ± 0.01	0.12 ± 0.04	0.03 ± 0.01	34.40 ± 6.43
Sphagnum fuscum	0.00 ± 0.00	0.02 ± 0.00	0.06 ± 0.00	0.01 ± 0.00	21.20 ± 0.50

Mean ± standard error.

n = 5. n = sample size.

TABLE 7

NON-EXCHANGEABLE LEVELS OF SELECTED CATIONS DETERMINED IN A SERIES OF BRYOPHYTE SPECIES USING DISTILLED WATER

	Per gram dry weight				
Species	Potassium mgm	Sodium mgm	Calcium mgm	Magnesium mgm	Lead µgm
Campylium stellatum	0.00 ± 0.00	0.06 ± 0.01	38.16 ± 0.82	2.33 ± 0.02	41.80 ± 1.02
Scorpidium scorpioides	0.00 ± 0.00	0.05 ± 0.01	116.64 ± 2.02	2.15 ± 0.00	51.20 ± 3.38
Cratoneuron falcatum	0.00 ± 0.00	0.04 ± 0.01	60.80 ± 0.82	2.59 ± 0.02	30.40 ± 1.17
Sphagnum palustre	0.70 ± 0.02	0.16 ± 0.02	3.42 ± 0.24	1.00 ± 0.01	17.80 ± 2.73
Sphagnum plumulosum	0.55 ± 0.00	0.19 ± 0.00	1.07 ± 0.01	0.46 ± 0.00	27.80 ± 2.06
Sphagnum fuscum	0.31 ± 0.00	0.07 ± 0.00	0.91 ± 0.02	0.33 ± 0.00	24.20 ± 1.86

Mean ± standard error.

n = 5.

acetate, Campylium stellatum, Sphagnum plumulosum and Sphagnum fuscum appear to store lead in such a way, whereas for the water treated samples Campylium stellatum, Scorpidium scorpioides and Sphagnum palustre appear to store lead in a non-exchangeable form.

For the other three cations studied, the form in which such cations are stored in Bryophyte samples seems to vary considerably with respect to the species concerned and the extraction procedure performed. Such forms are probably specific to a particular species considered e.g. Scorpidium scorpioides appears to bind its total calcium in a non-exchangeable form (under both treatments no exchangeable calcium was extracted), whereas Sphagnum fuscum appears to bind a relatively smaller amount of its total calcium in such a form.

Estimates of the exchangeable levels of cations by the two procedures are given in tables 8 and 9. All values in the tables are given at the $P < 0.05$ level, a value of zero being placed when the difference between the two levels of the particular cation recorded was not significantly different below the significance level quoted above.

As a general rule, the exchangeable level of a particular cation in most cases was seen to be higher when the Bryophyte species were treated with ammonium acetate than with distilled water as an extraction liquid. Although, as noted above, the levels of exchangeable potassium for the species sampled are similar under both treatments. Such would indicate that most potassium contained in such species of moss would be easily removable. Such, however, is not the case when exchangeable lead levels determined for the series of species is considered. Thus it seems likely that most of the total levels of lead contained in the moss species are fairly firmly bound to the plant tissue.

The difference in the exchangeable levels of cations obtained under the two treatments may represent the degree of binding of a particular cation to the plant tissue. It appears that under such an hypothesis, most of the exchangeable monovalent cations such as potassium and sodium may be fairly easily removed by simply washing the tissue samples in distilled water.

TABLE 8

AN ESTIMATE OF THE EXCHANGEABLE LEVELS OF SELECTED CATIONS USING AMMONIUM ACETATE

	Per gram dry weight				
Species	Potassium mgm	Sodium mgm	Calcium mgm	Magnesium mgm	Lead µgm
Campylium stellatum	0.88 ± 0.05	0.12 ± 0.02	76.40 ± 4.36	2.50 ± 0.05	0.00 ± 0.00
Scorpidium scorpioides	0.64 ± 0.06	0.09 ± 0.01	0.00 ± 0.00	1.47 ± 0.05	0.00 ± 0.00
Cratoneuron falcatum	1.39 ± 0.17	0.09 ± 0.01	63.96 ± 9.80	2.50 ± 0.11	0.00 ± 0.00
Sphagnum palustre	3.24 ± 0.42	0.90 ± 0.14	3.33 ± 0.24	0.98 ± 0.01	0.00 ± 0.00
Sphagnum plumulosum	1.26 ± 0.10	0.67 ± 0.03	1.01 ± 0.21	0.64 ± 0.01	0.00 ± 0.00
Sphagnum fuscum	2.11 ± 0.06	1.36 ± 0.01	1.36 ± 0.02	0.41 ± 0.03	14.30 ± 2.28

Mean ± standard error

All levels shown at the $P < 0.05$ level

TABLE 9

AN ESTIMATE OF THE EXCHANGEABLE LEVELS OF SELECTED CATIONS USING DISTILLED WATER

	Per gram dry weight				
Species	Potassium mgm	Sodium mgm	Calcium mgm	Magnesium mgm	Lead µgm
Campylium stellatum	0.88 ± 0.05	0.10 ± 0.02	61.04 ± 4.40	0.53 ± 0.05	0.00 ± 0.00
Scorpidium scorpioides	0.64 ± 0.06	0.06 ± 0.01	0.00 ± 0.00	0.64 ± 0.03	0.00 ± 0.00
Cratoneuron falcatum	1.39 ± 0.17	1.35 ± 0.17	40.00 ± 9.75	0.50 ± 0.11	3.40 ± 1.42
Sphagnum palustre	2.54 ± 0.40	0.75 ± 0.14	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Sphagnum plumulosum	0.71 ± 0.10	0.52 ± 0.03	0.00 ± 0.00	0.21 ± 0.00	14.00 ± 3.89
Sphagnum fuscum	1.80 ± 0.06	1.31 ± 0.01	0.51 ± 0.03	0.19 ± 0.03	11.20 ± 2.90

Mean ± standard error

All levels shown at the $P < 0.05$ level.

A larger difference between the two exchangeable levels obtained under such treatments occurs when divalent cations are considered, calcium and magnesium, such a difference may indicate a stronger degree of binding of such cations to the plant tissue than is the case when monovalent ions are considered.

Various authors have proposed a site for the cation exchange properties of Sphagnum species, e.g. Puustjarvi (1959) (whose theory was based on the use of the Nernst equation originally formulated by Lundegardh (1942))and Bell (1959). Indeed, the above result supports Bell's original observation that trivalent and divalent cations that are absorbed by Sphagnum species are absorbed more strongly (and hence more may be stored in a non-exchangeable form) than monovalent ones.

A large amount of work has been carried out on the determination of the chemical nature of the exchange sites of Sphagnum species (Theander 1954, Knight et al. 1961, Clymo 1963, Craigie and Mass 1966). The most widely held theory concerns that of Clymo (1963) who proposed the nature of such exchange sites comprise of unesterified polyuronic acids, possibly mixed sugar uronic acid molecules in the cell walls. Clymo (1963, 1964) also demonstrated that Sphagna, as a group, contained quite a large proportion of their dry weight as uronic acid residues.

Since the original work performed by Clymo, extensive studies on the cation exchange ability of Sphagnum magellanicum have been made (Rudolph and Brehm 1965, Brehm 1967, 1968, 1970, 1971). Schwartzmaier and Brehm (1975) give evidence based on a more sophisticated assay procedure than that used by Clymo (1963), that in the case of Sphagnum magellanicum, the chemical nature of the cation exchanger comprises of polygalacturonic acid molecules. Such evidence confirms the original theory of Clymo.

Recent work by Spearling (1972) demonstrated a correlation between the varying amounts of galacturonic acid in a variety of species of Sphagna which show a marked distribution with respect to the water table at Sandy Ridge Bog, New York. From this she concluded that the amount of galacturonic acid found within a species might confer a specific range of exchange ability to that taxon. This capacity for cation exchange may enable the species to occupy a particular habitat within the bog. It may be interesting for future workers at Tarn Moor to repeat such a study as was undertaken by Spearling. Such data would provide evidence on the site of exchange capacity of Sphagna in the area and may also go part way to explain the observed distribution of Sphagna on the hummock series of the site.

3. ANALYSIS OF PEAT AND WATER SAMPLES

Such values of the levels of cations analysed above give data concerning an artificial situation, i.e. by viewing each species of Bryophyte in isolation. To gain a basic insight into the level of storage of such cations in the system itself, a series of peat and water samples were analysed for the same cations as above.

The detailed results for the levels of cations measured in each separate hummock profile and in the series of water samples collected around the hummock are given in appendix 1.

There was found to be little variation in the levels of cations measured in the water samples, any variations present being probably mainly due to topographical features of the site area. Thus all the samples were combined to yield mean values of :

pH before filtering	7.40 ± 2.14
pH after filtering	7.46 ± 0.05
Potassium	2.87 ± 0.30 mg/l
Sodium	5.40 ± 0.21 mg/l
Calcium	42.87 ± 2.12 mg/l
Magnesium	13.50 ± 0.82 mg/l
Lead	*2.19 ± 0.30 µg/l

Mean ± standard error

n = 40. n = number of samples

* All values of lead levels in the water samples shown in appendix 1 showing a value of <0.01 µg/l, for the purposes of finding a mean for such values, such were taken to be 0.005 µg/l.

The above values compare reasonably favourably with those quoted by Bellamy and Rieley (1967) for the mean of four mixed mire ground water samples i.e. pH 7.34, potassium 2.6 mg/l, sodium 3.9 mg/l, calcium 12.1 mg/l and magnesium 4.5 mg/l. However, in their survey the level of lead in the ground water was not recorded and thus no comparison may be made. The level of lead recorded above appears to be fairly low when compared with values of lead in surface waters of lakes in the London area quoted by Harrison et al. (1975) (such values quoted fell in the range of 4.5 to 5.5 µg/l).

Determinations of the levels of various cations contained in the peat samples collected showed variations with respect to the size of the hummock sampled and the actual sample position. Such differences that are shown in such cation levels are unlikely to arise from variations in the levels of cations derived from the ground water.

The pH values of the peat samples analysed are given in table 10. The order of values for the pH of Sphagnum peat for the top peat samples of the hummocks range from about 4.0 to 4.5. There appears to be no real marked difference between the pH values of _Sphagnum plumulosum_ and _Sphagnum fuscum_ dominated hummocks (the dominance of the particular species of Sphagnum being mirrored by hummock size). Such low values of pH of Sphagnum dominated peat are frequently quoted (Poore and Walker 1959, Clymo 1967, Allen 1974). Indeed, Bellamy and Rieley (1967) quote a lower value of pH for the top sample of their boring of a hummock contained in the study area.

The pH of the middle peat samples of the hummock series sampled does show a marked decrease as hummock size increases ($r = -0.85$, $r^2 = 0.71$) (graph 1). However, in contrast there was found a small difference between the pH of the bottom samples of the series of hummocks sampled. This is to

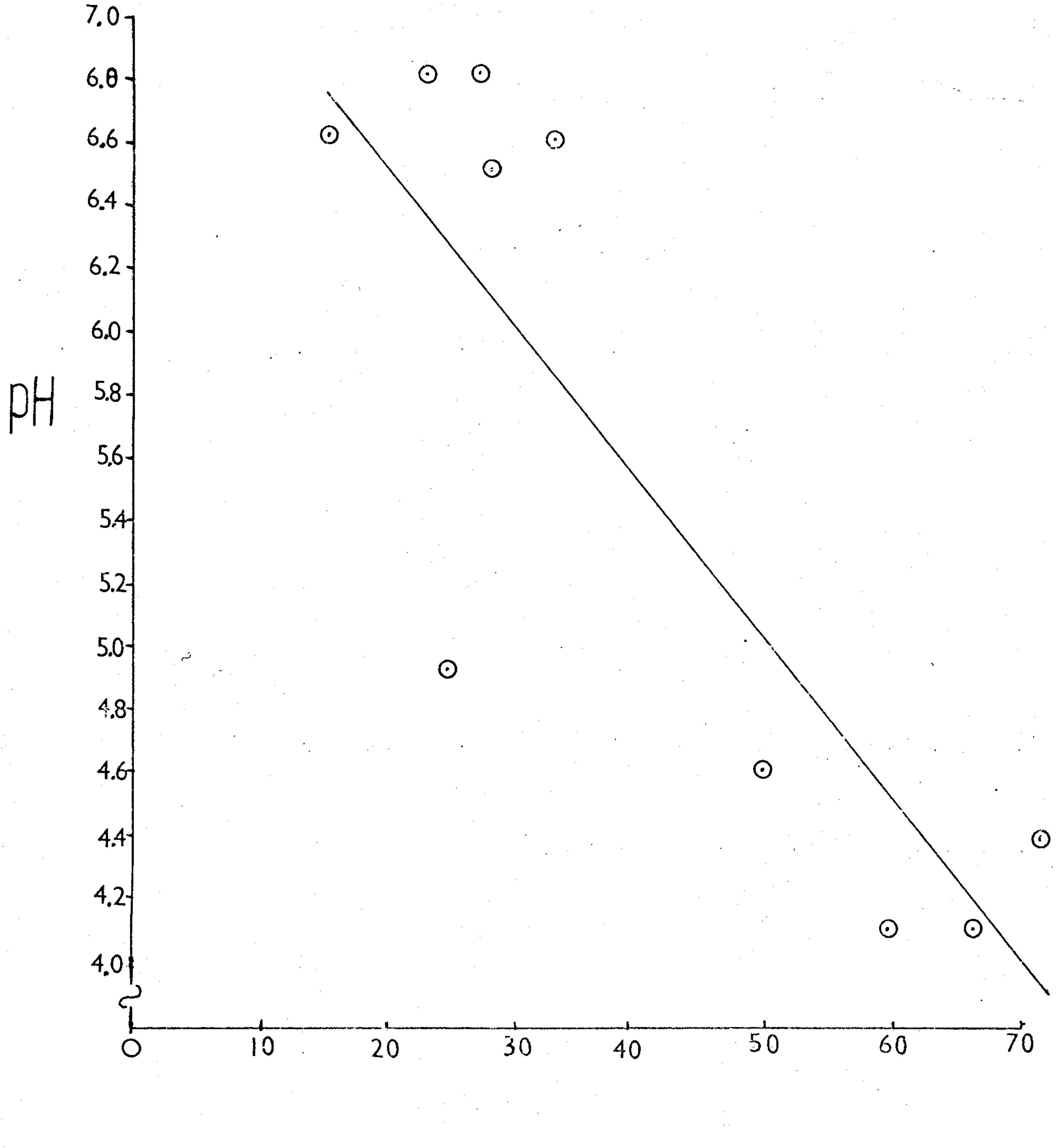
TABLE 10

pH VALUES OF PEAT SAMPLES TAKEN FROM THE HUMMOCK SERIES

Sample position	Hummock Height (cm)									
	15	23	25	27	28	33	50	60	67	72
Top	5.4	4.6	4.0	4.4	4.2	4.5	4.4	4.0	4.3	4.3
Middle	6.6	6.8	4.9	6.8	6.5	6.6	4.6	4.1	4.1	4.4
Bottom	6.9	7.4	6.6	7.3	6.8	6.9	7.1	6.8	7.3	6.7

GRAPH 1

PH VALUES OF MIDDLE PEAT SAMPLES TAKEN FROM THE HUMMOCK SERIES



HUMMOCK HEIGHT (c.m.)

be expected since there seems to exist a large degree of uniformity in the cation component of the ground water over the area of the site.

Tables 11 to 15 illustrate the values of total potassium, sodium, calcium, magnesium and lead in the peat samples analysed.

Due to the uniformity of the ground water in the sample area for each of the above five cations, no real variation existed in the concentrations contained in the bottom peat samples of the hummocks sampled. It is of interest that the levels of all five cations sampled in the top peat samples also did not change markedly as hummock size increased (see tables 11 to 15).

The greatest fluctuation in the total levels of the cations measured appears in the middle peat samples collected from each hummock, the total potassium level in the peat being the only one not to show a large alteration in level as hummock size increases. Most total levels i.e. calcium, magnesium and lead, seem to decrease markedly as hummock size increases (for calcium $r = -0.8253$, $r^2 = 0.6811$, for magnesium $r = -0.8023$, $r^2 = 0.6436$, for lead $r = -0.7710$, $r^2 = 0.5944$) (graphs 2 to 4). However, total sodium levels show the reverse trend ($r = 0.7865$, $r^2 = 0.6185$) (graph 5).

A different effect is seen when one looks at the distribution of the total levels of the cations studied as sample position varies through a hummock profile. As a general trend, viewing the ten hummocks sampled as a whole, higher levels of hydrogen (as derived from the pH values of the peat samples (table 16), potassium and sodium tend to accumulate towards the top of each profile studied (see tables 11 and 12) whilst the total levels of calcium, magnesium and lead tend to show the reverse trend (see tables 13 to 15).

Such changes in the cation and anion content of ground waters, and extended by Bellamy and Rieley (1967) to include peat material, form the basis of Kulcynski (1949) classification of rheophilous, transition and ombrophilous mire systems. However, due to the lack of time for the

TABLE II

Sample position	Hummock Height (cm)									
	15	23	25	27	28	33	50	60	67	72
Top	0.40	1.30	0.52	0.32	1.70	0.74	0.50	0.90	0.60	0.76
Middle	0.24	0.29	0.52	0.16	0.20	0.24	0.27	0.32	0.30	0.19
Bottom	0.25	0.11	0.27	0.17	0.29	0.21	0.14	0.18	0.27	0.27

Values in M gms. per gram dry weight.

TOTAL POTASSIUM LEVELS IN PEAT SAMPLES TAKEN FROM THE HUMMOCK SERIES

TABLE 12

Sample position	Hummock Height (cm)									
	15	23	25	27	28	33	50	60	67	72
Top	0.16	0.38	0.12	0.16	0.40	0.30	0.20	0.10	0.24	0.14
Middle	0.08	0.10	0.12	0.12	0.08	0.08	0.30	0.20	0.22	0.62
Bottom	0.08	0.06	0.08	0.06	0.10	0.04	0.04	0.06	0.06	0.28

Values in M gms. per gram dry weight.

TOTAL SODIUM LEVELS IN PEAT SAMPLES TAKEN FROM THE HUMMOCK SERIES

TABLE 13

Sample position	Hummock Height									
	15	23	25	27	28	33	50	60	67	72
Top	8.36	1.72	1.24	4.88	1.36	1.10	7.80	1.38	1.34	1.52
Middle	13.32	14.34	4.90	15.64	15.42	14.62	7.82	2.12	1.28	1.32
Bottom	14.36	16.08	13.00	17.44	14.08	15.64	14.82	15.06	13.20	14.00

Values in Mgms per gram dry weight.

TOTAL CALCIUM LEVELS IN PEAT SAMPLES TAKEN FROM THE HUMMOCK SERIES

TABLE 14

Sample position	Hummock Height (cm)									
	15	23	25	27	28	33	50	60	67	72
Top	1.60	0.84	0.44	1.04	0.58	0.48	0.64	0.62	0.52	0.66
Middle	2.02	1.80	1.02	1.80	2.10	2.12	1.30	0.68	0.54	0.88
Bottom	1.94	2.24	1.94	2.20	1.82	2.08	2.00	2.12	2.00	2.14

Values in Mgms. per gram dry weight.

TOTAL MAGNESIUM LEVELS IN PEAT SAMPLES TAKEN FROM THE HUMMOCK SERIES

TABLE 15

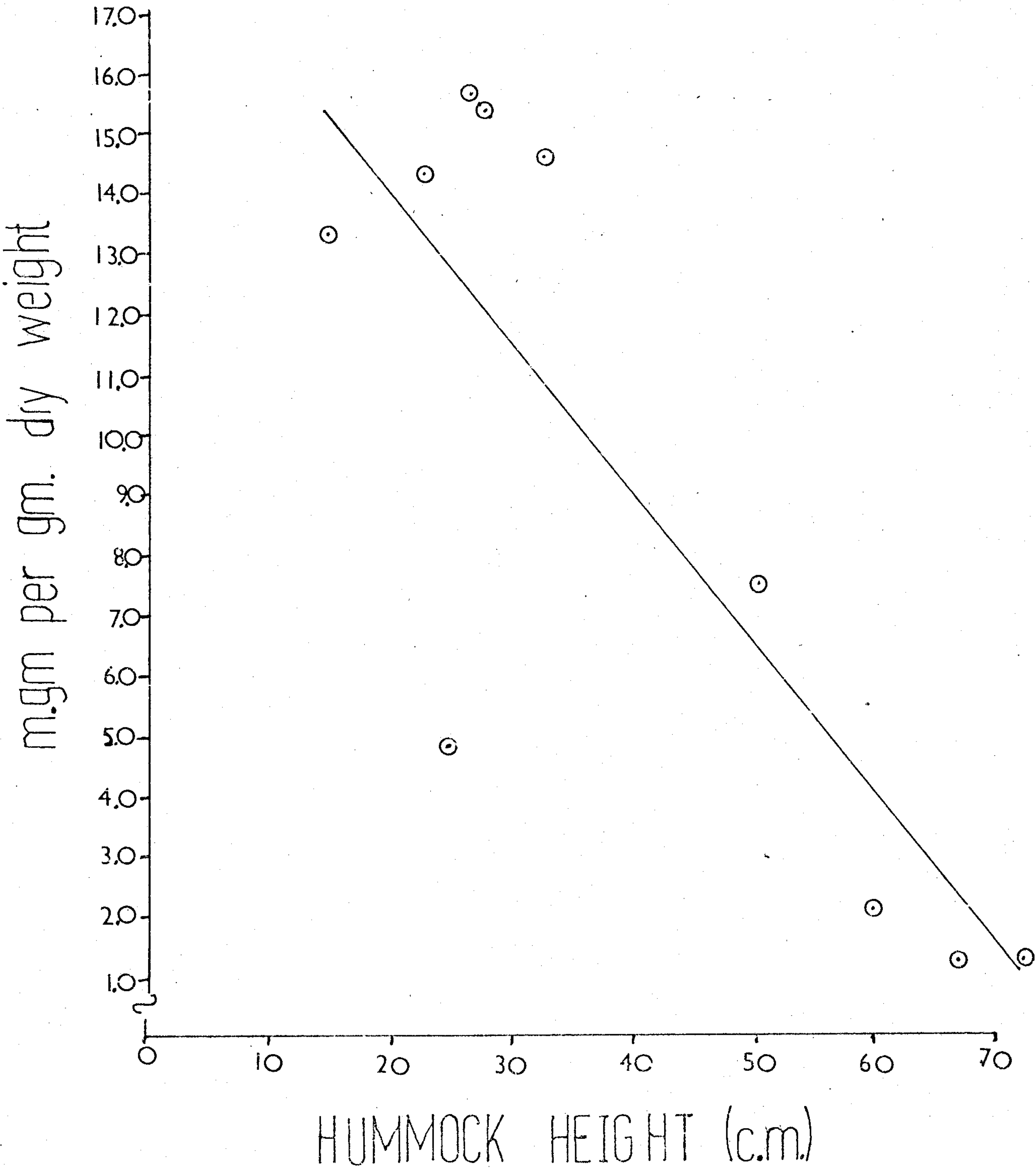
Sample Position	Hummock Height (cm)									
	15	23	25	27	28	33	50	60	67	72
Top	112.0	52.0	32.0	58.0	28.0	16.0	50.0	48.0	28.0	38.0
Middle	146.0	184.0	74.0	126.0	98.0	174.0	86.0	50.0	38.0	48.0
Bottom	198.0	282.0	142.0	140.0	120.0	214.0	186.0	218.0	148.0	188.0

Values in µgms. per gram dry weight.

TOTAL LEAD LEVELS IN PEAT SAMPLES TAKEN FROM THE HUMMOCK SERIES

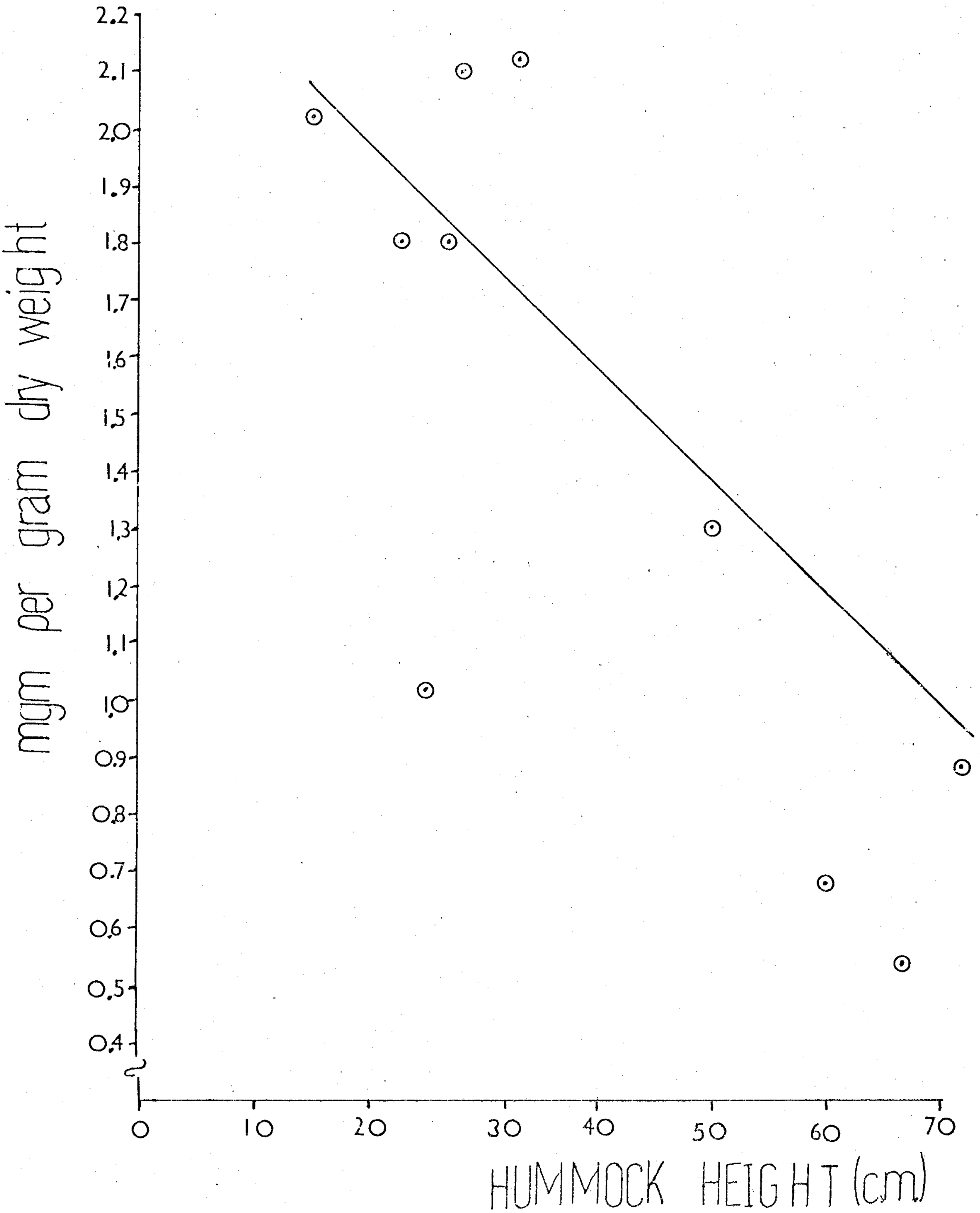
GRAPH 2

TOTAL CALCIUM LEVELS OF MIDDLE PEAT SAMPLES TAKEN FROM THE HUMMOCK SERIES



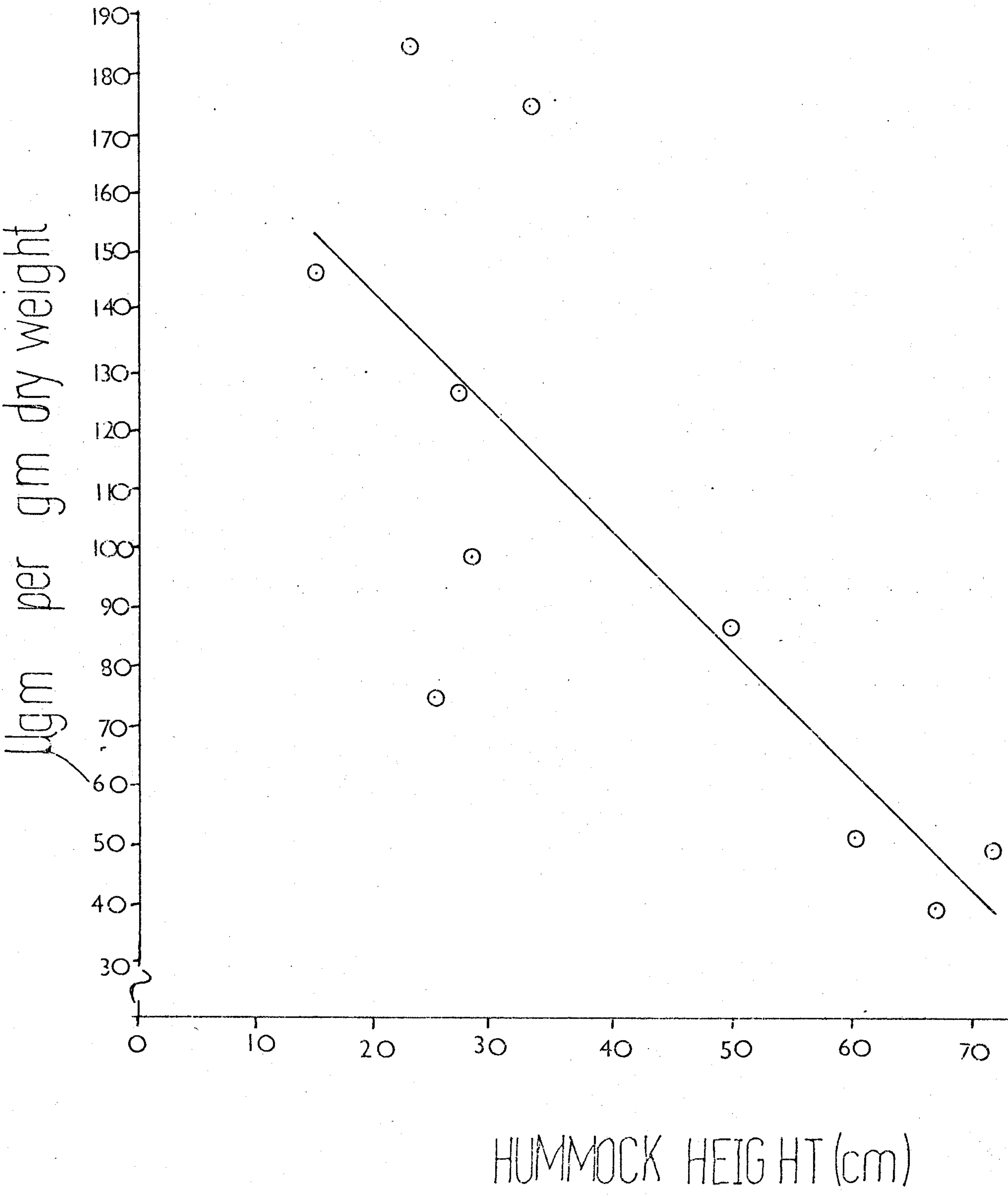
GRAPH 3

TOTAL MAGNESIUM LEVELS OF MIDDLE PEAT SAMPLES TAKEN FROM THE HUMMOCK SERIES



GRAPH 4

TOTAL LEAD LEVELS OF MIDDLE PEAT SAMPLES TAKEN FROM THE HUMMOCK SERIES



GRAPH 5

TOTAL SODIUM LEVELS OF MIDDLE PEAT SAMPLES TAKEN FROM THE HUMMOCK SERIES

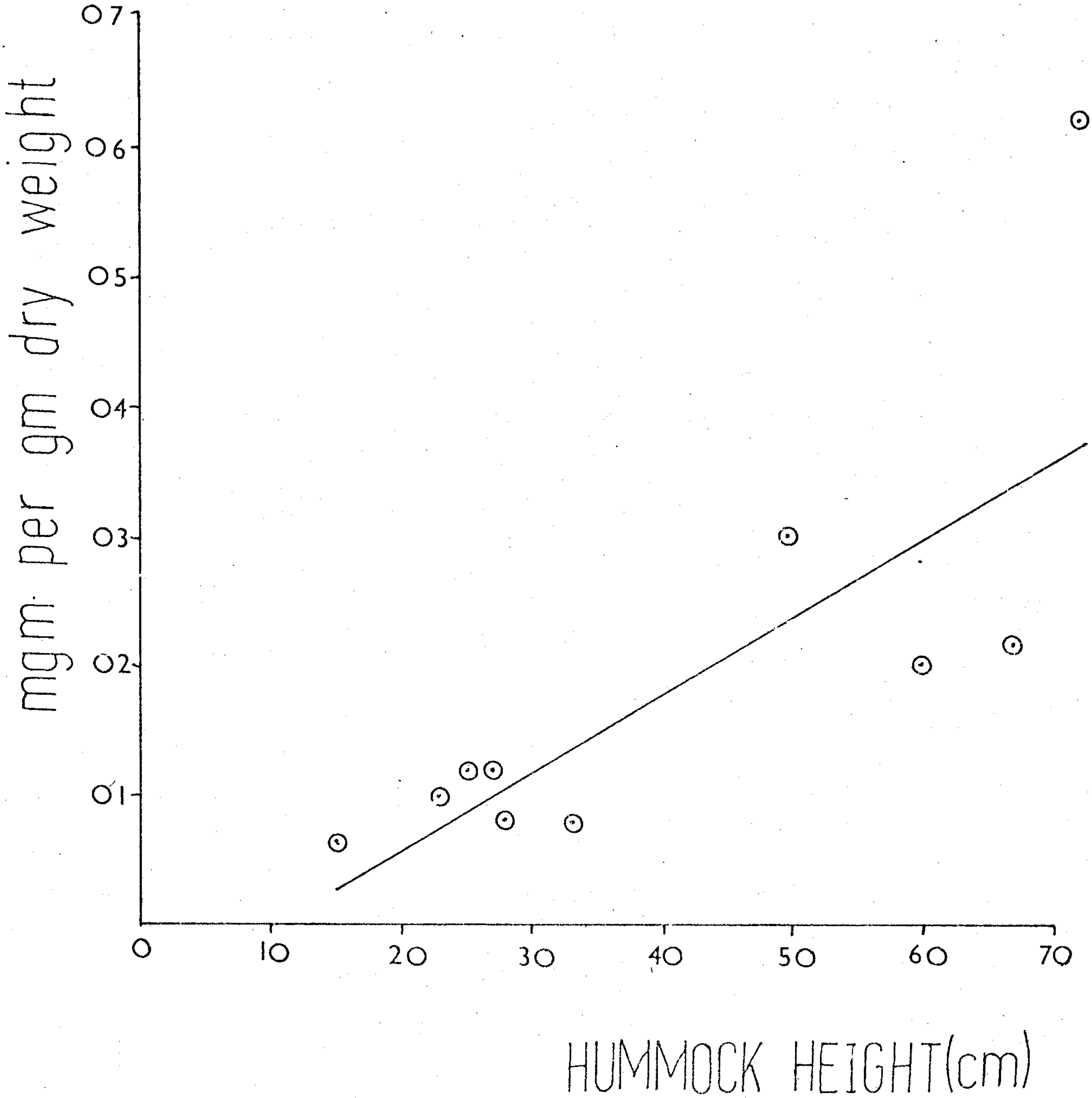


TABLE 16

Sample position	Hummock Height (cm)									
	15	23	25	27	28	33	50	60	67	72
Top	3.98	25.10	100.00	39.80	50.10	31.60	39.80	100.00	50.10	50.10
Middle	0.25	0.16	12.60	0.16	0.32	0.25	25.10	79.40	79.40	39.80
Bottom	0.13	0.04	0.25	0.05	0.16	0.13	0.08	0.16	0.05	0.20

Values in μ moles per litre.

HYDROGEN ION CONCENTRATION DERIVED FROM PEAT pH VALUES study, no quantification of anion content of the peat and ground water samples was, in fact, undertaken. Thus, for the purposes of the study it is assumed that the 'mineral soil water limit' of Thunmark (1942) and the 'calcarious water limit' of Witting (1948) would approximate the boundaries of Kulcynski's groupings. Using the data in table 10, for peat samples whose pH value lay at or below 4.0 was thus classified as an ombrophilous mire type, peat samples whose pH value lay between pH 4.1 to 6.7 was classified as a transitional mire type and finally, the remaining samples whose pH value was at or higher than 6.8 was classified as a rheophilous mire type (table 17).

Such a classification of peat samples as is made in table 17, represents a crude method to illustrate the changes in the levels of cation concentrations found in the peat samples as the hummock size and sample position is altered.

Under conditions that exist at Tarn Moor, there probably exist two major sources of obtaining the major cations (sensu Rohde 1949) analysed in the peat samples. An obvious means of supply of such minerals is via the movement of cations from the ground water into the peat of the hummock series by capillarity. The second major source of minerals is via the direct action of rain over the area.

The ground water of the site contains fairly high concentrations of calcium and magnesium, whereas potassium and sodium are present to a lesser extent (see above). The concentrations of such divalent cations analysed in the peat samples show a marked variation with hummock height and sample position. Such indicates that as the hummock height increases an increasingly effective barrier may be operating to regulate the effective uptake of divalent cations by the peat from the capillary strain from the ground water below.

The total sodium levels analysed in the series of peat samples shows a large variation when the middle peat samples are considered (graph 5). As was noted above, there appears to be only a small amount of

TABLE 17

Sample position	Hummock Height (cm)									
	15	23	25	27	28	33	50	60	67	72
Top	Transitional	Transitional	Ombrophilous	Transitional	Transitional	Transitional	Transitional	Ombrophilous	Transitional	Transitional
Middle	Transitional	Rheophilous	Transitional	Rheophilous	Transitional	Transitional	Transitional	Transitional	Transitional	Transitional
Bottom	Rheophilous	Rheophilous	Rheophilous	Rheophilous	Rheophilous	Rheophilous	Rheophilous	Rheophilous	Rheophilous	Rheophilous

CLASSIFICATION OF PEAT SAMPLES TAKEN BASED ON THAT OF KULCYNSKI (1949) sodium ions contained in the ground water of the site. Due to the proximity of Tarn Moor to the sea, a major means of entry of sodium into the site is probably effected by rainfall.

In contrast to the pattern exhibited by the total calcium and magnesium levels within the middle peat samples, the total sodium levels of the same sample series shows the opposite trend. This may indicate that as the effects of the main cations contained in the ground water are progressively negated as hummock height increases, the relative importance of minerals entering the system via rainfall gain a higher degree of importance in the nutrient regime of the peat.

An interesting result is seen when total lead levels on the same series of peat samples are considered (graph 4). Such atrend which is observed follows the same pattern exhibited by that of calcium and magnesium discussed above. This would tend to indicate that the major source of lead contained in the peat is via the ground water of the area and not rainout of airborne pollution.

The hummock which was the subject of Bellamy and Rieley's paper was also sampled in the above survey (hummock R in the present study). On the previous occasion, the sample procedure was carried out in December 1966 under different weather conditions to those existing in May 1975, when the samples were taken for the present study. The 1966 samples were taken under conditions where the surface water and water contained in the hummock was frozen (D. J. Bellamy pers. comm.). Such extreme conditions at the site were noted by Holdgate (1955a) where he mentions that in December 1950, the water flowing through the open areas of the site was also frozen to varying thicknesses. On comparing the values for the cations determined by Bellamy and Rieley (1967) and those determined in the same hummock, the values quoted by the previous authors for the four common cations analysed tend to be larger than those quoted in the present work (see appendix 1). Also, the pH values given by them for the same hummock tend to be lower than those given above. Such a difference may indicate that there may be a seasonal variation in the levels of the various cations contained in a particular hummock.

Bearing in mind the major drawbacks involved in the sampling procedure adopted, namely, a small number of hummocks were in fact sampled and that no replication of samples was in fact made, the results do indicate that there is a mechanism in the hummock complex which limits the effects of the ground water of the site through the hummock profiles.

Bellamy and Rieley (op. cit.) quote three possible mechanisms in an attempt to explain such a phenomenon:

1. Any ions that exist in capillary water may be fixed at exchange sites in the bottom few cm of peat in a large peat profile. Such exchange sites may be expected to become fully saturated fairly quickly due to high concentrations of minerals contained in the water. Under such a system unless new exchange sites were being continuously produced, the exchange sites would be rapidly inactivated as buffers to further ion migration.
2. Due to the high rainfall of the area, most of the ions following the path of capillary water are leached back down the profile.
3. That some 'block' exists, again in the bottom few cm of peat in the profile, thus preventing any effect of the ground water to act in the rest of the peat profile. Any minerals that do exist above this level are envisaged to enter the system entirely by rainfall.

Bellamy and Rieley (op.cit.) also found at the bottom of their profile a portion of humified peat of 8 cm in depth at the base of the hummock. Results from Ingram et.al. (1974) indicate that the rate of water flow through a highly humified peat $H_3 - H_6$ (Von Post and Granlund 1926) tends to be reduced as compared with the rate of water flow through less humified peat $H_1 - H_2$. It may be that the degree of humification of the peat may also be instrumental in effecting a control on the ground water at the site.

The analysis of the peat samples collected in the present survey shed no light on a possible mechanism to explain the observed distribution of cations actually analysed in them. More work of a sophisticated nature e.g. the compilation of a complete nutrient budget of the system, may provide information concerning the dynamic aspect of such mineral uptake and distribution in the system.

4. ANALYSIS OF THE EXCHANGEABLE CHARACTERISTICS OF THE PEAT SAMPLES OF THE HUMMOCK SERIES

Such total levels of cations as analysed for above indicate little concerning the contemporary budget of such a system. Thus information was collected on the exchangeable levels of bases and hydrogen contained in the peat samples collected. Due to a shortage of time to carry out such an analysis, the method of Brown (1943) was chosen. The main virtue of such a system lies in the fact that a large number of peat samples may be analysed fairly rapidly. However, such a method has been criticised on various grounds. Sjors (1961) pointed out that such a method only determines the excess of extractable cations over anions present in the peat sample. Such a factor ought to be considered in the case of samples with a low metal ion content. Also, that fraction of cations which are dissolved in the water is also included in such a determination.

Unfortunately, due to the lack of time for the analysis, the conversion of pH values obtained when using the method, into values of exchangeable hydrogen and bases was made by the use of the two calibration curves given by Brown in his original paper. Thus the values quoted in tables 18 and 19 may not reflect the absolute values of exchangeable hydrogen and bases at the site, but individual values may be comparable with one another. Indeed, as Allen (1974) points out, there are serious limitations inherent in any extraction procedure performed to obtain the level of available nutrients in soil samples. Such values obtained by such a means are, at best, regarded as an approximate measure of the nutrients which are available at any one particular time (Kaila and Kiveras 1956).

Tables 18 and 19 show the levels of exchangeable hydrogen and exchangeable bases determined for the series of peat samples analysed.

TABLE 18

Sample position	Hummock Height (cm)									
	15	23	25	27	28	33	50	60	67	72
Top	6.1	11.5	15.0	12.7	11.0	11.5	12.0	14.0	14.5	12.7
Middle	1.8	1.1	11.0	0.5	1.1	1.8	2.7	13.3	13.3	4.8
Bottom	2.4	0.8	1.5	1.1	1.6	1.8	1.8	1.8	0.8	2.4

Values in m.eq. per 100 gm. peat

LEVELS OF EXCHANGEABLE HYDROGEN CONTAINED IN PEAT SAMPLES TAKEN FROM THE HUMMOCK SERIES

TABLE 19

Sample position	Hummock Height (cm)									
	15	23	25	27	28	33	50	60	67	72
Top	4.9	3.5	1.4	1.8	3.0	1.8	4.8	2.1	1.8	3.5
Middle	9.5	10.4	3.1	14.2	12.2	11.0	8.3	7.2	2.1	11.0
Bottom	12.2	10.5	10.5	14.2	15.0	11.0	11.0	10.4	15.0	12.2

Values in m.eq. per 100 gm. peat

LEVELS OF EXCHANGEABLE BASES CONTAINED IN PEAT SAMPLES TAKEN FROM THE HUMMOCK SERIES

In both cases, a small difference in the exchangeable levels appears to exist in all three sample positions i.e. top, middle and bottom samples, with respect to increasing hummock size. However, large variations in both exchangeable levels exists through a particular hummock profile.

The large variation in exchangeable hydrogen through a particular hummock profile (table 18) may be explained by the difference in pH of the peat samples already noted (table 10). Towards the top of any of the hummocks sampled, the pH of the peat is markedly acidic i.e. thus showing the cation exchange properties of the species of Sphagna. Under such conditions the peat shows a high concentration of hydrogen ions, as derived from the pH value, and thus would be expected to show a high level of exchangeable hydrogen. When moving down the peat profile, the peat is increasingly affected by the ground water which, by increasing the pH of the peat, causes the opposite effect on the level of exchangeable hydrogen.

The levels of exchangeable bases contained in the peat profiles show the reverse trend (table 19), with the highest level occuring at the bottom of a particular profile and the lowest level at the top. Kaila and Kiveras (1956) noted in their work on Finnish peatlands that the main exchangeable cation found in their peat samples was that of calcium with the exchangeable content of magnesium being almost of the same order. They also found that such values recorded for potassium and sodium were far lower and such values were nearly equal to one another. If such is the case at Tarn Moor, the distribution of exchangeable bases through a particular peat profile could be explained via a gradual limiting of the effects of the ground water through it.

Such an hypothesis may be tested by detailed analysis of the levels of the major cations present in peat samples from the area and could form the basis of further work. Such detailed analyses have been carried out at other sites (Malmer 1962a) using various extraction techniques (Malmer 1962a) (During 1973).

Bearing in mind the limitations noted above, an estimate of the cation exchange capacity of the series of peat samples may be made by the addition of the levels of exchangeable hydrogen and bases (table 20). Such an estimate of cation exchange capacity was also made by Gorham (1953) and Puustjarvi (1955).

The estimate of cation exchange capacity of the peat samples produced by such a means shows a large degree of uniformity throughout the hummock profiles sampled and with increasing hummock height. All values quoted in the table seem to lie at the lower end of the usual ranges of cation exchange capacity quoted in the literature (Puustjarvi 1968). Although the values do approximate to values quoted for Indian peaty soils by Tiwari and Kumar (1974).

Various factors which affect the cation exchange capacity of a particular peat sample are given in length by Puustjarvi (1956) and Curlick et.al. (1973). Bearing in mind such variables demonstrated by these workers, the cation exchange capacity of peat collected from the site would be expected to lie at the lower end of the usual scale noted. When the determinations were carried out, the excess moisture was hand squeezed out of each peat sample which may have affected the estimate of the cation exchange capacities of the samples obtained (Puustjarvi 1956, 1969).

A theory of cation exchange occuring in a peaty soil is proposed by Puustjarvi (1969) to involve hydrogen ions dissociated from carboxyl groups distributed towards the surface of acid peat particles. Under such a system, the degree of dissociation into the solution of hydrogen ions of the active groups, and thus the degree of cation exchange would be largely determined by the acidic nature of the particular sample i.e. the particular pH of the sample.

Such a relation between percentage base saturation (given as an expression of total exchangeable bases as a percentage of the cation exchange capacity) and pH was demonstrated by Gorham (1953) when using Brown's method on a variety of different soil types sampled from the

TABLE 20

Sample position	Hummock Height (cm)									
	15	23	25	27	28	33	50	60	67	72
Top	11.0	15.0	16.4	14.5	14.0	13.3	16.8	16.1	16.3	16.2
Middle	11.3	11.5	14.1	14.7	13.3	12.8	11.0	20.5	15.4	15.8
Bottom	14.6	11.3	12.1	15.3	16.6	12.8	12.8	12.5	15.8	14.6

Values in m.eq. per 100g peat

ESTIMATED CATION EXCHANGE CAPACITY OF PEAT SAMPLES
TAKEN FROM THE HUMMOCK SERIES

Lake District. Malmer (1960), working on fresh samples of the bottom substratum of lakes, and later Malmer (1962a) working on the Akhult mire system of Sweden, found a correlation between pH and percentage base saturation. More recent evidence supporting Puustjarvi's theory of cation exchange is given by During (1973).

Values for percentage base saturation for the series of peat samples from the site are given in table 21. A correlation ($r = 0.9123$, $r^2 = 0.8322$) was found between the pH of the peat samples and the percentage base saturation calculated (graph 6).

A good deal of similarity exists between the values given by Malmer (1962a) and those obtained in the present study. In both cases a percentage base saturation of 50% roughly corresponds to a peat pH of about 5.0. A slight variation exists towards the bottom end of the pH range recorded, Malmer noting the percentage base saturation of zero at a pH of about 2.5, whereas the corresponding value for the above study lies slightly higher at a pH of about 3.3. Such differences that are observed are probably due to geographical and topographical differences between the two study areas.

5. DETAILED ANALYSIS OF ONE HUMMOCK IN THE STUDY AREA

In the light of the small amount of information gathered concerning the levels of selected cations in samples of peat collected through the centre of each of the hummocks sampled, the study was widened to include the more immediate effects of the ground water on the vegetation surrounding such hummocks. In the time available, only a detailed analysis of one specific hummock in the study area could in fact be carried out. This meant resampling the water and peat of one of the hummocks already sampled in the initial survey and also to sample the edge vegetation.

The values of the cations analysed for in the water samples showed a small variation with sample position (table 22). Thus all the values for all parameters sampled were pooled to yield a mean value as was done previously.

TABLE 21

Sample position	Hummock Height (cm)									
	15	23	25	27	28	33	50	60	67	72
Top	44.6	23.3	8.5	12.4	21.4	13.5	28.6	13.0	11.0	21.6
Middle	84.1	90.4	22.0	96.6	91.7	85.9	75.5	35.1	13.6	69.6
Bottom	83.6	92.2	86.8	92.8	90.3	85.9	85.9	85.3	94.9	83.6

PERCENTAGE BASE SATURATION CALCULATED FOR PEAT SAMPLES TAKEN FROM THE HUMMOCK SERIES

GRAPH 6

THE RELATION BETWEEN BASE SATURATION AND pH

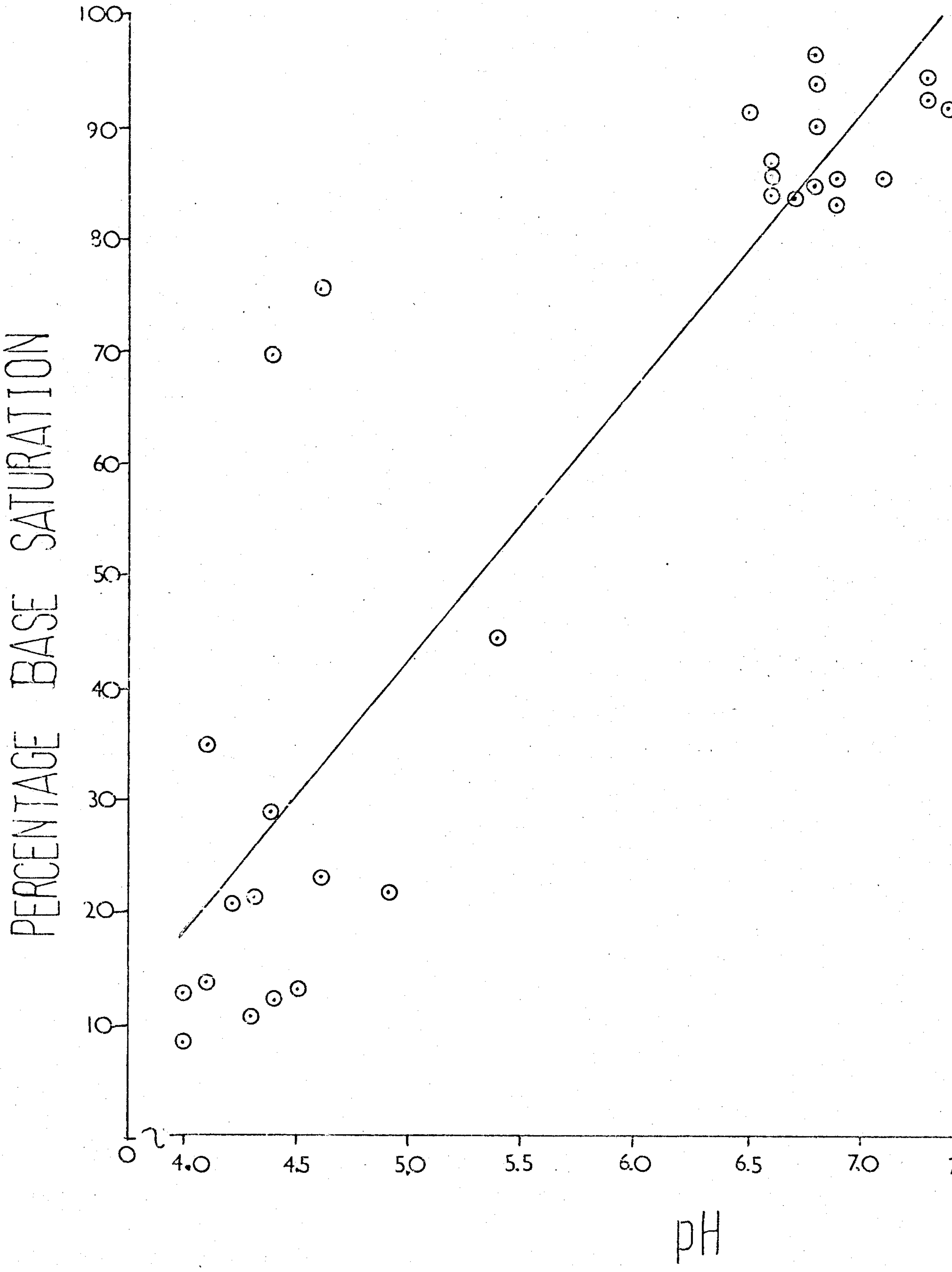


TABLE 22 ANALYSIS OF THE WATER SAMPLES COLLECTED AROUND ONE HUMMOCK

Sample position	pH		mgm/litre				µgm/l
	Before Filtering	After Filtering	Potassium	Sodium	Calcium	Magnesium	Lead
1	8.10± 0.01	7.72± 0.06	4.66± 0.04	6.48± 0.04	45.60± 6.37	28.04± 0.17	4.40± 0.68
2	8.08± 0.05	7.82± 0.12	3.86± 0.35	9.34± 0.25	74.00± 0.88	23.42± 0.38	2.00± 0.32
3	8.30± 0.02	8.14± 0.03	2.44± 0.05	7.58± 0.09	45.12± 3.47	29.12± 0.35	3.40± 0.25
4	8.20± 0.04	7.86± 0.07	1.86± 0.07	5.92± 0.04	30.48± 1.16	25.84± 0.50	0.50± 0.00

ANALYSIS OF PEAT SAMPLES TAKEN THROUGH THE HUMMOCK PROFILE

TABLE 23

		Per gram dry weight				
Sample position	Percentage Saturation	Total Potassium Mgm.	Total Sodium Mgm.	Total Calcium Mgm.	Total Magnesium Mgm.	Total Lead µgm.
Top	91.4	0.13± 0.00	0.23± 0.00	16.00± 0.17	2.13± 0.01	251.60± 2.23
Middle	89.6	0.16± 0.00	0.12± 0.02	16.68 ± 0.31	2.44± 0.02	209.00± 2.38
Bottom	89.3	0.40± 0.00	0.07± 0.03	1.86± 0.09	0.57± 0.01	63.50± 2.36

pH before filtering	8.16± 0.02
pH after filtering	7.38± 0.05
Potassium	3.21± 0.27 mg/l
Sodium	7.33± 0.31 mg/l
Calcium	48.80± 4.00 mg/l
Magnesium	26.61± 0.53 mg/l
Lead	2.60± 0.38 µg/l

Mean ± standard error

n = number of samples. n = 20

On comparison with the values obtained earlier for the original survey, the pH values given above exceed those given earlier, whilst values for the five cations measured show the opposite trend. However, the samples were collected on different days and under different conditions. The above set of samples were collected during a period of heavy rainfall over the area, whilst the original set of water samples were collected when climatic conditions were more favourable. Such may indicate that an increased level of cations enter the mixed mire system under such wet conditions, thus increasing the observed pH value. Other workers have also noted variations in the levels of cations in mire waters when collected from the same site on different occasions e.g. Witting (1948).

Various authors have reported high contents of potassium in species of Sphagna as compared with peat (Anschutz and Gessner 1954, Malmer and Sjors 1955, Kaila and Kiveras 1956). Such an observation is also made when a comparison is made between the total levels of potassium recorded in the vegetation and the peat samples taken (tables 23 and 24). However, such low levels of total cations that are recorded through the peat profile may have been due to the disturbance caused by the initial sample survey. When the original values of cations recorded for the particular hummock are observed (see appendix I), such values are seen to be also lower than that found in the vegetation sampled.

In a recent study of Sphagnum magellanicum, Brehm (1971)

TABLE 24

ANALYSIS OF THE VEGETATION SAMPLES COLLECTED AROUND ONE HUMMOCK.

		Per gram dry weight				
Sample position	Percentage Saturation	Total Potassium Mgm.	Total Sodium Mgm.	Total Calcium Mgm.	Total Magnesium Mgm.	Total Lead µgm.
1. Above ground	93.3	1.34± 0.06	0.76± 0.03	14.66± 0.18	4.43± 0.07	42.00± 2.85
Below ground	94.8	0.24± 0.00	0.16± 0.03	12.93± 0.22	1.74± 0.08	50.00± 3.37
2. Above ground	95.5	1.67± 0.04	0.65± 0.03	4.68± 0.36	1.74± 0.08	38.50± 3.40
Below ground	94.1	1.81± 1.47	0.20± 0.03	12.14± 0.16	2.30± 0.05	69.00± 13.77
3. Above ground	94.7	0.47± 0.02	0.40± 0.02	20.60± 0.67	5.04± 0.17	55.00± 0.58
Below ground	93.7	0.68± 0.07	0.13± 0.00	15.36± 0.36	2.80± 0.06	75.20± 1.63
4. Above ground	94.3	0.76± 0.02	0.35± 0.03	30.64± 3.01	5.38± 0.36	48.40± 1.17
Below ground	93.0	0.31± 0.00	0.17± 0.04	19.55± 0.29	2.63± 0.01	86.50± 2.63

Mean ± standard error. n = 5.

envisaged a model of cation exchange within a single plant. In such a system, due to the transpiration of water in the upper parts of the plant, monovalent ions such as potassium and sodium tend to move upwards, whereas divalent cations, tend to be already bound to the cation exchanger in the lower sections of the plant. The result in table 23 for the monovalent cations, potassium and sodium, tend to bear out the observations of Brehm (1971) and Malmer (1962b). Taken as a general trend, there appears to be an accumulation of monovalent ions in the above ground vegetation sampled as compared with the values found in the below ground samples. Thus, such indicates that cation exchange is occuring in the edge vegetation of the hummock sampled.

In order to gain an approximate indication of the transpirational state of the vegetation, the percentage water saturation of the samples was calculated. However, no real definite trend can be noted in the values obtained.

However, the result for the total calcium and magnesium levels recorded for the vegetation do show very high total levels in both the above and below ground samples. As was noted previously, such ions are the major ones existing in the ground water flowing through the area. Thus the Sphagnum plants contained around the edge of the hummock are probably supersaturated with such divalent cations due to the close proximity of the ground water to them.

Such also seems to be the case when the lead levels for the vegetation samples are considered. This again implies that the major source of the heavy metal is probably via the ground water of the area.

The work of Clymo (1973) demonstrated that a series of species of Sphagna grow poorly under conditions of a high calcium concentration, of high pH e.g. 7.6 and with a surface water table. All three of the above conditions exist at the edges of the Sphagnum hummocks thus, it would be expected that the Sphagnum plants growing in such an area would have a fairly low growth rate. Visual observation of the condition of Sphagna growing around the hummock bears this out. The Sphagnum plants were seen to be small and largely discoloured. However, experiments also carried out by Brehm (1970) on Sphagnum magellanicum show that elution with sodium and potassium affect Sphagna more drastically than divalent cations. Eluting with sodium and potassium was shown to cause a general discolouration of the Sphagnum species and a total inhibition of growth within six weeks. Thus, conditions existing around the edges of such a hummock are far from favourable for the growth of Sphagna, as is reflected in the obvious state of the plants growing in this location.

Under conditions prevailing at Tarn Moor, the overall model of Brehm (1971), where the cation exchange occuring in the Sphagnum plants appears to be regenerating itself by means of movement of water through the plant, seems to be overlaid by the supersaturation effect seemingly exerted by the effects of the ground water. Both monovalent and divalent ions are caused to move upwards during period of dryness and thus transported to the living regions of the plants. Periods of heavy rain may cause the reverse effect. Such a system would thus be in a state of dynamic equilibrium with conditions prevailing at the time, thus may act as a dynamic 'barrier' system, limiting the effects of the ground water through part of the hummock profile. This may operate, providing that conditions do not become too unfavourable for the growth and regeneration of new Sphagnum plants in such a habitat.

SECTION 4 GENERAL DISCUSSION

One of the basic aims of the study was to extend our information concerning the mixed mire ecosystem. Thus it is necessary to link up the threads of the information gained in the study so far and attempt to build an overall picture, as far as is possible, of the processes which may be instrumental in the development of such a system.

It was shown earlier that the cation content of samples of water collected from the site were of a fairly uniform nature. Thus, it may be assumed that the starting point for the development of a mixed mire ecosystem would probably comprise of such conditions.

The observations of Bellamy and Rieley (1967) have been confirmed in the above study. Both indicate that mat forming species e.g. *Cratoneuron falcatum*, *Scorpidium scorpioides*, *Campylium stellatum* and *Schoenus nigricans* may play an important role in the initiation of the hummock forming process at the site. In the case of the latter species, its role in hummock formation has been noted by Holdgate (1955a).

Such species are envisaged to become established under such conditions by propagules entering from both inside and outside the study area onto favourable areas of open ground water. Once such species have become established, the mat forming habit of the species already noted may deflect the ground water to a sufficient extent to allow the growth of *Sphagnum palustre*, which acts as a hummock former (Watson 1955). Once the process of hummock formation commences, it appears that *Sphagnum plumulosum* *Sphagnum capillaceum* and *Sphagnum rubellum* appear to act as pioneer species. It is interesting to note that *Sphagnum fuscum* is only found to dominate the larger hummocks.

The analysis of the total levels of cations contained in the species of Bryophytes analysed, indicated a marked difference between species which grow under the influence of such mineral rich ground water and the Sphagnum species which grow under less mineral rich conditions.

Such differences may be explained by the cation exchange properties of Sphagna noted by various workers (Skene 1915, Williams and Thompson 1936, Ramault 1954 and Anschutz and Gessner 1954). Indirect evidence of such process occuring is provided by the difference in pH noted of the ground water and peat samples collected.

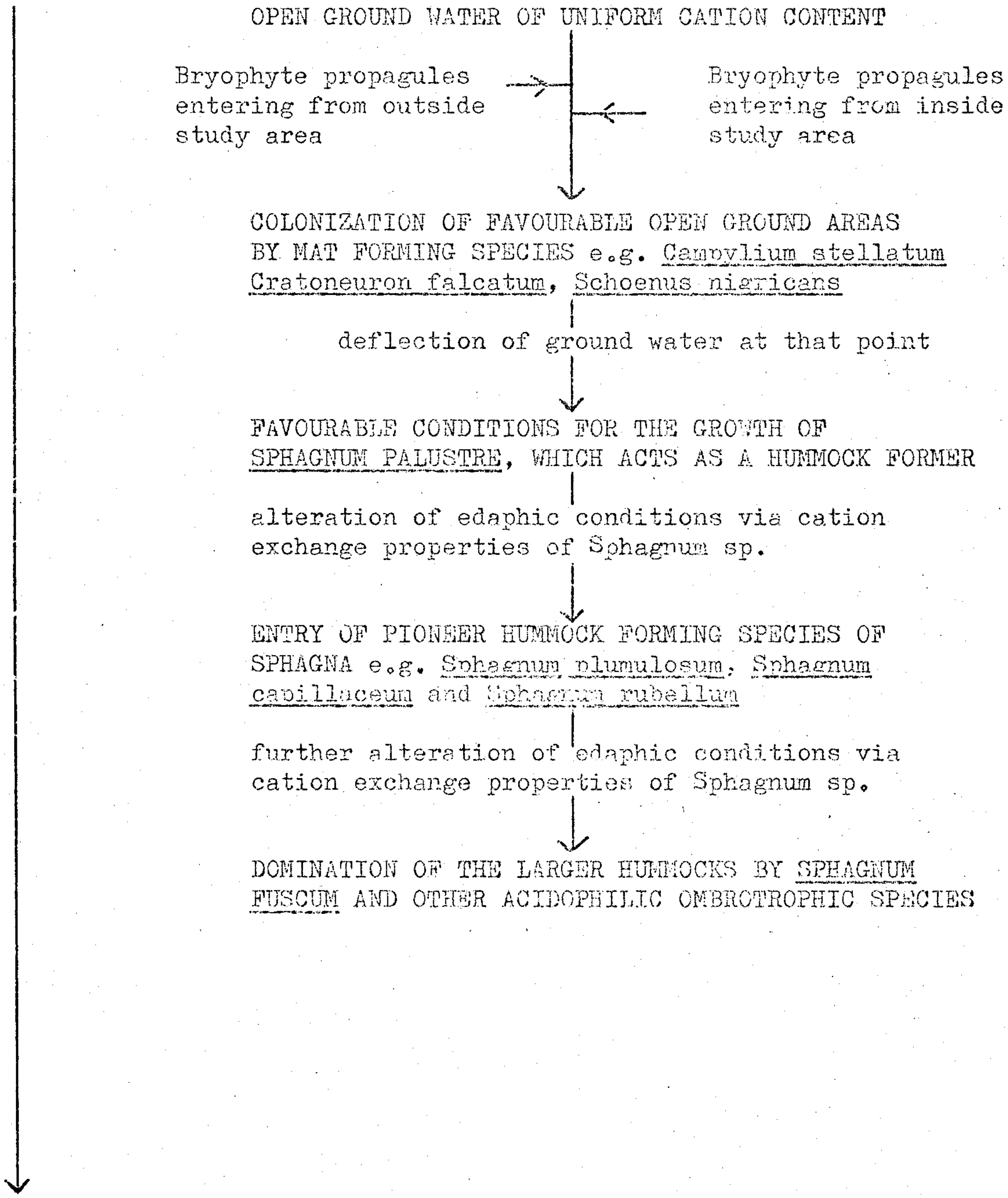
Thus, once species of Sphagna become established on a raized peaty soil above the ground water level, the edaphic conditions could alter markedly as the process of hummock formation commences. Spearling (1972) concluded that the capacity for cation exchange to occur within a particular species of Sphagnum may enable the species to occupy a particular habitat within the bog. Such a distribution of Sphagnum species that exists at Tarn Moor may be explained by such a distribution of cation exchange.

Floristic evidence i.e. the result of the identifiable plant species contained in the middle and top peat samples of the hummock series and the contemporary sociology of the hummocks chosen, indicate that a change in edaphic conditions has occured during the hummock forming process. Both show that conditions are changed sufficiently by the presence of pioneer species to allow acidophilous species to grow under such conditions on the larger hummocks sampled. Indeed, the latter evidence indicates that all meaningful effect of the ground water at the surface of a hummock has been shut off once a hummock reaches a height of approximately 30 cm. Such processes which seem to be involved in such a developmental process are given in diagram 1.

Such a gradual removal of the major effects of the base rich flowing ground water i.e. as mirrored by the total levels of calcium and magnesium found in the peat samples, was also found when detailed analysis was undertaken for a series of selected cations over a whole range of hummock heights and through specific hummock profiles. When consdering the larger hummocks studied e.g. of 60 cm. and above, no effect of the ground water was recorded.

DIAGRAM 1

TENTATIVE HYPOTHESIS FOR THE FORMATION OF A MIXED MIRE ECOSYSTEM AT TARN MOOR, CUMBRIA.



OPEN GROUND WATER OF UNIFORM CATION CONTENT

Bryophyte propagules entering from outside study area

Bryophyte propagules entering from inside study area

COLONIZATION OF FAVOURABLE OPEN GROUND AREAS BY MAT FORMING SPECIES e.g. Campylium stellatum Cratoneuron falcatum, Schoenus nigricans

deflection of ground water at that point

FAVOURABLE CONDITIONS FOR THE GROWTH OF SPHAGNUM PALUSTRE, WHICH ACTS AS A HUMMOCK FORMER

alteration of edaphic conditions via cation exchange properties of Sphagnum sp.

ENTRY OF PIONEER HUMMOCK FORMING SPECIES OF SPHAGNA e.g. Sphagnum plumulosum, Sphagnum capillaceum and Sphagnum rubellum

further alteration of edaphic conditions via cation exchange properties of Sphagnum sp.

DOMINATION OF THE LARGER HUMMOCKS BY SPHAGNUM FUSCUM AND OTHER ACIDOPHILIC OMBROTROPHIC SPECIES

Decreasing effect of the ground water on the peat as hummock height increases.

However, in contrast, using the method of Brown (1943) to measure the cation exchange capacity of the series of peat samples taken, very little change in the levels of cation exchange capacity was noted with increasing hummock height or with position within a particular profile (table 20). Although, when viewing the levels of exchangeable hydrogen and exchangeable bases recorded through a particular profile, a marked change was noted (tables 18 and 19). The change in the level of exchangeable hydrogen (table 18) could be explained by the change of pH of the peat samples through the profile. On the other hand, the changes in the levels of exchangeable bases (table 19), if the observations of Kaila and Kiveras (1956) hold for conditions at Tarn Moor, may be explained by a gradual reduction of the effect of the ground water with position in a particular peat profile.

Bellamy and Rieley (1967) postulated three possible mechanisms which may explain the observed gradual reduction of the effect of the ground water when a peat profile of a large hummock e.g. about 60 cm. in height, is considered. Another possible explanation may be based on the recent observations of Ingram et.al. (1974) on peats of differing humification, but such an explanation may remain speculative until more data is collected on the area.

In order to ascertain another possible mechanism, the edge vegetation around one particular hummock was also sampled. Such results indicate, following the work of Brehm (1971), that cation exchange of the species of Sphagna present under such conditions occur, but is also overlaid by a supersaturation effect of calcium and magnesium due to the close proximity of the vegetation to the mineral rich ground water. Such a system may be regarded as a dynamic 'barrier' system, the exchange capacity of the Sphagnum species being affected by climatic conditions, thus limiting the effects of the ground water through a part of the hummock profile.

SECTION 5 SUGGESTIONS FOR FURTHER WORK

1. For the present study, a series of ten hummocks were chosen, obviously in order to gain a more representative sample of the mixed mire area, a larger sample number should be used for further work undertaken. Also the peat sampling procedure described should also be extended to provide samples consisting of whole peat profiles.

2. Obviously, more work should be done on the developmental sequence of the site. Further information may be gained by making a series of borings through raized areas at the site dominated by Sphagnum palustre and Polytrichum strictum to ascertain their role in the developmental process.

3. Following the work of Spearling (1972), determinations on the galacturonic acid levels, and hence information concerning the exchange capacities, of various species of Sphagnum found at the site could be made to possibly explain the distribution of Sphagnum species noted.

4. The present study was mainly concerned with selected cations contained in the peat and water samples from the site. The work may be extended to include information concerning levels of anions in samples collected from the same sources.

5. The study may have shown a seasonal variation in the levels of cations recorded in the peat samples, as compared with those noted by Bellamy and Rieley (1967). Samples from the site may be taken at different time periods to ascertain whether such a variation exists.

6. One major drawback to the present study was that no information was collected on the exchangeable levels of the selected cations in the peat samples. Such could be carried out using various extraction procedures.

7. Due to the shortage of time for study, a rapid method for the determination of the cation exchange capacity of the peat samples was used. In further work a more accurate method may be used on the peat samples collected from the site.

8. It is evident that from the preliminary survey of Bellamy and Rieley (1967) and from the present study that a mechanism exists within the hummock complex to negate the effect of the ground water through a hummock profile, detailed hydrology of a series of hummocks at the site is needed to elucidate such a process.

9. In order to ascertain the role for each of the major ions sensu Rohde (1949) a complete mineral budget should be drawn up for the system.

SUMMARY

1. The results of the present study confirm those of Bellamy and Rieley (1967) that such species as Cratoneuron falcatum and Campylium stellatum may play a role in the initiation of hummock formation of the mixed mire association at Tarn Moor, Cumbria.

2. Over the whole of the sample area, there appeared to be little variation in the levels of pH, potassium, sodium, magnesium, calcium and lead recorded in the ground water samples.

3. There was found to be a marked variation in the levels of cations derived from the ground water i.e. calcium and magnesium, in peat sampled from a series of hummocks of varying size. Such observations confirm those of Bellamy and Rieley (1967) who proposed that a mechanism exists within a large hummock profile (hummock height 55cm) to negate the effects of the ground water.

4. Very little variation could be found in the estimate of the cation exchange capacity, obtained by the method of Brown (1943), for the series of peat samples taken. Variations did exist within a single peat profile when levels of exchangeable hydrogen and exchangeable bases were viewed separately. The former being explained via the distribution of pH through the profile, the latter by invoking a possible 'barrier' mechanism as proposed by Bellamy and Rieley (1967).

5. Another possible 'barrier' mechanism which could negate the effect of the base rich ground water on such peat profiles studied may act via the vegetation surrounding such hummocks. It was noted that such vegetation was supersaturated by the major ions comprising the

ground water of the site. As a result, a dynamic 'barrier' system is proposed for such vegetation.

In the light of the observations made in the present study, a tentative hypothesis for the formation of a mixed mire at the site was proposed.

ACKNOWLEDGEMENTS

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APPENDIX 1: ANALYSIS OF PEAT AND WATER SAMPLES COLLECTED DURING THE INITIAL SURVEY

Peat samples

			Per gram dry weight				
Sample position	Percentage Saturation	pH	Total Potassium Mgm.	Total Sodium Mgm.	Total Calcium Mgm.	Total Magnesium Mgm.	Total Lead µgm.
Top	93.4	5.4	0.40	0.16	8.36	1.60	112.0
Middle	92.0	6.6	0.24	0.08	13.32	2.02	146.0
Bottom	89.8	6.9	0.25	0.08	14.36	1.94	198.0

Hummock J

Height = 15 cm.

Water samples

Sample position	pH		Mgm/litre				µgm/l
	Before Filtering	After Filtering	Potassium	Sodium	Calcium	Magnesium	Lead
1	6.94	7.30	4.1	6.6	32.3	9.4	9.0
2	7.00	6.90	3.1	6.5	20.2	5.4	3.0
3	7.16	7.46	2.2	5.7	37.1	9.5	4.0
4	7.24	7.70	3.5	7.2	37.3	9.2	2.0

Peat samples

Sample position	Percentage Saturation	pH	Per gram dry weight				
			Total Potassium Mgm.	Total Sodium Mgm.	Total Calcium Mgm.	Total Magnesium Mgm.	Total Lead µgm.
Top	89.5	4.6	1.30	0.38	1.72	0.84	52.0
Middle	88.1	6.8	0.29	0.10	14.34	1.80	184.0
Bottom	88.9	7.4	0.11	0.06	16.08	2.24	282.0

Hummock K

Height = 23cm.

Water samples

Sample position	pH		Mgm/litre				µgm/l
	Before Filtering	After Filtering	Potassium	Sodium	Calcium	Magnesium	Lead
1	7.58	7.50	4.3	6.2	57.4	17.2	4.0
2	7.30	7.60	3.0	5.2	48.3	15.9	2.0
3	7.54	7.52	2.6	6.0	64.8	17.4	2.0
4	7.26	7.66	3.8	6.4	46.5	16.3	2.0

Peat samples

Sample position	Percentage Saturation	pH	Per gram dry weight				
			Total Potassium Mgm.	Total Sodium Mgm.	Total Calcium Mgm.	Total Magnesium Mgm.	Total Lead µgm.
Top	91.2	4.0	0.52	0.12	1.24	0.44	32.0
Middle	93.0	4.9	0.52	0.12	4.90	1.02	74.0
Bottom	92.0	6.6	0.27	0.08	13.00	1.94	142.0

Hummock L

Height = 25cm.

Water samples

Sample position	pH		Mgm/litre				µgm/l
	Before Filtering	After Filtering	Potassium	Sodium	Calcium	Magnesium	Lead
1	6.60	6.42	1.5	2.5	9.7	2.3	4.0
2	7.20	7.02	1.8	3.6	21.1	4.7	2.0
3	7.60	7.44	2.6	7.5	46.4	14.1	3.0
4	7.64	7.12	2.3	4.8	32.9	8.9	2.0

Peat samples

			Per gram dry weight				
Sample position	Percentage Saturation	pH	Total Potassium Mgm.	Total Sodium Mgm.	Total Calcium Mgm.	Total Magnesium Mgm.	Total Lead µgm.
Top	91.5	4.4	0.32	0.16	4.88	1,04	58.0
Middle	92.0	6.8	0.16	0.12	15.64	1.80	126.0
Bottom	92.0	7.3	0.17	0.06	17.44	2.20	140.0

Hummock M
Height = 27cm.

Water samples

Sample position	pH		Mgm/litre				µgm/l
	Before Filtering	After Filtering	Potassium	Sodium	Calcium	Magnesium	Lead
1	7.32	7.52	1.8	3.8	50.6	13.1	2.0
2	7.46	7.56	2.9	5.1	53.2	14.5	2.0
3	7.56	7.84	1.6	4.1	50 .1	10.3	2.0
4	7.22	7.68	2.3	5.3	50.8	13.2	2.0

Peat samples

			Per gram dry weight				
Sample position	Percentage Saturation	pH	Total Potassium Mgm.	Total Sodium Mgm.	Total Calcium Mgm.	Total Magnesium Mgm.	Total Lead µgm.
Top	92.1	4.2	1.70	0.40	1.36	0.58	28.0
Middle	93.6	6.5	0.20	0.08	15.42	2.10	98.0
Bottom	91.7	6.8	0.29	0.10	14.08	1.82	120.0

Hummock N

Height= 28cm.

Water samples

Sample position	pH		Mgm/litre				µgm/l
	Before Filtering	After Filtering	Potassium	Sodium	Calcium	Magnesium	Lead
1	7.50	7.80	1.7	5.0	46.7	15.0	2.0
2	7.48	7.74	1.8	4.2	37.4	11.3	2.0
3	7.38	7.76	3.8	7.0	67.8	24.3	2.0
4	7.38	7.68	1.0	3.4	36.4	9.9	< 1.0

Peat samples

Sample position	Percentage Saturation	pH	Per gram dry weight				
			Total Potassium Mgm.	Total Sodium Mgm.	Total Calcium Mgm.	Total Magnesium Mgm.	Total Lead µgm.
Top	92.1	4.5	0.74	0.30	1.10	0.48	16.0
Middle	90.8	6.6	0.24	0.08	14.62	2.12	174.0
Bottom	89.4	6.9	0.21	0.04	15.64	2.08	214.0

Hummock O

Height=33cm.

Water samples

Sample position	pH		Mgm/litre				µgm/l
	Before Filtering	After Filtering	Potassium	Sodium	Calcium	Magnesium	Lead
1	7.50	7.88	0.50	5.6	30.1	21.1	5.0
2	7.54	7.68	0.90	5.6	51.3	19.5	4.0
3	7.34	7.24	1.30	7.3	49.6	14.6	5.0
4	7.38	7.50	0.80	4.1	56.6	14.6	6.0

Peat samples

			Per gram dry weight				
Sample position	Percentage Saturation	pH	Total Potassium Mgm.	Total Sodium Mgm.	Total Calcium Mgm.	Total Magnesium Mgm.	Total Lead µgm.
Top	91.9	4.4	0.50	0.20	7.80	0.64	50.0
Middle	89.1	4.6	0.27	0.30	7.82	1 .30	86.0
Bottom	88.6	7.1	0.14	0.04	14.82	2.00	186.0

Hummock P

Height=50cm.

Water samples

Sample position	pH		Mgm/litre				µgm/l
	Before Filtering	After Filtering	Potassium	Sodium	Calcium	Magnesium	Lead
1	7.80	7.70	0.20	4.2	50.3	11.6	<1.0
2	7.50	7.12	1.9	4.6	34.0	8.6	<1.0
3	7.72	7.56	0.3	3.6	40.5	10.2	<1.0
4	7.72	7.42	2.9	4.6	40.4	12.0	<1.0

Peat samples

Sample position	Percentage Saturation	pH	Per gram dry weight				
			Total Potassium Mgm.	Total Sodium Mgm.	Total Calcium Mgm.	Total Magnesium Mgm.	Total Lead µgm.
Top	83.9	4.0	0.90	0.10	1.38	0.62	48.0
Middle	92.9	4.1	0.32	0.20	2.12	0.68	50.0
Bottom	90.7	6.8	0.18	0.06	15.06	2.12	218.0

Hummock Q
Height=60cm.

Water samples

Sample position	pH		Mgm/litre				µgm/l
	Before Filtering	After Filtering	Potassium	Sodium	Calcium	Magnesium	Lead
1	7.44	7.96	3.3	7.4	53.1	15.6	2.0
2	6.82	7.02	9.8	6.6	24.5	7.0	5.0
3	7.60	7.32	4.6	5.4	53.9	18.2	<1.0
4	7.38	7.50	2.3	4.4	55.6	16.4	<1.0

Peat samples

Sample position	Percentage Saturation	pH	Per gram dry weight				
			Total Potassium Mgm.	Total Sodium Mgm.	Total Calcium Mgm.	Total Magnesium Mgm.	Total Lead µgm.
Top	87.5	4.3	0.60	0.24	1.34	0.52	28.0
Middle	93.1	4.1	0.30	0.22	1.28	0.54	38.0
Bottom	92.6	7.3	0.27	0.06	13.20	2.00	148.0

Hummock R
Height=67cm.

Water samples

Sample position	pH		Mgm/litre				µgm/l
	Before Filtering	After Filtering	Potassium	Sodium	Calcium	Magnesium	Lead
1	7.44	7.52	7.6	6.2	59.8	18.1	<1.0
2	7.74	7.72	2.2	3.4	53.5	12.9	<1.0
3	7.64	7.44	4.9	6.4	27.8	20.5	<1.0
4	7.68	7.34	2.8	7.7	39.8	9.7	<1.0

Peat samples

Sample position	Percentage Saturation	pH	Per gram dry weight Total Potassium Mgm.	Total Sodium Mgm.	Total Calcium Mgm.	Total Magnesium Mgm.	Total Lead µgm.
Top	84.6	4.3	0.76	0.14	1.52	0.66	38.0
Middle	91.7	4.4	0.19	0.62	1.32	0.88	48.0
Bottom	91.2	6.7	0.27	0.28	14.00	2.14	188.0

Hummock S
Height=72cm.

Water Samples

Sample position	pH		Mgm/litre				µgm/l
	Before Filtering	After Filtering	Potassium	Sodium	Calcium	Magnesium	Lead
1	7.66	7.54	4.7	6.6	57.5	20.9	<1.0
2	6.80	6.86	4.6	5.9	19.9	5.7	<1.0
3	7.56	7.42	4.2	5.7	39.9	22.6	<1.0
4	7.42	7.42	3.3	4.6	29.7	18.2	<1.0

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