ECOLOGICAL STUDIES IN THE INLAND HALOPHYTIC VEGETATION OF THE BRITISH ISLES

by

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being

the first volume of a thesis submitted to the University of Manchester for the degree of Doctor of Philosophy in the Faculty of Science.

October 1978

I declare that to the best of my knowledge and apart from any text references to published works, no portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

R. A. Mirza

October 1978.

Postgraduate Experience.

I graduated with B.Sc. Hons. (2nd class) in 1963 and M.Sc. (2nd class) in 1964 from the University of Punjab, Pakistan. Since 1967 I have been a lecturer at Government College, Lahore, Pakistan teaching Botany and Plant Ecology both at undergraduate and postgraduate levels. From October 1976 to the present date I have been a full time postgraduate research student for the degree of Ph.D. in the Geography Department, University of Manchester, sponsored by a Central Overseas Training Scholarship from the Government of Pakistan.

ABSTRACT

The thesis attempts a broad overall phytosociological/ecological survey and classification of the inland halophytic vegetation of the British Isles. The vegetation description, survey and classification is according to the National Vegetation Classification Project, and is based on over 300 relevés. In all, 15 associations are recognised and each association is classified into its respective class, order and alliance, according to the Zurich-Montpellier system of plant sociology. Four associations Lemnetum salinae sensu lato, Potamogetonetum pectinati, Zannichellietum palustris and Myriophylletum salinae are described from the vegetation type of pioneer, floating communities of static or slow-moving water. Five associations - Scirpetum tabernaemontani, Scirpetum maritimi, Phragmitetum eurosibericum, Typhetum angustifolio-latifoliae and Caricetum otrubae are described from the vegetation type of emergent sedge and reedswamp vegetation at the margins of open water. Two associations, the Atriplicetum salinae deviense and Cotuletum coronopifoliae are described from the vegetation type of annual herb communities of periodically inundated saline soils and from the inland salt marsh vegetation dominated by perennial rush and grass species, four associations - Juncetum gerardii, Puccinellietum maritimae, Spergularietum marinae and Puccinellietum distantis are described. The ecological gradients in each vegetation type are discussed in relation to Na^+, Mg^{2+}, Ca^{2+} and Cl^-.

The sources of salinity in the inland locations are discussed in relation to Na^+ and Cl^-, and the sites are described in terms of Na^+ and Cl^- in their associated soils and water. The soils of semi-natural salt marshes and natural salt marshes are classified into major group, group, sub-group and series according to the prevalent systems of soil classification in Britain. The ecological characteristics and affinities of the alkaline and saline industrial waste lagoons in Cheshire are discussed.

The plant species found in the inland saline localities are classified according to the range of Na^+ in their habitats, and in the shoots. Five different approaches are taken into consideration for defining the halophytic tendencies in the inland plant species. Four inland plant species, Ranunculus sceleratus, Cotula coronopifolia, Aster

tripolium and Puccinellia distans are grown at controlled glasshouse conditions in culture media and their growth and cation accumulation capacity are studied at varying external concentrations of NaCl and $MgCl_2$.

The thesis is divided into two volumes. Volume I contains all the textual description and discussion associated with the project, while Volume II contains the phytosociological and ecological tables and Appendices on methodology, results of soil, water and plant analysis and localities visited and sampled.

ACKNOWLEDGEMENTS

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CONTENTS

CHAPTER I

INTRODUCTION

The distribution of inland saline lands and their supporting vegetation had been studied in many parts of the world, and Chapman in his comprehensive reviews (1960, 1972, 1975) has given the geographical distribution of inland salt marshes and salt deserts of the world. Describing the Inland European Group he states, 'Whilst there is general similarity throughout, they can be subdivided biogeographically into northern and south-eastern subgroups. The northern subgroup is clearly related to the northern European maritime marshes because some species are common. The grass Puccinellia distans is a characteristic species of this subgroup". This is true of the inland saline sites in the British Isles which are either natural salt marshes, associated with the Keuper Saliferous Beds or semi-natural salt marshes whose development was originated through the activities of the salt industry. A third type of saline site is the waste lagoons, where saline and alkaline residues from salt industries are pumped out to evaporate and solidify.

The existence of salt springs has been known since at least Roman times and apart from the work of Lee (1975, 1977) no detailed phytosociological and ecological study has been carried out. The early works which include those of Plot (1686), Clifford & Clifford (1817), Amphlett & Rea (1909), Druce (1897) and some recent observations by Burke (1942, 1943 and 1944) and Chapman (1960) in Cheshire and Fincher (1950) and Williams (1973) are mainly floristic. The more comprehensive works are by Lee (1975) who has described the inland salt marshes and their problems of conservation and the vegetation of the natural salt marshes (1977). Lee described in detail the vegetation of Nantwich salt marshes, largely destroyed in 1974, using the normal association-analysis technique of Williams & Lambert (1959). Similarly, information-analysis techniques have been used for the vegetation classification at Pasturefields, in Staffordshire.

Taking Lee's work as the basis and that of Wallwork (1956, 1959, 1960, 1967) as a background to the ecological survey, the study was designed to investigate four main problems:

(i) to define the soil types in the saline and alkaline environments;

(ii) to describe the vegetation using methods adopted by National Vegetation Classification Project and to generate comparable data;

(iii) to classify the plant species of inland saline sites according to the presence of Na^+ in their habitats and the accumulation of cations in shoots;

(iv) to undertake autecological studies in the growth, salinity tolerance and cation accumulation of selected halophytes.

Thus, the thesis attempts to describe the above aspects and is comprised of five parts dealt with in the subsequent text. The second chapter gives definitions of saline soils and discusses the distribution of Saliferous beds and sources of salinity in inland localities. The soils are described according to the Na^+ and Cl^- levels in soil extracts and in the associated waters. Natural and semi-natural salt marshes are described using the soil profile as the basic unit of study and, thus, the soils are classified into major group, group, subgroup and series. The chapter also describes the characteristics of waste lagoons and their ecological affinities.

The third chapter describes the phytosociological methods used in the survey, description and classification of the vegetation and provides reasons for the adoption of National Vegetation Classification Project. It also surveys the methods of collection, extraction and analysis of the ecological materials.

The fourth chapter deals with the procedure used for the description of the plant communities, provides a conspectus of the classification of the plant communities and details the description of each plant association, sub-association and nodum. The vegetation is described under four sections:

(i) Pioneer, floating communities of static or slow moving water.
(ii) Emergent, reedswamp vegetation at the margins of open water.
(iii) Species poor, annual herb communities of periodically-inundated saline soil.
(iv) Inland salt marsh vegetation dominated by perennial rush and grass communities.

At the end of each section, a summary of the ecological gradients in each type of the vegetation is given.

The fifth chapter attempts to summarize the various definitions and classifications of halophytes and suggests a classification for some British inland halophyte species. Four different approaches have been adopted to categorise the plants and their halophytic tendencies.

The sixth chapter discusses the growth in culture solutions of four selected species under controlled glasshouse conditions and analyses the growth and cation accumulation with regard to different concentration of salts in the external medium.

Nomenclature

1. Phanerogam nomenclature : Clapham, A.R., Tutin, T.G., & Warburg, E.F. (1962). Flora of the British Isles, 2nd ed., Cambridge.

2. Mosses. A.J.E. Smith (1978), The Moss Flora of Britain and Ireland, Cambridge University Press. 706pp.

CHAPTER 2

SOURCES OF SALINITY AND SOIL TYPES IN INLAND SALINE AND ALKALINE ENVIRONMENTS

A. General Introduction

The most generally accepted definition of a saline soil is one with a salt content above 0.5% sodium chloride, calculated on dry weight basis (Waisel 1972), and the species capable of tolerating this amount of sodium chloride or more are regarded as halophytes (Chapman 1942, 1972). Alternatively, Kearney & Schofield (1936) and de Sigmond (1938) regard saline soils, as those with salt concentrations above the 0.1% level. These definitions of salinity and halophytes seem to be arbitrary, because in the definition of salinity no mention is made of ion activity and the concentrations of different ions, which vary in different soils developed under different conditions. Therefore the difficulties in defining salinity and the delimitation of saline habitats also influences the definition of halophytes and Barbour (1970) has concluded that very few species are restricted to concentrations above 0.5% NaCl. At what salt composition and concentrations the actual salinization of soil or water starts, differs from one habitat to another and therefore, different investigators have dealt with this subject in a variety of ways. Allen (1974) has given the following concentration ranges of different ions generally encountered in fresh water and normal soils:

Fresh Water

Sodium 2 to 100 mgl^{-1}
Chlorine 2 to 100 mgl^{-1}
Calcium 1 to 100 mgl^{-1}
Magnesium 0.5 to 20 mgl^{-1}
Potassium 0.5 to 10 mgl^{-1}

Soils (dry weight basis)

Sodium 2 to 20 mg/100 gram
Chlorine 1 to 40 µg./gram
Calcium 10 to 200 mg/100 gram
Magnesium 4 to 50 mg/100 gram
Potassium 5 to 50 mg/100 gram

It is obvious that waters having concentrations of ions higher than the maximum given by Allen are either saline or alkaline, depending on the composition of ions. The same is true for the soils. Therefore, in this thesis the maximum figures given by Allen for different ions are taken as non-saline and above those as being the start of salinity. The interpretation of the degree of salinity in the soils and water is taken according to Gemmell (1977). Gemmell has measured the salinity in terms of the electrical conductance of saturated moisture extracts and his interpretation of conductance results are as follows:

Conductance (mmhos/cm at 25°c)	Degree of salinity
0 - 2	non-saline
2 - 5	slightly saline
5 - 10	moderately saline
10 - 15	highly saline
15+	intensely saline

The study of saline habitats goes as far back as 1885, when Hilgard probably first used the term saline for such types of soils. From that time onwards , workers have tended to distinguish between saline (salt-affected with a high sodium chloride or sulphate content) and alkali soils (soil-affected by a high percentage of exchangeable sodium and carbonates) (de Sigmond 1927). Later on, more effective classification of alkali and saline soils was put forward (Hayward 1956) to secure some sort of agreement among the soil scientists. More recently many different types of classifications have developed (Waisel 1972), so the terminology regarding salt-affected soils is not uniform and is usually governed by the type of studies undertaken, whether geomorphological, pedological or ecological and agricultural. The saline soils are more precisely defined and classified by Richards (1954,1969) and categories based on conductivity, percentage of exchangeable sodium and pH are as follows.

1. Saline soils - the soluble salt content is high enough to inhibit growth of most agricultural crops; the conductivity of the saturated extract of such a soil is above 4 mmhos/cm; pH is below 8.5; and exchangeable sodium percentage is below 15%.

2. Alkali-sodic soils - soils with enough absorbed sodium to inhibit growth of most agricultural crops ; pH of such soils is above 8.5; two sub-types of alkali-sodic soils are recognised.

   I. Non-saline, alkali soils - soils in which the conductivity of the saturated extract is below 4 mmhos/cm, but which have an exchangeable sodium percentage above 15%.

II. Saline-alkali soils - such soils have a high content of soluble salts; the conductivity is above 4 mmhos/cm ; and the exchangeable sodium percentage 15% or more.

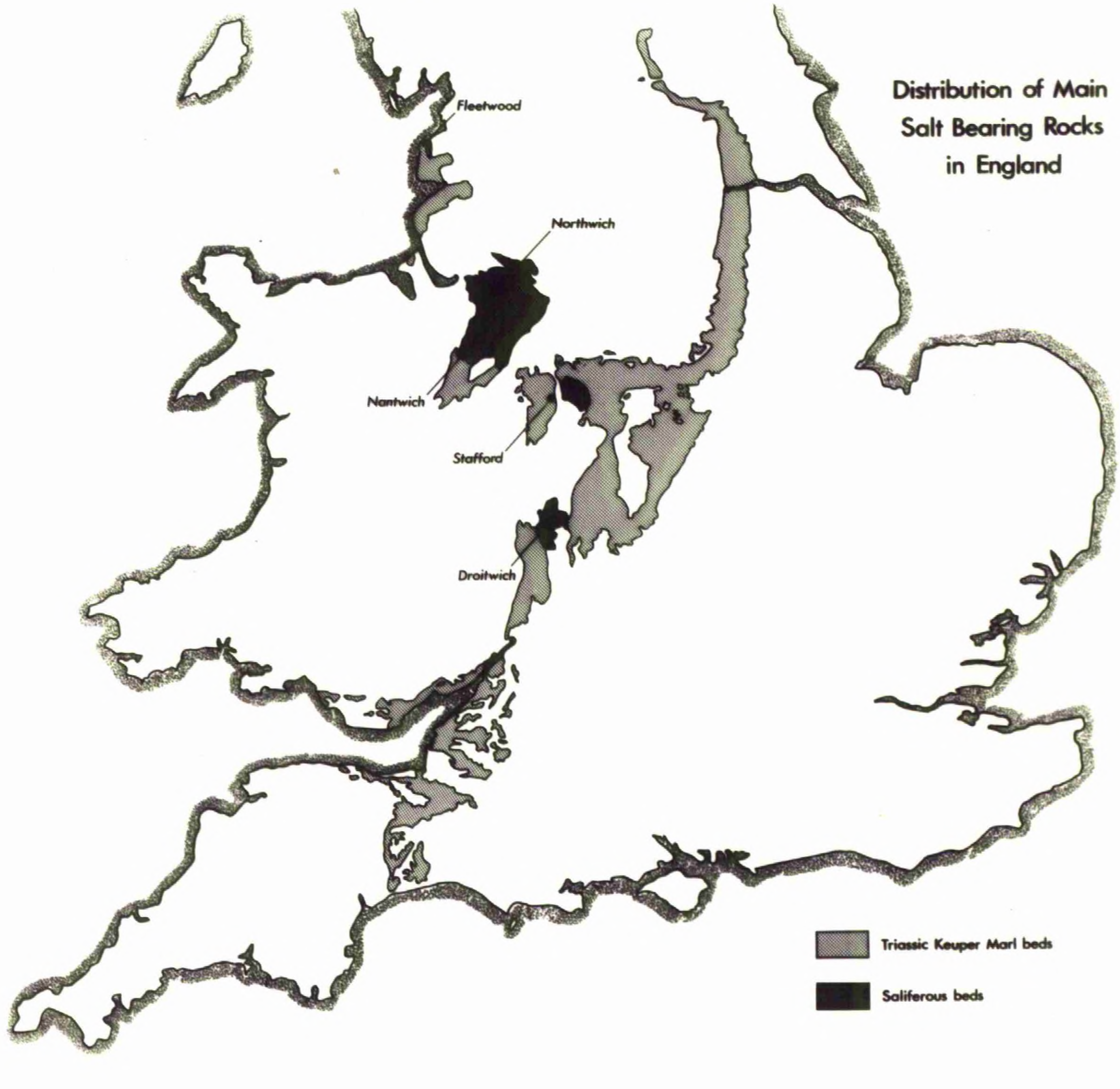
The inland saline and saline/alkaline sites of the British Isles fall into all the three major saline soil types described above and as the salts in these sites are mainly composed of a mixture of sodium, magnesium, calcium and chloride ions, with sodium chloride being dominant, the alkaline soils are not sodic as well. Rather the alkalinity is due to excess of calcium or magnesium ions. Thus, the soils of natural salt marshes and semi-natural salt marshes (Figs. 2.8 and 2.9) are saline, while soils of other sites which are industrial in origin are either saline/alkaline or non-saline alkaline (Fig. 2.10) according to the definitions of Richards.

The salinization of the soil is primarily by three major sources: marine, lithogenic and anthropogenic and either of these can add soluble salts to the soil. Consequently, in places where salts are deposited and accumulated saline habitats are encountered,and the British saline sites are associated either with brine springs of the Keuper Saliferous Beds or are developed in the vicinity of salt industries. In the following section the origin, distribution and characterization of these two saline and saline/alkaline habitats is discussed and examples of the various habitats are mapped in Figures 2.3 to 2.7.

B. Distribution of Saliferous Beds and Sources of Salinity in Inland Localities.

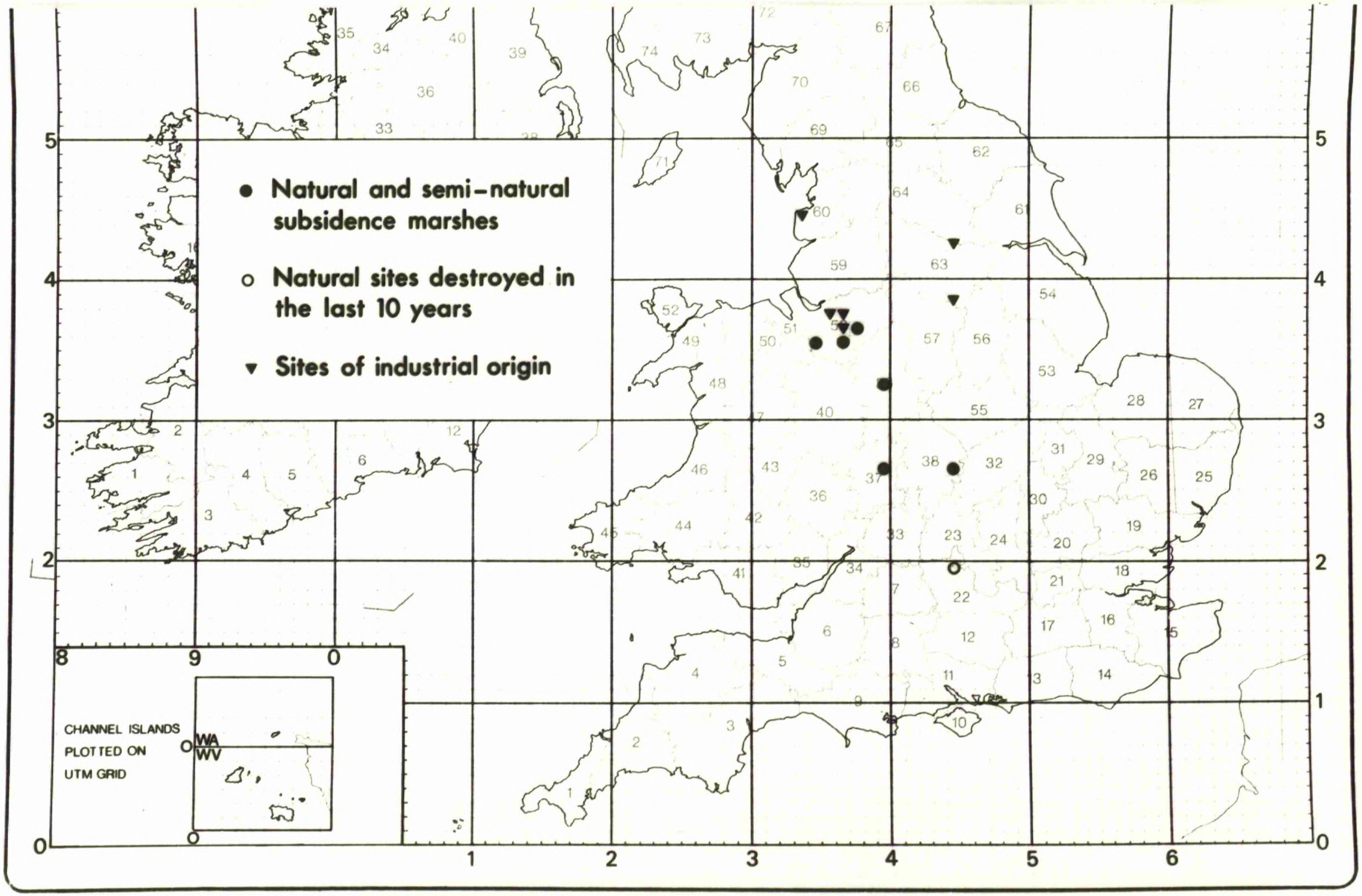
Brine and rock salt (Halite) primarily consists of common salt with a small amount of impurities of other salts of calcium and magnesium. Rock salt is a sedimentary rock and as Sherlock (1921) had pointed out, the British deposits of rock-salt occur in the Keuper Series of the New Red Sandstone formation of Triassic Age. In the Keuper Series, it is assumed that barren, arid and shallow marine conditions prevailed and on two occasions, once for the Lower and once for the Upper Keuper Saliferous Beds, the region was temporarily occupied by a wide embayment of the sea, having a restricted connection with the open sea through a narrow strait. At the same time, the deposition of red sediments from the surrounding area and an intense rate of evaporation resulted in the formation of the most extensive salt deposits in the British Isles

Figure 2.1 Geographical distribution of saliferous beds of the Keuper Series of Triassic Age.



Distribution of Main Salt Bearing Rocks in England
Fleetwood
Northwich
Nantwich
Stafford
Droitwich
Triassic Keuper Marl beds
Saliferous beds

Figure 2.2 Location of inland Saline sites surveyed.



Natural and semi-natural subsidence marshes
Natural sites destroyed in the last 10 years
Sites of industrial origin
CHANNEL ISLANDS PLOTTED ON UTM GRID
WA
WV

Figure 2.3 Aldersey Salt Marsh : Sodium concentration levels of selected water samples.

Legend details (ppm Na^+; WS ref. Appendix IIIa)

A	=	13250	(WS 50)
B	=	8250	(WS 52)
C	=	5125	(WS 53)
D	=	193	(WS 54)
E	=	3750	(WS 55)
F	=	33	(WS 58)
G	=	275	(WS 59)

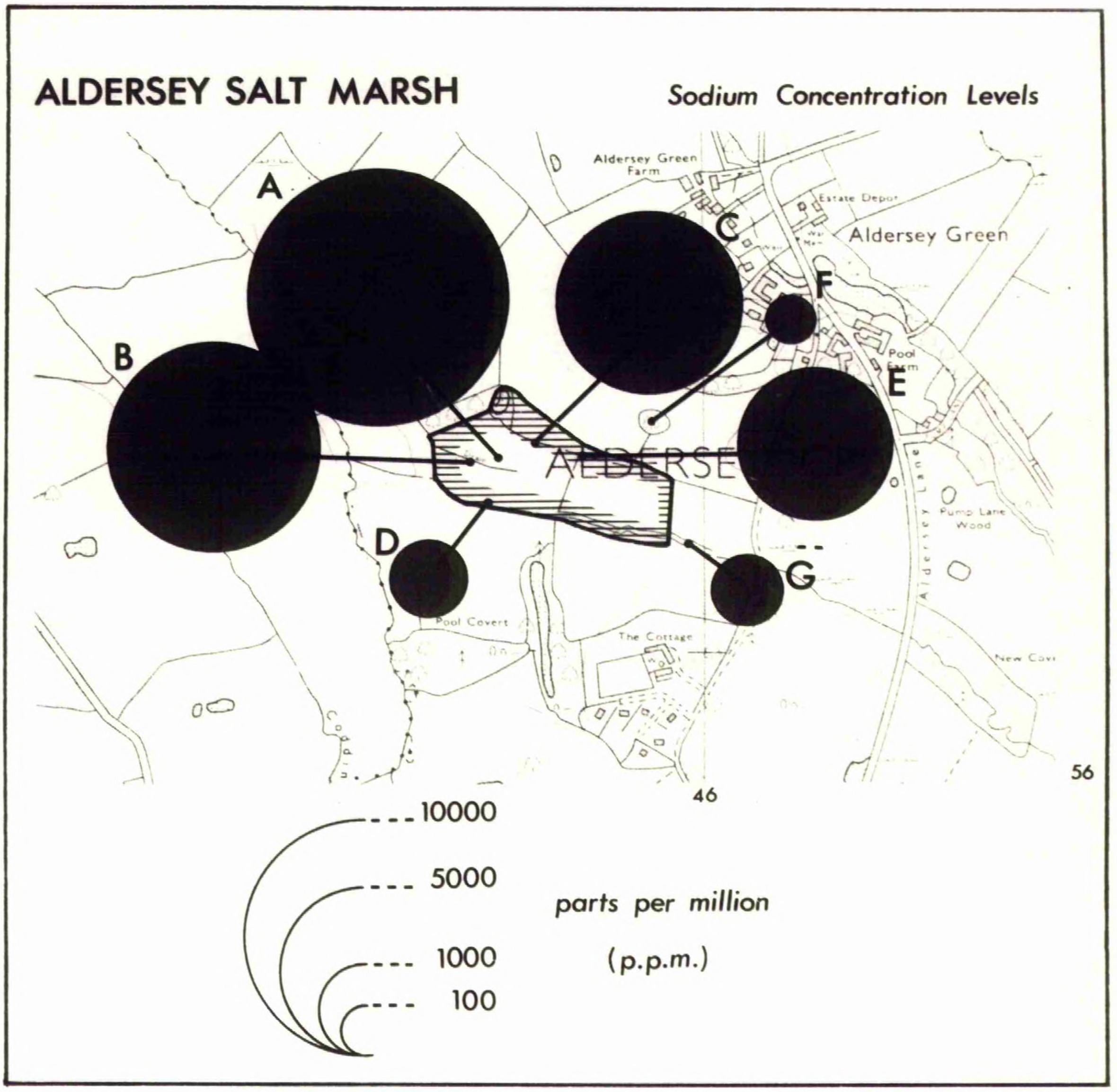
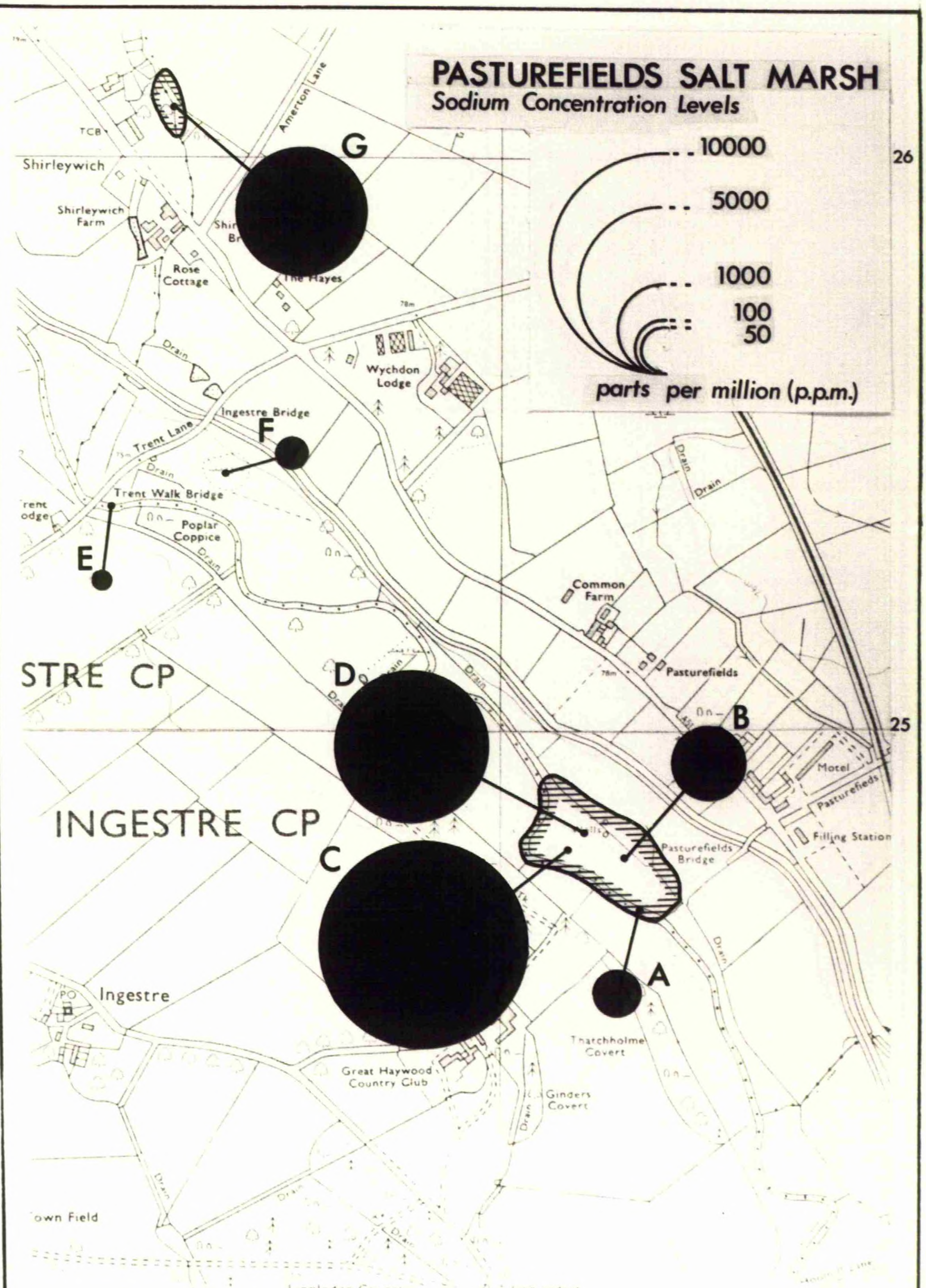

ALDERSEY SALT MARSH
Sodium Concentration Levels
A
B
C
D
E
F
G
Aldersey Green Farm
Estate Depot
Aldersey Green
Pool Farm
Pump Lane Wood
Pool Covert
The Cottage
Aldersey Lane
New Covt
46
56
10000
5000
1000
100
parts per million
(p.p.m.)

Figure 2.4 Pasturefield/Shirleywich Marsh :
Sodium concentration levels of selected water samples.
Legend details (ppmNa^+; WS ref Appendix IIIc)

A	=	99	(WS 68)
B	=	925	(WS 69)
C	=	7500	(WS 70)
D	=	4000	(WS 71)
E	=	100	(WS 73)
F	=	45	(WS 74)
G	=	3000	(WS 76)

Base map reproduced from the 1977 Ordnance Survey 1:10,000 map with permission of The Controller of Her Majesty's Stationery Office, Crown Copyright Reserved


PASTUREFIELDS SALT MARSH
Sodium Concentration Levels
10000
5000
1000
100
50
parts per million (p.p.m.)
A
B
C
D
E
F
G
Shirleywich
Shirleywich Farm
Rose Cottage
The Hayes
Amerton Lane
Wychdon Lodge
Ingestre Bridge
Trent Lane
Trent Walk Bridge
Poplar Coppice
Common Farm
Pasturefields
Motel
Pasturefields
Filling Station
Pasturefields Bridge
STRE CP
INGESTRE CP
Ingestre
Great Haywood Country Club
Thatchholme Covert
Ginders Covert
Town Field
Lionlodge Covert
26
25

(Poole et al 1966, Furness 1978).

A geographical distribution of saliferous beds is given in Figure 2.1 and the location of the different types of site visited in the present survey is shown in Figure 2.2.

a. Salinity caused by brine springs and upwellings and the development of natural salt marshes.

Naturally occurring salt marshes are developed around brine springs. As Lee (1975, 1977) has pointed out, these inland salt marshes have originated by the percolation of water from the wet rock-head of the Keuper Saliferous Beds, to issue at the surface as local brine springs. This type of habitat was common in Cheshire, Staffordshire and Worcestershire in the eighteenth and nineteenth centuries, but during the Industrial Revolution and afterwards, improved techniques of winning the salt and ruthless exploitation of this mineral resource, both by wild brine pumping and controlled brine pumping, resulted in a reduction of brine flows to the surface and hence the number of brine springs decreased considerably. The surviving two marshes at Pasturefields, Staffordshire, and Aldersey, Cheshire were thoroughly studied. Figure 2.3 shows the map of Aldersey salt marsh. The marsh consists of a brine pit and localised area of upwellings in the adjacent fields. The brine pit water had a sodium concentration of 13250 ppm and an upwelling in an adjacent field had a sodium concentration of 3750 ppm (see Appendix IIIa. W.S.50,55). A number of soil samples were analysed from this area and turf as far away as 150 metres from brine pits was fairly saline and concentrations as high as 26.25 mg/gram were recorded (see Appendix IIa. S.S.127) from this area. The analyses confirm that there are a number of localised upwellings and seepages in addition to the brine pit. A representative soil profile from this area is shown in Figure 2.8 and the soil type is described in a later section of this chapter.

A map of Pasturefields salt marsh is given in Figure 2.4. At present the salt marsh consists of a small bare area which has a surface salinity of sodium 14.50 mg/gram (See Appendix IIa. S.S.170) and upwellings or seepages. The salinity of seepage water was 7500 ppm of sodium (see Appendix IIIa.W.S.70). The marsh is developed around these seepage areas and a number of water samples (see Appendix IIIa.W.S.69-72) and soil samples (see Appendix IIa.S.S.146-173) were analysed to ascertain the salinity. The three soil profiles described from three different areas show that surface salinity is different but salinity at the lower horizons, especially in the underlying peat, is almost the same, and highly saline. Hence, at the sub-surface level there is considerable salinity even quite far away from the seepage areas, while surface salinity is different and is considerably less within two metres away from the seepage areas. If, somehow, brine flows could be maintained at all levels, then the area would develop into a beautiful salt marsh.

At Southam, Warwickshire a large saline pool is present. The salt spring is weak in salinity and the water sample analyses show a maximum sodium concentration of 1950 ppm (see Appendix IIIa. W.S. 26-30) and soil salinity varies from 2.00 mg/gram to 7.50 mg/gram (see Appendix IIa. S.S. 62-66). The area is colonised by a number of reedswamp emergent halophytes.

b. Salinity caused by subsidence and the subsequent development of semi-natural salt marshes and flashes.

The salt extraction and manufacturing industries are the other causes which have led to the production of new saline habitats. Small and temporary saline sites are developed in the immediate vicinity of brine pipes wherever there are brine spillages or leakages, but the major saline sites have developed due to soil subsidence. Subsidence caused by wild brine pumping and solution of salt beds has resulted in the development of hollows, known as flashes, some of which are contaminated by underground brine flows and hence are saline. Around these saline pools, vegetation typical of salt marshes has developed. The saline pools at Upton Warren, Worcestershire and Sandbach, Cheshire are examples of semi-natural salt marshes.

Wallwork (1956, 1959, 1960, 1967) has at length dealt with the subsidence in the mid-Cheshire industrial areas, where the most affected districts are Middlewich, Winsford and Northwich. The subsidence was more severe in these areas as compared to coal-mining districts, because of wild-brine pumping, solubility of the exploited mineral and the long distances over which brine flows to the pumping shafts. Wallwork (1956) has recognised two types of subsidence, the second having three variants. The first type consisted of funnel-shaped holes which were formed on the collapse of rock-salt mines and the second resulted from natural-brine pumping and consisted of the formation of trough-like hollows. As a background to the ecological survey, a summary of the main phases of subsidence, their causes and areas affected during each phase is as follows (after Wallwork 1956):

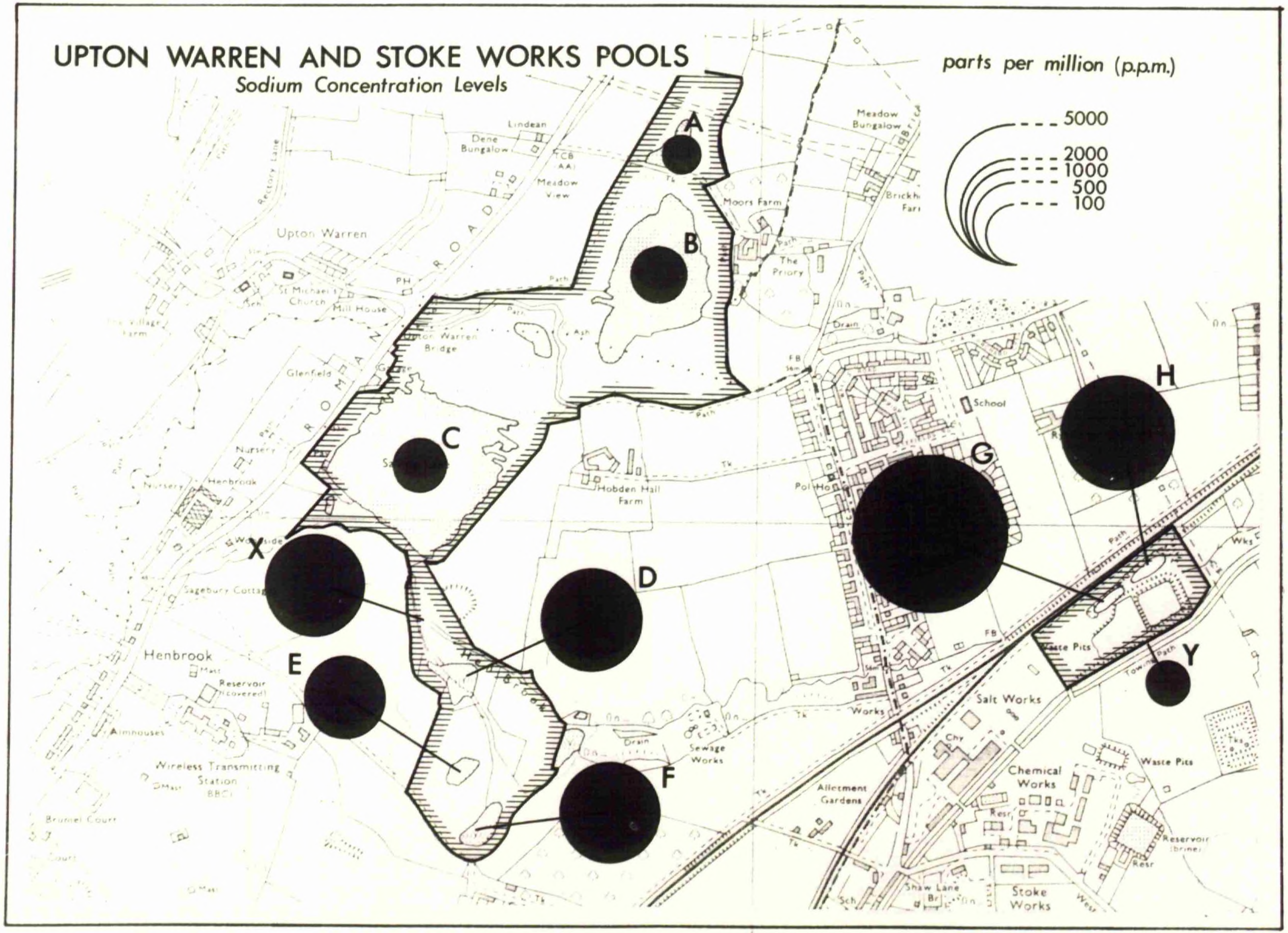
Phase	Characteristics and causes	Location affected
Rock-salt mining subsidence; 1750-1870	Large funnel-shaped holes, caused by collapse of rock-salt mines; later occurs in association with brine pumping subsidence	Northwich (Witton and Dunkirk), Marston and Wincham.
Natural-brine pumping subsidence; 1790 - to date.	Trough-shaped depressions of varying dimensions, according to thickness of overlying strata and geographical disposition of pumping shafts.	Winsford, Marston, Billinge Green, Middlewich, Northwich, Wincham
Flooded-mine pumping subsidence 1873-1935	Combination of funnel-shaped holes and trough like depressions caused by pumping brine from flooded rock-salt mines	Northwich (Witton and Dunkirk), Wincham and Marston.
Controlled brine-pumping. 1924- to date	No subsidence as yet	Marston, Holford and Wincham.

The various phases of subsidence as outlined above resulted in the development of large flashes such as Bottom Flash or several small lakes in Boggart Brook and Winsford. As most of the trough-like subsidences associated with the natural brine-pumping were developed in the valleys of rivers and small streams, so the troughs were soon flooded with water. Neumann's Flash, Billinge Green, Ashton Flash, Witton Flash, Elton Hall Flash, Watch Lane Flash, and Fodens Flash, Cheshire were the other flashes formed due to subsidence. Controlled pumping techniques have lessened the possibility of subsidence and hence the development of new flashes, and those already in existence have grown little, rather many have begun to silt up, while others are being used for the deposition of waste from

Figure 2.5 Upton Warren and Stoke Works Pools: Sodium Concentration levels of selected water samples.

Legend details (ppm Na^+ ; WS ref. Appendix IIIa)

A	=	20	(WS 17)
B	=	45	(WS 18)
C	=	35	(WS 20)
D	=	1625	(WS 08)
E	=	550	(WS 09)
F	=	1775	(WS 14)
G	=	5750	(WS 02)
H	=	1725	(WS 01)
X	=	725	(WS 725)
Y	=	20	(WS 03)


UPTON WARREN AND STOKE WORKS POOLS
Sodium Concentration Levels
parts per million (p.p.m.)
5000
2000
1000
500
100
A
B
C
D
E
F
G
H
X
Y
Upton Warren
Henbrook
Hobden Hall Farm
Moors Farm
The Priory
School
Salt Works
Chemical Works
Waste Pits
Stoke Works
Sewage Works
Allotment Gardens
Wireless Transmitting Station
Almhouses
Shaw Lane
Reservoir (brine)

the chemical industries.

A survey of all these sites was undertaken, and soils and water associated with the saline pools, marshes and flashes were analysed to ascertain their salinity. The existing pools and flashes can be classified into three categories on the basis of salinity.

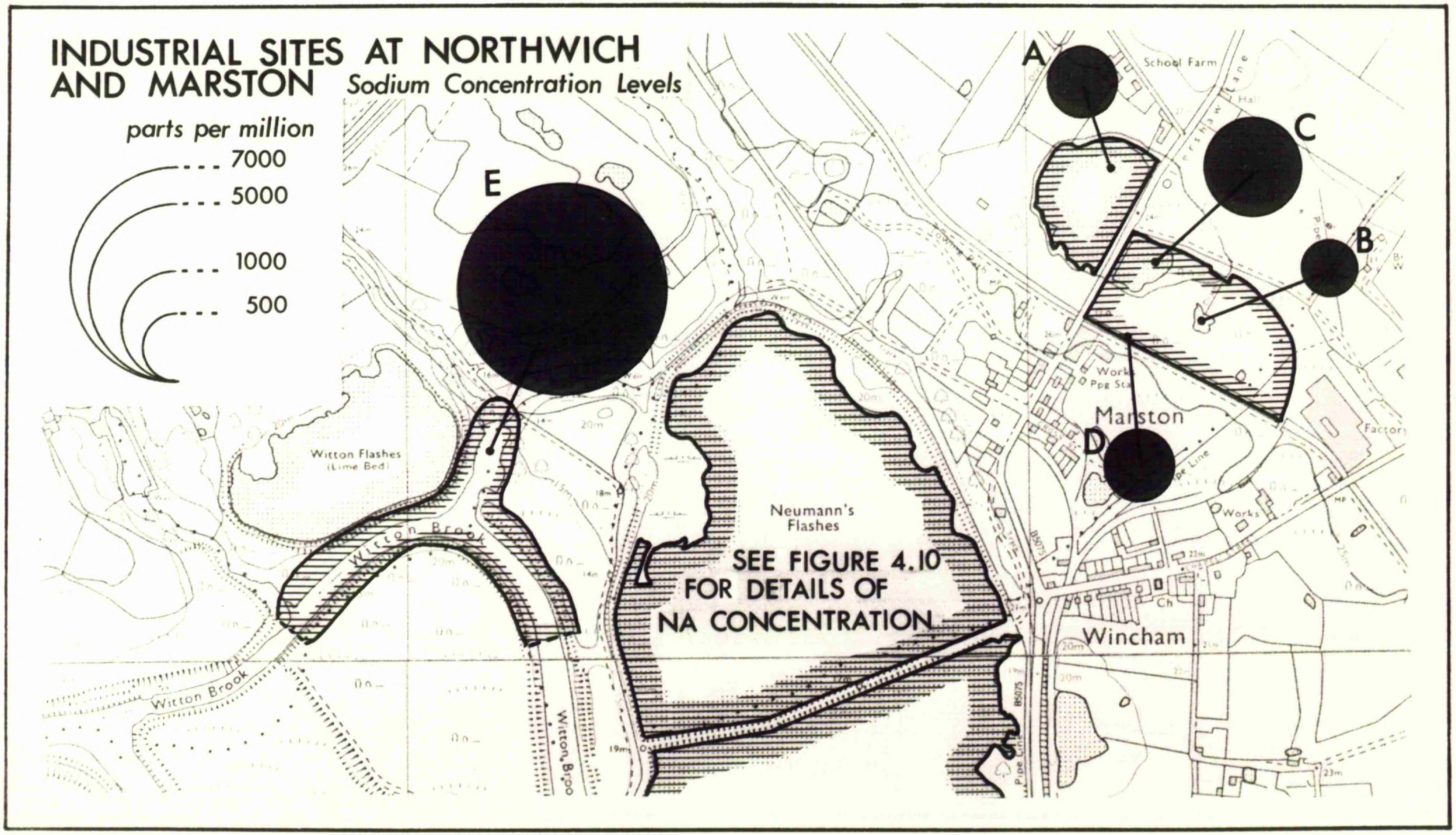
i. Freshwater Flashes - Many flashes developed as a result of subsidence are non-saline, such as Bottom Flash (Appendix IIIa, W.S.56), Fodens Flash (Appendix IIIa, W.S.100,101), Boggart Brook Flash (Appendix IIIa, W.S. 46), Upton Warren, Worcestershire (pools A,B,C. Fig 2.5) and Billinge Green pool (Appendix IIIa, W.S.42).

ii. Saline Flashes - These are also known as saline pools, where subsidence has resulted in the surface water becoming contaminated by underground brine flows and seepages. It is around these saline pools that vegetation typical of salt-marsh is developed. As such sites have formed due to subsidence and brine flows or seepages, so they may be referred to as semi-natural salt marshes. An example of this is Upton Warren, Worcestershire (Fig 2.5), where the marsh has developed around three saline pools (pools D,E.F. Fig.2.5). Many water samples and soil samples from this marsh were analysed, and they show that there are localised pockets of highly saline soils, Pool F has a very high chloride concentration of 20,000 ppm, while D and E are less saline. Similarly, bare areas have very high salinity (see Appendix IIa. S.S.41, 44). The salinity of two pools located at Stoke Works and shown as G and H in Figure 2.5 is comparatively less than pool F. It seems that at Upton Warren, high salinity is due to seepages and subsidence caused by the mining at Stoke Works. Other subsidence sites such as at Sandbach, have been subjected to considerable distrubance from continuing subsidence and human pressure (Lee 1975). The Watch Lane pools support a vegetation typical of semi-natural salt marsh and can be compared with Upton Warren saline pools in terms of salinity. These subsidence sites have a number of pools, the salinity of whih varies from almost non-saline to highly saline (see Appendix IIIa. W.S. 83 to 89). Similarly there are localised pockets of highly saline areas,and a sodium concentration as high as 27.50 mg/gram was recorded at one place (see Appendix IIa. S.S.20). The highest sodium concentration of 6250 ppm was recorded from the small pool or lake at Watch Lane. So, it seems that salinity at Sandbach is due to subsidence and water being contaminated with an underground brine flow.

Figure 2.6 Industrial sites at Northwich and Marston : Sodium concentration levels.

Legend details (ppm Na^+ : WS ref. Appendix IIIa)

A	=	650	(WS 32)
B	=	250	(WS 34)
C	=	1150	(WS 35)
D	=	625	(WS 33)
E	=	7125	(WS 36)


INDUSTRIAL SITES AT NORTHWICH AND MARSTON Sodium Concentration Levels
parts per million
7000
5000
1000
500
A
B
C
D
E
School Farm
Hall
Works
Ppg Sta
Marston
Factory
Works
Wincham
Ch
Pipe Line
Witton Flashes (Lime Bed)
Neumann's Flashes
SEE FIGURE 4.10 FOR DETAILS OF NA CONCENTRATION
Witton Brook
Witton Brook
B5075

iii. The third type of flash is the <u>alkaline type</u>, an example of which is Elton Hall Flash. The flash comprises two areas of standing water, one with extensive marginal expanses of periodically inundated alkaline waste and sparse vegetation, receiving residues from the ammonia-soda process of alkali manufacture (Mirza & Shimwell 1977). The water samples analysed from the flash, show a maximum sodium concentration of 812 ppm (see Appendix 111a, 90) for the water inflow from the chemical works. The soils are quite low in sodium concentration but very high in magnesium (see Appendix 11a, SS.5-15). The highest magnesium concentration, 35.00 mg/gram was recorded from Elton Hall's soil. The salinity of such type of flashes depends on the nature of the industrial waste which they receive, and in terms of salinity the Elton Hall Flash is non-saline/alkaline and supports a vegetation of both halophytic and glycophytic phanerogams and several species of tolerant bryophyte . Neumann's Flash and Ashton Flash (Figure 2.6) are other examples of this type of flash.

c. Other sources of salinity.

A number of other sources of salinity are met with and have affected small pockets of soils which support halophytic vegetation. The most important are as follows:-

i. <u>Old brine pits, cisterns and lagoons</u>. Good examples of cisterns, seepages and pools causing the development of saline sites are to be seen at Anderton, Cheshire. The seepage water here was extremely saline with a conductivity of 221.99 mmhos/cm and sodium concentration of 262500 ppm (see Appendix 111a. W.S. 38). This water was contaminating the nearby pools and soils and thus was encouraging the growth of good halophytic vegetation of all physiognomic types.

ii. <u>Old saline ponds and salt pans</u>. At Marston, Cheshire, (Figure 2.6) a few old saline ponds and salt pans are present. The waters and soils of these areas are moderately saline (see Appendix 111a, W.S. 31,32, 34, 35 and Appendix 11a, S.S. 76,77,78). The pools and marshy areas are colonized by local patches of halophytic vegetation of the floating, emergent and salt marsh types of vegetation.

iii. <u>Industrial waste lagoons</u>. A number of sludge and active lagoons are present in the close vicinity of salt and alkaline industries in Cheshire

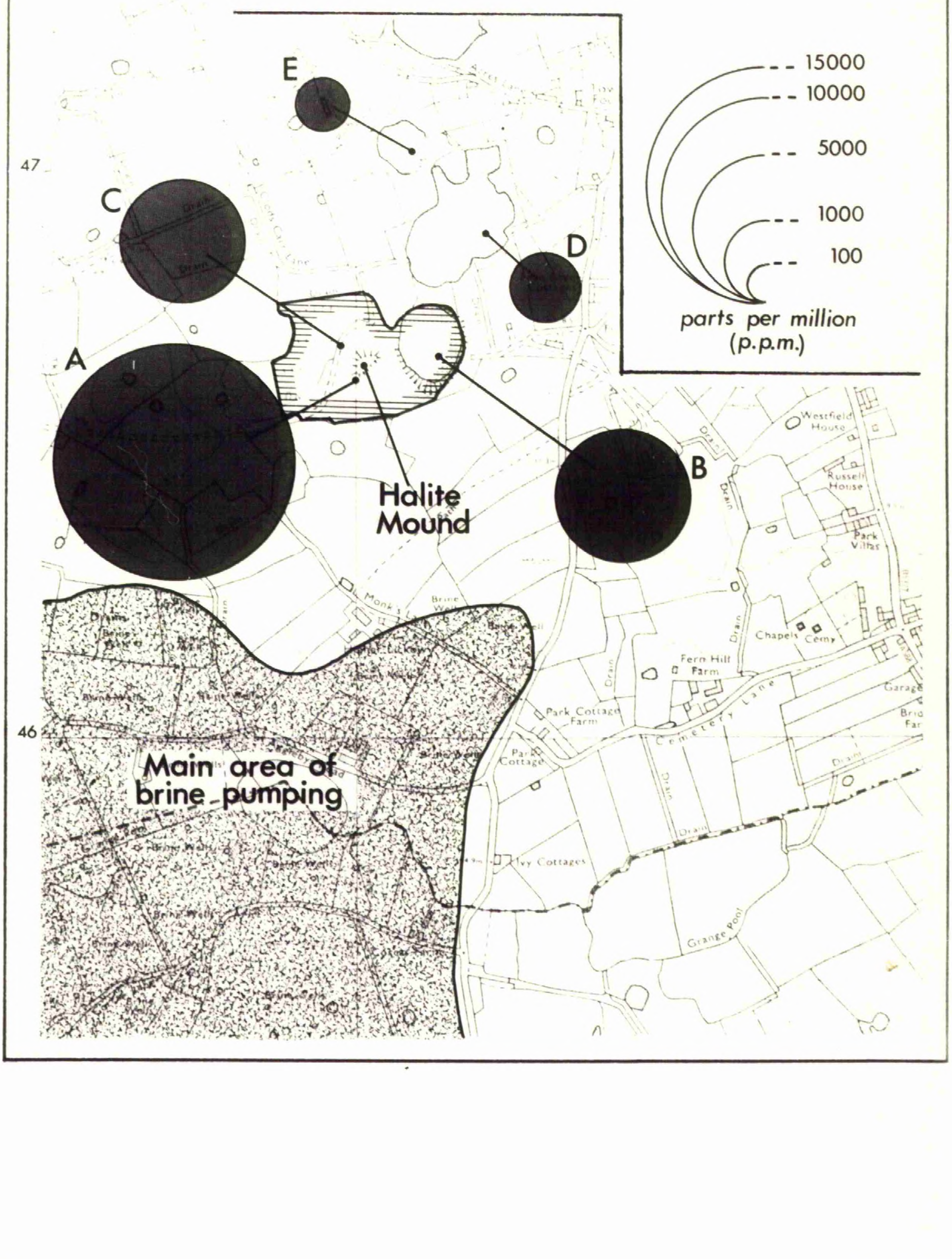
Figure 2.7 Saline Pools and Marshes at Preesall : Sodium concentration levels.

Legend details (ppm Na^+ : WS ref. Appendix IIIa)

A	=	16250	(WS 79)
B	=	3500	(WS 78)
C	=	3000	(WS 81)
D	=	525	(WS 80)
E	=	200	(WS 82)

SALINE POOLS AND MARSHES AT PREESALL

Sodium Concentration Levels



and Stoke Works, Worcestershire, where industrial wastes were dumped, or even now are being used for this purpose. The characteristics of alkaline waste lagoons in Cheshire are given in Figure 2.10 and their cation composition is described in detail in the section on soil types.

iv. Rotting halite mounds. At Preesall, seepages from a rotting halite mound (Lee 1977) have given rise to an extensive marshy area. The seepage water (see Appendix 111a, W.S.79) has a sodium concentration of 16250 ppm and chloride 62500 ppm and probably was contaminating the lakes or subsidence flashes. The area and sodium figures are shown in Figure 2.7. The marshy area and flashes are colonised by both perennial and annual species of halophytes and a number of other species of lower salt tolerance.

v. Seepages from coal mines. Only one such area was studied. The Mickletown subsidence flash in West Yorkshire has developed a beautiful vegetation of the Cotuletum coronopifoliae. Though the flash was not very highly saline, at the time of visit the seepage from the coal waste had a sodium concentration of 880 ppm (see Appendix IIIa W.S. 105), and soils supporting the Cotula coronopifolia had a sodium concentration of 2.49 mg/gram. The salinity from colliery spoil is due to the presence of soluble salts, especially chlorides of sodium, potassium and magnesium (Doubleday 1971, Gemmell 1977), which are leached from the several marine bands found throughout the Coal Measures Series. Other examples of fragmentary salt marsh formation as a result of seepage from coal spoil are to be seen in east Derbyshire and Warwickshire.

C. Soil Types.

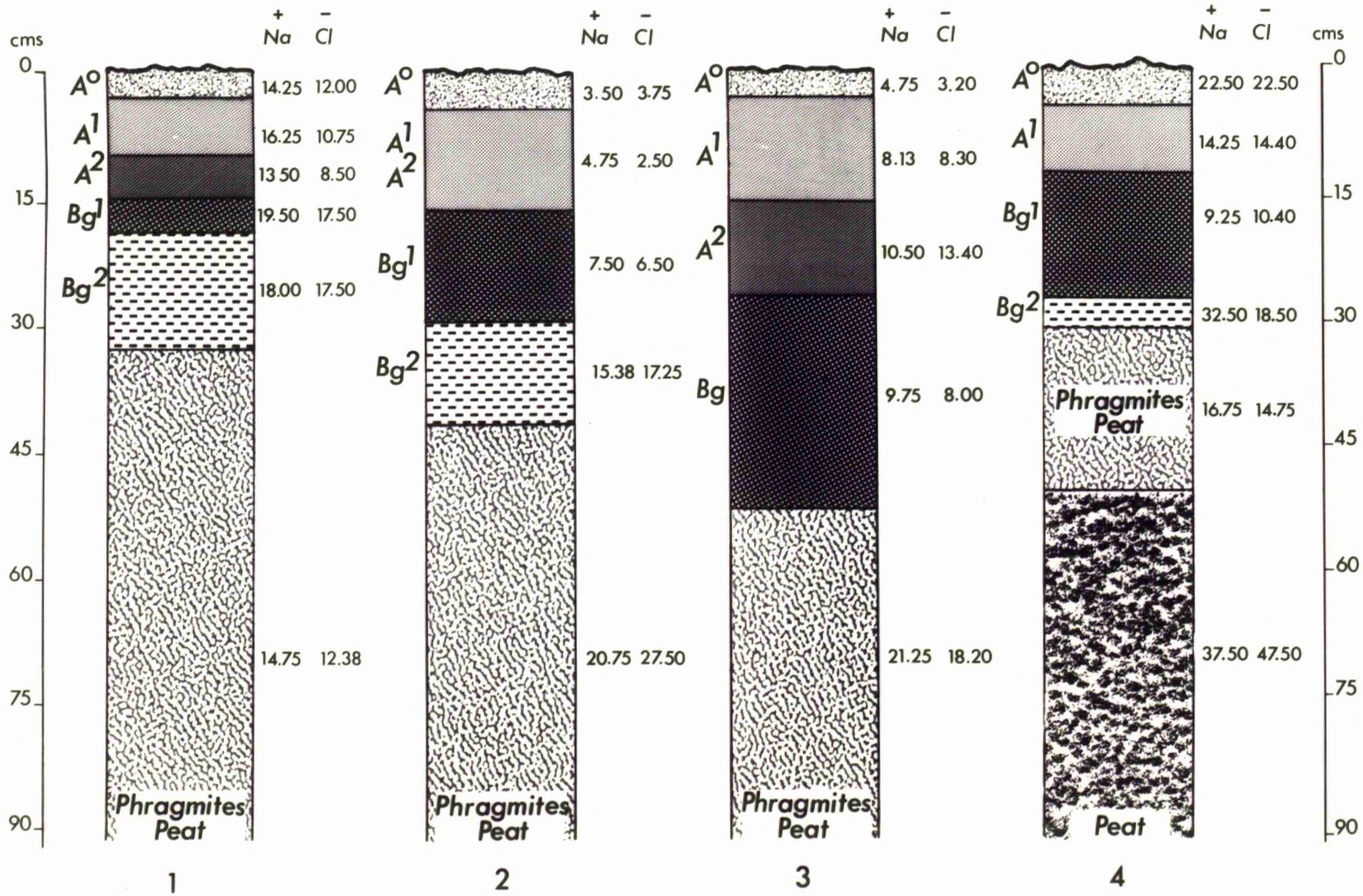
Soil forms the uppermost layer of the earth's crust and is considered the product of the interaction of such pedogenic factors as parent material, geology, climate, biological activity, relief and time (Jenny 1941). Each of these factors plays an important role in soil development, and the intensity of the action of each factor varies from place to place, but at the same time is interdependent on other factors. Salinity, water table status and parent material are the main effective contributors to soil development in the salt-affected areas of the British Isles. In the following text, the soil types of such areas are described, taking the soil profile as the basic unit of study, and using the descriptive procedure laid down by Hodgson (1974) in the Soil Survey Field Handbook. The soil types in three main habitats in the salt-affected areas are thus

Figure 2.8 Soils of Inland Natural Salt Marshes.

Legend details (Na^+ = mg/gram : Cl^- mg/gram:)

Profile Number 1	Pasturefields	(Puccinellietum maritimi)
2	Pasturefields	(Juncetum gerardii)
3	Pasturefields	(Agrostis stolonifera Nodum)
4	Aldersey	(Spergularietum marinae)

SOILS OF INLAND NATURAL SALT MARSHES



described and classified according to the classification of Avery (1973) and Furness (1978).

a. Soils of natural salt marshes. (Fig. 2.8).

The soils of the natural salt marshes are described from Aldersey, Cheshire and Pasturefields, Staffordshire in sites near to brine springs. The soils from both sites are characterised by having the same type of development over Phragmites peat. The soils are distinguished by the gleyed Bg and Cg horizons saturated from below by water held by a deeper impermeable horizon. Above, there are two or three rusty, reddish brown mottled horizons, which correspond to the upper and lower limits of fluctuating ground water. Four soil profiles from these marshes are described and are grouped under Ground-water Gley soils. The soils at the two sites are almost the same in horizon description and differentiation, and are distinguished by a well developed Phragmites peat, which occurs at a depth of 30-50 cm and continues to a considerable depth. The soils have a very high salinity at the peat level and at the surface level, salinity variation is due to localised seepages. The soils from both areas belong to:-

the major group - Ground-water gley soils

the group - Alluvial gley soils

the sub-group - Clayey pelo-alluvial gley soils of river flood plains.

and the Midelney Series.

The soils are mapped in Cheshire by Furness (1978), (Unit 31) - " a clayey over earthy, peaty pelo-alluvial gley soil on interbedded riverine alluvium and peat", and labelled the Midelney Series. This series was first described in Somerset by Avery (1955) and later by Findlay (1965). In Cheshire these soils are common along the larger rivers such as the Dee, Weaver and Dene, where thin peat has formed under very wet conditions and been preserved by later accumulations of clayey alluvium. The site at Aldersey is in the valley of a tributary stream of the River Dee, while that at Pasturefields is immediately adjacent to the River Trent. The soils from both sites are very wet, drought resistant and support a good halophytic vegetation.

Profile No: 1.

Location: Pasturefields, Staffordshire (33/992748)

Elevation: 76m

Vegetation: *Puccinellietum maritimi*

Horizons cm.

0 - 2.5 A^o — Very dark grey (5YR3/1) stoneless, silty loam with very few reddish brown mottlings, moderately developed peaty structure fine and friable, firm on drying; roots common, fine fibrous merging and diffuse.

2.5 - 10 A^1 — Dark grey (5YR3/2) stoneless, silty clay loam moderately developed medium crumb,structure friable but firm on drying, roots few fine and fibrous, sharp, undulating.

10 - 15 A^2 — Dark reddish grey (10R3/1) stoneless, clayey loam, strong medium angular, very few fine fibrous roots, merging indistinct, undulating.

15 - 17.5 Bg_1 — Reddish black (10R2/1) stoneless, clayey, gleyed, sticky strongly developed, medium blocky, occasional remnants of fossil, no roots, merging.

17.5 - 32.5 Bg_2 — Very dark grey (7.5YR NS/0) stoneless, clayey, gleyed, sticky, strongly developed, blocky, remnants of *Phragmites* leaves, no roots.

32.5- 122+ Peat — Dark reddish brown (5YR3/2) stoneless clayey peat, loose, *Phragmites* peat, one piece of birchwood.

Analysis

Horizon.	A^0	A^1	A^2	Bg_1	Bg_2	Peat
Depth cm.	0-2.5	2.5-10	10 - 15	15-17.5	17.5-32.5	32.5-122+
Loss on ignition %	41.5	32.5	27.10	31.60	22.96	36.80
pH	5.9	5.2	5.7	4.1	2.8	5.1
Sodium	14.25	16.25	13.50	19.50	18.00	14.75
Potassium	0.35	0.20	0.15	0.18	0.23	0.15
Magnesium	0.39	0.38	0.21	0.33	0.28	0.28
Calcium	3.75	5.00	6.50	2.75	2.50	2.13
Chloride	12.00	10.75	8.50	17.50	17.50	12.38

Profile No: 2

Location: Pasturefields, Staffordshire, (33/992248)

Elevation: 76m

Vegetation: Juncetum gerardii

Horizons cm.

0 - 5 A^o — Very dark brown (10YR2/2) stoneless, silty clay, reddish brown mottling common, friable, moderately developed medium crumby structure; extremely abundant fine fibrous roots, sharp and even boundary.

5 - 17.5 A^1-A^2 — Dark brown (10YR 3/3) stoneless, silty clay loam; strongly developed medium crumby structure, firm on drying, roots rare fine fibrous;merging and indistinct undulating boundary.

17.5 - 30 Bg_1 — Very dark grey (10YR 3/1) stoneless gleyed layer of silty clay;moderately developed platy structure, firm,rootless; merging and diffused boundary.

30 - 42 Bg_2 — Very dark grey (2.5YR N3/1) stoneless clayey gleyed, transitional layer; moderately developed platy structure, firm, few macrofossil of Phragmites visible, rootless, merging and diffused, very moist.

42 - 132+ Peat — Very dark grey (10YR 3/1) stoneless, clayey peat composed of the macroscopic remains of Phragmites

Analysis

Horizons	A^o	A^1,A^2	Bg_1	Bg_2	Peat
Depth cm.	0-5	5-17.5	17.50-30	30-42	42-132
Loss on ignition %	37.40	16.50	31.70	31.75	58.60
pH	5.1	5.2	4.4	3.3	3.9
Sodium	3.50	4.75	7.50	15.38	20.75
Potassium	0.38	0.13	0.16	0.20	0.13
Magnesium	0.25	0.25	0.30	0.40	0.68
Calcium	2.88	2.50	3.00	3.75	5.25
Chloride	3.75	2.50	6.50	17.25	27.50

Profile No: 3

Location: Pasturefields, Staffordshire. (33/992248)

Elevation: 76m

Vegetation: Agrostis stolonifera Nodum

Horizons cm.

0 - 4 A^o Dark reddish brown (5YR 2/2) stoneless silty loam. Very few reddish brown mottling, humose, friable, strongly developed medium crumby structure; abundant fine fibrous roots; merging and diffuse boundary.

4 - 16 A^1 Very dark brown (10YR 2/2) stoneless silty clay loam with reddish brown mottles common, strong medium crumby structure, firm; fine few roots, narrow and merging boundary, irregular.

16 - 28 A^2 Very dark brown (10YR 2/2) stoneless clayey loam with few distinct reddish brown mottles, moderately medium crumbly structure, very firm on drying, roots rare, sharp undulating boundary.

28 - 53 Bg Very dark grey, (10YR 3/1) stoneless clayey gleyed with few black and occasional reddish spots. Strong medium crumby structure firm; few macrofossils of Phragmites leaves, merging and diffuse boundary.

53 - 143+ Peat Very dark grey (10YR 3/1) stoneless clayey peat, many macrofossils of Phragmites.

Analysis

Horizons	A^o	A^1	A^2	Bg	Peat
Depth cm.	0 - 4	4 - 16	16 -28	28 - 53	53 - 143
Loss on ignition %	29.10	42.50	40.60	43.90	56.65
pH	5.6	4.5	3.0	3.2	4.7
Sodium mg/gram	5.75	8.13	10.50	9.75	21.25
Potassium mg/gram	0.14	0.10	0.10	0.18	0.14
Magnesium	0.35	0.28	0.25	0.34	0.59
Calcium	5.00	3.75	5.75	2.50	4.75
Chloride	3.20	8.30	13.40	8.00	18.20

Profile No. 4

Location: Aldersey, Cheshire , (33/457567)

Elevation: 15m

Vegetation: Spergularietum marinae

Horizons cm.

0 - 5 A^0 — Very dark brown (10YR 2/2) stoneless, undecomposed litter, silty clay loam; strongly developed medium crumb structure, friable, roots common fine fibrous, merging and diffused.

5 - 12.5 A^1 — Dark reddish brown (5YR 2/2) few stones, occasional reddish brown mottles; silty clay loam, strongly developed medium crumb, friable, roots rare fine, merging and diffused boundary.

12.5 - 28 Bg_1 — Very dark greyish brown (10YR 3/2), stoneless clayed, gleyed with common and prominent dark reddish brown (2.5 YR 3/4) mottles. Strongly developed medium blocky structure, friable, no roots, merging and irregular, strong evidences of oxidising and reducing conditions.

28 - 30 Bg_2 — Dark greyish brown (10YR 4/2) stoneless, no mottling, lacustrine clay, medium developed blocky structure, friable, chestnut brown layer in between, no roots, sharp and even boundary.

30 - 50(140) C Peat — Dark reddish brown (5YR 2/2) clayey peat, stoneless macroscopic remains of Phragmites numerous, no roots merging into the peat of Phragmites to 140cm.

Analysis.

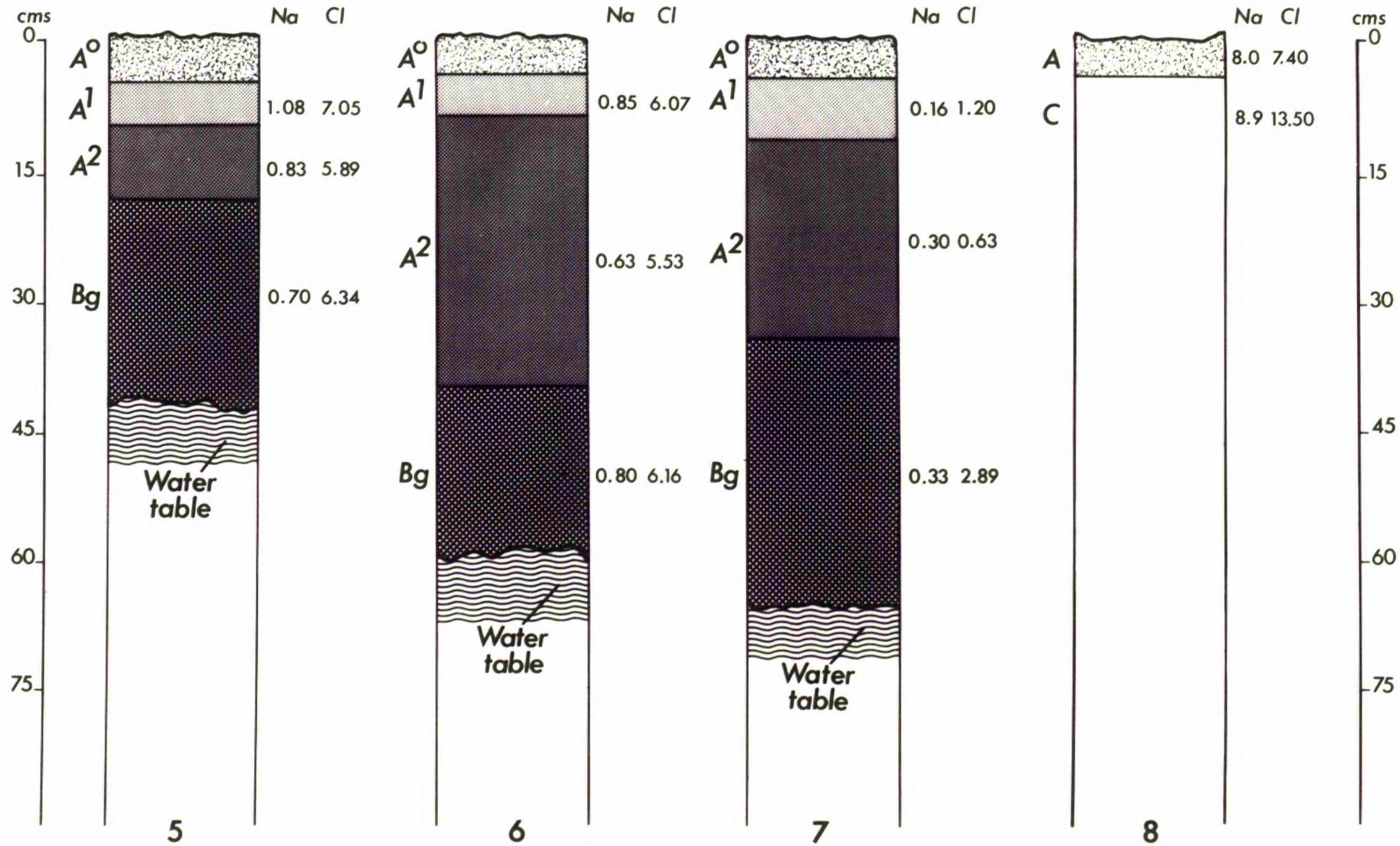
Horizons	A^0	A^1	Bg_1	Bg_2	Peat
Depth cm.	0-5	5 - 12.5	12.5-28	28-30	30-50-140
Loss on ignition %	61	36	19	29.55	74.30
pH	5.7	5.5	5.7	6.0	3.6
Sodium	22.50	14.25	9.25	32.50	37.50
Potassium	0.62	0.30	0.20	0.22	0.27
Magnesium	1.66	1.00	0.68	1.00	0.41
Calcium	5.50	3.75	2.50	3.38	6.50
Chloride	22.50	14.40	10.40	18.60	47.50

Figure 2.9 Soil Sequence of Semi-Natural Salt Marshes.

Legend details (Na^+ : mg/gram)
(Cl^- : mg/gram)

Profile Number 5	Upton Warren	(Puccinellietum distantis)
6	Upton Warren	(Puccinellietum distantis the sub-association hordeetosum
7	Upton Warren	Lolium - Cynosurus cristatus pasture
8	Neumann's Flash	(Puccinellietum distantis)

SOIL SEQUENCE ON SEMI-NATURAL SALT MARSHES



b. Soil Types of Subsidence, Semi-natural Salt Marshes.

The soils of the semi-natural salt marshes are described from Upton Warren, Worcestershire, where their development has been caused as a result of subsidence and seepage due to brine extraction and salt working at Stoke Works, about one kilometre from the site. Three soil profiles are described from this site and the horizon differentiation and salinity gradients are shown in Figure 2.9. The salinity gradient changes from salt marsh to pasture with respect to a change from high salinity to low salinity and local saline seepages are present. The soil profiles show that the A horizon is a dark brown stoneless, humose silty loam with a few faint to distinct rusty mottles. The Bg horizon is usually dark brown to dark greyish brown and is a prominently reddish brown mottled gley clay and starts at 20-30 cm from the surface and merges into regional groundwater at a 40-65cm depth. Thus, the soils at Upton Warren may be classified as follows:-

The major group	-	ground-water gley
The group	-	alluvial gley soil
The sub-group	-	pelo-alluvial gley soils of the river flood plains

and the Crompton Series or variant of this series - a clayey pelo-alluvial gley soil.

The series was first mapped by Avery (1955) and later by Findlay (1965) in Somerset and also in Worcestershire (Hollis and Hodgson 1974). As may be seen from the following representative profiles, soils of this series differ from those of the Midelney Series mainly in the absence of an underlying peat horizon. The grassland vegetation in both the natural salt marshes surveyed, in subsidence sites and on pastures reclaimed from former areas of brine production was quite heavily grazed by cattle and sheep, without any apparent problems of nutrient deficiency in the animals. In one locality near Marston, Cheshire, several acres overlying former salt works were arable and relatively productive in terms of a barley crop. However, underground seepage of brine solution had caused crop damage in several places and the soil surface and upper horizons had become impregnated with brine. Concentrations of 37.50mg/gram and 16·25 mg/gram of sodium were measured in the surface crust and A horizon respectively. No other adverse effects of brine pollution on agriculture were observed during the survey.

Profile No:	5
Location:	Upton Warren, Worcestershire (32/934665)
Elevation:	50m
Vegetation:	Puccinellietum distantis

Horizons cm.

0- 7 A^0	Very dark brown (10YR 2/2) stoneless humose silty loam; strongly developed medium crumby structure friable, abundant fibrous roots, merging and diffuse, boundary.
7 - 12 A^1	Dark reddish brown (5 YR 3/2) stoneless silty clay loam; strongly developed firm granular structure, few small fibrous roots, diffuse and merging boundary.
12 -20 A^2	Dark brown (10YR 3/3) occasional large pebbles, clay loam, strongly developed medium angular blocky structure, plastic, uncommon distinct fine red brown mottles: no roots, merging and indistinct undulating boundary.
20 - 44 Bg	Dark brown (10YR 3/3) clay, strongly developed medium to large blocky structure, mottling greyish prominent, blue gleyed, no roots, down to water table.

Analysis.

Horizons	A^0	A^1	A^2	Bg
Depth cm.	0 - 7	7-12	12-20	20-44
Loss on ignition %	-	27	16.40	24.70
pH	-	5.7	5.5	6.2
Sodium	-	1.08	0.83	0.70
Potassium	-	0.09	0.09	0.09
Magnesium	-	1.75	1.78	1.43
Calcium	-	8.75	7.25	6.25
Chloride	-	7.05	5.89	6.34

Profile No: 6
Location : Upton Warren, Worcestershire (32/934665)
Elevation: 50m
Vegetation: Puccinellietum distantis, the sub-association of Hordeum secalinum

Horizons cm.

0 - 5 A^0 — Dark Brown (10YR 3/3) stoneless humose distinct common mottling, abundant fibrous roots, sharp and distinct boundary.

5 - 10 A^1 — Dark brown (10YR 3/3) few stones, few distant mottles strong developed granular silty clay, friable, few small fibrous roots; diffuse and merging boundary.

10 - 43 A^2 — Dark brown (10YR 3/3) few stones, oxidated clay much evidence of ions, rusty red brown ions staining few rootlets and pebbles, strongly developed coarse granular structure, firm, merging and indistinct undulating boundary.

43 - 60 Bg — Dark greyish brown (10YR 4/2) stoneless; blue gley clay, much evidence of gleying ions in ferrous form, strong developed medium to large blocky structure, firm, reddish brown distinct common mottles, down to water table.

Analysis.

Horizons	A^0	A^1	A^2	Bg
Depth cm.	0-5	5-10	10-43	43-60
Loss on ignition %	-	18.35	12.50	16
pH	-	5.3	5.1	6.2
Sodium	-	0.85	0.63	0.80
Potassium	-	0.15	0.10	0.11
Magnesium	-	3.13	2.00	3.00
Calcium	-	8.00	6.00	6.75
Chloride	-	6.07	5.53	6.16

Profile No: 7

Location: Upton Warren, Worcestershire (32/934665)

Elevation: 50m

Vegetation: Lolium-Cynosurus cristatus pasture

Horizons cm.

0 - 5 A^0 — Dark brown (10YR 3/3) stoneless, silty loam,moderately developed, medium crumby structure, friable, abundant fine fibrous roots, sharp and distinct boundary.

5 - 12 A^1 — Dark reddish brown (5YR 3/2), stoneless, silty clay loam, few faint reddish brown mottles, strongly developed medium granular structure, firm, few fine fibrous roots, diffused and merging boundary.

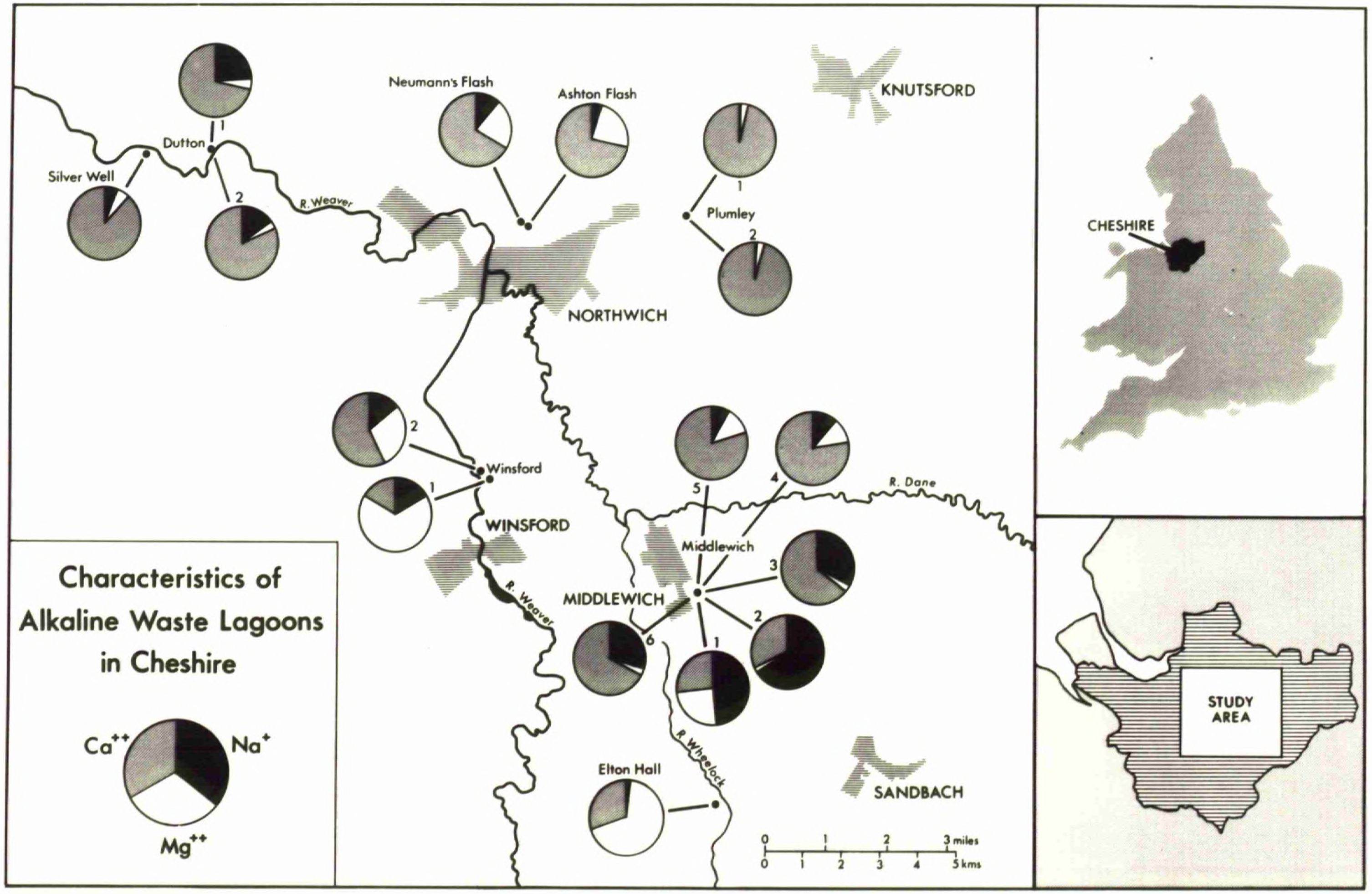
12 - 35 A^2 — Dark greyish brown (10YR 4/2) stoneless, silty clay, few distinct reddish brown (2.5 YR 4/4) mottles, strongly developed medium granular structure, firm, very rare fine fibrous roots, narrow and irregular boundary.

35 - 65 Bg — Dark greyish brown (10 YR 4/2) blue gleyed, rust down to water table. Common distinct mottles, strongly developed medium to large blocky, firm, no root, down to water table.

Analysis.

Horizons	A^0	A^1	A^2	Bg
Depth cm.	0-5	5-12	12-35	35-65
Loss on ignition %	-	42.0	36.5	15.20
pH	-	5.2	6.5	6.5
Sodium	-	0.16	6.30	0.33
Potassium	-	0.25	0.14	0.18
Magnesium	-	1.38	1.50	1.58
Calcium	-	5.25	4.63	5.75
Chloride	-	1.20	0.63	2.89

Figure 2.10 Characteristics of Alkaline Waste Lagoons in Cheshire


Characteristics of
Alkaline Waste Lagoons
in Cheshire
Ca++
Na+
Mg++
Neumann's Flash
Ashton Flash
KNUTSFORD
Dutton
Silver Well
R. Weaver
Plumley
NORTHWICH
Winsford
WINSFORD
R. Weaver
R. Dane
Middlewich
MIDDLEWICH
R. Wheelock
Elton Hall
SANDBACH
0 1 2 3 miles
0 1 2 3 4 5 kms
CHESHIRE
STUDY AREA

c. Soil Types on Waste Lagoons and their characteristics.

An example of the soil type and its formation on waste lagoons can be seen at Neumann's Flash, where the margins of the lagoon have a surface deposition of dark reddish brown (5YR 3/4) silty clay loam (0-5cm) with a narrow organic matter layer, developed on a calcareous lime waste parent material. Four soil profiles for this area are described later on, which are similar in horizon differentiation and description. The soils are classified as incipient and are at the earliest stage in the evolutionary sequence of soil formation.

The characteristics of alkaline waste lagoons in Cheshire are shown in Figure 2.10 from which it can be seen that exchangeable calcium content is generally higher than sodium in most of the bare parent materials. Elton Hall Flash is richest in magnesium followed by calcium and then sodium, and in some places magnesium as high as 35.00 mg/gram was recorded. Large areas of alkaline waste remain bare, the pH is very high (9.8) and the mean average cations ratio follows the sequence Mg 40 > Ca 18 > Na 1. The Flash is sparsely colonised by both halophytic and glycophytic phanerogams and several species of tolerant bryophyte (Mirza & Shimwell 1977). Plumley lime waste beds are also floristically poor. The concentrations of magnesium, potassium and sodium are significantly small, while the highest calcium value was 5.75 mg/gram. Soil samples from two lagoons were analysed and values are shown in Appendix IIa, S.S.31-33, 35 and 36. The Winsford alkaline waste lagoons are slightly contaminated with brine. The two sites have large areas unvegetated and within surface cracks <u>Puccinellia distans</u> is common and bare areas have high magnesium concentrations. The sludge lagoon at Silver Well is also rich in calcium but some areas have pronounced sodium concentration, while the six lagoons at Middlewich vary in the concentration of exchangeable cations, the older ones (3,4,5) being calcareous, the younger ones (1 and 2) being comparatively rich in sodium. Lagoon 6 is the active lagoon which was receiving the waste and the ratio of the sodium, calcium and magnesium follows the sequence Ca 2.28 > Na 1 > Mg 0.09.

To determine the ecological affinities of these lagoons it seems better to arrange them according to the relative concentrations of the major cations, expressed in terms of ratios of the sodium ion. Soils of inland salt marshes have a cation series Na > Ca > Mg > K, and lagoons 1 and 2 at Middlewich are related to this series. The sequence Ca > Na > Mg > K is a common feature of various types of exposed dune (Gorham 1958), and the lagoons at Silver Well, Dutton and Middlewich lagoons 3,4, and 6 are related to this type of habitat. Alternatively Willis et al (1959) have shown that Ca > Mg > Na > K is the expected situation in a variety of calcareous dune and dune slack habitats, and soils at Winsford, Elton Hall, Neumann's Flash, Ashton Flash, Plumley and Middlewich lagoon 5 seem to be more closely related to calcareous dune and dune slack habitats.

Profile No.	8
Location:	Neumann's Flash (33/665749)
Elevation:	19m
Vegetation:	Puccinellietum distantis.

Horizons cm.	
0 - 4 A	Dark reddish brown (5YR 3/4) stoneless, friable clay loam, weakly developed platy structure; few roots, sharp and even boundary.
4 - 10+ C	White (2.5 YN 8/0) stoneless, friable, lagoon deposits, weakly developed platy structure.

Analysis.

Horizons	A	C
Depth cm.	0-4	4-10+
Loss on ignition %	9.10	25.50
pH	8.0	8.9
Sodium	8.75	4.75
Potassium	0.15	0.05
Magnesium	0.53	6.75
Calcium	12.50	17.25
Chloride	7.40	13.50

Profile No:	9
Location:	Neumann's Flash (33/665749)
Elevation:	19m
Vegetation:	Atriplicetum salinae

Horizons cm.

0 - 5 A	Dark reddish brown (5YR 3/4) stoneless silty clay loam, weakly developed platy structure; common fibrous roots; sharp and even boundary.
5 - 10+ C	White (2.5 YN 8/0) stoneless lagoon deposit, weakly developed plates of lagoon material, some fibrous roots present.

Analysis.

Horizons.	A	C
cm.	0-5	5.10
Loss on ignition %	6.8	26
pH	8.4	8.6
Sodium	0.48	0.88
Potassium	0.12	0.04
Magnesium	1.00	4.25
Calcium	7.75	15.00
Chloride	0.75	6.50

Thus, in conclusion, it may be seen that the soils associated with natural, semi-natural and colonising salt marshes differ widely in terms of structure, age, horizon differentiation, sodium concentration and cation ratio and there are few, if any, features which generally characterise soils on which halophytic vegetation grows. However, all the soils described have an annually fluctuating ground water level which deposits cations throughout most layers of the soil profiles and may result in sodium concentrations as high as 22 mg/gram in the upper horizons.

CHAPTER 3

A REVIEW OF THE PHYTOSOCIOLOGICAL AND ECOLOGICAL METHODS USED

A. A Review of Phytosociological Methods Used

Present day phytosociology has a wealth of literature (Shimwell 1971, Whittaker 1973) mainly due to the fact that during the last two decades many phytosociologists have developed different methods or approaches for the organisation of data and subsequent classification or ordination. In the same period, continental workers have collected such a wealth of material on European vegetation that schemes for vegetation units and nomenclature comparable for that available for taxonomic units have been developed (Barkman 1950). In the light of these two trends it is interesting to review the development of plant sociology in the British Isles.

The origin of scientific classification of vegetation appears in the work of two plant geographers, Humboldt (1807) and Grisebach (1838). Their physiognomic concept (growth forms) for characterising plant communities had a pronounced effect on the early workers in plant ecology and phytosociology in Europe. Further development was due to two main approaches, an ecological approach relative to environmental gradients (Clements 1904, 1916, Moss 1910, Tansley 1920) and a floristic-sociological approach (Du Rietz et al 1920, Braun -Blanquet 1928, Raunkiær 1928). These two approaches acted as the basis for further development of methods in Britain and Europe, which resulted in not only two different methods, but also nomenclature.

The study of plant associations was introduced in Britain by Smith (1898,1899), and regarded by Tansley (1904) as the main subject of ecology. The attempts of Warming (1895) to classify plant communities through physiognomy and dominance also left a mark for future ecological workers in Britain, and, for the first thirty years of the twentieth century, British ecology was mainly dominated by an ecological approach to vegetation description in relation to environment or habitat. (Clements 1904, Tansley 1920). Tansley attempted to apply continental techniques (Tansley & Adamson 1926), but was unable to form an opinion as to their usefulness.

Thirty years later Poore (1955a, 1955b,1955c,1956) reviewed the application of the methods of the continental phytosociologists of the Zurich-Montpellier School. Unfortunately for vegetation Science, Poore criticised the methods on several grounds, including the emphasis of fidelity, the lack of appreciation of the importance of dominant species and the belief that associations can be naturally classified into a hierarchy (Shimwell 1968). Poore (1955,1956) approaches the vegetation through the Nodum, a neutral term for a plant community, analogous to with the taxon in systematics. He also pleaded against the loose naming of units by dominants, so common in British ecology and put forward the idea of multidimensional approach for vegetation description, derived from the work of Dahl (1956). Poore and McVean (1957), Gimingham (1961) and McVean & Ratcliffe (1962) later adopted this multidimensional approach and there evolved what has been termed by Shimwell (1971) the Norse-Scots approach.

Moore (1962) reassessed the Braun-Blanquet system and points out that "many of Poore's conclusions are ambiguous and may be proposed either to uphold or negate the system of phytosociology in question". The first major application of the techniques of the Zurich-Montpellier School in Britain was by Shimwell (1968) in his work on the phytosociology of calcareous grasslands in the British Isles. His work is a good example of phytosociology in Britain, using the Braun-Blanquet methodology and the negation of Poore's criticism proved the validity of this system for vegetation description and classification. Shimwell (1971) is not satisfied with fidelity as the sole criterion for distinguishing vegetation units but advocates the use of fidelity in association with high constancy, thus amalgamating two of the basic principles of the Zurich-Montpellier system and the Norse-Scots school. This led to an evolution of a 'hybrid' British tradition, now being used by the National Vegetation Classification. The main features of this tradition have been taken both from the Norse-Scots School, for example the use of Domin scale of cover values in the field description, character species being also species of high constancy,and the importance of constancy and dominance, while use of differential species to characterise groups, presentation of data in the form of a structured table were adapted from the Zurich-Montpellier School.

In the light of this development, the following procedure was adopted in field work and subsequent tabulation:

1. Field description of homogeneous stands, using the Domin Scale (Sensu Dahl and Hadac 1941) an eleven category scale of cover values;

Table 3.1 Raw Table

Relevé No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Scirpus tabernaemontani	9	9	-	-	-	-	-	-	7	8	6	-	-	-	-	-	-	-
Rumex hydrolapathum	+	4	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-
Enteromorpha intestinalis	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lemna minor	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Solanum dulcamara	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Typha latifolia	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scirpus maritimus	-	-	6	9	6	10	6	7	-	-	-	-	-	-	-	-	-	-
Agrostis stolonifera	-	-	5	3	4	-	-	4	3	4	+	-	3	-	4	-	-	-
Puccinellia distans	-	-	5	-	8	-	-	-	-	-	-	-	-	-	-	-	-	-
Atriplex hastata	-	-	4	4	4	-	6	4	-	3	-	-	4	4	-	-	-	+
Carex otrubae	-	-	4	-	3	-	-	-	-	-	4	-	-	-	-	-	-	-
Agropyron repens	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Festuca arundinacea	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arrhenatherum elatius	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spergularia marina	-	-	3	3	-	-	7	-	-	-	-	-	-	-	-	4	5	+
Ranunculus sceleratus	-	-	-	3	-	-	-	-	+	-	-	-	-	-	-	-	-	-
Phragmites communis	-	-	-	-	-	4	-	3	-	-	-	10	10	9	6	8	7	7
Berula erecta	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-
Calystegia sepium	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-
Glyceria maxima	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-
Triglochin maritima	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-
Aster tripolium	-	-	-	-	-	-	-	-	4	4	6	-	-	-	-	-	-	-
Chenopodium rubrum	-	-	-	-	-	-	-	-	4	3	-	-	-	-	-	-	-	-
Juncus bufonius	-	-	-	-	-	-	-	-	3	3	-	-	-	-	-	-	-	-
Eleocharis palustris	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Eupatorium cannibinum	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-
Acrocladium cordifolium	-	-	-	-	-	-	-	-	-	-	7	-	-	-	-	-	-	-
Festuca rubra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	4	-	-
Plantago maritima	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	5	4	6
Puccinellia maritima	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	4	5	4
Species No.	5	3	9	5	5	2	3	8	7	7	6	1	3	2	5	5	4	5

Table 3.2 Annotated Raw Table

Relevé No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Scirpus tabernaemontani	9	9	-	-	-	-	-	-	7	8	6	-	-	-	-	-	-	-
Rumex hydrolapathum	+	4	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-
Enteromorpha intestinalis	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lemna minor	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Solanum dulcamara	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Typha latifolia	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scirpus maritimus	-	-	6	9	6	10	6	7	-	-	-	-	-	-	-	-	-	-
Agrostis stolonifera	-	-	5	3	3	-	-	4	3	4	+	-	3	-	4	-	-	-
Puccinellia distans	-	-	5	-	8	-	-	-	-	-	-	-	-	-	-	-	-	-
Atriplex hastata	-	-	4	4	4	-	6	4	-	3	-	-	4	4	-	-	-	+
Carex otrubae	-	-	4	-3	3	-	-	-	-	-	4	-	-	-	-	-	-	-
Agropyron repens	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Festuca arundinacea	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arrhenatherum elatius	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Spergularia marina	-	-	3	3	-	-	7	-	-	-	-	-	-	-	-	4	5	+
Ranunculus sceleratus	-	-	-	3	-	-	-	-	+	-	-	-	-	-	-	-	-	-
Phragmites communis	-	-	-	-	-	4	-	3	-	-	-	10	10	9	6	8	7	7
Berula erecta	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-
Calystegia sepium	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-
Glyceria maxima	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-
Triglochin maritima	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-
Aster tripolium	-	-	-	-	-	-	-	-	4	4	6	-	-	-	-	-	-	-
Chenopodium rubrum	-	-	-	-	-	-	-	-	4	3	-	-	-	-	-	-	-	-
Juncus bufonius	-	-	-	-	-	-	-	-	3	3	-	-	-	-	-	-	-	-
Eleocharis palustris	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
Eupatorium cannibinum	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-
Acrocladium cordifolium	-	-	-	-	-	-	-	-	-	-	7	-	-	-	-	-	-	-
Festuca rubra	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	4	-	-
Plantago maritima	-	-	-	-	-	-	-	-	-	-	-	-	-	-	6	5	4	6
Puccinellia maritima	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4	4	5	4

Table 3.3 : Partial Table

Relevé No.	1	2	9	10	11	3	4	5	6	7	8	12	13	14	15	16	17	18
Group A																		
Scirpus tabernaemontani	9	9	7	8	6													
Aster tripolium	-	-	4	4	6													
Group B																		
Scirpus matitimus						6	9	6	10	6	7							
Atriplex hastata						4	4	4	-	6	4							
Puccinellia distans						5	-	8	-	-	-							
Spergularia marina						3	3	-	-	7	-							
Group C																		
Phragmites communis												10	10	9	6	8	7	7
Plantago maritima												-	-	-	6	5	4	6
Puccinellia maritima												-	-	-	4	4	5	4
Festuca rubra												-	-	-	6	5	-	-

Table 3.4 Differentiated Table

Relevé No.	1	2	9	10	11	3	4	5	6	7	8	12	13	14	15	16	17	18
Group A.																		
Scirpus tabernaemontani	9	9	7	8	6													
Aster tripolium	-	-	4	4	6													
Group B.																		
Scirpus maritimus						6	9	6	10	6	7							
Atriplex hastata				3		4	4	4	-	6	4		4	4				+
Puccinellia distans						5	-	8	-	-	-							
Spergularia marina						3	3	-	-	7	-					4	5	+
Group C.																		
Phragmites communis									4		3	10	10	9	6	8	7	7
Plantago maritima												-	-	-	6	5	4	6
Puccinellia maritima												-	-	-	4	4	5	4
Festuca rubra												-	-	-	6	4	-	-
Group D.																		
Agrostis stolonifera	-	-	3	4	+	5	3	4	-	-	4	-	3	-	4	-	-	-
Rumex hydrolapathum	+	3	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-
Carex otrubae	-	-	-	-	4	4	-	3	-	-	-	-	-	-	-	-	-	-
Chenopodium rubrum	-	-	4	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Juncus bufonius	-	-	3	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ranunculus sceleratus	-	-	+	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-
Typha latifolia	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Agropyron repens	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-
Festuca arundinacea	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-
Arrhenatherum elatius	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Triglochin maritima	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Eleocharis palustris	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Solanum dulcamara	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Berula erecta	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-
Calystegia sepium	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-
Glyceria maxima	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-
Eupatorium cannibinum	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-
Acrocladium cordifolium	-	-	-	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-
Lemna minor	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Enteromorpha intestinalis	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

2. a). Presentation of data in a tabular form and erection of differentiated tables in the process described by Shimwell (1971);

   b) Use of differential species and differential species groups to characterise units;

   c) Erection, differentiation and characterisation of associations, sub-associations, variants and noda on the basis of overall floristic similarity, character species of high constancy, constancy and dominance;

3. Classification of associations into higher units using the Zurich-Montpellier School of hierarchical classification;

4. Reference of these units to major environmental gradients, from which the groups of ecological related species could be extracted.

The construction of a differentiated table is the basis of this method. A differentiated table as defined by Shimwell (1971) is one which shows the differential species and differential species groups sorted into blocks and separated from the other species which are listed in order from high to low constancy. This may be illustrated by relevé s collected from emergent, brackish water vegetation.

First, the relevés were aggregated together in a raw table, using squared paper and each relevé was assigned a single vertical column and addition of new species resulted in the characteristic tailing off to the right of table. The relevé number and species number were other information recorded at this stage (Table 3.1). The second stage involves the outlining of differential species and differential species groups, on the basis of species group combination to form a partial table (Table 3.2). Third follows the ordination of the partial table, in which the outlined or boxed species were extracted and used to rearrange the table in both a vertical and horizontal manner. Thus, the sequence of the relevé numbers will be changed. This is shown in Table 3.3. Fourthly, completion of a differentiated table involves the coupling of the partial table with the rest of the species as companions under the differential species and differential species groups. The relevé numbers were rearranged and the table was tidied up in such a manner that species were arranged in descending order of presence. Thus, in the finished table, the species were listed from high to low constancy (Table 3.4) (ref. Shimwell, 1971, tables 44-48).

This differentiated table determined the delimitation of possible units and further relevés helped determine the status of these units. By this process, three associations, Scirpetum maritimi, Scirpetum tabernaemontani and Phragmitetum, were delimited on the basis that the same pattern emerged. But, had the further data given a different pattern, then these might be three sub-associations under a broader association. Associations thus delimited can be defined as groups of relevés from stands of homogeneous vegetation, characterised by a differential species or a group of differential species with constancy class V more than IV. The sub-associations differ by the presence of plants that form certain floristic and ecological sub-units within an association, but such units occur in other associations also. Variants are usually characterised by one or two species having dominance within the sub-association.

The survey work of brackish water vegetation, inland salt marshes, brine springs, saline and alkaline industrial wastelands and lagoons in the British Isles was completed using the sampling procedure as laid down by National Vegetation Classification. This sampling procedure was followed in order to maintain uniformity with methods currently used and thus to provide comparable data. For relevé collection, the field manual N.V.C./COORD 32 was followed with adjustment, wherever required. In sampling it was found that for most situations areas of 2x2m were suitable, this being based upon the minimal area determination as described by Poore (1955a). For bryophyte communities a $0.25m^2$ quadrat was used. For every relevé, the location, grid reference and region were noted. Soil profiles in several localities were also described and samples of water and soil taken from a representative number of sites for analysis for pH, conductivity, sodium, potassium, magnesium, calcium and chloride. For an estimate of the quantitative presence of plants, the Domin scale of cover/abundance (Sensu Dahl and Hadac, 1941) was used.

Relevés thus collected were separated initially as aquatic vegetation, emergent vegetation and salt marsh, including vegetation of saline industrial waste. Relevés were grouped into associations, sub-associations and noda on the basis of character species, constancy, dominance and referred to an ecological framework according to the methods previously described. It was decided to adopt this method of description, tabulation and classification for two main reasons:-

1. to provide comparable data, not only with previous work on inland saline vegetation (Duvigneaud 1967, Dangien et al 1974, Lee 1977), but also for the on-going project, the National Vegetation Classification.
2. the thesis concerns itself with both syn-ecological and aut-ecological studies of problems within the subject of inland saline vegetation and is not purely a phyto-sociological study; a comparatively rapid and rewarding method of field survey was thus considered necessary.

B. The Collection, Extraction and Analysis of Ecological Materials.

The standard methods as advocated by Allen (1974) for the collection and storage of field samples were followed during the field work. Similarly the extraction and analytical procedures as described by Bower et al (1952), Allen (1974), Chapman (1976) were used. For the extraction of soil, use of 1 M ammonium acetate of pH 7 was preferred for all types of soils, so that the results represented are for exchangeable and soluble cations and chloride, as opposed to total concentrations in the soil. This was done to produce not only comparable results with other workers in the field (Lee 1975, 1976, 1977) and also earlier work of Mirza & Shimwell (1977), but also to standardize the general ecological procedure prevalent in Great Britain at the present time.

The results in the text and appendices for soil and plant analyses are presented as mg/gram in the case of exchangeable and soluble cations and chloride in the soil and total cations in the plant materials. The results for water analysis for the four cations, sodium, potassium, calcium and magnesium, and also for chloride, are presented as parts per million (ppm). The conductivity of water and soil is presented as mmhos/cm at 25c.

The procedures adopted were as described below:

a. Sample collection, initial treatment and storage.

Soil. Samples of soil were collected from bare areas, the rooting zone (to 5cm) and each horizon of the soil profile, where appropriate, in the immediate vicinity of the releves. Within 48 hours of collection the pH of the fresh samples was measured using a 1-1 soil and deionised water suspension in the case of saturated soils and 1:2 ratio in the case of unsaturated soils. The 291 Pye Unican Model pH meter was always checked against two buffer solutions, one each side of the expected pH. The pH of every sample was recorded to one decimal place. After the removal of roots, the remaining soil samples were dried at laboratory temperature for two days, and then oven dried at 40 C for 24 hours. The samples were then ready for extraction.

Water. Samples were collected in plastic bottles, pre-washed with deionised water. On arrival at the laboratory, pH and conductivity of unfiltered samples were determined using 50 ml. water samples. Standard laboratory procedures were followed for the determination of both pH and conductivity. The water samples were then filtered using No.50 Whatman filterpaper into 100 ml. flasks, labelled and stored in a refrigerator at 4^{o}C.

Plant Materials. Plant material (shoots only) was collected from different relevés, relevant to soil and water samples taken. In the laboratory the shoots of flowering plants were washed with deionised water. The bryophyte samples were teased into individual shoots to remove adhering soil and washed five times with deionised water to remove extracellar cations, so that remaining cations were exchangeable and intracellular (Bates & Brown 1974, Mirza & Shimwell 1977). Samples were oven-dried overnight at 8^{o}C and then taken for extraction.

b. Extraction procedures.

Soils. Ten grams of oven dried, 2mm. sieved, fine samples were weighed out into 250 ml. beakers and extracted using 1 M ammonium acetate of pH 7 as an extractant (Bower et al 1952) 70 cc of extractant were added to the sample, the contents were thoroughly stirred several times during half an hour and were then allowed to stand overnight. The soil suspension was filtered through a No. 50 Whatman filter paper and the residue was filtered again into the original filtrate, using another 30 ml. ammonium acetate, thus bringing the extract to 100 ml. The extracts were stored in 100 ml. volumetric flasks in the refrigerator at 4^{o}C.

Plant Material. One gram oven dried, ground samples were weighed out into acid-washed, dry silica crucibles and ashed in the muffle furnace at 500°C for three hours. The crucibles were then removed from the muffle furnace and allowed to cool in a desiccator. The resultant ash was digested in 5 ml. concentrated hydrochloric acid. At the dissolution stage, 2 ml. of concentrated nitric acid were added and the solution was filtered into a 100 ml. flask using deionised water. The filtrate was made up to 100 ml. with deionised water in a stoppered 100 ml. volumetric flask and stored in refrigerator at 4°C.

c. Analysis procedure.

Cations. Samples of soil, water and plant extracts were analysed for four cations, sodium, potassium, magnesium and calcium using a Perkin Elmer 360 Atomic Absorption Spectrophotometer, at the following wavelengths (Na^+ - 589 nm, K^+ - 766 nm, Mg^{2+} - 285 nm, Ca^{2+} - 423 nm) and slit widths Mg^{2+}, Ca^{2+}, Na^+ - 0.7 nm: K^+ - 2.0 nm. All the standard solutions were prepared by suitable dilution of the stock standard solutions described under the standard conditions for each element. Standards of 1 ppm and 2 ppm were used for the calibration of the instrument and the chart recorder. In the determination of calcium and magnesium, lanthanum chloride at a concentration of 1% weight/volume was added to the standards and extracts to suppress phosphate interference. Initially it was found that the original extracts had to be diluted a number of times to obtain a reading within the calibration range. The number of dilutions made and sample numbers were carefully noted on the chart recorder output (see Appendix 1.f).

Chloride. Samples of water and soil were analysed on a Technicon Autoanalyser II, using a chloride Cartridge/Manifold. Mercuric thiocynate at a concentration of 0.35 g in one litre and ferric nitrate at 0.25M were used as reagents. A stock standard solution was prepared by dissolving 0.165 gm Sodium chloride in one litre and from this stock solution, standards of 0.2, 0.5, 1,2,5,10,15, and 20 ppm were made and then used for the calibration of the instrument. Two blanks were introduced after every five samples to maintain the appropriate sample and wash ratio for the auto-analyser. It was noted that to obtain a reading on the calibration curve, the original sample solutions required dilution. The number of dilutions were carefully recorded on the chart recorder output (see Appendix 1-g).

Conductivity. The conductivity of water samples from Worcestershire and Warwickshire was determined in the field and from the other localities in the laboratory for unfiltered water, using the WPA/EM 25 conductivity meter. The cell constant and temperature of the sample were carefully taken and results were corrected at 25^{o}C, applying the appropriate temperature conversion factor obtained from Richards (1969 Table 15). Saturated soil extracts were obtained for the determinationsof the conductivity of the soil (Richards 1969).

Details of the experimental and analytical procedure are given in Appendix 1.

CHAPTER 4

PHYTOSOCIOLOGICAL AND ECOLOGICAL CHARACTERISATION OF THE PLANT COMMUNITIES

A. Description of the Plant Communities.

The British inland saline habitats provide a good subject for research in terms of both phytosociology and ecology, because the sites and species are valuable for both comparative ecological experiments and conservation (Lee 1975). Besides the work of Lee (1977) no detailed phytosociological study on such sites has been carried out. An extensive survey was undertaken during the period 1976-1978 and over 300 relevés were collected and classified into associations, sub-associations and noda according to the procedure outlined in the previous chapter. Each community thus recognised is described in the ensuing text, using the procedure as adopted by Shimwell (1971), a brief format of which is as follows:

Name of association - whenever possible referred to a unit or association already described;
Number of samples - the number of relevés collected for each association, subassociation and nodum;
Floristic characteristics - reference to overall physiognomic structure and dominants, constants and differential species; the constancy class of these species; and the presence of any other important or rare species; a constant species in the following text is a species having constancy class III; dominant and constant taxa are those of constancy class V;
Geographical distribution - the geographical distribution of the relevés collected;
Ecological characteristics - the concentration of sodium, potassium, magnesium, calcium, chloride; conductivity and other ecological characters as soil type, water depth and habitat details, wherever appropriate;
Zonation and succession - the zonal and seral relationships of the association.

B. Classification of Salt Tolerant Vegetation.

The system of classification proposed by Chapman (1958) and modified by Waisel (1972) for coastal salt marshes is not really applicable, being almost exclusively ecological. Duvigneaud (1967) and Dangien et al (1974) have proposed a classification of inland saline sites in Belgium and France, but their classification does not include aquatic and emergent, brackish water vegetation. Similarly Lee (1977) described the vegetation of inland salt marshes and four associations, already recognised on the continent, have been recorded from the British Isles. However, these classifications are incomplete in several respects. Thus the following classification based upon the work of these authors, and systems of vegetation classification advocated by Lohmeyer et al (1962), Segal (1968), Oberdorfer (1967) and Adam (1977) is proposed.

a. Pioneer Floating Communities of Static or Slow-moving Water.

Cl. Lemnetea Koch et Tx. 1954 apud Oberdorfer 1957
  O. Lemnetalia Koch et Tx. 1954 apud Oberdorfer 1957
    All. Lemnion minoris (Koch et Tx. 1954) Den Hartog et Segal 1964.
    All. Lemnion trisulcae Den Hartog et Segal 1964.
      Ass. Lemnetum sensulato

Cl. Potamogetonetea (Potametea) (Tx.et Prsg.1942) Den Hartog et Segal 1964
  O. Potamogetonetalia (Potametalia) W.Koch 1926
    All. Potamogetonion (Potamion) W.Koch 1926 em. Oberd. 1957
      Ass. Potamogetonetum pectinati (Carstensen 1957)
      Ass. Zannichellietum palustris G.Lang em. Oberd. 1967.
    All. Nymphaeion Oberd. 1957.
      Ass. Myriophylletum sensu lato.

b. Emergent Reedswamp Vegetation at the Margins of Open Water.

Cl. Phragmitetea Tx. et Prsg. 1942.
  O. Phragmitetalia eurosibrica (W.Koch 1926) Tx. et Prsg.1942.
    All. Phragmition W.Koch 1926
      Ass. Typhetum angustifolio-latifoliae (Eggl.1937)Schmale 1939.
      Ass. Scirpetum maritimi (Br. -Bl. 1931) R.Tx. 1937.
      Ass. Scirpetum tabernaemontani Pass. 1964.
      Ass. Phragmitetum eurosibiricum (Gams 1927) Schmale 1939.
  O. Magnocaricetalia Lohmeyer 1962.
    All. Magnocaricion elatae W. Koch 1926.
      Ass. Caricetum otrubae ass. nov. prov.

c. Species-poor, Annual Herb Communities of Periodically Inundated Saline Soils.

Cl. Cakiletea maritimae R.Tx. apud Oberd. 1950
O. Atriplicetalia littoralis Sissingh 1946
All. Atriplicion littoralis R.Tx. 1950.
Ass. Atriplicetum salinae deviense (Duvigneaud 1967)

Ass. Cotuletum coronopifoliae ass.nov.prov.

d. Inland Salt marsh Vegetation Dominated by Perennial Rush and Grass Species.

Cl. Asteretea tripolii Westhoff et Beeftink 1962
O. Glauco-Puccinetal ia Beeftink et Westhoff 1962.
All. Armerion maritimae Br.-Bl. et Van Leeuw 1936.
Ass. Juncetum gerardii Warming 1906.
All. Puccinellion maritimae Christ. 1927 em.R.Tx. 1937
Ass. Puccinellietum maritimae (Warming 1906) Christ.1927
All. Puccinellio-Spergularion salinae Beeftink 1965
Ass. Spergularietum marinae ass.nov.prov.
Ass. Puccinellietum distantis Feekes (1934) 1943.
Sub-association initial
Sub-association degraded
Sub-association asteretosum
Sub-association vulpietosum
Sub-association agropyretosum
Sub-association hordeetosum
Sub-association apietosum
Sub-association funarietosum hygrometricae
Sub-association barbuletosum tophaceae
Sub-association pohlietosum annotinae

e. Noda of Uncertain Affinities:

Saline *Agrostis stolonifera* Nodum.
Saline *Ranunculus sceleratus* Nodum.
Agropyron repens Nodum.
Vulpia-Agrostis stolonifera Nodum.
Aster tripolium Nodum.
Apium- Poa Nodum.

C. Ecological gradients in the Inland Salt Marsh Communities.

There is a paucity of literature on the inland halophytic plant communities of England and their correlation with edaphic conditions (Lee 1975, 1977, Mirza & Shimwell 1977). In consequence, relatively little is known of the limitations of plant communities to specific ecological conditions. On the other hand, studies by Schaffner (1898), Flower (1934), Hanson & Whitman (1938), Bolen (1964), Dodd et al.(1964) and Ungar (1966,1972) describe some species-soil relationships in saline habitats of North America and Bolen (1964) and Dodd et al.(1966b) and Ungar (1964,1972) have described the vegetation of the inland saline sites of North America. These studies indicate that the plant species appear to be selected out by highly saline environments in a gradient from the most to the least salt tolerance with other factors playing secondary roles. This results in the lowest species diversity in the most saline soils and the maximum in non-saline soils. Thus, in the evolution of inland plant communities, salinity must have played an important part and their present distribution also appears to be limited by salinity and depth of watertable, as well as by competitive ability of members of the next community in the halosere. As submergence of the inland halophytic communities is only occasional after heavy rain, so zonation of these communities mainly depends on salinity, contrary to the coastal habitat where zonation is mainly determined by factors other than salinity, inundation being the most important factor (Chapman 1938, 1960, Adams 1963).

To summarise in the words of Ungar (1972), " .... dynamics in plant communities of saline soil is best thought in terms of a cyclical invasion and retrogression pattern. These vegetation cycles are closely related to soil water potentials which are themselves affected by precipitation and evaporation." However, in the inland saline soils of England, the soil water potential seems to be mostly dependent on the quantities of the salts in the soil, evaporation and precipitation being of only secondary importance.

The literature on the correlation between soil salinity and distribution of plant communities (Adriani 1945, Burvin 1963, Waisel 1972; Kieth 1956, Ungar 1972; Lee 1977, Mirza & Shimwell 1977) describes the ranges of different salts that these plant communities can tolerate. In the following text the ranges of concentration of three main cations (sodium, calcium and magnesium) and chloride are summarised as ecological gradient diagrams (Fig 4. 1-9) for each of four main vegetation physiognomic types and for the various sub-associations of the Puccinellietum distantis. A short summary of the major variations in the gradients is provided in the appropriate section of the text.

a. Pioneer Floating Communities of Static or Slow moving Waters.

(i) Association Lemnetum sensu lato

(Table 4. 1a. 6 relevés)

Characteristics of the association.

The association is fairly well characterised by the presence of *Lemna gibba* and *Lemna trisulca*. In three stands *Lemna gibba* is dominant with a high cover value while *Lemna trisulca* predominates in two stands. *Lemna minor* was present in one stand with *Ceratophyllum demersum* as co-dominant, but the water was less saline. Other species of low constancy and cover values are *Enteromorpha intestinalis*, *Callitriche stagnalis*, *Apium nodiflorum*, *Potamogeton natans* and *Potamogeton berchtoldii*. The association has not been recorded previously from inland saline sites, but the Atlas of the British Flora shows the wide occurrence of *Lemna gibba* and *Lemna trisulca* in inland localities of England. The association is homogeneous as far as structure and floristic composition is concerned and is often a pioneer component of other floating leaved communities.

Geographical distribution.

In Cheshire, the Nantwich saline pools contain good examples of this association, while at Pasturefields it was present in one saline ditch. Stands referable to this association are also found in the River Weaver, near Winsford, saline lagoons and, at Billingegreen, a pool formed by subsidence is inhabited by *Lemna minor*. The association Lemnetum salinae was also recorded from West Yorkshire.

Ecological Characteristics. (Table 4.1b).

Lemnetum occurs in low to moderately saline water between 15 and 60cm. in depth. The highest conductivity recorded was 6.5 mmhos/cm, sodium 925 ppm and chloride 1450 ppm. Table 4.1b shows the concentrations of four cations, chloride, pH and conductivity of the waters pertaining to the stands of the association. The range of conductivity is between 0.46 to 6.50 mmhos/cm., sodium 23 to 925 ppm, potassium 04 to 20ppm., magnesium 19 to 29 ppm, calcium 50 to 100 ppm, chloride 65 to 1450ppm and pH 7.2 to 8.9.

Zonation and succession.

Lemna minor is a ubiquitous species of stagnant waters and sometimes forms a part of understory of reedswamp communities, while other more frequent species of the association Lemna gibba and Lemna trisulca appear to be better adapted to saline waters. Thus, the association occupies a transitional stage between fresh and saline water habitats and is often a pioneer component of other floating leaved associations of saline waters.

(ii) Association Potamogetonetum pectinati (Carstensen 1957) (Table 4. 2a; 14 relevés)

Characteristics of the association.

The Potamogetonetum pectinati is characterised by the presence of Potamogeton pectinatus as dominant and constant species. Fourteen relevés are grouped together in Table 4.2a which shows the gregariousness and constancy of this species in the association. Five stands are monospecific with cover values from 80 to 100%. Myriophyllum spicatum, Enteromorpha intestinalis, Potamogeton crispus and Lemna spp., though not constant, form an important constituent of the association, while the other associated species Ceratophyllum demersum, Myriophyllum alterniflorum, Elodea canadensis, Callitriche stagnalis and Zannichellia palustris are of low coverage and constancy.

There are several spatial differences within the association; Cladophora sp. are co-dominant with Potamogeton pectinatus in slow running water; Ceratophyllum demersum shares dominance with Potamogeton pectinatus in saline ponds; and Lemna trisulca and Lemna minor are either dominant or co-dominant with Potamogeton pectinatus in saline pools. The association has not been previously recognised from inland sites, but according to the Atlas of the British Flora Potamogeton pectinatus in England is predominantly a widespread inland species. It is also abundant in base-rich lochs in Scotland where it is calcicolous in nature (Spence 1964).

Two sub-associations are recognizable. The sub-association salinetosum is predominant in saline and calcicolous waters and is widespread in rivers, canals and pools contaminated with various salts.

The stands are either monospecific with Potamogeton pectinatus as dominant and constant or with Myriophyllum alterniflorum, Ceratophyllum demersum and Cladophora sp. with low constancy and cover value. The sub-association lemnetosum is characterised by the high constancy and dominance of Lemna trisulca and Lemna minor. Other constant species are Enteromorpha intestinalis, Potamogeton crispus and Myriophyllum spicatum. This sub-association perhaps represents a group of transitional communities between this association and the Lemnetum salinae.

Geographical distribution.

The association is described mainly from the brackish ponds, saline pools, rivers and canal waters contaminated with salts in Cheshire. Relevés referable to this association were collected from Trent and Mersey Canal at Winsford, Anderton, Marston and the River Weaver, near Silver Well, where the river water was being contaminated by an outflow from a brine pipe. Other stands included in this association are from the River Trent at Pasturefields, Staffordshire and the River Salwarpe, Worcestershire. These localities are either in the direct vicinity of saline lagoons or close by the saltworks.

Ecological characteristics. (Table 4.2b)

The association is characteristic of the brackish waters which show a broad fluctuation in salinity and alkalinity. Table 4.2b shows the water chemistry and pH of stands pertaining to this association. The range of pH is between 7.4 to 9 and conductivity between 0.45 to 25.37 mmhos/cm. The concentration of calcium varies between 50 to 20,000ppm, sodium 20 to 17,000ppm, potassium 04 to 25 ppm, magnesium 23 to 75ppm and chloride 130 to 18,000ppm.

Zonation and succession.

The available data for water preference confirms the calcicolous and saline nature of the association,and,with the increase in depth and salinity of water, the Potamogetonetum pectinati appeared to replace the other linear-leaved, submerged association, the Zannichelletum palustris. In conditions of high salinity and alkalinity the association occurred as pure stands of its character species.

(iii) Association Zannichellietum palustris. G.Lamg.em. Oberd. (1967).(Table 4.3a. 6 relevés)

Characteristics of the association.

The association is characteristic of open and shallow water between 2 and 25 cm in depth. In Table 4.3a, six stands from saline pools have been grouped together which show that only Zannichellia palustris is dominant and constant. In one relevé Enteromorpha intestinalis attains a co-dominance with Zannichellia palustris, while the other associate species Callitriche stagnalis, Myriophyllum alterniflorum, Lemna minor and Potamogeton crispus have low constancy and cover values. Two stands are monospecific and the general structure and floristic composition of the association is uniformly homogeneous, The association has not been recorded previously from inland saline habitats but Lee (1977) has recorded Zannichellia palustris as a component of the alliance Ruppion maritimae from Nantwich and Sandbach, Cheshire, where in the present survey it was not seen.

Geographical distribution.

In England this association is developed in brackish water and saline pools. Stands of the association were collected from saline pools at Upton Warren, Worcestershire, in the Birmingham and Worcester Canal, near Stoke Works, and in Cheshire, where at Anderton the association was present in a highly saline pool. Zannichellietum palustris also forms a stand of more than $4m^2$ in a saline pool at Winsford industrial saline lagoon.

Ecological characteristics.

The association is found mainly in pools with moderate salinity except in one highly saline pool, where there was a continuous inflow of saline water. The range of pH is between 7.2 to 9.2 and the conductivity between 1.57 to 25.37 mmhos/cm., while sodium is between 148 to 6625ppm, potassium 06 to 14 ppm, magnesium 15 to 550ppm, calcium 55 to 775 ppm and chloride 58 to 6,000ppm.

Zonation and succession.

The association occurs in shallow and moderately saline water, so in the early stages of succession of saline water, Zannichellietum palustris constitutes a pioneer component of other linear-leaved, submerged vegetation types.

(iv). Association Myriophylletum sensu lato.

(Table 4.4a. 5 relevés)

Characteristics of the Association.

The dominant species are Myriophyllum spicatum and Myriophyllum alterniflorum while Myriophyllum spicatum is constant. Potamogeton crispus, P. trichoides and Cladophora sp. were the only three companion species in the association. Five stands of the association which are grouped together in Table 4.4a, are pure stands of Myriophyllum spp. with almost 100% coverage. The association is characteristic of less saline stagnant water on muddy substrates.

Geographical distribution.

The association is confined to saline pools at Preesall, Lancashire; Droitwich canal, Worcestershire; Sandbach, Cheshire, and West Yorkshire. In the Droitwich canal, Worcestershire (32/876623) about 100 metres of the old canal was filled with Myriophyllum spicatum.

Ecological characteristics. (Table 4.4b).

The association is characteristic of deep muddy waters, the level of which ranges between 20 to 60 cm. or deeper. The conductivity ranges from 0.87 to 4.06 mmhos/cm; pH is between 8.0 to 8.8, sodium 30 to 525ppm, potassium 04 to 06 ppm, magnesium 11 to 28 ppm, calcium 38 to 48 ppm and chloride 25 to 1075 ppm.

Zonation and succession.

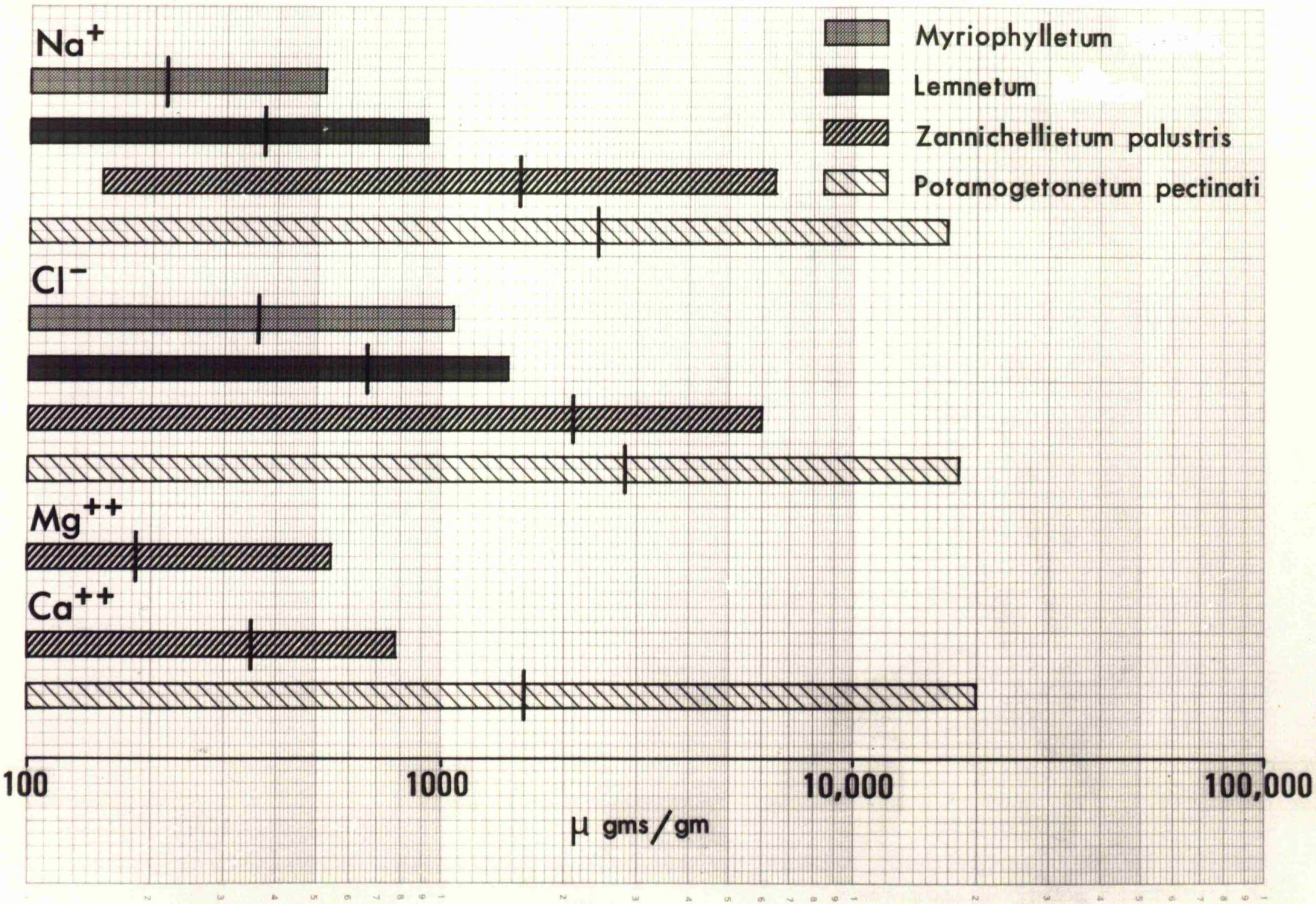
The association is a pioneer vegetation type of static or slow moving saline and freshwater habitats, and often forms the initial stage of a hydroseral development to Phragmites reedswamp.

(v). Summary of Ecological Gradients in Floating Aquatic Communities.

Figure 4.1 shows the ranges and mean values of the three major cations (sodium, calcium and magnesium) and chloride of the waters associated with these communities, from which it can be seen that despite a wide overlap in ecological conditions, a distinct range of tolerance of each ion is shown. The Potamogetonetum pectinati appears to have the highest tolerance of sodium, calcium and chloride ions. With decreasing salinity in water, the association Potamogetonetum

Figure 4.1 Ranges and means of Na^+, Cl^-, Mg^{2+} and Ca^{2+} concentrations of water in the floating associations of static or slow-moving water.

(vertical bars represent the mean concentrations)



Na^+
Cl^-
Mg^{++}
Ca^{++}
Myriophylletum
Lemnetum
Zannichellietum palustris
Potamogetonetum pectinati
100
1000
10,000
100,000
μ gms/gm

pectinati gives way to the Zannichellietum palustris, which can tolerate a medium concentration of all the three cations and chloride. With further decrease in salinity and values of calcium and magnesium as low as in freshwater, but sodium and chloride concentrations about four to five times more than normal water, the association Lemnetum salinae seems to appear. The least salinity tolerant amongst the floating aquatic communities is the Myriophylletum salinae, which is developed in waters with mean values of sodium of about 215 ppm and chloride of about 369 ppm and magnesium and calcium values as low as in freshwater.

b. Emergent Sedge and Reedswamp Vegetation at the Margins of Open Water.

(i) Association Typhetum angustifolio-latifoliae (Eggl. 1933) Schmale 1939. (Table 4.5a. 6 relevés).

Characteristics of the association.

The relevés from inland saline pools referable to this association have Typha latifolia as a character species instead of Typha angustifolia, the latter species being recorded as dominant with high cover from one saline pool only, while the former species is dominant and constant. The floating species in the association are Potamogeton pectinatus and Lemna trisulca in stands associated with relatively more saline water, while Lemna minor and Acrocladium cordifolium occur in less saline conditions. Aster tripolium and Agrostis stolonifera are constant species, but perhaps due to the fact that most of the stands are collected from Sandbach, where Aster tripolium is very widespread. Other associated species such as Ranunculus sceleratus, Scirpus tabernaemontani and Juncus inflexus are rare.

The association has not been recorded from the inland saline sites of England, but in coastal saltmarshes, Adam (1977) has reported stands dominated by Typha latifolia as extremely small and local in distribution.

Geographical distribution.

The association is described mainly from saline pools at Sandbach, Cheshire. Other localities are Winsford and a marsh at the side of the Trent and Mersey canal near Billingegreen, Cheshire. Stands of Typha latifolia are common along the margins of many inland freshwater pools, in which the concentration of sodium and chloride is low. (See Appendix IIIa, IIIb water samples nos. 17, 18, 19, 24).

Ecological characteristics (Table 4.5b).

The association is characteristic of open and shallow water between 0-15cm. in depth. The analyses of the associated waters show ranges of pH between 6.5 to 7.7, conductivity 1.25 to 16.80 mmhos/cm, sodium 93 to 3250 ppm, potassium 01 to 35 ppm, magnesium 24 to 68 ppm, calcium 95 to 275 ppm and chloride 55 to 4250 ppm. The concentration of sodium was 5.25 mg/gram and calcium 1.45 mg/gram in the Typhetum soil at Sandbach.

Zonation and succession.

From water depths of 60 cm to a surface water table, Typha latifolia forms reedbeds, along with other emergent vegetation.

(ii) Association Scirpetum maritimi (Br.-Bl. 1931) R.Tx.1937 (Table 4.6a. 8 relevés)

Characteristics of the association.

The association is restricted to two or three inland saline sites. The relevés from these inland saline sites referable to this association have Scirpus maritimus as a dominant and constant taxon. Contrary to the definition given by Lee (1977), where this association, typically lacks Scirpus maritimus, and contains instead Scirpus tabernaemontani as the characteristic species, in the present work such relevés are referred to the association Scirpetum tabernaemontani Pass 1964. Atriplex hastata occurs as a constant, while Spergularia marina and Puccinellia distans show high constancy and are good characteristics of the association Scirpetum maritimi. Other fairly common species with low cover values are Agrostis stolonifera, Phragmites communis, Carex otrubae, Agropyron repens and Festuca arundinacea.

The association forms marginal vegetation of saline sites and pools with Scirpus maritimus up to three feet in height. Dangien et al (1974) have recorded this association from inland industrial saline sites in France, where the Scirpetum maritimi is characterised by the presence of Atriplex hastata, Aster tripolium, Phragmites communis, Spergularia salina as constants with constancy class IV, in addition to the character species Scirpus maritimus. In comparison, the inland saline sites in England lack Aster tripolium, Salicornia ramosissima and Phragmites communis and Spergularia marina are of low frequency.

Geographical distribution.

The relevés assigned to this association were collected from Marston and Northwich, Cheshire, where a brine flow was pouring into the stream. The chemistry of the brine flow water is shown in Appendix IIIa (see water sample No.36) and Table 4.6a also includes one relevé from a weakly saline lagoon at Silver Well, Cheshire.

Ecological characteristics. (Table 4.6b).

The Scirpetum maritimi is found on soil of a wide range of salinity and occurs on wet, oozy muds (Lee 1977). At coastal sites it occurs on permanently wet soil and is most frequent in the upper marsh zone (Adam 1977). The Scirpetum maritimi at Marston occupies the margins of a stream which receives brine inflow with extremely high concentrations of sodium and calcium chloride. The pH of the soil ranges from 6.3 to 6.9, sodium 6.25 to 9.00 mg/gram, potassium 0.05 to 0.60 mg/gram, magnesium 0.25 to 0.38 mg/gram, calcium 9,00 to 12.25 mg/gram and chloride 5.00 to 17.75 mg/gram. The soil of Silver Well lagoon, from where one relevé was taken is almost non-saline (see Appendix IIa, soil sample No.111), but has a high concentration of calcium.

Zonation and succession.

The Scirpetum maritimi forms tall sedge swamp communities and marginal vegetation of saline pools. It also occurs in such situations where the muds are exposed in dry periods. Sometimes, along with such other emergent brackish vegetation types as the Phragmitetum and Scirpetum tabernaemontani, it forms dense stands along the margins of the saline and brackish pools.

(iii) <u>Association Scirpetum tabernaemontani</u> Pass. 1964.
(Table 4.7a. 14 relevés)

Characteristics of the association.

The Scirpetum tabernaemontani is a major association which forms reedswamp communities in inland saline springs and many saline pools. The association is characterised by the high constancy (V) and dominance of the character species <u>Scirpus tabernaemontani</u>, which occurs as almost pure, dense and extensive stands in these sites. Other plants of reedswamp such as <u>Scirpus maritimus</u>, <u>Phragmites communis</u> and <u>Typha latifolia</u> are of low frequency within this association. The relevés described from sites with a sub-surface water level have <u>Agrostis</u>

stolonifera, Aster tripolium, Chenopodium rubrum, Atriplex hastata and Juncus bufonius as common species. Eleocharis palustris, Carex otrubae and Ranunculus sceleratus are only locally present. The association is characteristic of permanently standing waters and situations of fluctuating water level, where muds are exposed during the summer. The exposed muds are soft, wet, oozy and smelly with a high percentage of organic material.

The association has not been described previously from inland saline localities in England. However, Lee (1977) had included releves referable to this association in Scirpetum maritimi- (Bl.Bl.1931) R.Tx. 1937. From coastal salt marshes Adam (1977) has reported a Scirpus tabernaemontani nodum, the stands of which are small and occur at lower levels of the shore, along with Spartinetum.

Two sub-associations are recognizable. The sub-association typicum is described from the springs and pools, where the standing water is permanently high and saline, and is found as an emergent fringe to these saline pools. The majority of the stands of this sub-association are monospecific with almost 100% cover of Scirpus tabernaemontani, while other emergent plants, such as Scirpus maritimus, Phragmites communis and Typha latifolia are present in only a few stands. The waters associated with the sub-association were moderately saline, the range of conductivity being 4.28 to 9.19 mmhos/cm, while in most of the water, the sodium concentration was more than 1000 ppm and chloride up to 2750 ppm.

The sub-association agrostetosum is described from localities where the water level fluctuates and in the summer months is at sub-surface level. The sub-association is mainly described from Sandbach and Winsford, Cheshire. Agrostis stolonifera and Aster tripolium are constant taxa within the sub-association, while Juncus bufonius, Atriplex hastata and Eleocharis palustris are also common. The soils are muddy, soft and smelly, and when dried in some situations crystalline salt crusts and pans are formed on the surface of the mud. This feature was noted at Sandbach and Anderton.

Geographical distribution.

The association is widespread. The best site described is at Anderton, where in a saline depression, an area of about 5 x 10 metres was colonised by the Scirpetum tabernaemontani. Also, at Sandbach, many small stands of this association are present. Other relevés referable to this association were described from Southam salt spring, Warwickshire; Upton Warren saline pools, Worcestershire; Preesall, Lancashire; and Marston and Winsford, Cheshire.

Ecological characteristics. (Table 4.7b)

The association is characteristic of both standing waters and wet, oozy mud. The conductivity of associated waters ranges from 4.28 to 9.19 mmhos/cm, pH 8.0 to 9.2; sodium 160 to 1950 ppm; potassium 05 to 14 ppm; magnesium 23 to 875 ppm; calcium 103 to 375 ppm and chloride 610 to 2750 ppm. The associated soils may have a very high salinity in summer when the water dries up. Values as high as 25.00 mg/gram for sodium and 14.00 mg/gram for chloride were recorded at Anderton, where during dry spells, salt crusts were present at the surface.

Zonation and succession.

The association starts in comparatively deep water, but at margins it is equally vigorous. It forms reedswamp communities along with other emergent vegetation. In marginal situations and with a falling water level, the frequency of the character species of the association decreases.

(iv) Association Phragmitetum eurosibiricum (Gams 1927) Schmale 1939. (Table 4.8a. 11 relevés)

Characteristics of the association.

The Phragmitetum is characteristic of the brackish/freshwater transition zone in many inland marshes of England, where extensive stands of Phragmites communis are found. Table 4.8a shows the structure and specific composition of the association, where Phragmites communis is dominant and constant. Other associated species appear to occur in two groups - Atriplex hastata, Juncus gerardii and Agrostis stolonifera represent a relatively less saline group as compared to a group comprising Plantago maritima, Puccinellia maritima, Spergularia marina and Festuca rubra of more saline sites. Within the association Atriplex hastata, Plantago maritima and Puccinellia maritima are constant.

Two sub-associations are recognisable. The sub-association salinetosum described from saline sites has two variants. The typical variant is monospecific, Phragmites communis being dominant with a high percentage cover, while the Atriplex variant is characterised by the presence of Atriplex hastata as an understorey constant; other species of the sub-association are Juncus gerardii, Agrostis stolonifera and Cladophora sp. The sub-association Plantaginetosum is characterised by the presence of Plantago maritima, Puccinellia maritima and Spergularia marina as understorey constant species.

Phragmites communis forms reedswamp communities along the margins of many inland pools, the waters of which are quite low in sodium and chloride concentrations (see Appendix IIIa, water samples 17,18,19,24).

The association Phragmitetum eurosibiricum has not been described previously from the inland saline marshes of England. Adam (1977) has described a Phragmites communis nodum from coastal saline marshes and according to him the majority of saltmarsh stands are species-poor, although an understorey of Atriplex hastata is frequent. Dangien et al (1974), similarly described the presence of the Phragmitetum from industrial saline sites in Northern France and have recognised three sub-associations. Most of the stands of their three sub-associations are similar to the stands grouped as the sub-association salinetosum.

Geographical distribution.

The Phragmitetum has been described from saline sites at Preesall, Lancashire, where a large area is occupied by this association. Most of the lower marsh is composed of pure Phragmites beds and, where there is a continuous seepage of saline water, Plantago maritima is common, along with Puccinellia maritima. A large vigorous stand of this association is found in a saline depression at Plumley, Cheshire and one relevé assigned to this association was collected from the margin of the River Weaver at Dutton Lock Bridge, Cheshire.

Ecological characteristics (Table 4.8b).

The association has been described from the brackish/freshwater transition zone and thus the soils vary from moderate to low salinity. The pH of the soil ranges between 7.2 to 8.2, sodium 0.68 to 5.00 mg/gram, potassium 0.05 to 0.17 mg/gram, magnesium 0.09 to 0.53 mg/gram, calcium 1.13 to 11.00 mg/gram and chloride 0.05 to 3.75 mg/gram. Table 4.8b shows the concentrations of cations and chloride of the associated waters and soils, from which it can be seen that the range of pH of the waters is between 7.3 to 9.0, conductivity 0.49 to 36.52 mmhos/cm., sodium

33 to 3000 ppm, potassium 04 to 35 ppm, magnesium 18 to 40 ppm, calcium 25 to 1875 ppm and chloride 37 to 8750 ppm.

Zonation and succession.

Pure stands of Phragmites are present as reedswamp communities at the margins of the saline pools or at other wet saline sites and, where there is a pronounced salinity gradient, Phragmites is replaced by more salt tolerant species. The zonation is clear at Preesall marsh where in the lower marshes pure stands of Phragmites are present. In areas which receive seepage of saline water, Plantago maritima is common along with Phragmites and, where saline water is continuously being renewed, Phragmites is mostly replaced by Plantago maritima and Puccinellia maritima. At the margins of less saline pools Phragmites is common with other reedswamp species such as Scirpus tabernaemontani, Typha latifolia and Eleocharis palustris.

(v) Association Caricetum otrubae ass. nov. prov.
(Table 4.9a. 8 relevés)

Characteristics of the association.

The Caricetum otrubae is a local association developed at the margins of saline pools and streams. Table 4.9a shows the composition and structure of the association, which is a new record from inland saline sites of England. The character and differential species Carex otrubae, which confers a uniform structure to the association is gregarious with a high percentage cover in most of the stands. Other constant species are Atriplex hastata and Agrostis stolonifera. A number of companions were also present, of which Juncus bufonius, Typha latifolia, Agropyron repens, Juncus effusus, Rubus fruticosus and Atriplex patula have Domin cover-abundance values of 2 to 4.

Geographical distribution.

The Caricetum otrubae is described from saline pools at Plumely, Cheshire and Upton Warren, Worcestershire. The association occupies the banks of pools at the level of the winter high water table and is rarely inundated for the six months from April to September.

Ecological characteristics. (Table 4.9b)

The association is characteristic of open and shallow waters with moderate to high salinity. Table 4.9b shows the chemistry of water associated with stands. The range of pH is between 7.5 to 8.5, conductivity 7.84 to 14.34 mmhos/cm, sodium 80 to 2250 ppm, potassium 03 to 12 ppm, magnesium 15 to 650 ppm, calcium 263 to 800 ppm and chloride 1400 to 3500 ppm.

Zonation and succession.

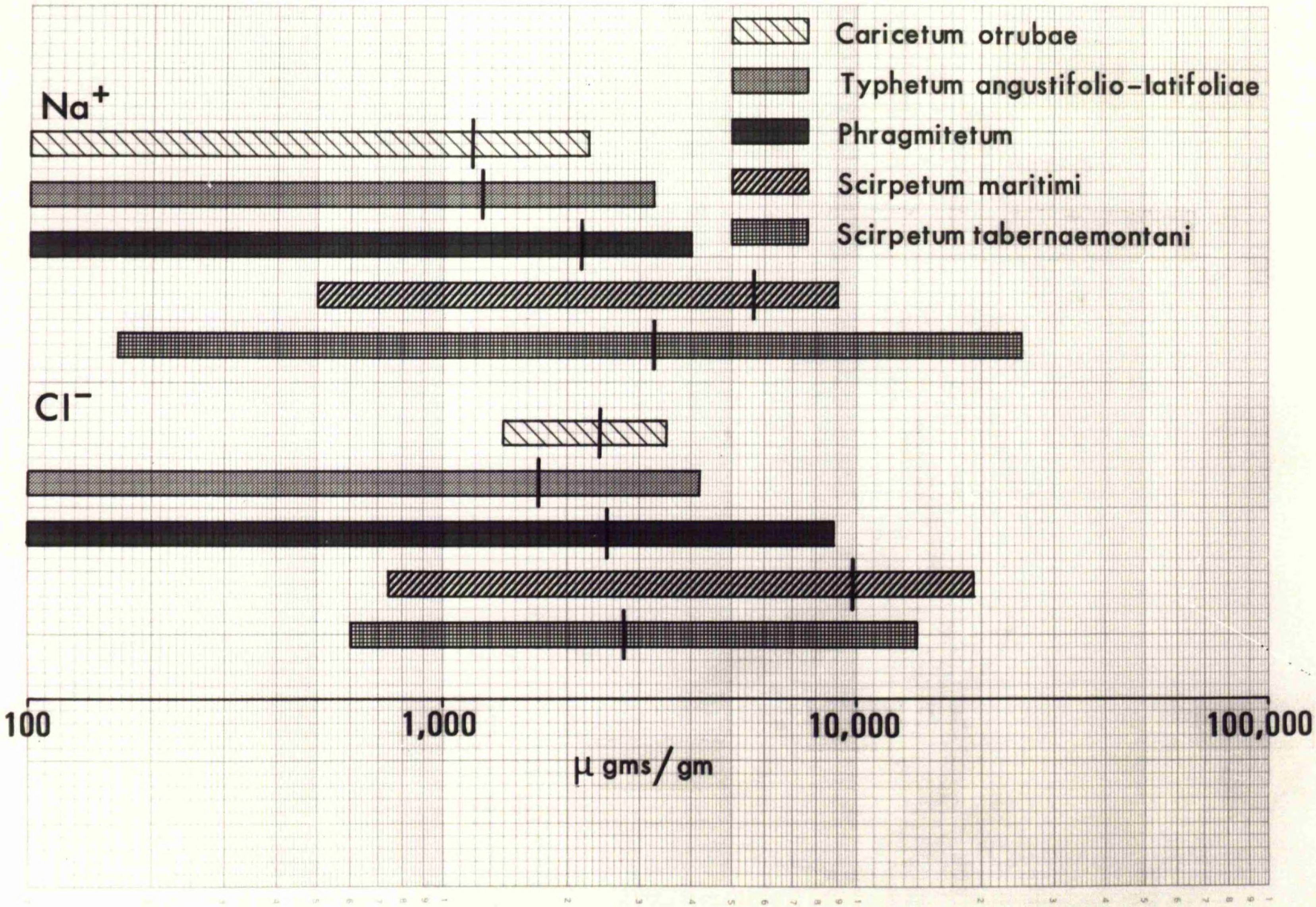
The association forms low sedgeswamp communities in saline pools, which develop in shallow water and occupy the narrow margins where muds are exposed for approximately six months of the year.

(vi) Summary of Ecological Gradients in Emergent Reedswamp Communities.

Figures 4.2 and 4.3 show the ranges and mean values of sodium and chloride, magnesium and calcium of the waters and soils associated with the emergent reedswamp communities, from which it can be seen that these associations show quite a distinct tolerance range of each ion. Thus, these associations may be arranged in a series, according to the sodium concentrations - Scirpetum maritimi > Scirpetum tabernaemontani > Phragmitetum > Typhetum angustifolia-latifoliae > Caricetum otrubae. The same order is true in the case of chloride concentrations except that Caricetum otrubae and Typhetum are reversed in the sequence. The waters associated with the Caricetum otrubae and the Scirpetum associations have magnesium value above normal, while other associations seem to develop in waters having magnesium concentration similar to those in fresh water. Calcium is generally abundant in these soils, concentrations in the soils of the Scirpetum associations are as high as sodium, while the Phragmitetum seems to develop in soils and water with calcium concentrations slightly higher than sodium.

Figure 4.2 Ranges and means of Na^{+} and Cl^{-} concentrations of water and soil in the emergent reedswamp associations.

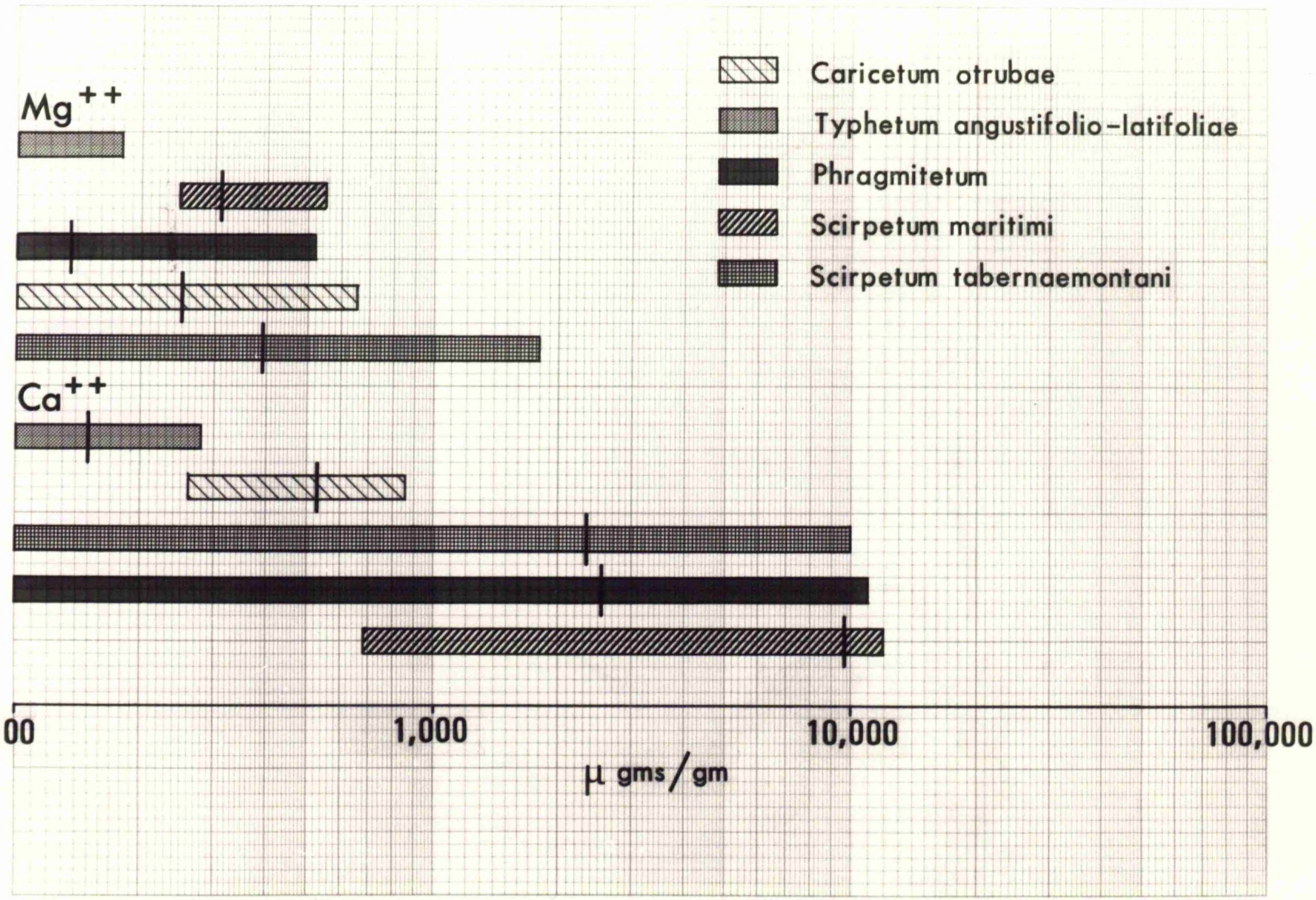
(vertical bars represent the mean concentrations).



Caricetum otrubae
Typhetum angustifolio-latifoliae
Phragmitetum
Scirpetum maritimi
Scirpetum tabernaemontani
Na+
Cl−
100
1,000
10,000
100,000
μ gms/gm

Figure 4.3 Ranges and means of Mg^{2+} and Ca^{2+} concentrations of water and soil in the emergent reedswamp associations.

(vertical bars represent the mean concentrations).



Caricetum otrubae
Typhetum angustifolio-latifoliae
Phragmitetum
Scirpetum maritimi
Scirpetum tabernaemontani
Mg++
Ca++
100
1,000
10,000
100,000
μ gms/gm

c. Species poor, Annual Herb Communities of Periodically Inundated Saline Soils.

(i) Association Atriplicetum salinae deviense (Duvigneaud 1967) (Table 4.10a. 27 relevés)

Characteristics of the association.

The Atriplicetum salinae is a major association found on the semi-natural saline muds and soils in the industrial areas of Western Europe. 27 relevés referable to this association are listed in Table 4.10a, which shows the species composition and structure of the association. Stands are normally species poor and dominated by Atriplex hastata, while in a few, the dominance is shared either by Chenopodium rubrum or Spergularia marina. In pastures on less saline soils, Agrostis stolonifera is co-dominant with Atriplex hastata; Puccinellia distans, Spergularia marina and Agrostis stolonifera are constant, and Agropyron repens is frequent. Other species locally important, but less frequent, are Tripleurospermum maritimum, Juncus bufonius, Tussilago farfara, Holcus lanatus, Sonchus arvensis and Atriplex patula. The association is characteristic of exposed and relatively less saline soils. Dangien et al (1974) have similarly described the presence of the Atriplicetum salinae lotharingiense Duvigneaud 1967 from the industrial saline sites in Northern France. The Atriplicetum salinae described from the inland saline sites of England is a distinct structural vicariant of the association described by Dangien et al (1974) and differs in the constancy of Agrostis stolonifera and absence of Salicornia ramosissima. Lee (1977) has described the Atriplicetum salinae lotharingiense Duvigneaud 1967 from the inland saline sites in England, but the association is under-recorded in his work. Because of the distinct nature of the variation of the English stands of the association, the continental regional adjective, lotharingiense is replaced with deviense - derived from Deva, the Roman name for Chester.

Three sub-associations are recognised. The initial sub-association is restricted to two or three localities in inland industrial sites and is probably a pioneer stage. The sub-association is developed on relatively dry, bare and slightly saline and calcareous soils and often with high concentrations of magnesium. The relevés referable to the initial sub-association are characterised by the high constancy of the differential species Chenopodium rubrum, which constitutes an important part in the composition and structure of the stands. The sub-association has been described from lagoons at Middlewich, Winsford and a saline site at Marston, Cheshire, where Chenopodium rubrum was frequent and mostly at the seedling stage.

The sub-association atriplicetosum is characterised by the dominance and constancy of Atriplex hastata over Puccinellia distans and Spergularia marina, which are also frequent. Extensive stands of the Atriplicetum salinae sub-association typicum are to be seen at Upton Warren, Worcestershire and Plumley and Dutton in Cheshire. At Dutton an area of about 50 x 50 metres is colonised by Atriplex hastata, which is from 45 to 50 cm in height. The soils on which this sub-association is developed are poorly-differentiated, recently exposed, saline and calcareous in nature with pH usually about 7.5 to 8.0.

The sub-association agrostetosum has Agrostis stolonifera as differential species. Within the sub-association, Puccinellia distans and Spergularia marina are either absent or very rare. The sub-association is described from Sandbach, where it occupies a narrow region between a saline site colonised by Puccinellietum distantis and communities lacking halophytes on non-saline soils. At Nantwich, Cheshire it is present as a narrow strip by the side of a boating lake. The soils on which this sub-association is developed are of the disturbed and/or grazed pasture type with low salinity.

Geographical distribution

The association is widespread in the inland salt marshes and saline soils in the industrial areas. The Atriplicetum salinae is described from Dutton, Plumley, Ashton Flash, Neumann's Flash, Sandbach, Middlewich, Nantwich, SilverWell and Upton Warren, Worcestershire. At Dutton, an area of about 50 x 50 metres was occupied by the Atriplicetum salinae and at Plumley an area of about 20 metres square. At Neumann's and Ashton lagoons, where industrial wastes are dumped, which are calcareous in nature, the margins of the flashes were colonised by the associations Atriplecetum salinae and Puccinellietum distantis. Relevés referable to this association were also collected from disturbed saline habitats at Nantwich and Amerton-Brook, Staffordshire and, at Upton Warren, the association was best developed on islands and at the fringes of saline pools.

Ecological characteristics. (Table 4.10b).

The association is best developed on bare, recently exposed soils, poorly differentiated into horizons, which are moderately saline or slightly saline and calcareous. The pH of the associated soil varies from 6.3 to 9.0. The concentration of sodium is generally low, but a few soils have quite high concentrations. The range of sodium is between 0.38 mg/gram to 15.00 mg/gram, potassium 0.05 to 0.38 mg/gram, magnesium 0.23 to 5.00 mg/gram. The concentration of calcium is usually higher than sodium and varies between 1.55 to 14.50 mg/gram; the range of chloride is between 0.10 to 20.10 mg/gram.

Zonation and succession.

The most abundant and widespread form of the association is the sub-association atriplicetosum, while the sub-associations agrostetosum and initial are restricted to one ot two localities. The succession within the association appears to be from initial to typicum and then to the agrostetosum, parallel to a transition from bare, drier soils of high salinity through wet moderately saline soils to pasture soils of low salinity. The zonation is best observed at Upton Warren pools, where with the increase in salinity and waterlevel, the frequency and size of the character species Atriplex hastata decreases and other halophytes like Spergularia marina increase in cover values.

(ii) Association Cotuletum coronopifoliae ass. nov.prov. (Table 4.11a. 14 relevés)

Characteristics of the association.

This association is mainly described from the inland marshes in West Yorkshire. The marshes were slightly saline due to the receipt of saline waters from Colliery spoil. The association is characterised by the dominance and constancy class V of the character species Cotula coronopifolia, In one stand Atriplex hastata is dominant and in another Juncus bufonius, while in some others both species are co-dominant with Cotula coronopifolia. Two types of stands are easily recognisable. Species-rich stands with Cotula coronopifolia reaching percentage cover values up to 50% and species-poor stands with much higher percentage cover of the character species. Other species attaining relatively high constancy are Ranunculus sceleratus, Juncus inflexus, Juncus articulatus, Rumex sanguineus, Typha latifolia, Phragmites communis, Polygonum persicaria and Hippuris vulgaris. The Cotuletum coronopifoliae has some linear-leaved submerged plants as

Potamogeton pectinatus, Myriophyllum alterniflorum, Callitriche platycarpa with low percentage cover values in several stands.

Two sub-associations are recognizable. The sub-association cotuletosum is characteristic of relatively dry, less saline and sandy soil. It is common in grazed areas and pastures in Mickletown marsh. Poa annua, Leontodon autumnalis, Juncus spp. are associated species with low frequency and cover values.

The sub-association atriplico-juncetosum is characteristic of relatively wet, moderately saline and muddy soils. It is common along the margins of the marsh and pools in Mickletown, West Yorkshire. The relevés referable to this sub-association are moderately species-rich; Atriplex hastata and Juncus bufonius are either dominant or co-dominant with Cotula coronopifolia and both taxa are constant. Other such as Ranunculus sceleratus, Juncus inflexus, Juncus articulatus, Rumex sanguineus, Typha latifolia and Phragmites communis are frequent, while Glaux maritima, Potentilla anserina, Scirpus tabernaemontani, Chenopodium rubrum and Agropyron repens are occasional.

Geographical distribution.

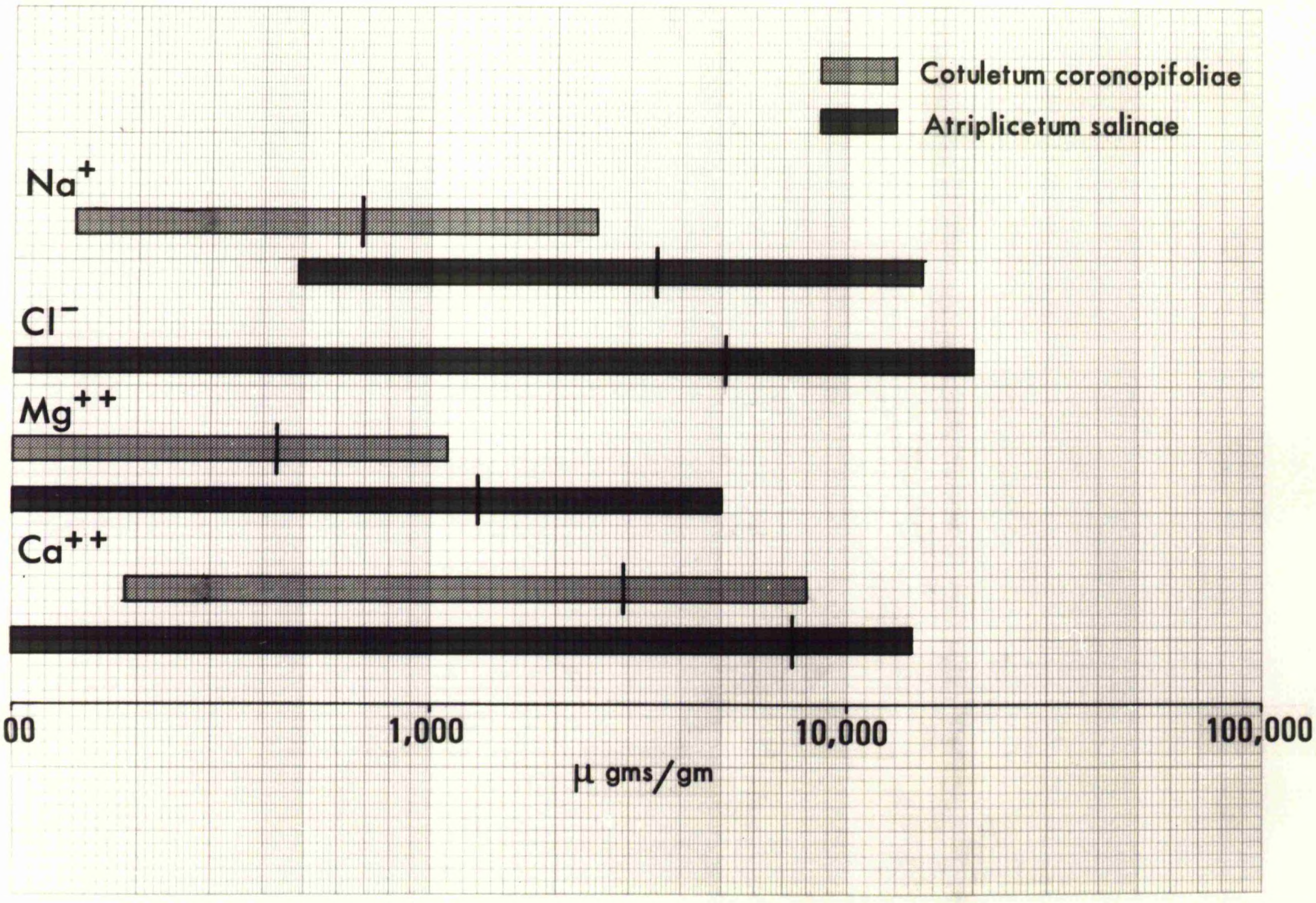
According to the Biological Records Centre, in Britain, Cotula coronopifolia has a very limited distribution. The relevés referable to this association are mainly described from Mickletown, West Yorkshire and Leasowe, Merseyside. Only one relevé was described from Leasowe in a brackish marsh, behind the sea wall. Hanson (1959) reported the distribution of Cotula coronopifolia along the Danish coast in the region of Thyøron-Harbøøre and the English Cotuletum coronopifoliae shows affinities with this coastal vegetation. However, in England, sites referable to this association lack Aster tripolium, Puccinellia maritima and Tripleurospermum maritimum, which are reported as associates of Cotula coronopifolia on the Danish Coast. Cotula coronopifolia had been reported from Hawkes' Bay and along creek banks at Porihue, New Zealand, on similar types of soil salinity by Chapman (1960).

Ecological characteristics (Table 4.11b).

The association is usually characteristic of sandy soil with slight salinity and a high and fluctuating water table. Table 4.11b shows the chemistry of water and concentrations of sodium, potassium, magnesium and calcium in the soils associated with the stands of this association. At the time of visit in October 1976, the marsh was receiving saline water

Figure 4.4 Ranges and means of Na^+, Cl^-, Mg^{2+} and Ca^{2+} concentrations of water and soil in the annual herb associations of periodically inundated saline soils.

(vertical bars represent the mean concentrations).


Cotuletum coronopifoliae
Atriplicetum salinae
Na+
Cl−
Mg++
Ca++
100
1,000
10,000
100,000
µ gms/gm

from colliery spoil at the concentration of sodium 880 ppm. (See Appendix 111a, W.S. 105). The range of sodium in the associated waters varies from 290 to 305 ppm, potassium 14 to 30 ppm, magnesium 51 to 123 ppm and calcium 186 to 578 ppm; the pH of soil varies between 3.8 to 7.2; and the maximum concentration of sodium in the soil was 2.49 mg/gram and calcium 7.92 mg/gram, with a maximum value of 1.19 mg/gram for magnesium and potassium 0.26 mg/gram.

Zonation and succession.

Cotula coronopifolia seems to colonise soils with a high water table and is joined by Juncus bufonius first, then Atriplex hastata on comparatively exposed soils. The species is apparently sensitive to grazing and hence is of less frequent occurrence in normal Coal Measures pastures, in which Agrostis stolonifera is an important associated species.

(iii) Summary of Ecological Gradients in Species-poor, Annual Herb Communities of Periodically Inundated Saline Soil.

Figure 4.4 shows the ranges and mean values of sodium and chloride, magnesium and calcium of the waters and soils associated with these associations. The association Cotuletum coronopifoliae seems to tolerate a moderate amount of sodium, but calcium values exceed those of sodium in both the waters and soils. The association Atriplicetum salinae also seems to be established on the soils with relatively more calcium than sodium and the magnesium values are also significant, though not very high.

d. Inland Salt Marsh Vegetation Dominated by Perennial Rush and Grass Species.

(i) Association Juncetum gerardii Warming 1906.

(Table 4.12a. 16 relevés)

Characteristics of the association.

In inland salt marshes this association is restricted to brine spring habitats and saline seepages issuing from the Keuper Saliferous Beds. The saline soils in industrial areas appear not to be inhabited by this association. In Table 4.12a, 16 relevés are grouped together to show the structure and composition of the association, which, for the most part is grassland dominated by Juncus gerardii and Agrostis stolonifera and/or Festuca rubra. The association is characterised by the constancy of Juncus gerardii and Agrostis stolonifera. Other differential species with higher constancy are Glaux maritima, Leontodon autumnalis, Carex distans, Festuca arundinacea, Alopecurus geniculatus and Trifolium repens.

Adam (1977) has described this association from coastal salt marshes of England and has recognised a number of noda within the association. Many of the noda recognised by Adam (1977) seem to be absent on inland salt marshes and also Armeria maritima, the character species of the alliance Armerion maritimae Br.-Bl. & De Leeuw 1936 is absent in the inland salt marshes of England.

Three sub-associations are recognisable. The sub-association agrostetosum is localised and restricted in distribution. Structurally and floristically it is homogeneous and mainly dominated either by Juncus gerardii or Agrostis stolonifera and both are constant taxa. Other associated species with low constancy are Lolium perenne, Atriplex hastata and Triglochin maritima. Some stands have a low percentage cover of other grasses such as Festuca arundinacea, Alopecurus geniculatus and Juncus bufonius while Potentilla anserina was recorded in one stand only. The sub-association is characteristic of soils which are groundwater gleys, well differentiated into horizons and sometimes highly saline.

The sub-association of Festuca and Glaux has Juncus gerardii, Agrostis stolonifera, Festuca rubra and Glaux maritima as constant taxa and dominance is shared by any of the three former species. Other frequent species are Poa pratensis and Trifolium repens and a few relevés have Plantago maritima, Lolium perenne and Hordeum secalinum of low constancy. The sub-association is characteristic of similar soils to the sub-association agrostetosum but with considerably less salinity and in somewhat elevated sites. It also has similarities with Festuca-Glaux nodum described from coastal salt marsh by Adam (1977) but differs in the absence of Armeria maritima.

The sub-association of Leontodon autumnalis is characterised by the constancy of Leontodon autumnalis and other constant taxa are Juncus gerardii, Agrostis stolonifera and Carex distans. Festuca arundinacea, Alopecurus geniculatus and Scirpus maritimus are frequent. Dominance is shared by the mixture of grasses mentioned above and within the sub-association Festuca rubra and Plantago maritima are also locally co-dominant. The sub-association is characteristic of soils which are less saline, and relatively stony and is found at higher levels of the salt marsh zonation than the other two sub-associations.

The Juncetum gerardii sub-association with Leontodon autumnalis described by Adam (1977) from coastal salt marshes of England is similar to this sub-association described from the inland localities but the latter differs in the absence of Trifolium repens. On the other hand Trifolium repens is frequent in the sub-association of Festuca and Glaux, while the reverse situation has been recorded by Adam in the coastal salt marshes.

Geographical distribution.

This association mainly occurs in those inland salt marshes located around the natural brine springs and saline seepage pools. The important localities of this association are Aldersey brin springs and adjacent fields, Pasturefields salt marsh, Staffordshire; Upton Warren saline pools, Worcestershire; Preesall, Lancashire and Southam salt spring, Warwickshire. At Aldersey there are a number of localised areas of salt-affected turf and upwellings in the fields adjacent to the main marsh, where the association occurs as small rushswamps. At Pasturefields, the tussocks of Juncus gerardii and Agrostis stolonifera are present close to a highly saline area colonised by the Puccinellietum maritimae. At Preesall, Lancashire the association was present along the bank of a saline lake, where saline water was percolating through the rotting halite mounds. At Southam salt spring, the relevés referable to this association were collected from elevated soils at the side of the spring, where Scirpus maritimus, Ranunculus sceleratus, Scirpus tabernaemontani and Phragmites communis were also recorded.

Ecological characteristics. (Table 4.12b).

The association is usually characteristic of moderate to highly saline soils with a high water table. The soils with a low water table are well differentiated into horizons and are formed over a peaty raft (Figure 2.8). One such soil profile described from Pasturefields had the following sodium concentrations.

A^{o} 4cm., pH 5.6, sodium 4.75 mg/gram

A^{1} 12cm., pH 4.5, sodium 8.13 mg/gram

A^{2} 10 to 12 cm, pH 3.0, sodium 10.50 mg/gram

Bg 25 cm., pH 3.2, sodium 9.75 mg/gram

Peat 120cm, pH 4.7, Sodium 21.25 mg/gram.

The concentrations of cations and chloride in the associated soils is as follows : sodium varies from 0.55 to 26.25 mg/gram; potassium 0.05 to 0.95 mg/gram; magnesium 0.10 to 1.58 mg/gram; calcium 2.00 to 10.50 mg/gram; and chloride 0.09 to 20.00 mg/gram. The range of pH is between 4.9 and 8.8.

Zonation and succession.

The sub-association agrostetosum is the pioneer sub-association and inhabits the soils with high water table and salinity. As the salinity decreases and the water table falls in the soils Festuca rubra becomes co-dominant with Juncus gerardii and Agrostis stolonifera, so at this stage of succession, the marshes are mostly colonised by either of these three grasses, but mainly by Festuca rubra. With the further decrease in the salinity and water table, a number of other grasses start invading the areas, thus giving rise to the specific composition pertaining to the sub-association of Leontodon autumnalis.

(ii) Association Puccinellietum maritimae (Warming 1906) Christiansen 1927. (Table 4.13a. 17 relevés)

Characteristics of the Association.

This association is described from inland salt marshes which support stands with Puccinellia maritima as a primary colonist, dominant and constant, and also those areas co-dominated by Puccinellia maritima and Plantago maritima. Within the association the quantitative balance between Puccinellia maritima and Plantago maritima varies, presumably according to variations in the concentration of salts. At Pasturefields, pure stands of Puccinellia maritima are present in the immediate vicinity of bare areas where brine water oozes out, (see Appendix IIIa, water samples Nos 70 and 79), while stands with Plantago maritima receive comparatively less saline water. Other associated species, Agrostis stolonifera and Festuca rubra, are of frequent occurrence while Juncus gerardii and Glaux maritima are rare.

Floristically, the relevés assigned to the association Puccinellietum maritimae, generally resemble the noda described by Adam (1977) from coastal salt marshes of England. The noda are as follows:

1. Species-poor nodum and moderately species-rich Puccinellia nodum (Puccinellietum maritimae) Adam 1977 .

2.	Festuca-Puccinellia nodum	{	Noda transitional between
3.	Festuca-Agrostis-Puccinellia nodum	{	the Armerion and the
4.	Puccinellia-Agrostis nodum	{	Puccinellion. (Adam 1977)

These noda are here included in the association Puccinellietum maritimae due to the predominant occurrence of Puccinellia maritima and Plantago maritima in the relevés assigned to this association. However, the localities which support this association show a gradual transition from communities referable to the alliance Puccinellion to those of the Armerion and transitional stages are present.

Three sub-associations are recognizable. The sub-association puccinellietosum is characterised by the dominance of Puccinellia maritima. The stands are either overwhelmingly dominated by Puccinellia maritima, being either monospecific or containing one or more species with cover/abundance values below 5 and still dominated by Puccinellia maritima. The sub-association floristically resembles the first nodum listed above and is described from Pasturefields, where it was present in the immediate vicinity of bare saline areas. The soils are highly saline, and well-differentiated into horizons, the lowermost horizon being Phragmites peat.

The sub-association agrostetosum is characterised by the presence of Puccinellia maritima, Plantago maritima, Spergularia marina and Agrostis stolonifera as constant taxa, and the stands are dominated by Puccinellia maritima or Plantago maritima or by both. The sub-association is described only from Pasturefields salt marsh, where it was present as a transitional community between the Puccinellietum maritimae sub-association typicum and the saline Agrostis stolonifera nodum. Floristically the sub-association shows affinities with Puccinellia-Agrostis nodum described by Adam. In the sub-association festucetosum, the stands are mostly dominated by Plantago maritima or Puccinellia maritima, but in some relevés Festuca rubra is dominant. This sub-association is characterised by the constancy of Festuca rubra and is described from Preesall and Pasturefields. At Preesall, the community occurs in a narrow zone between a Puccinellia maritima community and the Phragmitetum. The sub-association is characteristic of disturbed sites which are relatively less saline. Adam's Festuca-Puccinellia nodum and Festuca-Agrostis-Puccinellia nodum show affinities to the sub-association Festucetosum.

Geographical distribution

The Puccinellietum maritimae is mainly described from Pasturefields, Staffordshire, where it occupies a relatively extensive area throughout the highly saline marsh. A component of the association was present at Preesall, Lancashire.

Ecological characteristics. (Table 4.13b)

The Puccinellietum maritimae is characteristic of a semi-natural marsh habitat, developed in the immediate vicinity of brine seepages. The sub-association puccinellietosum is characteristic of highly saline soils reaching maximum cover on soils with sodium concentrations of 14.25 mg/gram or higher, while the sub-association agrostetosum occurs on soils of intermediate salinity, with sodium concentrations of around 9.25 mg/gram. The sub-association festucetosum is best developed on soils of low salinity with sodium concentrations of the range of 1.10 to 2.75 mg/gram. The association is found on the type of ground-water gley soil, developed over Phragmites peat as described in Chapter 2 (Figure 2.8). The range of pH in the associated soils of the Puccinellietum maritimae varies from 5.9 to 7.7.

Zonation and succession.

Puccinellia maritima colonises the highly saline areas of marshes which receive frequent irrigation with water from saline seepages. In the transitional areas it is joined by Agrostis stolonifera, where salinity is moderate and irrigation with saline water less frequent. Festuca rubra also starts invading the sward in this area and along with Agrostis stolonifera and Puccinellia maritima forms a transitional community between the Juncetum gerardii and the Puccinellietum. Puccinellia maritima is gradually reduced in terms of cover and then eliminated, while the other species such as Plantago maritima and Spergularia marina remain as associates.

(iii) Association Spergularietum marinae ass. nov. prov.
(Table 4.14a. 17 relevés)

Characteristics of the association.

The status of the 17 relevés grouped together in Table 4.14a and named as the association Spergularietum marinae is quite provisional. All stands listed in the table are characterised by the dominance and constancy of Spergularia marina and the complete absence of Puccinellia distans. Though Puccinellia distans and Spergularia marina are

characteristic of disturbed saline/alkaline and often artificial habitats, P. distans in inland localities occupies those places which are more calcareous and less saline, while the best and purest stands of Spergularia marina are found in places which are highly saline and relatively less disturbed. The definition of Spergularietum marinae thus seems to rely more on ecological characters than phytosociological. This community can also be classified as an initial sub-association of the association Puccinellietum distantis in the alliance Puccinellio-Spergularion salinae Beeftink 1965.
However, the initial sub-association of the association Puccinellietum distantis described by Lee (1977) has Puccinellia distans and Spergularia marina. The factors which determine the persistence of the Spergularietum marinae are the salinity of the soil and disturbance of the sites. Provided the soil salinity remains high and sites are also less disturbed, Spergularia marina remains the only abundant species, while Puccinellia distans starts invading the sites when salinity is decreased. The association is characterised by the dominance and constancy of Spergularia marina. Other constant taxa from dry and saline wastelands are Atriplex hastata, Agrostis stolonifera and Tripleurospermum maritimum, while Festuca rubra, Lolium perenne, Hordeum secalinum, Festuca arundinacea and Triglochin maritima are frequent in saline grassland habitats.

Two sub-associations are recognizable. A sub-association **initial** is best developed at Dairy House Farm, Middlewich and Stoke Works on highly saline soils. Two variants are recognizable - a monospecific variant is seen at Preesall, and at Dairy House Farm where areas about $8m^2$ are colonised purely by Spergularia marina; and an Atriplex variant is to be seen at Stoke Works, where it occupies localities relatively more saline than the Atriplicetum salinae; Tripleurospermum maritimum and Agrostis stolonifera are constants.

The sub-association festucetosum is described from Aldersey, where Festuca rubra is constant and usually co-dominant with Spergularia marina. Other associated species which are constant within the sub-association are Lolium perenne, Hordeum secalinum, Festuca arundinacea and Agrostis stolonifera. Triglochin maritima is frequent and, in one stand, it assumes dominance. The sub-association is present in the immediate vicinity of brine pits and is characteristic of soils which are moderately saline and with a high water table.

Geographical distribution.

The association Spergularietum marinae is restricted in two or three localities at Middlewich and Aldersey, Cheshire. At Stoke Works, Worcestershire, the relevés referable to this association were collected along the edge of two saline pools (see Appendix 111a.b. water samples 01 and 02), where a narrow zone of Spergularia and Atriplex was present.

Ecological characteristics.

The type of soil on which Spergularia marina attains maximum cover-abundance value of 9 is characterised by an exchangeable sodium concentration of about 17.75 mg/gram, chloride 43.00 mg/gram and calcium of about 15.57 mg/gram. The range of sodium in the associated soils varies between 0.55 and 17.75 mg/gram; potassium 0.04 and 0.60 mg/gram; magnesium 0.08 and 1.60 mg/gram; calcium 0.58 and 15.75 mg/gram; chloride 1.01 and 43.00 mg/gram; and pH ranges between 5.2 and 8.4. The types of soil also vary. At Stoke Works, the primitive soil is a heavily-impregnated saline industrial waste, where highly saline and calcareous areas are bare of vegetation. At Aldersey, the soil is a ground-water gley developed over Phragmites fen peat with a high and extremely saline water table (Appendix IIIa, W.S. 51).

(iv) Association Puccinellietum distantis (Feekes (1934) 1945. Tables 4.15 to 4.21; Constancy Table 4.22)

Characteristics of the association.

The association Puccinellietum distantis is the most widespread inland saltmarsh association and is found at all inland saline sites in the British Isles. The association is characterised by the constancy of Puccinellia distans and Spergularia marina and other associated species, which are constant and may be dominant in their own stands and act as differential species of the major sub-association recognised are Aster tripolium, Agrostis stolonifera, Lolium perenne, Atriplex hastata, Festuca rubra, Vulpia myuros, Agropyron repens, Hordeum secalinum, Apium graveolens, Funaria hygrometrica, Barbula tophacea and Pohlia annotina. A number of common companion species of constancy class II or higher are Holcus lanatus, Poa annua, Cirsium vulgare, Juncus bufonius, Tripleurospermum maritimum, Sonchus oleraceus, Festuca arundinacea, Triglochin maritima, Atriplex patula, Ranunculus sceleratus, Leontodon autumnalis and Poa trivialis.

The association or variants of the association can tolerate a wide range of salinity and stands are thus found on a range of habitats - saline and non saline, as well as mesic, xeric and hydric habitats. After a thorough survey of the inland industrial saline sites, saline springs, seminatural inland marshes and saline soils developed due to subsidence, ten sub-associations have been described, and their floristic characteristics are given in a constancy table. (Table 4.22).

1. Sub-association initial (Table 4.15a,31 relevés; Table 4.22. KA.KB.KC)

The sub-association initial is the major sub-association found on saline soils in industrial areas where it is most abundant and widespread. 31 relevés from inland saline sites referable to this sub-association are listed in Table 4.15a, which shows the structure and species composition of this community. Within the sub-association, Spergularia marina and Puccinellia distans are constant taxa; dominance is exerted by either or shared. Agrostis stolonifera and Lolium perenne are constant and important as far as cover-abundance values are concerned in some stands.

Three distinct variants are recognisable. The typical variant is a species-poor variant, overwhelmingly dominated by either Spergularia marina or Puccinellia distans or by both, with a few other minor species not attaining cover-abundance values greater than 4. Atriplex hastata is the only other frequent species. This typical variant is present at Stoke Works and Upton Warren, Worcestershire; and at Sandbach and Neumann's Flash, Cheshire. The associated soils have a pH range from 6.4 to 9.2 and are moderately to highly saline. An Agrostis variant is moderately species-rich and is characterised by the constancy of Agrostis stolonifera with Juncus bufonius, Triglochin maritima and Atriplex hastata as common assoaiated species. The stands are fragmentary, being described from inland salt pans at Marston and shallow, incipient soils with A/C profiles (See Chapter 2, Figure 9).

The pH of the associated soils ranges between 6.3 and 9.1 and the soils are moderately saline with a mean average concentration of sodium greater than calcium. A Lolium perenne variant is present in disturbed and revegetated areas of pre-existing marshes at Shrewbridge, near Nantwich, The stands are species-poor, being dominated by Lolium perenne. The associated soil is weakly saline with a pH range from 5.7 to 6.7 and a maximum sodium concentration 5.00 mg/gram.

The ranges of pH, cations and chloride concentrations for the Puccinellietum distantis typicum are listed in Table 4.15b. The range of pH varies between 5.7 to 9.2, sodium 1.08 to 11.50 mg/gram, potassium 0.05 to 0.43 mg/gram, magnesium 0.10 to 6.00 mg/gram, calcium 0.83 to 13.75 mg/gram and chloride 0.20 to 28.00 mg/gram.

2. Degraded sub-association. (Table 4.16a. 8 relevés; Table 4.22, KD)

The degraded sub-association is recognised by Piotrowska (1974) for the Polish coastal marshes and Lee (1977) for the British inland saline sites. In England, this sub-association is best developed as a pioneer community on calcareous waste which is slightly contaminated with brine and may rise to prominence as the salinity in the soil falls. At Elton Hall Flash and Winsford lagoons, where this sub-association occupies large areas, the primary colonisation is by Puccinellia distans in the cracks where damper conditions prevail throughout the dry season. Most of the stands are species-poor and overwhelmingly dominated by Puccinellia distans and Agrostis stolonifera. The degraded sub-association is characterised by the absence of Spergularia marina, a species which is more frequent on relatively more saline soils.

Geographically, the sub-association is distributed in those inland sites which are rich in calcium and magnesium salts as at Elton Hall Flash, Winsford, Neumann's and Ashton Flashes, Cheshire, where large areas are occupied by limebeds. The sub-association is also found at Silver Well, Cheshire and around the saline pools at Upton Warren, Worcestershire. Table 4.16b shows the range of pH, cation concentrations and chloride in the soil associated with this sub-association. In most of the soils pH is high, 9.9 being the highest recorded at Winsford. The sodium concentration is low, within the range of 0.13 to 1.83 mg/gram; potassium between 0.04 to 0.13 mg/gram; magnesium 1.00 to 4.25 mg/gram,; with a maximum figure of 32.50 mg/gram in one locality; calcium between 0.58 to 9.75 mg/gram; and chloride 0.75 to 11.65 mg/gram.

Two variants are recognisable. A monospecific variant is recognisable at Elton Hall and Upton Warren, where the soils have concentrations of exchangeable calcium and magnesium higher than sodium.

An Agrostis variant is described from Winsford and Neumann's Flash, where the soils are slightly saline and a number of species in addition to Agrostis stolonifera are present. Usually stands are species-rich, but Agrostis stolonifera is the only constant taxon.

3. Sub-association asteretosum. (Table 4.16a. 6 relevés. Table 4.22. KE)

This sub-association is similar to the Puccinellietum distantis asteretosum described by Lee (1977) from Sandbach. It is characterised by the constancy and dominance of Aster tripolium and the low cover-abundance of Puccinellia distans and Spergularia marina. At Sandbach, the stands of this sub-association are poor in species being dominated by Aster tripolium and at Winsford, where the community is present along a narrow strip around a saline pool at the northern end of the lagoon, a number of other species are also present. The sub-association is characteristic of moderately saline soils, which are muddy and permanently wet. The pH of the soil varies between 6.9 and 8.7; sodium concentration from 0.77 to 4.77 mg/gram; potassium 0.03 to 0.06 mg/gram; magnesium 1.16 to 2.00 mg/gram and calcium 3.50 mg/gram.

4. Sub-association of Agropyron repens (Transition Type 1) (Table 4.17a. 5 relevés).Table 4.22, KF).

The sub-association seems to represent a transitional community between salt marsh vegetation dominated by Puccinellia distans and a pasture type of vegetation dominated by Agropyron repens which probably prefers a relatively sub-xeric habitat. The Puccinellietum distantis agropyroetosum is characterised by the constancy of Agropyron repens and Puccinellia distans, Spergularia marina and Atriplex hastata are constant taxa. Other associated grasses such as Agrostis stolonifera Hordeum secalinum, Lolium perenne, Poa annua and Poa pratensis are of low frequency and vitality,but in some derelict sites Festuca rubra may be abundant. The sub-association is described from saline pools at Upton Warren, where it occupies an area about 30 m^2 between comparatively saline sites colonised by Puccinellia distans, Spergularia marina and Hordeum secalinum and non-saline areas dominated by glycophytes. One relevé referable to this sub-association was recorded at Amerton Brook, near a former salt mine at Shirleywich, Staffordshire.

The soils associated with this transitional community are moderately saline with pH 6.9; concentrations of sodium between 0.83 mg/gram and 6.50 mg/gram; potassium 0.12 to 0.20 mg/gram; magnesium 0.18 to 1.58 mg/gram; calcium 2.25 to 5.25 mg/gram; and chloride 2.75 to 4.80 mg/gram (Table 4.17b). The soils are typical ground-water gleys of the type described in Chapter 2.9 with a characteristic variation in sodium concentration down the profile to the water table and gleyed horizon at between 45 to 50 cms.

5. Sub-association vulpietosum (Transition Type 2)
(Table 4.18a. 2 relevés; Table 4.22.KG)

The sub-association is observable on dry, derelict, sandy soils at Sandbach, and represents a transitional community of the association Puccinellietum distantis which succeeds to a xeric, open pasture type of vegetation, discussed later as the Vulpia-Agrostis Nodum. The sub-association vulpietosum is low in cover of Spergularia marina, but Puccinellia distans is of frequent occurrence. The differential species Vulpia myuros is a constant taxon and in some areas, was quite abundant. The stands are rich in both herb and grass species and grasses such as Agrostis stolonifera, Holcus lanatus, Festuca arundinacea and Cynosurus cristatus are relatively common. The community is characteristic of sandy, slightly saline to calcareous soils with high pH values of about 8.4. The cations and chloride concentrations in the only associated soil sample taken are listed in Table 4.17b. (SS30) where it may be seen that the concentrations of the four cations are present in the sequence Ca > Mg > Na > K.

6. Sub-association of Hordeum secalinum (Transition Type 3)
(Table 4.19a. 10 relevés; Table 4.22, KH,Kl)

This sub-association is a third type of transition community from the association Puccinellietum distantis observable in the inland salt marshes and is characterised by the constancy and dominance of Hordeum secalinum. The frequent occurrence of typical salt marsh species such as Puccinellia distans, Atriplex hastata, Spergularia marina along with Hordeum secalinum, Agrostis stolonifera and Lolium perenne indicates a transition from salt marsh vegetation to a pasture type of vegetation. The sub-association is also differentiated by another marked group of species, most of which indicate the grazed, lowland, submesic nature of the stands, such as Bellis perennis, Cynosurus cristatus, Alopecurus geniculatus, Agrostis tenuis, Plantago lanceolata, Cerastium holosteoides.

Two variants are recognisable. A typical variant is either dominated by Hordeum secalinum or the dominance is shared by Lolium perenne, Puccinellia distans and Hordeum. It is differentiated by a group of species including Bellis perennis, Agrostis tenuis, Festuca pratensis, Leontodon autumnalis and Plantago lanceolata and is found on moderately saline soils at the Upton Warren salt marshes. An Agrostis variant is characterised by the marked decrease in cover and abundance of Puccinellia distans, Atriplex hastata and the absence of Spergularia marina as compared to the typical variant. The majority of the stands of this variant have Hordeum dominant and Agrostis stolonifera co-dominant. At Upton Warren, the Agrostis variant is found on higher ground and less saline soils than those of the typical variant.

The relevés referable to the Puccinellietum distantis hordeetosum are described mainly from Upton Warren, where it occupies a grassy region between three saline pools (See Figure 2.5). Small areas of grassland referable to this sub-association were present at Aldersey and further work in localities where Hordeum is recorded may reveal it to be more widespread. At Upton Warren, the soils are characterised by the high concentrations of magnesium and calcium as compared to sodium, but a higher chloride concentration. These values are listed in Table 4.19b where it may be seen that sodium ranges from 0.16 to 1.80 mg/gram; potassium from 0.12 to 1.50 mg/gram; magnesium 0.98 to 3.75 mg/gram; calcium 3.00 to 8.75 mg/gram and chloride 1.30 to 11.30 mg/gram. However, Hordeum secalinum can colonise a highly saline soil, and at Aldersey, where its cover values were never higher than 20%, the concentration of sodium in the associated soil was 12.50 mg/gram and chloride 18.10 mg/gram. Soil profiles from this sub-association are typically similar to those described from the sub-association of Agropyron repens at Upton Warren as far as horizon differentiation and their characteristics are concerned. However, the percentage of organic matter is comparatively high and water tables fluctuations comparatively less in the Hordeum sub-association.

7. Sub-association of Apium graveolens (Transition type 4.)
(Table 4.20a. 5 relevés: Table 4.22. KJ)

The sub-association apietosum is a fourth transition type of the association Puccinellietum distantis found on derelict lagoons and brine cisterns, the soils of which are slightly saline and mesic. The sub-association is characterised by the constant occurrence of the differential species, Apium graveolens, which is also dominant in the majority of stands. Other species of high constancy are Puccinellia distans, Atriplex hastata, Agrostis stolonifera and Spergularia marina. The sub-association is differentiated by another set of mesophyllous species - Juncus bufonius, Ranunculus sceleratus, Carex otrubae and Phragmites communis, of which only Juncus bufonius is of frequent occurrence. The Puccinellietum distantis apietosum is restricted to sludge lagoons at Silver Well, and to cistern seepage sites at Anderton. The sub-association shows the trend towards a mesic habitat and it is apparent that the cover and abundance of Apium graveolens decreases with increase in soil salinity and xeric conditions. The soils on which this sub-association occurs have a high pH (7.9 to 8.9), low sodium levels (0.30 to 3.00 mg/gram) and a high calcium concentration (4.25 to 6.25 mg/gram). These figures are listed in Table 4.20b, which also shows the range of potassium to be 0.03 to 0.07 mg/gram, magnesium from 0.09 to 0.50 mg/gram and chloride from 0.60 to 3.40 mg/gram.

8. Sub-association funarietosum. (Table 4.21a. 6 relevés; Table 4.22. KK).

The details of the specific composition of this sub-association are given in Table 4.21a KK, from which it can be seen that the funarietosum is essentially a Funaria hygrometrica-dominated sub-association, with high cover of this moss, as compared to the associated phanerogams. The only phanerogams with high constancy but low cover value are Puccinellia distans, Spergularia marina and Agrostis stolonifera. The sub-association shows affinities to the Barbula-Funaria community described by Mirza & Shimwell (1977) from alkaline flashes at Elton Hall, Cheshire, where Barbula tophacea is dominant along with Funaria hygrometrica and Puccinellia distans being co-dominant.

The associated soils are rich in magnesium and calcium and have a high pH of about 9.0. At Stoke Works the sub-association is mainly present in the lagoon where Funaria hygrometrica occurs as pure stands along the margin, while areas used as rabbit latrines also have phanerogams such as Puccinellia distans, Spergularia marina and Agrostis stolonifera. One stand in this sub-association is, however, included from Silver Well where Puccinellia distans is dominant with a high percentage cover, but the ground layer was covered with Funaria hygrometrica. The cation concentrations, pH and chloride concentration are given in Appendix IIa, soil samples nos. 73, 74 and 112.

9. Sub-association of Barbula tophacea (Table 4.21a. 15 relevés, Table 4.22 KL)

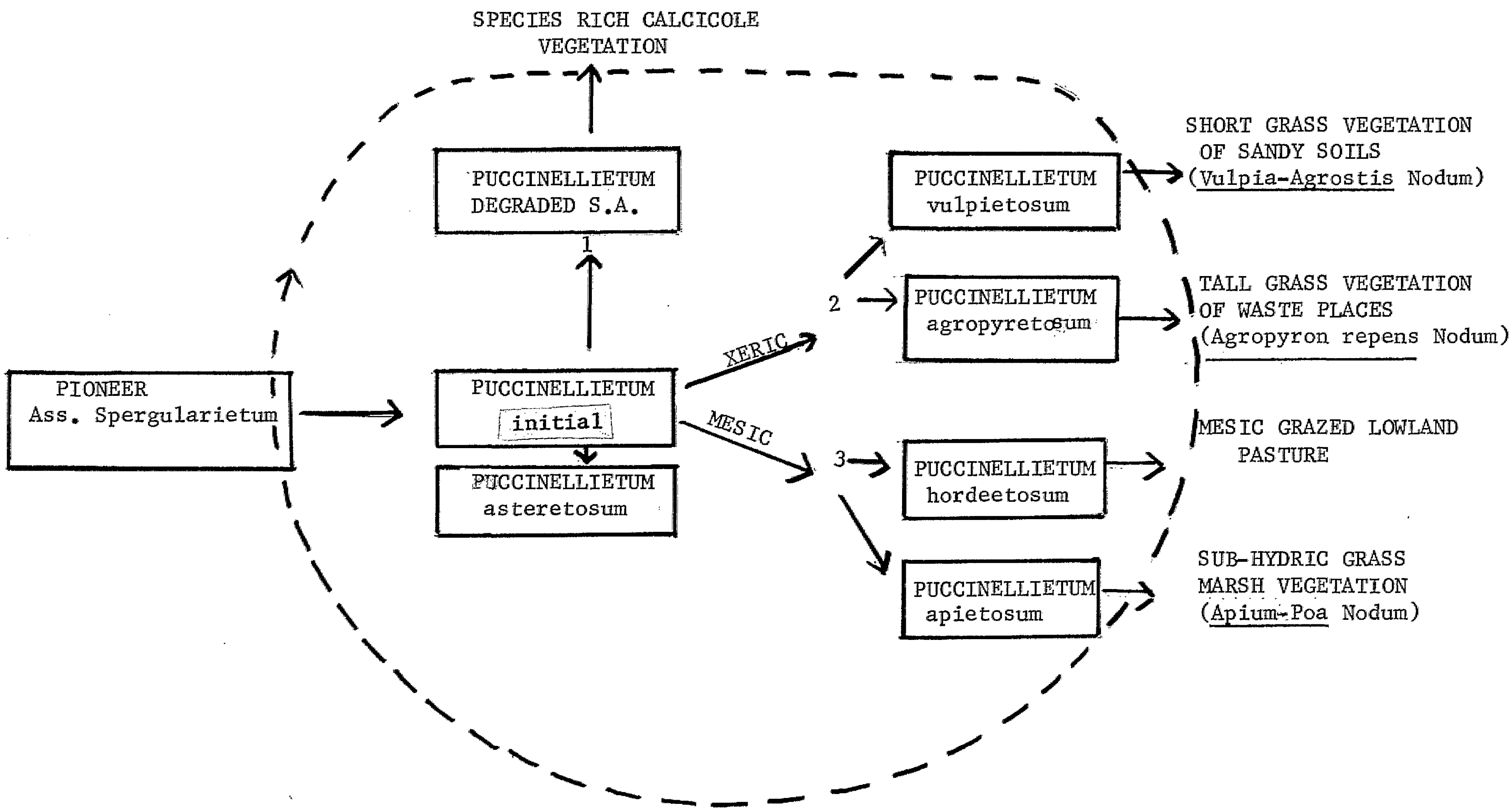
This sub-association is the same as that described by Mirza & Shimwell (1977) from Elton Hall Flash, Cheshire (Community A). The details of the specific composition and structure of the sub-association barbuletosum are given in Table 4.21a, from which it can be seen that the sub-association is poor in species numbers and is dominated by the moss Barbula tophacea. Other species which occur as constants, but with low frequency and vitality are Funaria hygrometrica and Puccinellia distans. Both this and the previous sub-association show affinities to the association Funarietum hygrometricae Gams 1927, which is a characteristic pioneer vegetation of sparse soils on sites rich in potassium, sodium, calcium and nitrates throughout central and western Europe (Hubschmann 1957) and North America (Hoffmann 1966a). Barbula tophacea has not been previously recorded as a component of the association and it seems that the pioneer vegetation at the Cheshire site represents a distinct sub-association. Although Funaria has been recorded as occurring on saline soils in North America (Flowers, 1933; Parker, 1931), and is also found occasionally as a ruderal in salt marshes, it is not generally regarded as a salt-tolerant species, unlike a third moss Pottia crinita (Gams, 1932), which was present but very rare. The releves referable to this sub-association were mainly recorded from Elton Hall Flash and Wilsford, Cheshire.

As Mirza & Shimwell (1977) have shown, the type of soil on which this sub-association grows is similar to the non-saline/alkaline group, characterised by exchangeable sodium percentages greater than 15, a pH range of 8.5 - 10 and a conductivity of saturated soil extract of less than 4 mmhos/em at 25C^{o} (Richards, 1969; Waisel, 1972). The Elton Hall soils are similar in terms of pH (7.9 - 9.3) and conductivity (1.29 - 4.81 mmhos/cm), but their industrial origin has resulted in lower sodium levels and much higher magnesium levels. The pH and magnesium concentrations are extreme and both are certainly important limiting factors in the growth of phanerogamic vegetation. The cation concentrations and pH in the soils associated with this sub-association are given in Table 4.21b under the soil sample nos. 13 - 15.

10. Sub-association of Pohlia annotina (Table 4.21a. 7 relevés; Table 4.22, KM)

This sub-association is another plant community met with only at Elton Hall Flash, and has already been described as community B by Mirza & Shimwell (1977, Table 1). The specific composition of the sub-association is given in Table 4.21a and is characterised by the dominance of Pohlia annotina and co-dominance of Puccinellia distans. Other species of high cover and abundance are Juncus bufonius, Atriplex hastata, Triglochin maritima and Juncus articulatus. A number of other associated glycophytic phanerogams are met within this sub-association similar to the funarietosum, but unlike the third bryophytic sub-association, the Puccinellietum distantis barbuletosum which is poor in terms of species number. The sub-association pohlietosum is closely related to the association Puccinellietum distantis Feeks (1934) 1945, sub-association juncetosum described by Lee (1977) from saline flashes at Winsford and Sandbach in Cheshire, wherein Puccinellia distans and Juncus bufonius are co-dominant. Bryophytes are absent in his data and it seems that the sub-association at Elton Hall is a distinct structural variant of the sub-association. For Pohlia annotina, this represents rather an unusual habitat, it being a moss which prefers damp, sandy earth, usually of a non-calcareous nature. Two variants are recognisable. The typical variant is a community dominated by Pohlia annotina, and Puccinellia distans is very important in terms of cover and abundance. No other species are of constant occurrence. Secondly, a Juncus variant is essentially a community where Juncus bufonius assumes more importance and is co-dominant, and Puccinellia distans less important in terms of cover. A number of other constant species such as Triglochin maritima and Atriplex hastata are met within this variant. The type of soil on which the sub-association grows is similar to that already described for the sub-association barbuletosum. However, flow of fresh water through this community at Elton Hall, resulted in lower concentrations of magnesium. The associated soils have a pH of 8.5; sodium concentration 0.12 mg/gram; potassium 0.11 mg/gram; magnesium 1.26 mg/gram and calcium 3.97 mg/gram.

Figure 4.5 The seral relationships of the association Puccinellietum distantis Feekes (1934) 1945.



SPECIES RICH CALCICOLE VEGETATION
PUCCINELLIETUM DEGRADED S.A.
1
PIONEER Ass. Spergularietum
PUCCINELLIETUM initial
PUCCINELLIETUM asteretosum
XERIC
MESIC
2
3
PUCCINELLIETUM vulpietosum
PUCCINELLIETUM agropyretosum
PUCCINELLIETUM hordeetosum
PUCCINELLIETUM apietosum
SHORT GRASS VEGETATION OF SANDY SOILS (Vulpia-Agrostis Nodum)
TALL GRASS VEGETATION OF WASTE PLACES (Agropyron repens Nodum)
MESIC GRAZED LOWLAND PASTURE
SUB-HYDRIC GRASS MARSH VEGETATION (Apium-Poa Nodum)

Zonation and succession. (Figure 4.5)

The Puccinellietum distantis is a major association with a number of sub-associations and variants, which colonise more or less every type of inland saline habitat in the British Isles. The variation in edaphic factors such as salt concentration and moisture in the association and a parallel variation in vegetation enables the suggestion of the succession in these inland saline sites. Lee (1977) has, at length, dealt with the zonation observable within vegetation referable to the Puccinellietum distantis. His observations at Sandbach, using a transect through the Puccinellietum distantis show that there is a decrease in Puccinellia distans and an increase in Spergularia marina towards the base of a saline depression in association with increasing soil salinity and height of water table. He has also concluded through field observations and laboratory growth experiments that Puccinellia distans appears to be less tolerant of high salinity than Spergularia marina. The phytosociological data presented here seem to confirm this conclusion when the associated soils of the pure stands of Spergularia marina with Domin cover-abundance values of 9 (Relevés C27, C72 in Table 4.14a and S.S. nos. 96 and 128 in Table 4.14b) are compared with the associated soils of the pure stands of Puccinellia distans having Domin cover-abundance values of 9 (Releves W58, C47, C48 in Table 4.16a and soil samples 42, 107, 108 in Table 4.16b). Here the concentrations of sodium are higher in the soils associated with Spergularia marina as compared to those in the Puccinellia distans soils.

The seral relationships of the association Puccinellietum distantis are outlined in Fig. 4.5. The initial colonizer on highly saline soils and in saline depressions is Spergularia marina and, provided the salinity remains high, this stage is maintained. The subsequent colonisation of these habitats is by Puccinellia distans, which tends to occupy the margins of the sites at first, thus leading to the development of the sub-association typicum which is most widespread. Further colonisation seems to be in one of three main directions - (1) degradation; and the development of either xeric (2) or mesic (3) conditions:

1). a degraded sub-association rises to prominence on calcareous sodium-poor flashes, and with the passage of time, may lead to the development of a flora typical of calcareous habitats;

2). the first stage in the development of a more xeric vegetation type is represented by the sub-association agropyretosum, a transitional stage from typical salt marsh to tall grass vegetation on soils with a low water table and moderate salinity; further xeric conditions and loss in salinity lead to the development of pure stands of Agropyron repens; a second, more xeric sub-association vulpietosum develops on dry, often derelict soils and represents a transitional stage to a short grass vegetation of acidic, sandy soils;

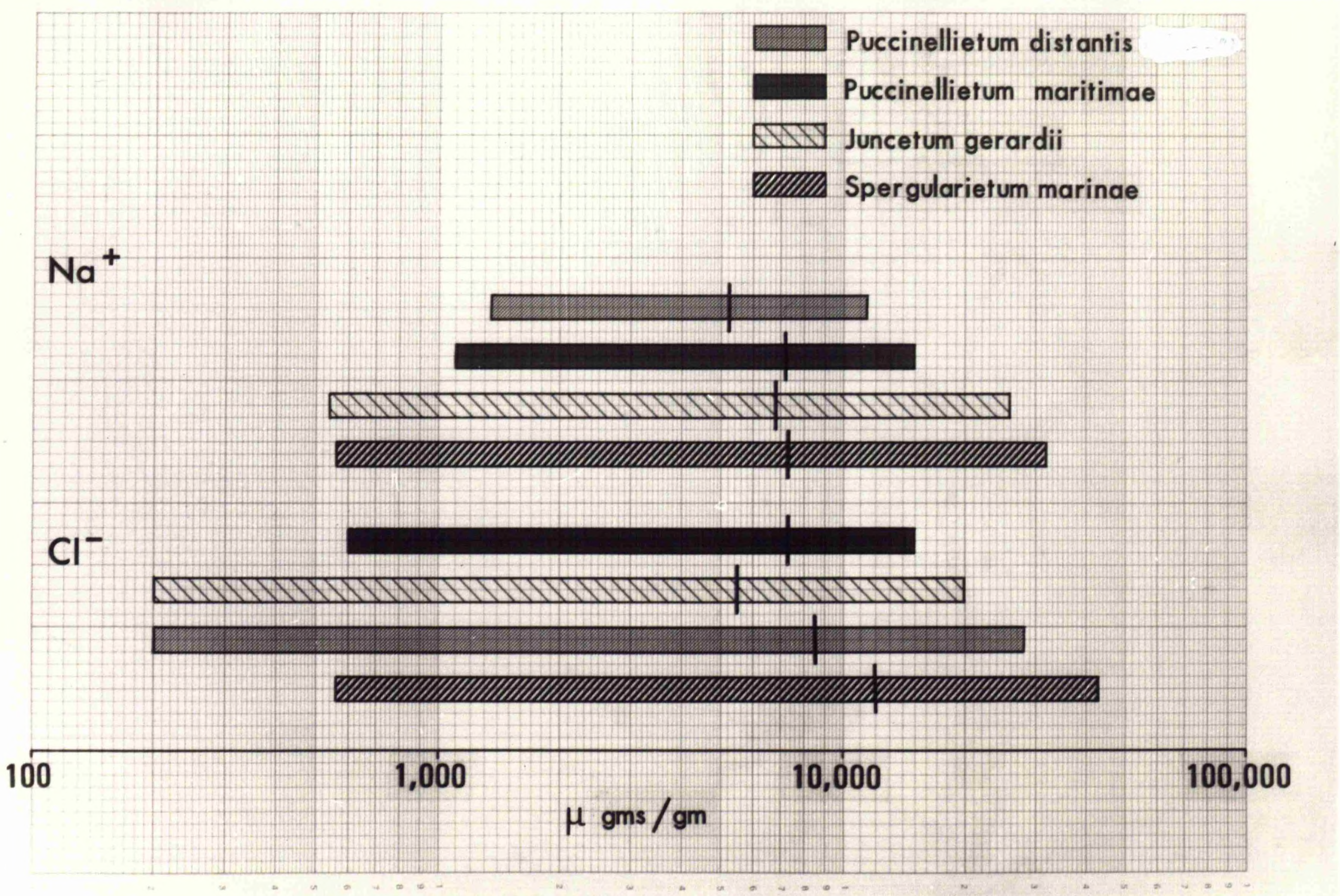
3) the sub-association hordeetosum seems to prefer less saline conditions as compared to typicum and further loss in salinity and increase in mesic conditions due to water table fluctuations leads to the development of a mesic, lowland pasture suitable for fairly intensive grazing; the most mesic, sub-hydric transition is to be seen via the sub-association apietosum which ultimately succeeds to a hydric, non-saline, grassy marsh vegetation of canal banks and riversides.

(v) Summary of ecological gradients in the salt marsh communities.

The ranges and mean values of sodium and chloride, magnesium and calcium of the soils associated with the four major salt marsh associations are shown in Figures 4.6 and 4.7. These communities are developed in distinct salt ranges. The four associations can be arranged in a series, according to their mean sodium concentrations - Puccinellietum maritimae > Spergularietum marinae > Juncetum gerardii > Puccinellietum distantis typicum. Due to the widespread occurrence of the Puccinellietum distantis typicum and Spergularietum marinae on industrial saline sites, these two communities seem to tolerate a wider range of calcium, magnesium and chloride as compared to Puccinellietum maritimae and Juncetum gerardii, which are generally more common in natural or semi-natural salt marshes. The association Puccinellietum distantis seems to have a wider ecological amplitude, and a number of the sub-associations recognised are developed on soils with quite distinct concentrations of certain ions. Figures 4.8 and 4.9 show the ranges and mean values of sodium and chloride, magnesium and calcium of the soils associated with these sub-associations. Thus, while the sub-associations can be arranged in a series, according to their chloride concentrations - typicum > asteretosum > hordeetosum > degraded > agropyretosum > apietosum > vulpietosum, they seem to show different affinities for the four major cations. Therefore, it may be seen that their preference for the four cations is as follows:-

Figure 4.6 — Ranges and means of Na^{+} and Cl^{-} concentrations of soils in the salt marsh associations.

(vertical bars represent the mean concentrations).



Puccinellietum distantis
Puccinellietum maritimae
Juncetum gerardii
Spergularietum marinae
Na+
Cl−
100
1,000
10,000
100,000
μ gms / gm

Figure 4.7 Ranges and means of Mg^{2+} and Ca^{2+} concentrations of the soils in the salt marsh associations.

(vertical bars represent the mean concentrations).

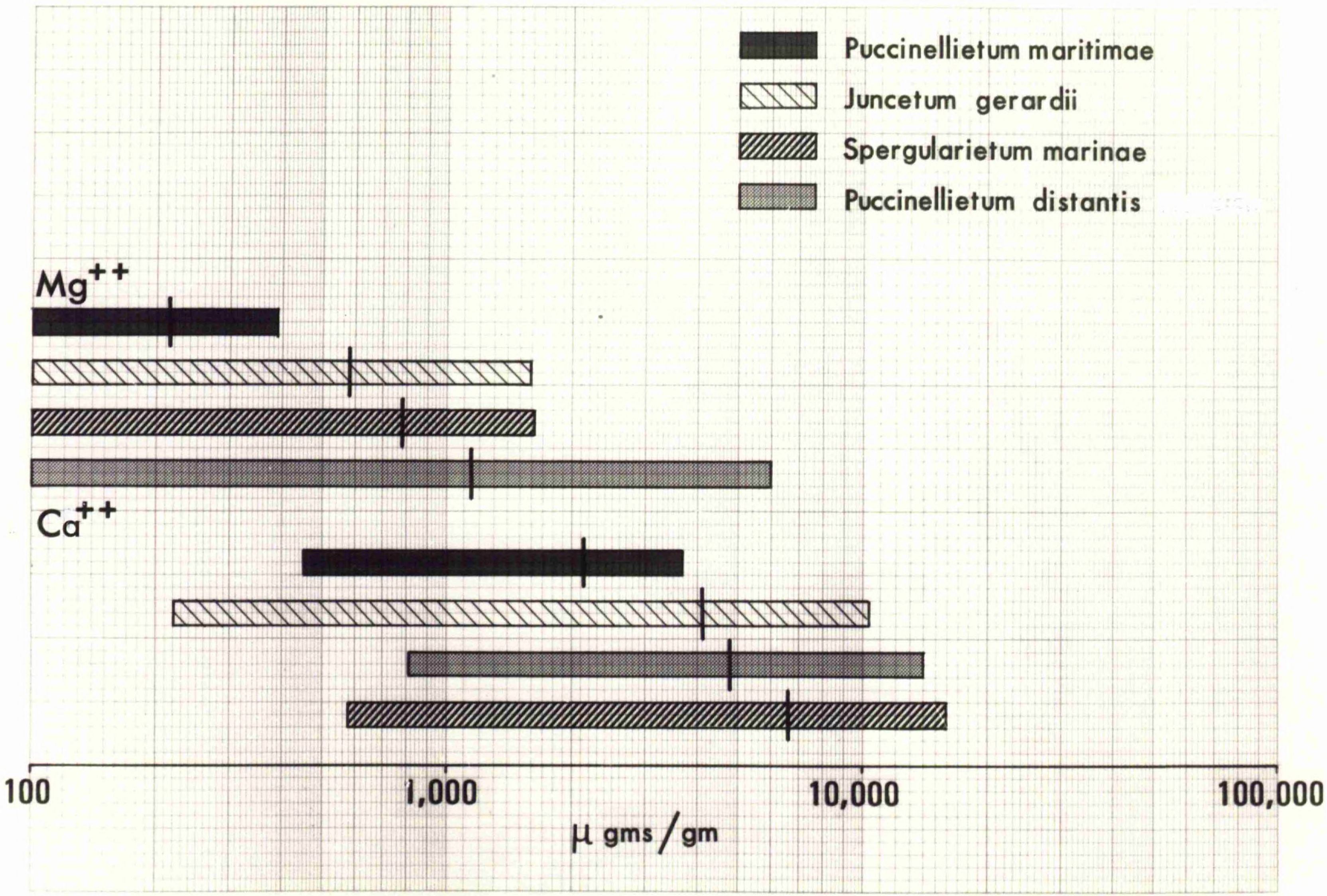
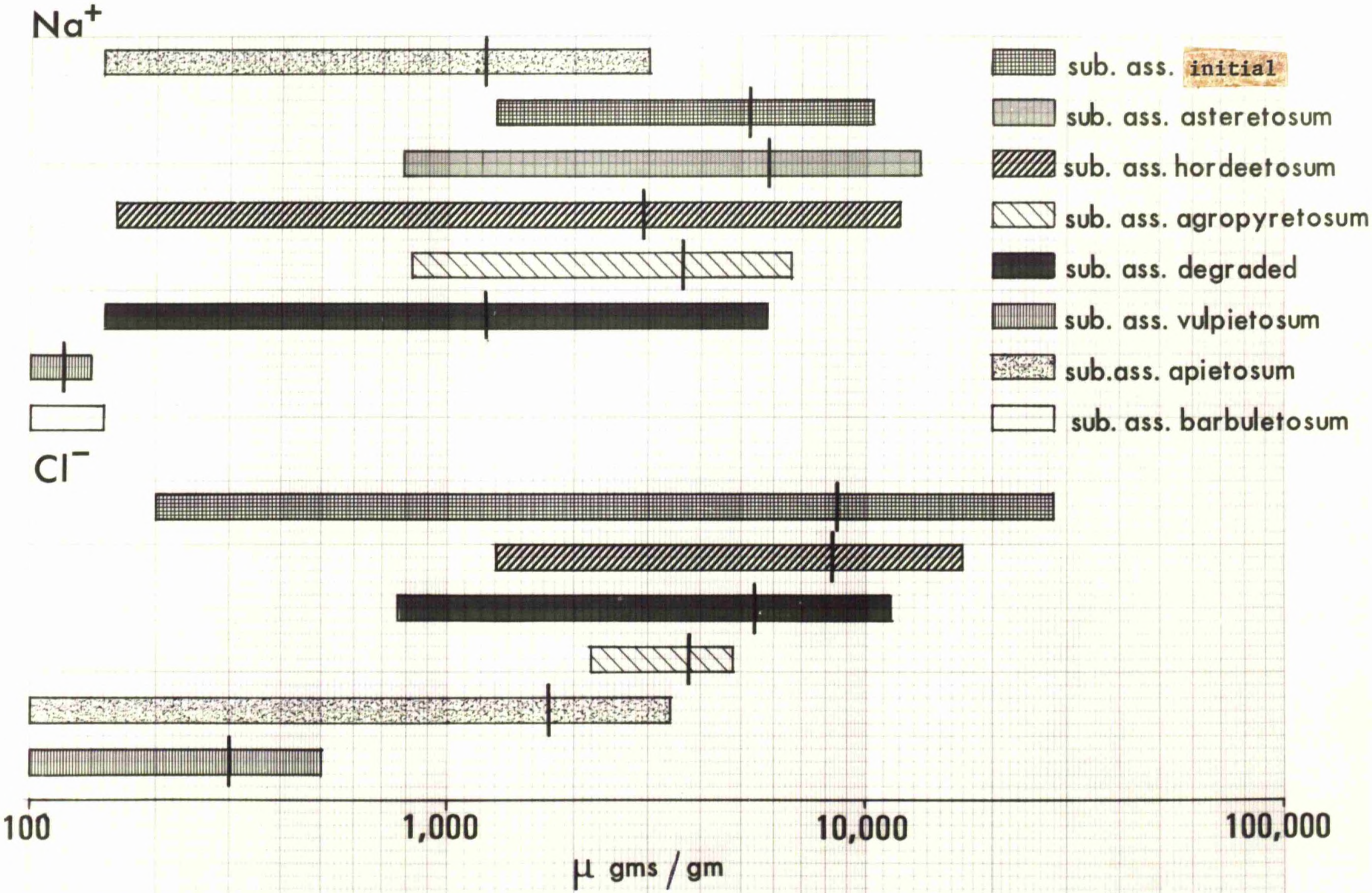

Puccinellietum maritimae
Juncetum gerardii
Spergularietum marinae
Puccinellietum distantis
Mg++
Ca++
100
1,000
10,000
100,000
µ gms / gm

Figure 4.8 Ranges and means of Na^{+} and Cl^{-} concentrations of the soils in the sub-associations of the association Puccinellietum distantis.

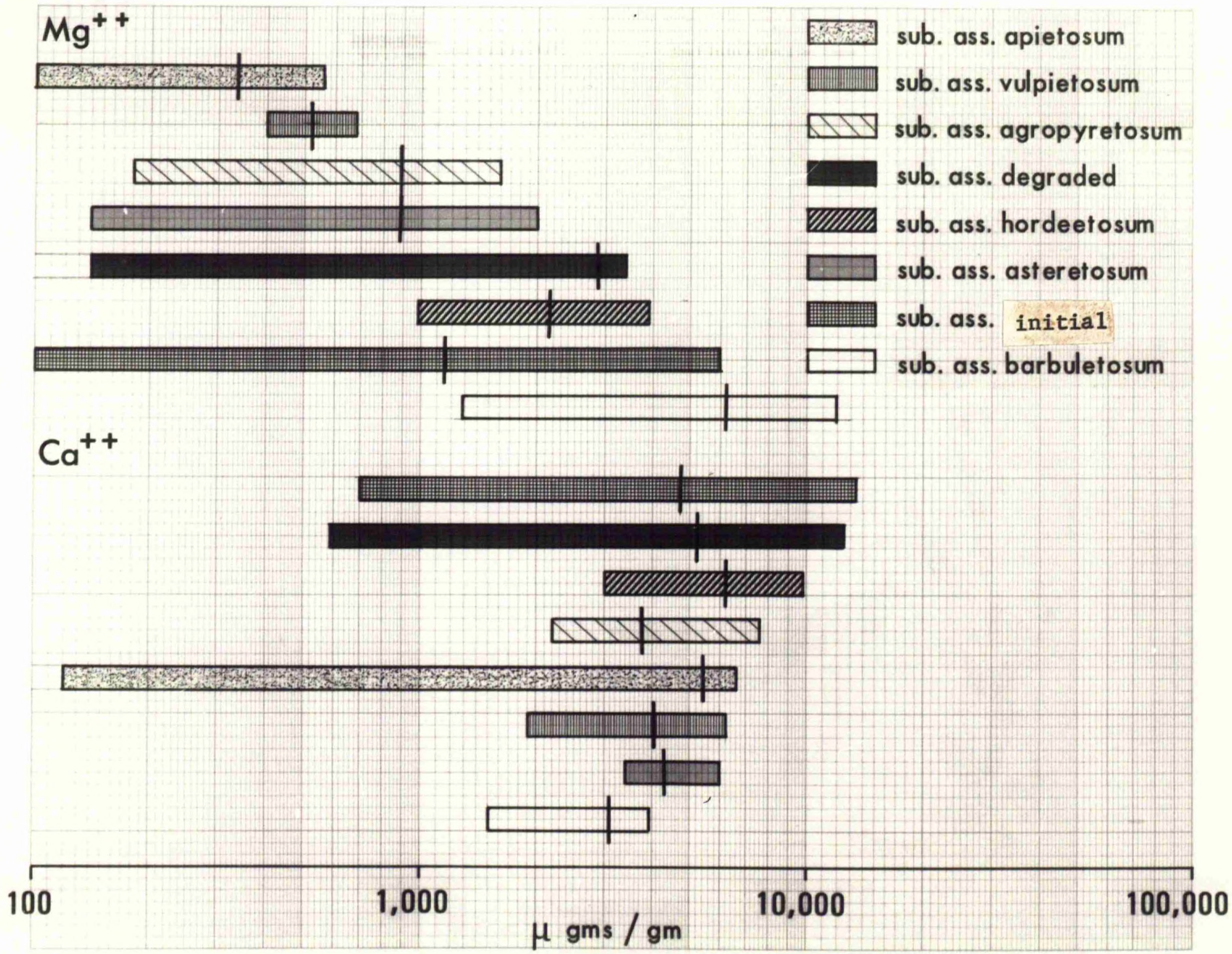
(vertical bars represent the mean concentrations).



Na+
Cl−
sub. ass. initial
sub. ass. asteretosum
sub. ass. hordeetosum
sub. ass. agropyretosum
sub. ass. degraded
sub. ass. vulpietosum
sub.ass. apietosum
sub. ass. barbuletosum
100
1,000
10,000
100,000
μ gms / gm

Figure 4.9 Ranges and means of Mg^{2+} and Ca^{2+} concentrations of the soils in the sub-associations of the association Puccinellietum distantis.

(vertical bars represent the mean concentrations).



Mg++
Ca++
sub. ass. apietosum
sub. ass. vulpietosum
sub. ass. agropyretosum
sub. ass. degraded
sub. ass. hordeetosum
sub. ass. asteretosum
sub. ass. initial
sub. ass. barbuletosum
100
1,000
10,000
100,000
μ gms / gm

initial Na > Ca > Mg > K;
degraded Ca > Mg > Na > K;
vulpietosum Ca > Mg > Na > K;
apietosum Ca > Na > Mg > K;
barbuletosum Mg > Ca > Na > K;
asteretosum Na > Ca > Mg > K;
agropyretosum Ca > Na > Mg > K;
hordeetosum Ca > Na > Mg > K;
funarietosum Ca > Mg > Na > K;
pohlietosum Ca > Mg > Na > K

e. Noda of Uncertain Affinities.

(i) Saline Agrostis stolonifera Noda. (Table 4.23a. 10 relevés)

The noda in this group are characterised by the dominance and constancy of Agrostis stolonifera and occur on soils of low to intermediate salinity, accompanied by a comparatively low water table. Two noda are recognizable. The typical nodum is essentially an Agrostis stolonifera lawn, and may also be referred to as a species-poor Agrostis-stolonifera nodum. The stands of this nodum are either monospecific or with other minor species not attaining cover-abundance values greater than 4. The Agrostis-Lolium nodum is characterised by the co-dominance of Lolium perenne with Agrostis. Other species of high constancy are Poa pratensis, Deschampsia caespitosa, Tripolium repens and Cirsium vulgare, Cirsium arvense are common, while Triglochin maritima and Potentilla anserina are rare.

The relevés referable to the species-poor Agrostis stolonifera nodum are scattered and are described from Stoke Works, Worcestershire and Sandbach, Cheshire. At Stoke Works, they occupy sites between the association Puccinellietum distantis and glycophytic communities. At Sandbach, the nodum occupies areas adjacent to the Atriplicetum salinae. Relevés referable to the Agrostis- Lolium nodum are described from Pasturefields, Staffordshire. The species-poor Agrostis stolonifera nodum is met with on comparatively less saline soil then the Agrostis-Lolium nodum. At Pasturefields, the latter nodum occupies an area with an intermediate salinity (Sodium 7.5 to 8.00 mg/gram). The pH of the soil ranges from 4.3 to 8.4; sodium 0.35 to 8.00 mg/gram; potassium 0.07 to 0.38 mg/gram; magnesium 0.28 to 1.45 mg/gram, calcium 2.50 to 7.50 mg/gram and chloride 0.94 to 8.75 mg/gram. (See Table 4.23b).

Agrostis stolonifera is a component species of many associations and sub-associations described from inland saline sites. Though it can colonise almost any type of soil, its cover-abundance values seem to decrease with increase in soil salinity and water table; thus, monospecific stands with 100% cover values are more common on relatively non-saline xeric soils. The phytosociological status of these noda is uncertain but, they can be equated with groups K.I.J. described from Nantwich by Lee (1977) and group U from Pasturefields. However, the noda differ from these groups in the absence of many salt marsh species such as Glaux maritima, Juncus gerardii, Puccinellia maritima and Puccinellia distans listed as components of these communities. There is a strong similarity in terms of soil salinity and the dominance of Agrostis stolonifera.

(ii) Saline Ranunculus sceleratus Nodum (Table 4.24a. 3 relevés)

This nodum is characterised by the dominance and constancy of Ranunculus sceleratus. Other species of high constancy are Zannichellia palustris and Alopecurus geniculatus and associated species include Ranunculus baudotii, Juncus gerardii, Juncus bufonius, Phragmites communis Festuca arundinacea, Agrostis stolonifera, Juncus inflexus and Poa trivialis. This nodum is mainly recorded from Southam salt spring, where a number of other associations of emergent reedswamp vegetation are present. One other relevé was described from Droitwich Canal, Worcestershire, the water of which was slightly brackish (See W.S.4. Table 4.24b).

Ranunculus sceleratus is a common species of freshwater marshes, but may also inhabit waters of low salinity. Waters associated with stands of Ranunculus sceleratus have a conductivity range of 1.57 to 6.60 mmhos/cm; pH 8.4 to 8.6; sodium 148 to 1100ppm, potassium 05 to 14 ppm, magnesium 63 to 75 ppm, calcium 28 to 168 ppm and chloride 58 to 950ppm.

(iii) Agropyron repens Nodum. (Table 4.17a. 4 relevés).

This nodum is characterised by the dominance and constancy of Agropyron repens; most of the stands are poor in species and no other species is constant. In one stand Brachythecium rutabulum was abundant as a moss layer. Other associated species with low constancy are Holcus lanatus, Festuca rubra, Atriplex hastata, Agrostis stolonifera and Cirsium arvense. Two stands of this nodum are described from the vicinity of Amerton Brook Salt Mine, near Shirleywich, Staffordshire and other releves were taken from revegetated lagoons at Middlewich and Dutton, Cheshire. The soils associated with this nodum are slightly to moderately saline and are like the soils of the association Atriplicetum salinae deviense. The range of pH is 7.3 to 8.1 ; sodium 1.53 to 6.00 mg/gram; potassium 0.13 to 0.20 mg/gram; magnesium 0.18 to 0.25 mg/gram; calcium 2.25 to 7.75 mg/gram and chloride 2.25 to 4.80 mg/gram (Table 4.17b. S.S. 176, 134, 142).

The phytosociological position of this nodum is not clear, but it seems to show affinities with the association Agropyretum repentis maritimum Nordhagen 1940, also described by Adam (1977), from coastal salt marshes of England, where Agropyron and Festuca rubra are constant taxa. If this phytosociological position is taken as certain, then in terms of syntaxonomy, this nodum is classified in the alliance Agropyrion pungentis Gehu & Gehu 1969 of the order Agropyretalia pungentis Gehu & Gehu 1969 and the class Agropyretea pungentis Gehu & Gehu 1969.

(iv) Vulpia-Agrostis stolonifera Nodum (Table 4.18a. 5 relevés)

This nodum is characterised by the dominance of Vulpia myuros with Agrostis stolonifera. The familiar species of wastelands, Cirsium vulgare, Holcus lanatus, Sonchus oleraceus and Crepis capillaris are constant and the nodum is also differentiated by the presence of another set of species which include Cerastium holosteoides, Linaria vulgaris Inula conyza and Achillea millefolium. The average number of species is more than in other noda and greater than in the other sub-associations already described. This nodum is a continuum of the Puccinellietum distantis vulpietosum, described from derelict, calcareous land at Sandbach, Cheshire. The associated soils are xeric and calcareous with a pH of 7.3. The concentrations of the various cations are as follows:- Sodium 0.14 mg/gram, potassium 0.38 mg/gram, magnesium 0.40 mg/gram, calcium 6.25 mg/gram and chloride 0.50 mg/gram.

(v) Aster tripolium Nodum. (Table 4.16a. 4 relevés)

The details of the species composition and the structure of this nodum show that stands are dominated by Aster tripolium and that Agrostis stolonifera is the only other associated species. At Sandbach, the nodum and the sub-association asteretosum of the association Puccinellietum distantis Feekes U934,1945 form a continuum. This inland Aster tripolium nodum shows affinities to the Aster tripolium var. discoideus nodum (Adam 1977) described from coastal salt marshes which have Puccinellia maritima and Salicornia spp. as additional constants. Stands of the nodum occur locally at Sandbach and are scattered on low lying areas of high salinity and standing water, on sites frequently flooded with saline water. The associated soils have a pH of around 7.0, sodium concentrations as high as 14.25 mg/gram, potassium 0.33mg/gram, magnesium 0.14 to 0.28 mg/gram and calcium 4.29 to 6.00 mg/gram (Table 4.16b. S.S. Nos. 16,19).

(vi). Apium-Poa Nodum. (Table 4.20a. 2 relevés)

The two stands assigned to this nodum have Apium graveolens as as dominant and Poa trivialis as co-dominant. Other species present are Agrostis stolonifera, Holcus lanatus, Cirsium vulgare and Epilobium hirsutum. The presence of many other glycophytic species also distinguishes this nodum. One stand of this nodum is described from the banks of the Droitwich canal, Worcestershire, where the associated water has a sodium concentration of 148 ppm. The other stand was recorded at Silverwell, Cheshire in an area adjacent to the sub-association apietosum of the association Puccinellietum distantis. The nodum is developed on non-saline, calcareous and mesic soils of pH 7.8, sodium concentrations of 0.50 mg/gram, potassium 0.06 mg/gram, magnesium 0.55 mg/gram, calcium 6.75 mg/gram and chloride 0.75 mg/gram.

f. Miscellaneous stands.

A number of other communities may occur on British inland saline sites, but for various reasons were under-represented in the present survey. The specific composition and structure of five such stands is given in Table 4.25, and until more relevés are available from similar habitats, their classificatory position must remain in doubt. Further description of the stands is unnecessary and they are simply listed below in terms of the sodium and chloride concentrations of associated waters and soils.

1. Eleocharis palustris stand; sodium 0.77 mg/gram, chloride 1.20 mg/gram.
2. Scirpus lacustris-Atriplex hastata stand; sodium 0.35 mg/gram, chloride 3.40 mg/gram.
3. Rumex hydrolapathum stand; sodium 650 ppm, chloride 1100 ppm.
4. Sparganium erectum -Eleodea canadensis stand. sodium 93ppm, chloride 55ppm.
5. Rorippa nasturtium-aquaticum stand. sodium 3000ppm, chloride 4500ppm.

CHAPTER 5

CATION CONCENTRATIONS AND RATIOS IN VASCULAR PLANTS OF SALINE ENVIRONMENTS AND THE DEFINITION OF A HALOPHYTE

A. Introduction

The fact that only a small group of higher plants can grow under saline conditions was known to plant physiologists many years ago, and early in the nineteenth century, the name 'halophyte,' was given to that group of plants by Pallas (see Schrader 1809). Afterwards, the interpretations of the word halophyte differed according to different workers and perhaps it is due to this fact that there exist many definitions and categories of this word. Waisel (1972) describes halophytes as "plants which grow and complete their life cycles in habitats with high salt content;" Fernald (1950) says they are plants "growing in saline soils;" according to Lawrence (1951) they are plants "tolerant of various mineral salts in the soil solution, usually sodium chloride;" and Dansereau (1957) states that a halophyte is "a plant that grows exclusively on salt soils such as species of Salicornia". Other definitions include: plants that can tolerate the concentrations of salts found in saline soil (Oosting 1956); plants of salty or alkaline soils (Correll & Johnston 1970). Chapman (1960,1974) is of the view that "generally species capable of tolerating 0.5% or more sodium chloride" are regarded as halophytes", while Barbour (1970) has discussed the aspect of obligate halophytes and concluded that very few species are restricted above 0.5% NaCl. The major problem is to draw a line between saline and freshwater habitats and to decide where the line should be drawn, no matter which definition is used. At the same time, it seems worthwhile to consider another aspect, mainly to attempt to define the halophyte tendency in plants according to their cation accumulating capacity and cation ratio in their shoots.

B. Some classification of halophytes.

The problem of classification is always a difficult task, because it involves the factor or factors on which categories are to be made and if the factor or factors are not natural, then personal criteria are usually arbitrary and artificial. The same type of difficulty is encountered when halophytes are classified. One has to face the same intricacies and difficulties as are found in the definition of halophytes. The varieties of ecological conditions in saline habitats are of prime importance, especially the salt composition and salt conditions which differ from one habitat to another. Similarly, the use of such classification features as the status of water in the soil and the growth form (aquatic or terrestrial) superimpose further subdivisions and make classification by several features a difficult task. Thus, the several attempts aimed at classification have tended to use different criteria, such as soil-salt content, sources of salts and the importance of plant responses to salinity. The internal salt content of the plants has also been taken as a measure to express the tolerance level in halophytes. In all these attempts, distinction between groups are artificially made and in many cases, as Waisel (1972) has pointed out, the dividing lines are arbitrary and are drawn across a continuous cline of gradually changing characteristics. Here four aspects are discussed in connection with the cation concentrations in the plants of inland saline environments and sodium levels in the associated habitats. The four aspects are :-

a. (i) Concentration range of sodium in the saline habitats and

(ii) sodium accumulating capacity on the basis of $\frac{\text{sodium in the shoot}}{\text{sodium in the soil}}$

(both expressed in mg/gram);

b. Sodium content in the shoots, the plants being arranged according to the maximum tolerance levels;

c. Na:K ratio in the shoots, the plants being arranged in a series from maximum to minimum ratio;

d. $\frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+}}$ ratio in the shoots to indicate the range of salinity and and alkalinity tolerated in the inland plants.

But, before these aspects are described, a review of literature concerning the classification of halophytes is necessary.

The early method of Stocker (1928) based its classification on the sources of salt and plant organs affected, and took the view that the limit of tolerance of ordinary glycophytes is about 0.5% sodium chloride. It divided halophytes into a number of groups, which are as follows:

i. Aquatic-haline = submerged halophytes.

ii. Terrestro-haline = emersed halophytes.

1. Hygrohaline
2. Mesohaline
3. Xerohaline

iii. Aero-haline

1. Salt spray (maritime)
2. Salt powder (salt desert)

Alternatively, another early classification of Iversen (1936) is based on the range of salt concentrations in the soil-water solution and three major ranges are termed as follows:

i. Oligohaline, habitats containing 0.01% - 0.1% NaCl

ii. Mesohaline, habitats containing 0.1% - 1.0% NaCl

iii. Polyhaline, habitats containing more than 1% NaCl

In many ways Chapman (1942) combined the classification of Stocker and Iversen, considering 0.5% NaCl as a boundary between glycophytes and halophytes and giving the following classification of halophytes.

Miohalophytes, plants growing in habitats of low salinity, below 0.5% NaCl

Euhalophytes, plants growing in highly saline habitats; these are subdivided into three categories.

1. Mesohalophytes, plants that grow in habitats with a range of 0.5% to 1% NaCl or Na_2So_4

2. Meso-euhalophytes, plants that grow in habitats with a range of 0.5% to more than 1% NaCl

3. Eu-euhalophytes, plants that grow in habitats with not less than 1% NaCl.

There have been several attempts to classify halophytes on the basis of growth (Weissenback 1969; Kreeb 1964; Harmer et al 1953) and also to determine the effects of salinity on non-halophytes. Van Eijk (1939), has recognised two major groups of terrestro-haline plants, which are as follows:

i. Plants which tolerate an excess of salt but whose optimal development occurs on non-saline ground, with a further sub-division into -

1. plants which always grow under glycophytic conditions, but nevertheless, have some resistance to salts.

2. plants which frequently occur on haline soil.

ii. Plants whose optimal development takes place on haline soil, comprising halophytes sensu stricto and subdivided as -

1. plants which are restricted to haline soil;

2. plants which also do well under glycophytic conditions.

Similarly, Tsopa (1939) based his classification on the response to salinity and recognised four groups for the inland halophytes of Rumania; the groups are as follows:

i. Obligatory halophytes, which must have some salt present in the soil at all seasons e.g. Salicornia, Suaeda, Limonium, Halimione, Glaux and Frankenia.

ii. Preferential halophytes, plants exhibiting their best growth on saline soils, despite their appearance in non-saline soil - Scirpus maritimus, Juncus gerardii and Lepidium latifolium,

iii. Supporting halophytes, non-aggressive plants which are capable of growing in saline habitats such as Phragmites, Eleocharis palustris, Trifolium fragiferum.

iv. Accidental halophytes, which have only an occasional existence in saline habitats, such as Molinia, Calamagrostis.

On the other hand, attempts to arrange or categorise the halophytes on the basis of their internal salt content have also been undertaken. Such characterisation can probably contribute more towards the understanding of the ecology and physiology of the tolerance of such plants. Steiner (1935) made an attempt to classify the halophytes according to their internal salt content by dividing salt marsh plants into three categories -

i. Succulent halophytes - plants which can tolerate high concentrations of chloride in their cell sap due to an increase in succulence (Salicornia herbacea)

ii. Non-succulent halophytes - plants which secrete salt excesses through salt glands and, hence, resist salts by desalinization of their tissues (Spartina alterniflora).

iii. Accumulating halophytes - plants with no special mechanism for salt removal, salt concentrations in the tissues of such plants increase until death. (Suaeda fruticosa). A similar classification is provided by Henkel and Shekhov (1945), who without mentioning the various effects of salts on plant growth and behaviour, distinguish three categories of halophytes on the basis of their systems of salt regulation -

i. Plants accumulating salts - euhalophytes
ii. Plants eliminating salts after salts have been absorbed - crinohalophytes.
iii. Plants which restrict salt accumulation - glycohalophytes
iv. Plants which accumulate salts and localise them in specific tissues.

Hence, a variable terminology has been developed due to the different aspects under consideration and perhaps the most comprehensive scheme is presented by Waisel (1972) wherein he has placed more stress on salt resistance mechanisms and on internal plant-salt relationships:

i. Euhalophytes

1. Salt requiring halophytes
   Obligatory halophytes e.g. *Salicornia*
   Preferential halophytes e.g. *Aster, Suaeda*

2. Salt resisting halophytes
   Salt-enduring halpphytes e.g. *Suaeda monoica*
   Salt-excluding halophytes e.g. *Limonium*
   Salt-evading halophytes e.g. *Prosopis farcta*

ii. Pseudohalophytes. Salt avoiding plants.

C. Classification of some British halophyte species

As is clear from the literature surveyed, most workers have placed more stress on the habitats and amount of salt present in them, than on internal salt concentration. However, there are several other methods (Levitt 1972) which supposedly measure the tolerance in the plants and internal cation ratios. The present work involves the analyses of about 53 vascular plant species, collected from inland saline environments. The plants are analysed for four cations; sodium, potassium, calcium, magnesium and data is presented in Appendix IVa,b. Each sample analysed is easily referable to its associated soils or water through Appendix IIa,b, and IIIa,b; and the amount of data provides a variety of ways for the expression and interpretation of results. Of course, it is much easier to express the degree of tolerance of each sample analysed in respect of cation ratios, through the absorptive capacity for the four cations Na^{+}, K^{+}, Mg^{2+}, Ca^{2+} and thence to categorise the plants according to the series $Na \lesseqgtr K \lesseqgtr Mg \lesseqgtr Ca$ or otherwise. These categories can be referred back to individual habitats and the amount of cations present in them and, hence, the relative preference for certain ions can also be ascertained. There are many other features of interest in the data, but in order to provide an overall comparative assessment of the relative halophytic tendencies of species, four approaches previously mentioned are taken.

a. The first uses the conventional method of expressing the degree of tolerance on the basis of salt present in the habitats and relates this to the sodium accumulation in the shoots on the basis of $\frac{\text{plant shoot sodium}}{\text{sodium in soil}}$

(both expressed in mg/gram).

Details of ranges of concentration of sodium in the soils associated with plants of saline habitats are given in Table 5.1. Also given is the maximum accumulating capacity of these plants, calculated on the basis of $\frac{\text{plant shoot sodium mg/gram}}{\text{Soil sodium mg/gram}}$ ratio. The following categories for the British inland halophytes are suggested:

i. Species of stenohaline habitats, with a maximum sodium concentration of up to 10.00 mg/gram.

1. Miohalophytes - plants growing in habitats with an Na^+ range of 0.2 mg/gram to 5.0 mg/gram.
2. Mesohalophytes - plants growing in habitats with a maximum sodium concentration of up to 10.00 mg/gram.

ii. Species of euhaline habitats, with sodium concentrations above 10.00 mg/gram.

3. Meso-euhalophytes - plants tolerating a maximum sodium concentration of 15.00 mg/gram in their habitats.
4. Poly-halophytes - plants tolerating a maximum sodium concentration above 15.00 mg/gram in their habitats.

In the data presented in Table 5.1 (column 1) the species are ordered according to the maximum sodium concentrations in the associated soils. The choice of concentrations for classification is, in part, based upon previous research on halophytes of both inland and coastal species (e.g. the use of 0.2 mg/gram lower limit as given by Allen (1974); but because the research is specific to British inland sites and because sodium values are taken as maximum in delimiting the categories, rather than sodium chloride, the levels chosen are different from those of other workers.

These plants can also be classified on the basis of maximum accumulating capacity $\frac{\text{max. sodium in shoot}}{\text{max. sodium in soil}}$. Such a type of division seems to be important for agricultural purposes, i.e. how much more sodium can be accumulated in shoots than is present in the soil. Hence, plants having a ratio value above 20 may be regarded as having

i. High Accumulating Capacity (HAC) e.g. *Spergularia marina*;

ii. Median Accumulating Capacity (MAC) - Maximum accumulating capacity between 10 and 20 e.g. *Aster tripolium*, *Scirpus tabernaemontani*.

iii. Low Accumulating Capacity (LAC) - maximum accumulating capacity for sodium up to 10 e.g. *Puccinellia distans*. The inland halophytes,

TABLE 5.1

Ranges of concentration of sodium in soils associated with species of inland saline habitats and the maximum accumulating capacity of sodium for selected species.

Species (arranged in order of maximum Na^+ concentration in habitat).	Range of Sodium (mg/gm)	Maximum accumulating capacity of Na^+	
Euhaline			
(Poly-halophytes)			
Triglochin maritima	0.65 - 32.50	6.92	(LAC)
Juncus gerardii	0.68 - 26.25	9.55	(LAC)
Scirpus tabernaemontani	0.65 -25.00	18.18	(MAC)
Spergularia marina	1.10 - 17.75	25.00	(HAC)
(Meso-euhalophytes)			
Aster tripolium	3.30 - 14.25	12.90	(MAC)
Puccinellia maritima	1.10 - 13.50	3.40	(LAC)
Glaux maritima	- 13.00	2.84	(LAC)
Puccinellia distans	0.13 - 11.50	7.38	(LAC)
Apium graveolens	0.50 - 11.50	24.00	(HAC)
Chenopodium rubrum	0.65 - 10.00	57.69	(HAC)
Stenohaline			
(Meso-halophytes)			
Plantago maritima	1.48 - 9.75	18.58	(MAC)
Festuca rubra	- 9.50	1	(LAC)
Atriplex hastata	0.30 - 9.25	87.5	(HAC)
Scirpus maritimus	0.35 - 7.00	33.57	(HAC)
Agropyron repens	- 6.00	5.71	(LAC)
Apium nodiflorum	- 5.75	3.91	(LAC)
Agrostis stolonifera	- 5.75	1.28	(LAC)
Sonchus arvensis	- 5.75	8.84	(LAC)
Typha latifolia	- 5.25	1.52	(LAC)
(Mio-halophytes)			
Phragmites communis	1.15 - 5.00	13.95	(MAC)
Tripleurospermum maritimum	- 4.75	3.26	(LAC)
Cirsium vulgare	- 4.75	3.10	(LAC)
Ranunculus sceleratus	0.66 - 4.00	8.00	(LAC)
Festuca arundinacea	- 3.25	1	(LAC)
Samolus valerandi	- 3.25	11.53	(MAC)
Carex distans	- 3.25	2.16	(LAC)
Cotula coronopifolia	0.14 - 2.49	62.40	(HAC)
Eleocharis palustris	- 0.77	20.00	(MAC)
Rumex crispus	- 0.66	29.54	(HAC)

HAC = High Accumulating Capacity

MAC = Median Accumulating Capacity

LAC = Low Accumulating Capacity

thus, can be divided into these categories and figures for the species are given in Table 5.1 (Column 2).

b. Sodium content in the shoots.

Table 5.2 shows the details of sodium concentrations (maximum, minimum and mean), and the number of analyses undertaken for each species. If the maximum values are taken as a basis for categories, then the species given in Table 5.2 can be classified as:

i. Plants with High Sodium Concentrations (HSC) - sodium content more than 30 mg/gram e.g. Spergularia, Aster, Atriplex.

ii. Plants with Median Sodium Concentrations (MSC) maximum sodium content up to 30 mg/gram. e.g. Triglochin maritima, Scirpus maritimus, Apium graveolens, Zannichellia palustris.

iii. Plants with Low Sodium Concentrations (LSC), maximum sodium concentrations up to 20 mg/gram e.g. Hordeum secalinum, Puccinellia distans, Agrostis stolonifera, Festuca rubra.

Plants with a maximum sodium concentration above 3.00 mg/gram are regarded as those at the lower limits of halophytic tendency (cf.Allen 1974). It is obviously clear that accumulating capacity and the sodium content in the shoots are a measure of halophytism. Some plants e.g. Puccinellia maritima, Juncus gerardii, though they occur on comparatively high saline soils are classified as LSC because they have a low accumulating capacity, and a similar case can be seen with salt secreting plants. This feature is a loophole in the use of sodium concentrations in the tissue as the sole criterion for the classification of halophytes.

The accumulation of sodium in the shoots of halophytic species may be taken as a matter of interest in terms of agriculture. As Waisel (1972) has pointed out, the sodium content of Suaeda vulgaris could reach, at maturity, approximately 20% of their dry weight and similar values have been reported by Choudhri et al (1964) for Suaeda fruticosa in Pakistan, where it was calculated that about 2.5 tons/hectare of sodium chloride could be accumulated annually by a dense stand of Suaeda fruticosa. Though there is not the least problem of high salt in inland localities in Britain, the high accumulating capacity and high sodium content in the shoots of Spergularia marina and Atriplex hastata is significantly important and can be taken as a matter of interest.

TABLE 5.2.

Concentrations of sodium in shoots (mg/gram on dry weight basis), and $Na^+:K^+$ ratios.

Species (ordered according to maximum Na concentration)	Number of Analyses.	Max.	Min.	Mean.	$Na^+:K^+$ K = 1	
High Sodium Concentration (HSC)						
Spergularia marina	12	80.00	27.50	47.75	2.114	(E)
Atriplex hastata	17	75.00	15.00	46.28	1.98	(ME)
Potamogeton pectinatus	12	62.50	3.00	17.07	1.35	(ME)
Aster tripolium	2	42.90	25.00	33.95	2.00	(E)
Cotula coronopifolia	1	42.90	-	-	1.07	(ME)
Chenopodium rubrum	4	40.00	35.00	36.87	1.32	(ME)
Scirpus tabernaemontani	8	37.50	8.00	18.14	1.06	(ME)
Samolus valerandi	3	37.50	20.00	25.83	1.83	(ME)
Sonchus arvensis	2	37.50	28.75	33.12	1.43	(ME)
Glaux maritima	1	37.00	-	-	4.35	(E)
Plantago maritima	2	32.50	27.50	30.00	5.22	(E)
Typha angustifolia	1	32.50	-	-	0.81	(O)
Triglochin maritima	2	30.00	4.50	17.25	0.70	(O)
Median Sodium Concentration (MSC)						
Zannichellia palustris	4	28.00	2.25	12.58	1.02	(ME)
Apium graveolens	4	27.50	12.00	19.25	0.65	(O)
Rumex hydrolapathum	1	25.00	-	-	0.82	(O)
Scirpus maritimus	3	22.50	8.63	14.29	1.00	(ME)
Juncus bufonius	1	22.50	-	-	1.80	(ME)
Apium nodiflorum	1	22.50	-	-	0.82	(O)
Ranunculus sceleratus	5	20.00	3.50	9.80	0.46	(O)
Low Sodium Concentration (LSC)						
Rumex crispus	1	19.50	-	-	1.57	(ME)
Atriplex patula	1	18.75	-	-	0.93	(O)
Callitriche intermedia	1	18.00	-	-	1.56	(ME)
Hordeum secalinum	3	17.50	5.00	12.00	0.99	(O)
Carex otrubae	6	17.50	1.63	7.92	0.45	(O)
Potamogeton crispus	2	16.50	8.50	12.50	0.59	(O)
Elodea canadensis	1	16.50	-	-		
Puccinellia distans	15	15.50	0.96	5.75	0.35	(O)
Puccinellia maritima	2	15.00	3.75	9.38	0.85	(O)
Eleocharis palustris	2	15.50	9.50	12.50	0.60	(O)
Tripleurospermum maritimum	1	15.50	-	-	1.05	(ME)
Cirsium vulgare	1	14.50	-	-		
Myriophyllum alterniflorum	1	14.22	-	-	1.18	(ME)
Ceratophyllum demersum	3	11.25	6.25	8.50	0.32	(O)
Myriophyllum spicatum	5	11.25	3.19	7.28	0.70	(O)
Festuca rubra	1	9.50	-	-	0.29	(O)
Typha latifolia	1	8.00	-	-	0.64	(O)
Agrostis stolonifera	3	7.38	1.50	3.96	0.39	(O)
Juncus acutiflorus	1	7.50	-	-	0.53	(O)
Juncus gerardii	4	6.00	4.00	5.50	0.25	(O)
Phragmites communis	4	6.25	0.46	4.18	0.19	(O)
Juncus effusus	1	5.50	-	-	0.36	(O)
Carex distans	2	5.25	1.50	3.38	0.25	(O)
Festuca arundinacea	2	5.13	4.75	4.94	0.25	(O)
Lemna gibba	1	4.25	-	-	0.21	(O)
Agropyron repens	3	3.75	1.00	2.42	0.15	(O)
Poa annua	1	3.50	-	-	0.13	(O)
Vulpia myuros	1	3.00	-	-	0.57	(O)
Tussilago farfara (leaf)	1	2.50	-	-	0.08	
Prunella vulgaris	1	2.50	-	-	0.02	

E = Euhalophyte ME = Mesohalophyte O = Oligohalophyte

c. Na^+ and K^+ ratios, (Table 5.2, Column 5).

There are many controversial reports about the uptake of sodium and potassium when plants are subjected to a wide range of salt concentrations. The behaviour of two cations may be different in the same species growing under different ecological conditions and uptake of these cations has been explained on the basis of a dual mechanism (Black 1960; Epstein et al. 1963; Epstein 1966; Rains et al. 1967; Osmond et al. 1968; Rains 1972). The first mechanism operates at low salt concentrations (below 0.5 mM) and its affinity for potassium is high, whereas System II absorbs most of the sodium ions and operates at a high salt concentration only (1mM and above). Whether either of these mechanisms or any other are operating in field conditions cannot be determined because in addition to salt concentrations many other factors are also operating simultaneously. As was shown by Rehman et al. (1975), plant materials from wet halophytes have more K^+ than the same from dry halophytes. Beadle et al. (1957) have also shown that for some species of Atriplex in Australia, there is preferential absorption for potassium rather than sodium from sodium-rich soil. Rogonese (1951) has also shown that potassium is present in much greater proportion than sodium in the plants from the Salinas Grandes of Argentina. However, it is generally believed (Waisel 1972) that halophytic species usually exhibit a clear preference for sodium over potassium and rates of sodium uptake are usually high. The results of the analysis for sodium and potassium of various plants sampled are given in Appendix IVa,b. and Na : K ratio for each species on the basis of mean average sodium and potassium present in each species along with the number of analyses for each species is also given in Table 5.2. (Column 5). Potassium is generally very low in concentration as compared to sodium and the range of Na:K ratio in the soil is from 10:1 to 200:1 and even in some cases up to 800:1 or more, but the maximum Na:K ratio encountered in the shoot is 5.23:1. In spite of luxury absorption of K^+ in many plants, if the Na:K ratio is taken as being indicative of a halophytic tendency, then inland plants of saline environment can be categorised accordingly:

Euhalophytic = shoots having an Na:K ratio of 2 or above
Mesohalophytic = shoots having an Na:K ratio of between 1 and 2
Oligohalophytic = shoots having an Na:K ratio of 0.1 to 1.

In glycophytes the Na:K ratio is about 0.1:1 (Allen 1974). Whether there is any justification for these categories on the basis of $Na^+:K^+$ ratio in shoots is open to question. However, on the basis of these ratios, inland halophytes can easily be arranged in a descending order as Glaux maritima > Spergularia marina > Aster tripolium, and some unexpected results such as the ratios for Puccinellia maritima and Juncus gerardii may be due to either the small number of analyses undertaken or some very special mechanism for ion transport that may be present in these species.

d. $\frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+}}$ ratio in the shoots of plants to indicate a range of saline and alkaline tolerance.

Some plants analysed from the inland saline environments seem to show a very wide ecological amplitude for the accumulation of cations. Potamogeton pectinatus, Zannichellia palustris and Puccinellia distans, on one hand, can accumulate quite high sodium concentrations, while on the other hand, they seem to grow equally well in alkaline habitats, and calcium concentrations in the shoots may be higher than sodium. For example, the calcium concentration range in Potamogeton pectinatus is from 2.25 to 117.50 mg/gram in contrast to sodium from 3.00 to 62.50 mg/gram and for Zannichellia palustris the range of calcium is from 32.50 to 75.10 mg/gram as compared to a sodium range of 2.25 to 28.00 mg/gram. Thus, these plants may be regarded as strong halophytes as far as sodium tolerance is concerned, but, alternatively, they show a strong tendency for alkaline habitats. Hence, the term 'Alkalohalophyte' is suggested for such plants. Therefore, a ratio of monovalent to divalent cations present in the shoot can be taken as a measure to express the range of saline and alkaline tolerance. The $\frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+}}$ ratio in every individual plant sample analysed is calculated and in Table 5.3. a maximum and a minimum ratio encountered in each species is given. The maximum figure could show the maximum halophytic tendency as compared to the minimum which shows the maximum alkaline tendency. In Table 5.3. the mean of ratios and the number of analyses undertaken for each species is also given. Thus, Puccinellia distans shows an 8.38 maximum ratio and 0.12 minimum ratio, figures which indicate that this species can be a halophyte, but may also tolerate alkalinity. Hence, it is termed an alkalohalophyte. Plants where both maximum and minimum ratios are less than 1 show a strong alkaline tendency and are thus labelled as alkalophytes. Where the minimum ratio is above 1.5 and the maximum above 4.5 a strong preference for sodium uptake is shown, hence, these species may be regarded as true halophytes. However, these ratios and ranges also show the ecological

TABLE 5.3.

The ratios of monovalent (Na^+ and K^+) to divalent (Ca^{2+} and Mg^{2+}) cations in the shoots.

Species (ordered according to maximum ratios)	Number of analyses	Max.ratio in a plant	Min.ratio in a plant	Mean of ratios	
Phragmites communis	4	14.98	1.51	6.37	(H)
Spergularia marina	12	14.02	1.39	6.37	(H)
Juncus gerardii	4	12.12	0.74	4.43	(H)
Hordeum secalinum	3	11.66	1.46	6.66	(H)
Chenopodium rubrum	4	8.69	1.92	4.04	(H)
Puccinellia distans	15	8.38	0.12	3.64	(AH)
Atriplex hastata	17	8.33	1.59	4.05	(H)
Potamogeton pectinatus	12	8.27	0.08	1.48	(AH)
Triglochin maritima	2	8.18	3.18	5.68	(H)
Carex otrubae	6	7.84	2.08	4.29	(H)
Eleocharis palustris	2	7.92	0.88	4.39	(AH)
Scirpus maritimus	3	6.82	5.11	6.16	(H)
Festuca rubra	1	6.33	-	-	-
Festuca arundinacea	2	6.27	1.76	4.01	(H)
Aster tripolium	2	6.22	3.59	4.91	(H)
Scirpus tabernaemontani	8	6.08	1.160	3.53	(H)
Puccinellia maritima	2	5.68	1.58	3.63	(H)
Cotula coronopifolia	1	5.65	-	-	
Sonchus arvensis	2	5.19	2.06	3.62	(H)
Agropyron repens	3	4.51	1.51	2.68	(H)
Ranunculus sceleratus	5	4.24	0.88	2.10	(AH)
Rumex crispus	1	4.16	-	-	
Poa annua	1	4.09	-	-	
Agrostis stolonifera	3	3.39	0.85	1.96	(AH)
Glaux maritima	1	3.46	-	-	
Ceratophyllum demersum	3	3.14	0.52	1.50	(AH)
Juncus bufonius	1	2.93	-	-	
Carex distans	2	2.93	1.57	2.25	(H)
Apium graveolens	4	2.62	0.98	1.68	(AH)
Typha angustifolia	1	2.39	-	-	-
Juncus effusus	1	2.65	-	-	-
Plantago maritima	2	2.52	2.00	2.26	(H)
Samolus valerandi	3	2.51	2.22	2.41	(H)
Rumex hydrolapathum	1	2.09	-	-	-
Vulpia myuros	1	1.79	-	-	-
Callitriche intermedia	1	1.75	-	-	-
Tripleurospermum maritimum	1	1.51	-	-	-
Atriplex patula	1	1.46	-	-	-
Apium nodiflorum	1	1.47	-	-	-
Myriophyllum alterniflorum	1	1.52	-	-	-
Typha latifolia	1	1.07	-	-	-
Zannichellia palustris	4	0.83	0.41	0.556	(A)
Myriophyllum spicatum	5	0.82	0.103	0.402	(A)
Tussilago farfara	2	0.73	0.31	0.51	(A)
Cirsium vulgare	1	0.66	-	-	
Potamogeton crispus	3	0.53	0.52	0.53	(A)
Elodea canadensis	1	0.40	-	-	(A)
Lemna gibba	1	0.46	-	-	(A)
Prunella vulgaris	1	0.11	-	-	(A)

A = Alkalophyte AH = Alkalo halophyte H = Halophyte amplitude for the species and it is easy to determine the type of habitat in which they could be encountered.

D. Conclusions.

The following conclusions can be drawn from the previous observations:

1. A clear distinction between halophytes and glycophytes cannot always be made in the field.

2. Many species traditionally regarded as glycophytes were found growing in association with halophytes and examples are available in the phytosociological work presented in Chapter 4.

3. It is a number of adaptive (both ecological and physiological) features, very often quantitative, such as the five methods previously outlined which enable an accurate definition of a halophyte. These methods clearly define the ecological amplitude of the halophytes commonly encountered in the British inland saline habitats.

4. However, working on all the five methods is a laborious and time-consuming task. Therefore, for a broad and general ecological view the determination of the relative concentrations of the cations Na^{+}, K^{+}, Mg^{2+}, Ca^{2+} in the habitat provides a broad indication about the type of plants growing in these habitats.

5. The use of five methods provides a good basis for clearly defining the eco-physiological affinities of any species and it becomes easy to select species for any further work under controlled glasshouse and laboratory conditions. For example, the following five species are classified on the basis of these measures (see Table 5.4.)

Table 5.4.

	Na^+ in soil	Na^+ accumulating capacity	Na^+ concentration	Na^+:K^+ ratio	Monovalent-Divalent ratio
Puccinellia maritima	Meso-euhalophyte	Low Accumulating Capacity	Low Sodium Concentration	Oligohalophytic	Halophyte
Puccinellia distans	Meso-euhalophyte	Low Accumulating Capacity	Low Sodium Concentration	Oligohalophytic	Alkalohalophyte
Aster tripolium	Meso-euhalophyte	Median Accumulating Capacity	High Sodium Concentration	Euhalophytic	Halophyte
Cotula coronopifolia	Mio-halophyte	High Accumulating Capacity	High Sodium Concentration	Mesohalophytic	Halophyte
Ranunculus sceleratus	Mio-halophyte	Low Accumulating Capacity	Low Sodium Concentration	Oligohalophytic	Halophyte

Hence, Puccinellia distans (on the basis of these measures) is an alkalohalophyte which can tolerate more divalent ions as compared to Aster tripolium which is a euhalophyte; as compared to Cotula coronopifolia, a meso-halophyte with a capacity to accumulate more sodium ions: and Ranunculus sceleratus a very low salt-tolerant species, an oligohalophyte with a slight tendency towards alkalinity.

The four plants thus possess a range of eco-physiological features which provide a detailed basis for further investigation under controlled culture experimental conditions.

CHAPTER 6

AUTECOLOGICAL STUDIES IN THE GROWTH, SALINITY TOLERANCE AND CATION ACCUMULATION OF SELECTED HALOPHYTES

A. Introduction

Among the many ecological and physiological characters which distinguish halophytes from glycophytes, growth in response to salinity, the amount of various cations taken up and their ratios in the plant parts are useful and meaningful features to study. Whereas, it is generally accepted that salts in the soil solution cause retardation in the growth of glycophytes, it has long been known that a certain concentration of salts in a growth medium may actually stimulate halophyte growth. There is no paucity of literature on this subject, in which growth and cation uptake of many plants under controlled conditions have been studied. The stimulation of growth in halophytes by salts, particularly NaCl is shown by many workers (Montfort & Brandrup 1928; Hayward 1956; Williams 1960; Black 1960; Greenway 1968; Chatterton & KcKell 1969; Gale *et al* 1970). Some workers, such as Brownell (1965) and Brownell & Crossland (1972) have reported sodium as an essential micronutrient for some halophytes while, on the other hand, sodium and chloride ions are considered toxic to salt-susceptible plants (Hayward & Long 1943; Magistad *et al* 1943; Bernstein & Hayward 1958; Hayward & Bernstein 1958; Nieman 1962; Strognov 1964; Levitt 1972). Similarly, Proctor (1970) has shown the toxicity of magnesium, when *Agrostis stolonifera* was grown in water culture solutions.

The growth of agricultural crops and wild halophytes have been studied under controlled conditions, but only a few of them are of relevance to the present study. The variety of growth responses may be best illustrated by a series of examples : growth of *Zea mays* dropped more or less linearly with the increase in salinity of the medium (Montfort & Brandrup 1928) and almost the same is true in the case of the tomato (Ashby & Beadle 1957) and other glycophytes; growth of sugar beet has been demonstrated by Ulrich & Ohki (1956) and El Sheikh *et al* (1967) to increase with the addition of sodium chloride in culture solutions; growth of *Aster tripolium* by the addition of potassium in the saline media was substantially improved (Baumeister & Schmidt 1962); growth of *Salicornia oliviera* and *Salicornia ramosissima* was greatest when 2-3% NaCl was present in the medium (Halket 1915) and, similarly, growth of *Salicornia bigolovii* is stimulated by the addition of NaCl (Webb 1966). Other experiments on taxonomically related species have demonstrated the different growth responses to a range of culture solutions of varying molarity. For example, *Atriplex inflata* and Atriplex nummularia show increase in their dry matter up to a concentration of 0.6M NaCl (Ashby & Beadle 1957), while that of Atriplex hastata is severely inhibited in concentrations above 0.3M NaCl (Black 1960); Atriplex halimus shows increase in growth both in NaCl and KCl, but addition of KCl in NaCl results in more growth than either KCl or NaCl alone (Mozafer et al 1970a). Many species of Suaeda are known to tolerate a high concentration of NaCl and thus show better growth than in non-saline solutions. Only at high salinity is Glaux maritima reduced in growth and at 300mM NaCl concentrations, some vegetative growth still occurs, but optimum growth under slightly saline conditions can neither be decided nor denied (Rozema 1975). Maritime populations of Agrostis stolonifera and Juncus gerardii when grown in sand culture with the addition of seawater resulted in the reduction of growth in Agrostis stolonifera, while Juncus gerardii was not significantly affected (Rozema et al 1977).

The mineral nutrition of plants under saline conditions has been exhaustively reviewed by Rains (1972), and Waisel (1972) has also dealt with this problem with specific reference to halophytes. From the preceding review and from these two extensive reviews it is obvious that there have been few detailed eco-physiological growth experiments on species of inland saline habitats, and only a small amount of work on those halophytes from coastal sites which also occur inland. With these factors in mind, the halophytic tendency of few species from inland saline sites was investigated in terms of growth and cation accumulation in culture solutions of varying concentrations of NaCl and KCl and $MgCl_2$.

B. Experimental Design.

The detailed ecological study of the plants of inland saline environments, as given in Chapter 5, provided the field basis for the culture experiments. Analysis of the cation concentrations of plants growing under field conditions, analysis of the amount of sodium present in the associated soil, the calculation of $Na^+:K^+$ ratio in the shoots and the range of salinity and alkalinity tolerated by the species provided a sound data set for the choice of species for culture experiments. It soon became obvious that many of the species tolerate a range from low to high level of salts and that perhaps salt level plays an important role in the distribution and abundance of these species in the field. The main question that arises concerns the correlation of field salt tolerance and toxic levels with those manifest under controlled conditions in the glasshouse and the laboratory. It is upon these ecological points that experiments are primarily based and also upon the well-known feature that the physiological responses to added salt are twofold :

i. growth of certain species is increased with appropriate salt levels;

ii. growth of other species is limited to a greater or lesser extent by added salt.

Thus, on the basis of these ecological and physiological premises the experiments were designed and carried out.

a. Types of Plant Chosen and Seed Sources.

On the basis of the analysis of halophytic tendency shown under field conditions (Chapter 5, Table 5.4) the following four plant species were chosen as being representative of the range of halophyte present in the inland habitats.

(i) Ranunculus sceleratus - an oligohalophyte
(ii) Cotula coronopifolia - a stenohaline, mesohalophyte
(iii) Aster tripolium - a euhaline, preferential halophyte
(iv) Puccinellia distans - an alkalohalophyte

i. Ranunculus sceleratus L. Ranunculus sceleratus is an annual plant species, found in muddy ditches and sides of ponds and a saline Ranunculus sceleratus Nodum is described in Chapter 4. The phytosociological and ecological characters of the nodum are given in Table 4.24a, b. In Tables 5.1 and 5.2 (Chapter 5) are given sodium levels in associated soils and in shoots. The experimental studies utilized the seedlings about two weeks old from Mickletown Marsh, where it was growing as a co-dominant with Cotula coronopifolia. At this site, the sodium range in the soil was from 0.66 mg/gram to 2.49 mg/gram and it was 0.66 mg/gram in the associated soil of Ranunculus sceleratus.

ii. Cotula coronopifolia L. The plant is an annual species, alien to in this country, is found in sandy marshes, and is rare. The Cotuletum coronopifoliae association is described in Chapter 4 and its phytosociological and ecological characters are given in Table 4.11a, b. The present study utilised the seeds collected from Mickletown, West Yorkshire in October 1976. The sodium concentration in the associated soil was 2.49 mg/gram and the sodium concentration in the leaves was 42.90 mg/gram.

iii. Aster tripolium is a perennial plant species common in salt marshes. An Aster tripolium nodum is described in Chapter 4, and its phytosociological and ecological characters are given in Table 4.14a, b. The glasshouse studies utilised the seeds collected from Watch Lane, Sandbach in March 1977. The sodium concentration in the soil was up to 14.25 mg/gram and the sodium concentration in the shoots was 42.90 mg/gram.

iv. Puccinellia distans (L) Parl. is a perennial species common in salt marshes and on saline and alkaline industrial wastes. The association Puccinellietum distantis has numbers of sub-associations and these are described in Chapter 4 (Table 4.22). In eco-physiological studies the seeds used were collected from Silverwell on 16th August 1977.

b. Selection of Salts and their Concentrations.

Most of the studies concerning the salt tolerance of any particular species have consisted of subjecting the plants in solution cultures to to high concentrations of different salts of either sodium or potassium. Salts used are mostly chloride or sulphate and very rarely any other. The salts used in these experiments were Chloride of sodium, potassium and magnesium. In some inland industrial waste lagoons magnesium concentrations were very high, and appeared to be a factor limiting colonization and growth. Thus, $MgCl_2$, NaCl and KCl were selected and their effect on the growth and cation accumulation were studied.

A very wide range of concentrations of these salts were used. In each experiment, the following series of concentrations were used : 0, 0.005M, 0.01M, 0.02M, 0.05M, 0.1M, 0.2M, 0.3M, 0.4M, NaCl or $MgCl_2$.

This range of concentrations was used for three reasons :

(i) to determine the actual concentrations at which maximum growth occurs;

(ii) to investigate the toxic levels of NaCl and $MgCl_2$ through the observation of growth increase or decrease relative to increase in salt concentrations;

(iii) to observe the minimum and maximum Na^+ and Mg^{2+} accumulation in the shoots and roots at different concentrations.

On the basis of field analysis, it was assumed that hardly any of these species will tolerate a concentration of NaCl and $MgCl_2$ above 0.4M, since most halophytes show maximum growth between 50mM NaCl to 150mM NaCl.

c. Measurement of Growth Features.

Most of the features concerned with the physiology of plants could be investigated through these experiments, because the experiments were planned and carried out with all possible care and attention. But, because the experiments were essentially eco-physiological in design, the following measurements were taken at harvest:

(i) Total biomass production at each concentration.

(ii) Total and mean fresh and dry weight of plant (both shoot and root separately) in each concentration; especially dry weight to show increase or decrease in growth at each concentration level.

(iii) Other morphological characters, such as shoot number, length and root length were measured, wherever possible, and general features such as chlorosis, flowering, secretion of salts, leaf area and succulence were observed, wherever possible.

(iv) Plants from each concentration of each experiment were analysed (both shoot and root separately) for Na^+, K^+, Mg^{2+}, Ca^{2+} and cations were expressed on a dry weight basis of shoot and root in mg/gram.

d. Aims of the Experiments.

The experiments were designed to produce a series of results on the autecological characters of four selected halophyte species from inland saline sites. Specifically, the aims were as follows:

(i) the definition of the growth curves of the species in response to NaCl and $MgCl_2$;

(ii) a study of retardation of growth in increasing concentrations of NaCl and $MgCl_2$ as compared to control conditions;

(iii) the investigation of which is the more toxic salt and at which concentration NaCl and $MgCl_2$ become toxic to the test species;

(iv) the definition of the conditions under which the maximum accumulation of sodium and magnesium occur in both root and shoot and Na^+/K^+ ratio;

(v) the investigation of whether there is selective absorption of ions and the behaviour of divalent cations.

C. Experimental Methods

a. Growth media.

Both water culture and sand culture were used in the experiments. Sand culture was only used in the preliminary investigations concerning the selection of salts and their tolerance ranges. All other experiments were carried out using water culture. All solutions were prepared according to the formula for solution I of Hoagland & Arnon (1938), except ferrous sulphate was used instead of ferric tartrate. The chemical composition of Solution I of Hoagland & Arnon is as follows : (all concentrations in gms/litre^{-1})

KNO_3 - 0.51
$Ca(NO_3)_2$ $4H_2O$ - 1.18
KH_2PO_4 - 0.14
$MgSO_4 \cdot 7H_2O$ - 0.49
$FeSO_4$ $7H_2O$ - 0.005

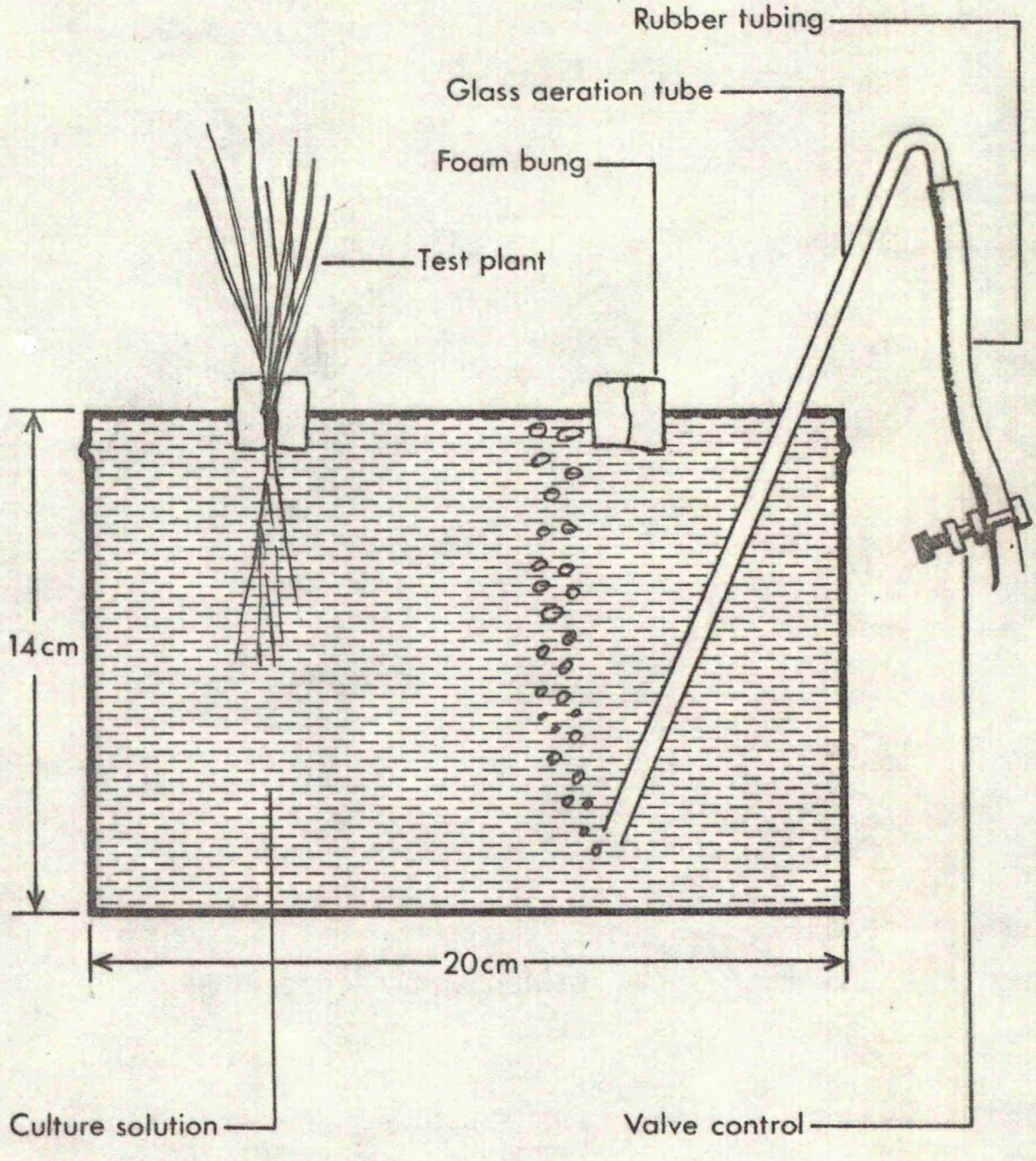
+ 1cc/litre of a solution containing

H_3BO_3 0.6
$MnCl_2 \cdot 4H_2O$ - 0.4
$ZnSO_4$ - 0.05
$CuSO_4 \cdot 5H_2O$ - 0.05
$H_2MoO_4 \cdot 4H_2O$ - 0.02

To the base of one strength of the above solution NaCl, KCl or $MgCl_2$ was added in required quantities to give the following series: 0, 0.005M, 0.01M, 0.02M, 0.05M, 0.1M, 0.2M, 0.3M, and 0.4M of $NaCl_2$ or $MgCl_2$ (0 = Hoagland solution only).

In sand culture, pots were irrigated twice and, later on, thrice a week with stock solutions, and at the end of every week were thoroughly flushed with distilled water to remove the excess accumulated nutrient salts. The sand cultures proved very laborious and were subjected to greater chance of contamination and so were not used in all the subsequent experiments. Water cultures were used in the experiments concerning NaCl and $MgCl_2$ salinity tolerance and toxicity levels, and deionised water was used in the preparation of stock water culture solutions.

Figure 6.1   Diagram to show design of water culture experiment.


Rubber tubing
Glass aeration tube
Foam bung
Test plant
14cm
20cm
Culture solution
Valve control

In water culture, the solutions were contained in polythene culture vessels of 4 litre capacity. The culture vessels were enamelled outside thoroughly to exclude all light from the interior. The plants were suspended in the culture solution in a foam sheath at a density of seven plants per vessel, and a 24 hour continuous aeration system was used to aerate the solutions (Fig. 6.1). The culture solutions were topped up with deionised water whenever the level fell and all the solutions were changed after every fortnight (c.f. Ahmad & Wainwright 1977).

b. Plant Cultures.

In all experiments, the Cotula coronopifolia, Aster tripolium and Puccinellia distans seeds were germinated on sand, many times pre-washed with deionised water. The seedlings were transplanted to the culture solutions at the cotyledon stage. The seedlings were initially set into only Hoagland solution and when established, the salinity treatment was started. To avoid any osmotic shock, the higher concentrations were achieved by gradual addition at 1-6 day intervals (Black 1960; Rozema 1975). The time allowed for growth for every species in all experiments was 16 weeks, after which the plants were harvested. After every four weeks general observations on growth were taken.

c. Experiments and Timetable.

The experiments were carried out under the standard glasshouse conditions available at the Botany Department Experimental Gardens, i.e. artificial illumination for a 16 hour day length, a relative humidity of 80% and diurnal temperature range of 70-80°F. The series of experiments and timetable was as follows:

Series I : Preliminary Sand Culture experiments on the effect of NaCl, KCl and NaCl/KCl interaction on the growth and cation accumulation of Cotula coronopifolia and Ranunculus sceleratus. A series of six experiments.

Concentration range for C.coronopifolia 0 - 0.4M

Concentration range for R. sceleratus 0 - 0.3M

Duration - 25 January 1977 to 20 May 1977.

Series II : Water Culture Experiments on the effect of NaCl on the growth and cation accumulation of <u>Cotula coronopifolia</u> and <u>Aster tripolium</u>.

A series of two experiments on <u>C. coronopifolia</u> and <u>A. tripolium</u> using a concentration range 0 - 0.4M NaCl.

Duration - 23 May 1977 - 2nd September 1977.

Series III : Water Culture Experiments on the effect of $MgCl_2$ on the growth and cation accumulation of <u>Cotula coronopifolia</u> and <u>Aster tripolium</u>.

A series of two experiments for the concentration range 0 - 0.4M $MgCl_2$

Duration - 23 September 1977 to 25th January 1978.

Series IV : Water Culture Experiments on the effects of NaCl and $MgCl_2$ on the growth and cation accumulation of <u>Puccinellia distans</u>.

A series of two experiments for NaCl and $MgCl_2$.

Concentration range 0 - 0.4M NaCl and $MgCl_2$

Duration - 5 January 1978 to 3rd May 1978.

d. Measurements of Morphological Characters and Sampling.

The morphological characters, such as flowering, maximum shoot length, mean shoot length, root length and the number of shoots or tillers were measured wherever appropriate, and general features such as chlorosis, secretion of salts, leaf area and succulence were observed wherever possible, before harvest.

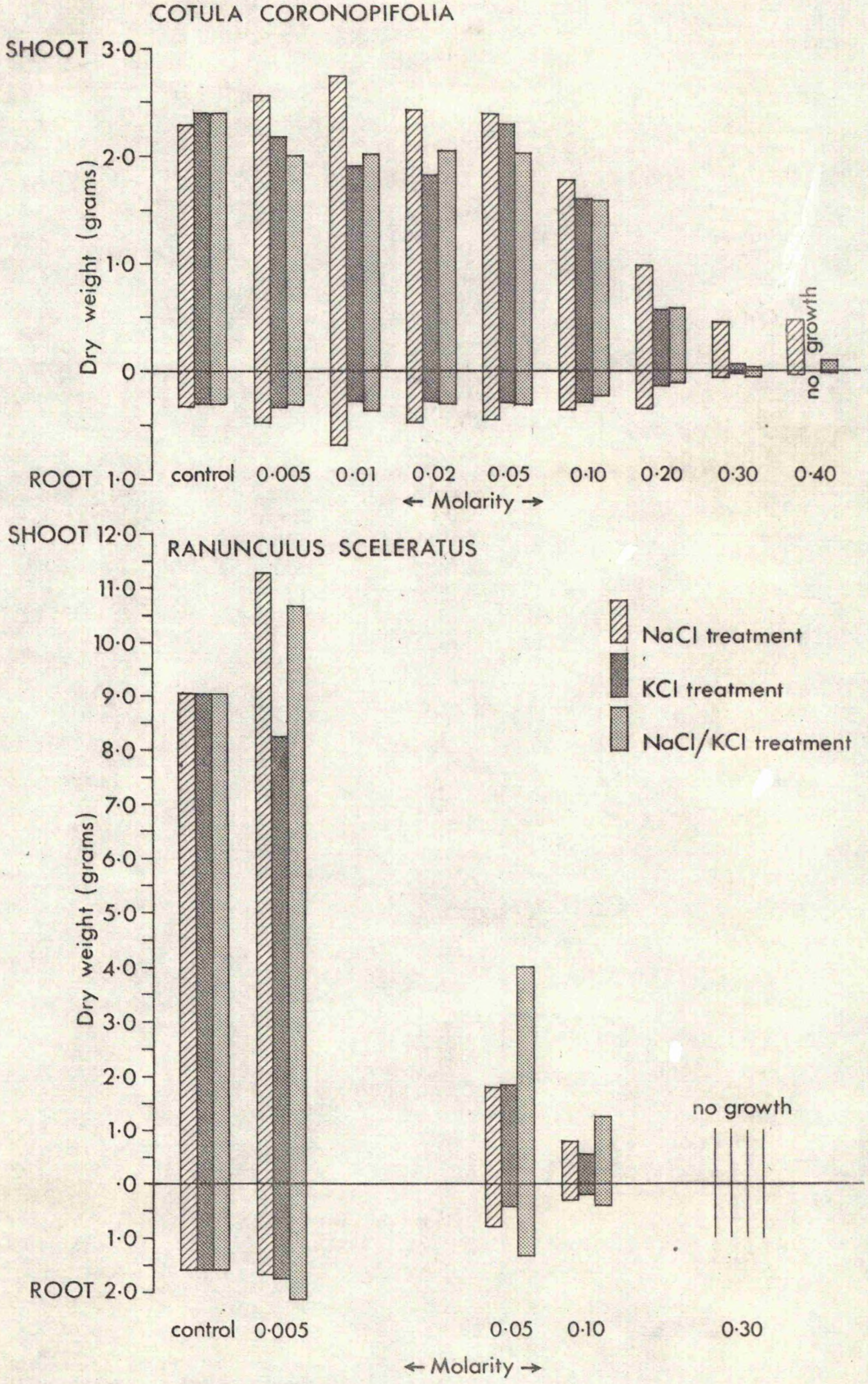
Growth was measured as total biomass production per vessel for each concentration, and mean dry weight of shoots and roots was calculated. On the day of harvest, the plants were brought into the laboratory and were thoroughly washed (roots three times) with deionised water. Fresh plants were weighed, then the roots and shoots separated and weighed, and then, oven dried at 80°C for 12 hours. The oven dried shoots and roots of each plant for every salt concentration were weighed and results are expressed as mean and standard error of all plants grown in each solution.

e. Root and Shoot Analysis.

The detail of extraction procedure and analysis is given in Chapter 3.

Figure 6.2 Comparative growth of *Cotula coronopifolia* and *Ranunculus sceleratus* at varying concentrations of NaCl, KCl, and NaCl/KCl interaction in Sand Culture.

(Experimental Series I cf. Table 6.1)


COTULA CORONOPIFOLIA
SHOOT 3·0
2·0
1·0
0
ROOT 1·0
Dry weight (grams)
no growth
control
0·005
0·01
0·02
0·05
0·10
0·20
0·30
0·40
← Molarity →
SHOOT 12·0
RANUNCULUS SCELERATUS
11·0
10·0
9·0
8·0
7·0
6·0
5·0
4·0
3·0
2·0
1·0
·0
1·0
ROOT 2·0
Dry weight (grams)
NaCl treatment
KCl treatment
NaCl/KCl treatment
no growth
control
0·005
0·05
0·10
0·30
← Molarity →

Both shoots and roots from each experiment for each solution were extracted separately and analysed for four cations, Na^+, K^+, Mg^{2+}, Ca^{2+} and results are expressed on a mg/gram dry weight basis.

D. Results and Discussion

a. Growth.

(i) Results from sand culture experiments (Series I).

The preliminary investigation for the selection of tolerance ranges yielded very interesting results. Initially, Cotula coronopifolia and Ranunculus sceleratus were grown in NaCl, KCl and NaCl and KCl in 0.05M equimolar concentrations e.g. 0.1M equimolar NaCl/KCl (0.05M NaCl + KCl). The growth results from these six experiments in this series are shown in Table 6.1 and Figure 6.2, where the growth is expressed as a mean dry weight of the four best plants grown. From the results it may be seen that the growth of Cotula coronopifolia was stimulated by low levels of NaCl, while KCl seemed to have a depressive effect. At every concentration, the growth of both shoot and root was less in the KCl and NaCl/KCl treatments than in the NaCl treatment. Shoot growth of Cotula coronopifolia was best in 0.01M NaCl, and roots also grew best at this concentration. However, shoot growth was greater than in the control in 0.05 M NaCl, while roots grew well to the 0.2M NaCl level. The commencement of shoot growth reduction was noted above 0.05M NaCl, while reduction of root growth began above 0.2M NaCl. The growth reduction between 0.05M and 0.1M NaCl was about 45%, while at 0.3M NaCl it was only about 20% as compared to the control. However, the plants can survive a salinity of NaCl up to 0.4M at the expense of a tremendous decrease in both shoot and root growth.

The growth of Ranunculus sceleratus dropped in a more or less linear progression with increase in salinity of the culture solutions. It was slightly increased (by about 20%) in 0.005M NaCl. At the 0.05M NaCl level it was only 10% as compared to that of the control. At the 0.3M NaCl level and also 0.3M KCl level and NaCl/KCl interaction all the plants died.

Thus, from these preliminary sand culture experiments several points, which influenced the design of the next series of water culture experiments, became clear:

1. The choice of Cotula coronopifolia as experimental material was validated and its halophytic tendencies well-illustrated; for the opposite reasons, the culture of Ranunculus sceleratus was abandoned;
2. Because of the comparatively poor growth of Cotula in the KCl and NaCl/KCl treatments as compared to NaCl, and the apparent absence of a NaCl/KCl substitute mechanism in the halophyte, only the NaCl treatment was chosen for future experiments;
3. A concentration range of 0.005M to 0.4M was thus selected for the water culture experiments.

(ii) Results from water culture experiments (Series II,III,IV).

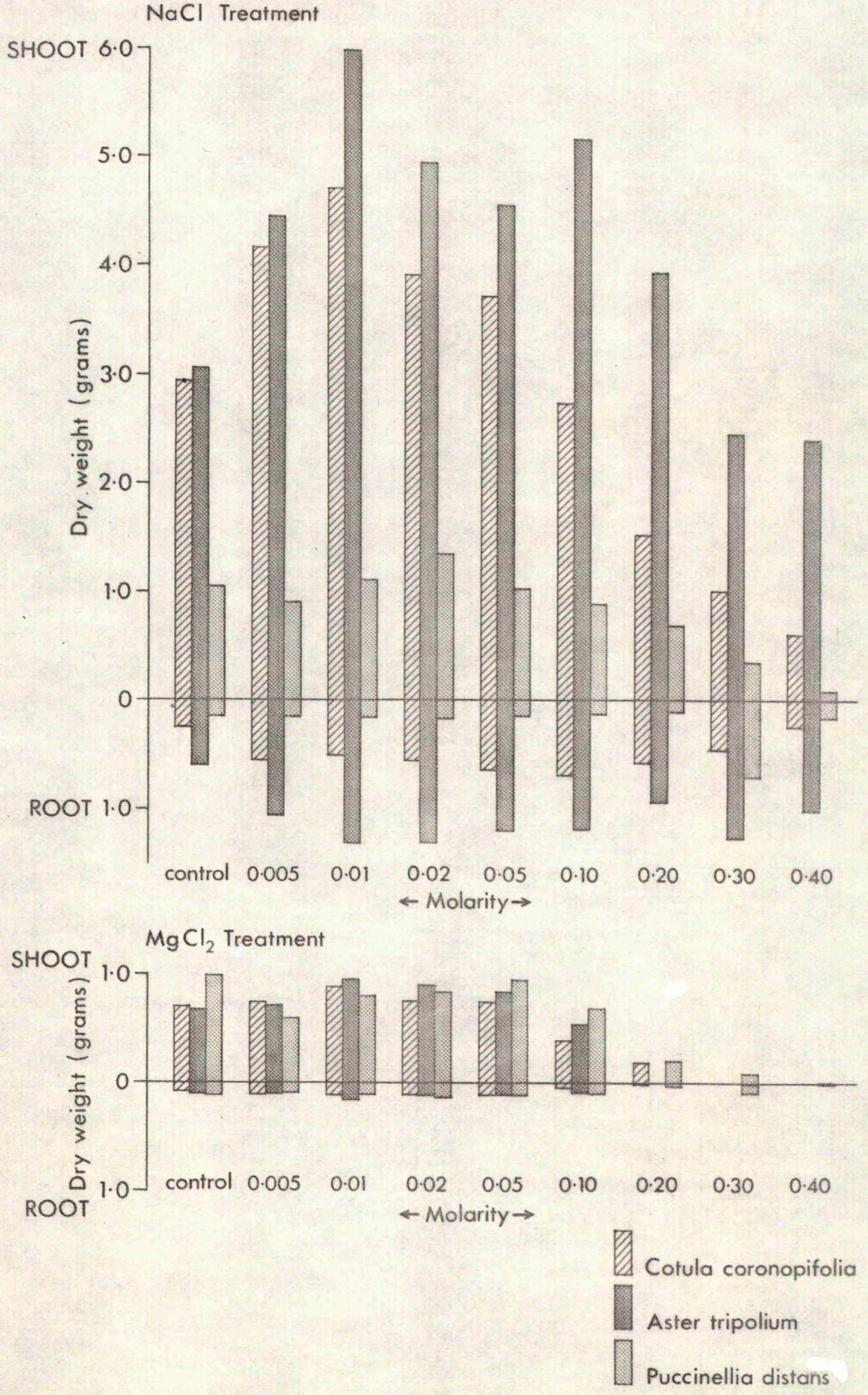
For the previously mentioned reasons, three series of water culture experiments were designed to study the comparative growth and cation accumulating capacity of Cotula coronopifolia and two well-known halophytes Aster tripolium and Puccinellia distans. In these series of experiments, an $MgCl_2$ treatment was introduced, mainly because magnesium appears to be a limiting factor in colonization and growth in inland saline sites (see Chapter 2; Mirza & Shimwell 1977).

I. The Comparative Growth of the Three Species in different Concentrations of NaCl (Table 6.5a,6.6a,6.9a; Figure 6.3).

The growth results of the series II experiments are given in Table 6.5a and 6.6a, where details of the influence of NaCl on the total biomass production, growth and other morphological characters, when applied in different concentrations are provided. In the case of Cotula coronopifolia, the results from water culture confirm those from sand culture. The concentration range 0.005M to 0.05M NaCl causes a significant increase of the values of all the above growth parameters and, therefore, it is obvious that optimum growth is under slightly saline conditions. The results also confirm that the toxicity of sodium chloride, in the form of reduction in shoot growth starts after 0.05M NaCl and that of roots after 0.3M NaCl. There was a decrease in the growth of shoot (dry weight) in 0.2M NaCl (about 47%); 0.3M NaCl (about 66%) and in 0.4M NaCl (about 80%), while the root growth was better than the control up to

Figure 6.3 Comparative growth of *Cotula coronopifolia*, *Aster tripolium* and *Puccinellia distans* at varying concentrations of NaCl and $MgCl_2$ in water culture.

(Experimental Series II,III,IV; cf. Tables 6.5 - 6.10)



NaCl Treatment
SHOOT
6·0
5·0
4·0
3·0
2·0
1·0
0
ROOT
1·0
Dry weight (grams)
control
0·005
0·01
0·02
0·05
0·10
0·20
0·30
0·40
← Molarity →
MgCl2 Treatment
SHOOT
1·0
0
ROOT
1·0
Dry weight (grams)
control
0·005
0·01
0·02
0·05
0·10
0·20
0·30
0·40
← Molarity →
Cotula coronopifolia
Aster tripolium
Puccinellia distans

concentrations of 0.3M NaCl in contrast to sand culture, where it was substantially reduced in this concentration.

In the case of Aster tripolium, added NaCl appears to be favourable for most of the characters measured. Total biomass per pot was less than in the control only at 0.4M NaCl concentration, in contrast to Cotula coronopifolia, where it was at the 0.2M NaCl level. Optimum shoot growth of Aster tripolium occurred when plants were grown in a salt solution of 0.01M NaCl, but the range 0.005M to 0.2M NaCl causes a significant increase of shoot and root growth (on dry weight basis). The commencement of shoot growth reduction may be seen above the 0.2M NaCl concentration, in 0.3M NaCl solution it decreases by 20% and in 0.4M NaCl by 25%. Root growth was more than in the control up to the 0.4M NaCl concentration.

Thus, a comparison of salt tolerance as indicated by shoot and root growth of Aster tripolium and Cotula coronopifolia reveals that the former species is more salt tolerant in high concentrations than the latter, and the reduction of growth in 0.4M NaCl is about 60% more in Cotula coronopifolia than is Aster tripolium.

Puccinellia distans was also subjected to the same range of NaCl concentrations as the other species (Series IV). The details of the growth parameters influenced by the various concentrations of NaCl in water cultures are shown in Table 6.9a, from which it can be seen that low concentrations from 0.005M to 0.02M NaCl actually increase the total biomass production per pot and the growth on a dry weight basis. It seems that optimum shoot growth occurs in the range 0.005M to 0.02M NaCl, while roots grow best in non-saline solution. The toxicity of NaCl starts in 0.05M, where shoot growth is reduced only slightly and in 0.1M NaCl shoot growth reduction is about 16%; in 0.2M 34%; in 0.3M NaCl 67% and in 0.4M NaCl 92%. Hence, the species survives in high salinity at the expense of a tremendous decrease in growth in terms of both fresh and dry matter.

II. The Comparative Growth of the Three Species in Different Concentrations of $MgCl_2$ (Table 6.7a, 6.8a, 6.10a;Figure 6.3)

The details of total biomass production per pot and growth of shoots and roots (on dry weight basis) is given for Cotula coronopifolia in

Table 6.7a; Aster tripolium in Table 6.8a and for Puccinellia distans in Table 6.10a. In Cotula coronopifolia, there is a slight increase in growth from 0.005 to 0.05M $MgCl_2$. The maximum increase in shoot growth is about 18% in a solution of 0.01M $MgCl_2$ in contrast to the NaCl treatment where an increase of 40% in the same concentration is seen. At higher concentrations of $MgCl_2$, plants were severely affected and, in 0.01M $MgCl_2$ solution, growth was reduced by 45% ; in 0.2M $MgCl_2$ solution growth was reduced by 80% and the plants died in 0.3M $MgCl_2$ and above.

Aster tripolium showed an almost similar pattern of growth to Cotula coronopifolia. The dry matter of shoot material increased from 0.005M $MgCl_2$ to 0.05M $MgCl_2$ only slightly, and was increased to a maximum of about 44% in 0.01M $MgCl_2$ as compared to 95% in the same concentrations of NaCl. Roots also grew slightly better in these lower concentrations. In 0.1M $MgCl_2$ solution, the growth was reduced to about 20% and in 0.2M $MgCl_2$ it was tremendously decreased and the plants could not survive concentrations above 0.3M $MgCl_2$.

The growth pattern of Puccinellia distans in the various concentrations of $MgCl_2$ was more interesting. There was not a marked increase in dry matter in shoot growth, though total biomass production was increased in 0.02M and 0.05M $MgCl_2$. Similarly, root growth was better in these ranges. However, the plants could stand concentrations of 0.4M $MgCl_2$ and growth of shoots and roots fell gradually. In 0.1M $MgCl_2$ the shoot growth was reduced by about 30%, in 0.2M $MgCl_2$ 77%; in 0.3M $MgCl_2$ 90% and in 0.4M $MgCl_2$ it was decreased by 98% i.e. plants could just tolerate this concentration of $MgCl_2$, but there was hardly any growth for about 12 weeks. Another interesting point to note was that Puccinellia distans could secrete salt at the 0.3M and 0.4M NaCl concentration levels, but there was no salt secretion at any $MgCl_2$ concentrations.

b. Observations on Flowering and other morphological Characters.

Flowering of Cotula coronopifolia took place under control and all levels of NaCl and KCl treatments, but not in $MgCl_2$ treatments. At 0.2M and 0.3M NaCl, there was a slight accumulation of a white crust of salt on some branches only. In 0.3M and 0.4M NaCl the leaves were short, thick and stout and brownish, other morphological characters such as shoot length and number of shoots per plant and mean root length in different NaCl levels are shown in Table 6.6a. The shoot number firstly increased with the increase in NaCl levels but it started to decrease at 0.1M NaCl and at 0.4M it was only 33% as compared to control growth. It was noted that in all salts (NaCl, KCl and $MgCl_2$) and at all levels, the growth of all plants (7 plants per pot) was almost uniform at their respective salt levels, in contrast to Aster tripolium, where plants in each level of NaCl and $MgCl_2$ showed variable growth. In the different levels of $MgCl_2$, plants were comparatively pale as compared to those of control. On the whole, there was less growth in all $MgCl_2$ concentrations as compared to NaCl concentrations, though the plants were grown for the same period of time in both salt treatments.

Flowering of the Aster tripolium took place under control and at all levels of sodium chloride. But, plants grown from the seeds from Watch lane, Sandbach, Cheshire were differentiated into tall, branched and flowering type (two to three plants in each pot), and comparatively short, branched and non-flowering in rest of the plants in each pot. There was no flowering at any level of $MgCl_2$. Other morphological characters such as fresh weight of shoots and roots; maximum shoot length, etc. are given in Table 6.5a. The plants growing in control conditions were pale compared to plants grown in other levels of NaCl and plants in 0.3M NaCl were comparatively more robust and green. The leaves at these concentrations were also comparatively thick but shorter than in other treatments. Plants growing at all the different levels of $MgCl_2$ were pale compared to control and growth per pot in each concentration was less in $MgCl_2$ compared to growth in similar NaCl levels.

There was no flowering of Puccinellia distans at any NaCl and $MgCl_2$ concentration, neither in the control. Other morphological characters, such as the number of tillers per plant, shoot length and root length in each NaCl treatment are given in Table 6.9a.

c. Concentrations of Cations in Shoots and Roots.

The cation composition of shoots and roots of the four species grown were strongly influenced by the salt types and their concentrations in the solution medium.

(i) Cotula coronopifolia, NaCl treatment: The results of this treatment are shown in Table 6.2 (Sand Cultures) and Table 6.6b (Water Cultures). In this plant preferential absorption of K^+ ions over Na^+ ions is clearly shown in 0.005M and 0.02M solutions, where the $Na^+:K^+$ ratio in the nutrient solutions is about 2:1; but K^+ is absorbed about three times more than Na^+ in the shoot. In low sodium concentrations, Na^+ is absorbed more by roots compared to shoots but at higher concentrations (0.1M - 0.4M NaCl) the Na^+ content of shoot material is either equal or more than in the roots. The absorption of Na^+ ions was increased as the Na^+ concentration in the medium was increased, and the absorption of K^+ was also affected. At the 0.1 M NaCl level, the ratio of Na^+ and K^+ is almost equal and afterwards, the absorption of K^+ dropped more quickly so that at the 0.4M NaCl concentration, the ratio of $Na^+:K^+$ in the shoot is about 4:1. The magnesium and calcium content of shoots and roots were decreased, as the NaCl concentration in the medium was increased and at 0.4M NaCl, magnesium is decreased by about 66% in roots and 75% in shoots compared to the control. The calcium content shows almost the same type of decrease. Another interesting point to note is that results for cation composition from sand cultures and water cultures are basically similar.

KCl treatment: The results of this treatment are shown in Table 6.3. The absorption of K^+ from solutions of high KCl concentration is so high that the plants are damaged, and are ultimately killed, as is clear from the results. The K^+ content in the roots is 341 mg/gram in 0.1M KCl, and perhaps this is the maximum tolerable before death, and in higher KCl concentrations are so damaged that absorption is less. The behaviour of divalent cations is almost similar to that in NaCl treatment but it seems that at higher KCl concentrations, their uptake is more severely reduced.

NaCl and KCl treatment: The results of this treatment, when Na^+ and K^+ are almost equimolar in external solutions are shown in Table 6.4. These results indicate that there is a preferential absorption of K^+ over Na^+. Toxicity of K^+ ions at higher levels (0.3M, 0.4M) is ameliorated by the presence of Na^+ ions, otherwise plants were killed when Na^+ was not given in KCl treatment. This is clear in the case of Ranunculus sceleratus, where even growth (dry matter) was more in this treatment as compared to the NaCl and KCl treatments. Otherwise, Ranunculus sceleratus also shows a similar cation absorption pattern as that shown by Cotula coronopifolia.

$MgCl_2$ treatment: The results of this treatment are given in Table 6.7b. One point to note is that absorption of Mg^{2+} by roots is about 5 times less than shoots absorption and it is at higher concentrations (0.1M $MgCl_2$) that absorption of Mg^{2+} is high. After this level, absorption is very high at the expense of other cations and plants are damaged. Calcium absorption is reduced to only 30% as compared to the control. K^+ absorption in low concentrations (0.005-0.05M $MgCl_2$) is slightly increased, and in higher concentrations is decreased substantially.

(ii) Aster tripolium: NaCl treatment: The cation concentrations of roots and shoots of Aster tripolium grown at varying concentrations of NaCl are shown in Table 6.6b. The uptake of K^+ is decreased even by the addition of a small amount of NaCl, but, in lower concentrations (0.005 to 0.05M NaCl), preferential absorption of K^+ is shown. In higher NaCl concentrations, Na^+ absorption is greater than K^+. Na^+ content in shoots and roots is almost equal or slightly less in roots. The magnesium content in shoots and roots is decreased by only 50% in 0.4M NaCl as compared to the controls, while Ca^{2+} content shows a slight increment.

$MgCl_2$ Treatment: The results of this treatment are shown in 6.8b. The absorption of magnesium increases with the increase in external solution, while calcium is slightly increased at low concentrations (0.005M $MgCl_2$), and then is decreased and in 0.1M $MgCl_2$. Calcium content is about 80% less in roots and 70% less in shoots as compared to the control. K^+ content shows a slight increment in shoots at low levels of $MgCl_2$, and then shows a decrease. The magnesium content is about 5 times higher in shoots than in roots and the Mg^{2+} ions are not luxuriously absorbed as is true for K^+ and Na^+. It appears that Mg^{2+} is more toxic than K^+ and Na^+ even at lower levels of ionic content.

(iii) Puccinellia distans : NaCl treatment: The results of this treatment are shown in Table 6.9b. The preferential absorption of K^+ over Na^+ is shown in lower NaCl concentrations (0.005 - 0.05M). At higher concentrations, Na^+ content is more, both in shoots and roots, as compared to K^+. The content of Na^+ in shoots is about twice as much as that of roots, but the Na^+ content of shoots (at 0.4M) is much less than in other test species i.e. 35.10 mg/gram as compared to Aster tripolium

87.50 mg/gram and Cotula coronopifolia 130.00 mg/gram. The Mg^{2+} and Ca^{2+} content decreases as the NaCl concentration in the medium increases.

$MgCl_2$ treatment. The cation content of roots and shoots of Puccinellia distans grown in varying concentrations of $MgCl_2$ is shown in Table 6.7b. The absorption of Mg^{2+} increases with increase of Mg^{2+} in culture solutions, and is about twice as high in shoots as in the root. As with sodium accumulation, Mg^{2+} accumulation is less in Puccinellia distans as compared to Aster tripolium and Cotula coronopifolia. K^+ is decreased with the increase of $MgCl_2$ in the medium and calcium is substantially decreased by 80% in roots at higher concentration (0.4M $MgCl_2$). The sodium content of shoot material is far higher compared to Mg^{2+} when plants from similar solutions are compared e.g. at 0.4M NaCl:Na^+ in shoot - 35.10 mg/gram; 0.4M $MgCl_2$: Mg^{2+} in shoot - 28.33 mg/gram.

As it has been previously mentioned, growth is either increased or decreased with added salt. Thus, simply according to the response of the test species Ranunculus sceleratus may be referred to as a glycophyte (growth is 90% reduced in 0.05M NaCl); Cotula coronopifolia is a mio-halophyte (growth is increased from 0.005 to 0.05M NaCl); Puccinellia distans is a mio-halophyte, but tolerant also of alkali salts; and Aster tripolium, a euhalophyte (growth is increased from 0.005 to 0.02M NaCl). Cotula coronopifolia and Aster tripolium are severely affected by Mg^{2+} ions. It appears K^+ enters all the test plants more rapidly than Na^+, when the K^+:Na^+ ratio in the solution is low, but at higher ratios Na^+ exceeds K^+ entry. In all the plants investigated, accumulation of K^+ is greater than Na^+ when the external concentration of NaCl was in the range 0.005 to 0.05M, (the K^+ concentration being constant in the Hoagland solution). It is interesting to note that the order of tolerance of sodium and magnesium of the investigated plants is the same as the order of the relative concentrations of their habitats. Another point to note is that Mg^{2+} toxicity seems to be balanced by the presence of potassium and calcium, hence their high uptake when the external concentrations of $MgCl_2$ were in the range 0.005 to 0.02M. At higher concentrations K^+ and Ca^{2+} uptake is severely cut down and increase of Mg^{2+} uptake is proportional to the increase in external solutions, while uptake of divalent ions is almost constant when external concentrations are low (0.005 to 0.01 M $MgCl_2$).

If cation concentration in the shoot is taken as an example to illustrate comparative accumulation of Na^+, K^+ and Mg^{2+} in Cotula coronopifolia, then in the external concentrations of 0.2M for all three ions the relative uptake is as follows:

K = 181 mg/gram

Na = 85 mg/gram

Mg = 31.25 mg/gram

Referring back to the figures for growth e.g shoot dry weight, it is clear that magnesium ions, even at low concentrations are by far the most toxic of the three ions.

E. Conclusions

Several important conclusions may be drawn from the preceeding results and discussion, concerning the halophytic tendencies and cation accumulation capacities of the four test species:

1. Ranunculus sceleratus shows only slight halophytic tendency - a feature manifest in its linear decrease in dry weight with increase in NaCl and KCl concentrations in culture solutions i.e. at 0.05M NaCl it was only 10% of that of the control.

2. Cotula coronopifolia is quite clearly a species capable of tolerating median saline treatments. This feature is exemplified by the fact that

   (i) it produced greater dry weight with added NaCl between 0.005M and 0.05M - the growth of shoots decreased by 47% in 0.2M, by 66% in 0.3M and by 80% in 0.4M NaCl;

   (ii) the addition of NaCl in KCl seemed to ameliorate the toxicity of K^+ ions at higher concentrations. Cotula coronopifolia is as tolerant of alkaline conditions as many other halophyte species, growth not being increased in $MgCl_2$ and toxicity becoming apparent at the 0.1M concentration. Levels of 0.3M and 0.4M $MgCl_2$ resulted in death of the plant.

3. Aster tripolium is quite clearly a species capable of tolerating highly saline treatments. This feature is exemplified by the fact that it produced greater dry weight with added NaCl between 0.005M and 0.2M NaCl. In 0.01M NaCl shoot growth was increased 95% as compared to the

control, and growth of shoots decreased by 20% in 0.3M and 25% in 0.4M NaCl.

Aster tripolium is as tolerant of alkaline conditions as Cotula coronopifolia, growth is not significantly increased in $MgCl_2$ and toxicity becomes apparent at the 0.1M concentration. Levels of 0.3M and 0.4M $MgCl_2$ resulted in death of the plants.

4. Puccinellia distans is a species capable of tolerating only low salt treatments. This is manifest by the fact that:

(i) it produced greater dry weight with added salt between 0.005M and 0.02M and growth of shoots decreased by 16% in 0.1M NaCl: 34% in 0.2M NaCl; 67% in 0.3M NaCl and 92% in 0.4M NaCl concentrations.

(ii) at higher concentration of NaCl i.e. 0.3M, 0.4M, it appears that shoots secrete excess of salts and hence increase tolerance.

Puccinellia distans is more tolerant of alkaline conditions than any other tested plants. Its growth was not only increased in low levels of $MgCl_2$ but it could also survive a high magnesium concentration, such as 0.4M.

5. The following general conclusions may be drawn about cation absorption:

(i) In all tested species, it appears that there is a preferential absorption of K^+ ions from solutions with the NaCl range 0.005 to 0.05M. At higher concentrations than this, absorption of K^+ is less compared to Na^+,

(ii) The absorption of K^+ ions from KCl solutions of high concentration is very high, e.g. 341 mg/gram in roots from a 0.1M KCl solution. This is such a high internal concentration that roots appeared to be damaged;

(iii) The divalent cations are not affected in 0.005M NaCl but at higher concentrations they show a decrease, though in Aster tripolium, Ca^{2+} decrease is not significantly affected by NaCl addition;

(iv) The absorption of Mg^{2+} at all $MgCl_2$ concentrations is usually not as high as compared to Na^+ in its respective concentrations. At 0.1M $MgCl_2$, calcium shoot uptake is cut down by 70% in Aster tripolium by 60% in Cotula coronopifolia, and by 80% in shoots of Puccinellia distans, at the 0.4M concentration.

TABLE 6.1

Series I : Results of Sand Culture Experiments.

Growth (mean dry weight) of *Cotula coronopifolia* and *Ranunculus sceleratus* at different concentrations of NaCl, KCl and NaCl and KCl interaction.

Salts	NaCl		KCl		NaCl + KCl (equimolar)	
Concentration	Root (grams)	Shoot (grams)	Root (grams)	Shoot (grams)	Root (grams)	Shoot (grams)
Cotula coronopifolia	*					
Control	0.33 ± 0.01	2.30 ± 0.15	0.31 ± 0.19	2.38 ± 0.02	0.31 ± 0.19	2.38 ± 0.02
0.005 M	0.49 ± 0.03	2.56 ± 0.41	0.34 ± 0.10	2.17 ± 0.04	0.32 ± 0.28	2.00 ± 0.12
0.01 M	0.69 ± 0.09	2.74 ± 0.21	0.29 ± 0.04	1.91 ± 0.08	0.37 ± 0.24	2.02 ± 0.15
0.02 M	0.49 ± 0.03	2.43 ± 0.35	0.29 ± 0.04	1.82 ± 0.11	0.30 ± 0.06	2.05 ± 0.05
0.05 M	0.45 ± 0.07	2.38 ± 0.07	0.29 ± 0.22	2.29 ± 0.01	0.32 ± 0.22	2.03 ± 0.02
0.1 M	0.36 ± 0.10	1.77 ± 0.13	0.29 ± 0.12	1.60 ± 0.04	0.23 ± 0.06	1.58 ± 0.02
0.2 M	0.35 ± 0.09	0.97 ± 0.21	0.13 ± 0.08	0.55 ± 0.02	0.11 ± 0.27	0.56 ± 0.05
0.3 M	0.06 ± 0.02	0.45 ± 0.15	0.02 ± 0.03	0.06 ± 0.01	0.05 ± 0.02	0.26 +
0.4 M	0.05 ± 0.01	0.59 ± 0.06	No growth		0.02 ± 0.004	0.10
Ranunculus sceleratus	*					
Control	1.60 ± 0.19	9.04 ± 0.43	1.60* ± 0.19	9.04 ± 0.43	1.60 ± 0.19	9.04 ± 0.43
0.005 M	1.67 ± 0.17	11.2[illegible] ± 1.01	1.77 ± 0.20	8.23 ± 0.78	2.14 ± 0.43	10.6 ± 0.90
0.05 M	0.80 ± 0.10	1.78 ± 0.30	0.43 ± 0.10	1.82 ± 0.32	1.33 ± 0.15	4.00 ± 0.40
0.1 M	0.31 ± 0.05	0.78 ± 0.10	0.20 ± 0.02	0.55 ± 0.05	0.42 ± 0.10	1.23 ± 0.12
0.3 M	No growth plants died		No growth plants died		No growth plants died	

*standard error of mean

TABLE 6.2

Series I : Results of Sand Culture Experiments (continued).

Cation concentrations (mg/gram dry weight in Root and Shoot material) of *Cotula coronopifolia* and *Ranunculus sceleratus* grown at different concentrations of NaCl.

Concentration	Root				Shoot			
	Na^+	K^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	Ca^{2+}	Mg^{2+}
Cotula coronopifolia								
Control 0	1.7*	90.00	7.26	2.20	0.70*	75.00	13.30	3.25
0.005 M	22.00	80.00	5.28	1.60	7.00	65.00	13.30	3.75
0.01 M	21.00	116.00	5.00	1.50	8.50	70.00	8.25	7.35
0.02 M	20.00	125.00	5.00	1.30	25.00	40.00	8.91	3.25
0.05 M	40.00	85.00	4.64	1.30	27.50	110.00	7.92	3.25
0.1 M	36.00	90.00	4.00	0.95	42.00	85.00	7.26	3.25
6.2 M	60.00	90.00	3.90	1.90	55.00	50.00	5.94	2.25
0.3 M	53.00	40.00	3.63	0.84	58.00	47.00	6.00	2.75
0.4 M	58.00	67.00	3.36	0.75	100.00	25.00	5.95	1.16
Ranunculus sceleratus								
Control	1.01*	115.00	8.58	2.75	0.35*	85.00	15.00	2.00
0.005 M	14.50	70.00	8.50	3.35	7.00	45.00	9.50	2.00
0.05 M	32.00	55.00	5.95	2.65	22.50	33.00	8.25	1.75
0.1 M	37.00	58.00	6.42	3.00	30.62	29.00	7.75	1.45
0.3 M	No growth. All plants died after treatment.							

* No Na^+ was added and the figures are perhaps due to contamination of solution or sand.

TABLE 6.3

Series I : Results of Sand Culture Experiments (continued)

Cation Concentrations (mg/gram dry weight in Root and Shoot material of *Cotula coronopifolia* and *Ranunculus sceleratus* grown at different concentrations of KCl.

Concentration	Root				Shoot			
	Na^{+}	K^{+}	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Ca^{2+}	Mg^{2+}
Cotula coronopifolia								
Control	1.7*	90.00	7.26	2.20	0.70	75.00	13.30	3.25
0.005 M	2.70	125.00	5.91	1.65	0.67	90.00	8.91	3.25
0.01 M	3.17	133.33	6.60	1.60	0.55	87.50	8.50	2.75
0.02 M	2.00	125.00	4.12	1.25	0.72	125.00	7.26	2.75
0.05 M	1.00	200.00	3.96	1.25	0.44	142.50	6.60	1.90
0.1 M	0.55	341.00	3.60	1.00	0.35	165.00	6.60	1.62
0.2 M	0.50	125.00	4.50	0.78	0.21	111.00	4.40	1.25
0.3 M		Plant material not sufficient for analysis					-	-
0.4 M		No growth					-	-
Ranunculus sceleratus								
Control	1.00 *	115.00	8.50	2.75	0.35	85.00	15.00	2.00
0.005 M	0.75	125.00	7.26	1.35	0.60	82.00	11.50	2.00
0.05 M	0.60	200.00	5.58	0.90	0.50	11.00	6.50	1.80
0.1 M	0.90	106.25	6.00	1.46	0.60	76.00	4.65	1.25
0.3 M	No growth. All plants died after treatment.							

* No Na* was added; the figures are probably due to contamination to solution or sand.

TABLE 6.4.

Series I : Results of Sand Culture Experiments. (continued)

Cation concentrations (mg/gram dry weight in Root and Shoot material of Cotula coronopifolia and Ranunculus sceleratus grown at different concentrations of interaction of NaCl and KCl.

Concentration	Root				Shoot			
	Na^+	K^+	Ca^{2+}	Mg^{2+}	Na^+	K^+	Ca^{2+}	Mg^{2+}
Cotula coronopifolia								
Control	1.7*	90.00	7.26	2.20	0.70*	75.00	13.30	3.25
0.005 M	14.00	65.00	4.85	1.25	9.50	87.00	10.33	2.50
0.01 M	12.00	100.00	5.46	1.60	10.25	87.00	10.68	2.00
0.02 M	15.00	90.00	5.28	1.70	11.25	102.00	8.9L	2.25
0.05 M	18.00	125.00	4.62	1.75	16.75	170.00	8.50	2.50
0.01 M	23.00	140.00	3.56	1.30	35.50	280.00	5.93	1.70
0.2 M	27.00	166.00	3.90	1.25	45.00	150.00	5.90	1.87
0.3 M	21.00	383.00	3.30	1.15	47.00	140.00	5.85	1.40
0.4 M	21.00	110.00	3.50	0.95	72.00	125.00	5.94	1.00
Ranunculus sceleratus								
Control	1.00*	115.00	8.58	2.75	0.35*	85.00	15.00	2.00
0.005 M	7.00	100.00	7.92	2.50	4.25	75.00	12.00	2.00
0.05 M	9.00	100.00	7.00	1.80	8.50	65.00	7.50	1.60
0.1 M	insufficient for analysis.				8.00	36.00	5.35	1.80
0.3 M	No growth							

* No Na^+ was added : the figures are perhaps due to contamination to solution or sand.

TABLE 6.5.

Series II : Results of Water Culture experiments on Aster tripolium NaCl treatments

Table 6.5a The influence of different concentrations of NaCl on some morphological characters of Aster tripolium.

NaCl concentration	Total biomass per pot (grams)	Mean fresh weight of shoot (grams)	Mean fresh weight of root (grams)	Mean dry-weight of shoot (grams)	Mean dry-weight of root (grams)	Max. Shoot length (cm)	Mean Shoot length (cm)
Control	206.73	34	5.23	3.06	0.60	60	27.75
0.005 M	335.55	48.50	9.07	4.44	1.05	75	40
0.01 M	397.33	58.61	12.43	5.98	1.32	50	27
0.02 M	350.35	51.8	14.08	4.93	1.03	60	36
0.05 M	353.08	52.04	14.21	4.54	1.192	60	31.5
0.1 M	339.96	49.67	13.29	5.16	1.17	65	35.5
0.2 M	303.95	42.57	13.53	3.93	0.93	50	40
0.3 M	209.12	29.07	12.58	2.46	1.20	45	14.75
0.4 M	170.25	24.25	9.44	2.40	1.00	45.	14.00

Table 6.5b Cation concentrations (mg/gram, dry weight) of roots and shoots of Aster tripolium grown in different concentrations of NaCl.

NaCl	Root				Shoot			
concentration	Na^+	K^+	Mg^{2+}	Ca^{2+}	Na^+	K^+	Mg^{2+}	Ca^{2+}
Control	0.85	35.00	3.00	5.00	0.70	67.50	6.38	7.50
0.005 M	5.50	17.75	2.25	5.13	7.50	60.00	6.38	17.00
0.01 M	6.50	17.75	2.13	4.88	11.00	57.00	6.25	14.25
0.02 M	11.50	22.50	1.76	5.13	15.75	55.00	5.75	13.50
0.05 M	19.50	32.50	1.62	3.13	36.25	52.00	5.75	16.50
0.1 M	27.50	30.00	1.37	3.13	40.00	45.00	5.50	8.75
0.2 M	57.50	40.00	1.25	2.50	70.00	37.00	3.75	9.50
0.3 M	62.50	35.00	1.13	1.75	75.00	45.00	3.25	9.50
0.4 M	95.00	35.00	1.50	1.50	87.50	39.00	3.25	9.25

Standard error of mean of dryweight (Table 6.5a)

	Control	0.005M	0.01M	0.02M	0.05M	0.1M	0.2M	0.3M	0.4M
Shoot	±0.43	±0.62	±1.37	±0.83	±0.58	±1.08	±0.42	±0.38	±0.43
Root	±0.11	±0.17	±0.33	±0.03	±0.11	±0.27	±0.12	±0.13	±0.12

TABLE 6.6

Series II : Results of water culture experiments on *Cotula coronopifolia* - NaCl treatments.

Table 6.6a The influence of different concentrations of NaCl on some morphological characters of *Cotula coronopifolia*.

NaCl concentration	Total biomass per pot (grams)	Mean fresh weight of shoot per plant (grams)	Mean fresh weight of root per plant (grams)	Mean dry weight of shoot (grams)	Mean dry weight of root (grams)	Mean shoot length (cm)	Mean shoot number	Mean root length (cm)
Control	245.47	40.34	2.97	2.94	0.25	34	17	16
0.005 M	346.17	57.85	8.21	4.16	0.56	36	22	48
0.01 M	333.54	52.89	5.38	4.07	0.51	41	24	40
0.02 M	346.33	52.33	6.56	3.91	0.56	38	22	45
0.05 M	297.97	45.11	5.59	3.72	0.64	30	20	50
0.1 M	268.30	37.45	7.38	2.73	0.69	29	16	60
0.2 M	127.53	17.83	3.82	1.53	0.57	20	8	75
0.3 M	72.79	10.41	2.53	1.01	0.45	13	7	75
0.4 M	38.03	5.82	0.73	0.617	0.24	10	6	50

Table 6.6b Cation concentrations (mg/gram, dry weight) of root and shoot of *Cotula coronopifolia* grown in different concentrations of NaCl.

NaCl concentration	Root				Shoot			
	Na^+	K^+	Mg^{2+}	Ca^{2+}	Na^+	K^+	Mg^{2+}	Ca^{2+}
Control	0.53	45.00	3.88	18.75	1.52	92.00	7.25	18.75
0.005 M	25.00	47.50	3.25	25.00	13.75	87.00	7.50	15.50
0.01 M	32.00	37.50	2.50	17.75	17.00	70.00	8.00	14.50
0.02 M	40.00	40.00	2.50	17.75	30.00	100.00	5.75	15.00
0.05 M	50.00	40.00	1.50	8.75	42.50	70.00	5.50	9.25
0.1 M	67.50	45.00	1.33	7.25	55.00	55.00	3.75	7.00
0.2 M	87.50	40.00	1.35	6.00	85.00	47.50	4.25	9.50
0.3 M	107.50	55.00	1.35	4.75	112.50	45.00	3.50	9.00
0.4 M	102.5	65.00	1.38	4.50	130.00	32.50	2.00	7.00

Standard error of mean of dryweight (Table 6.6a)

	Control	0.005M	0.01M	0.02M	0.05M	0.1M	0.2M	0.3M	0.4M
Shoot	±0.13	±0.37	±0.21	±0.14	±0.19	±0.16	±0.07	±0.11	±0.02
Root	±0.01	±0.07	±0.05	±0.03	±0.08	±0.05	±0.05	±0.03	±0.02

TABLE 6.7

Series III: Results of water culture experiments on *Cotula coronopifolia* - $MgCl_2$ treatments.

Table 6.7a Total biomass per pot and mean dry weight of plant of *Cotula coronopifolia* grown in different concentrations of $MgCl_2$

Concentration	Control	0.005	0.01	0.02	0.05	0.1	0.2	0.3 - 0.4
Total biomass (g)	78.28	82.38	92.22	84.72	77.54	29.47	0	-
Shoot (g)	0.725	0.76	0.89	0.77	0.76	0.40	0.19	-
Root (g)	0.08	0.11	0.12	0.11	0.12	0.04	0.01	-

Table 6.7b Cation concentrations (mg/gram on dry weight basis) of roots and shoots of *Cotula coronopifolia* grown in different concentrations of $MgCl_2$

Concentration	Root				Shoot			
	Na^+	K^+	Mg^{2+}	Ca^{2+}	Na^+	K^+	Mg^{2+}	Ca^{2+}
Control	2.00	10.75	1.38	4.50	6.00	115.00	7.50	15.50
0.005M	1.50	11.50	2.00	3.25	4.00	105.00	12.75	16.25
0.01 M	1.50	12.00	2.00	2.75	3.75	117.50	12.75	13.00
0.02 M	1.00	13.75	2.50	2.63	4.25	121.25	17.75	8.38
0.05 M	1.25	20.00	3.75	1.13	3.75	110.00	27.50	7.00
0.1 M	0.38	8.50	4.88	1.00	3.00	67.50	31.25	4.50
0.2 M	-	-	-	-	3.00	42.50	60.00	6.75

Standard error of mean of dryweight (Table 6.7a)

	Control	0.005M	0.01M	0.02M	0.05M	0.1M	0.2M
Shoot	$\pm$0.07	$\pm$0.06	$\pm$0.11	$\pm$0.13	$\pm$0.06	$\pm$0.04	$\pm$0.01
Root	$\pm$0.01	$\pm$0.07	$\pm$0.09	$\pm$0.04	$\pm$0.03	$\pm$0.002	$\pm$0.001

TABLE 6.8

Series III : Results of water culture experiments on *Aster tripolium* - $MgCl_2$ treatments.

Table 6.8a. Total biomass per pot and mean dry weight of plant of *Aster tripolium* grown in different concentrations of $MgCl_2$.

Concentration	Control	0.005	0.01	0.02	0.05	0.1	0.2*	0.3*	0.4*
Total biomass.	47.32	50.9	71.83	63.98	64.67	30.24	-	-	-
Shoot (g)	0.68	0.73	0.96	0.90	0.84	0.55	-	-	-
Root (g)	0.10	0.10	0.16	0.12	0.12	0.08	-	-	-

* There was little growth in 0.2M $MgCl_2$ and plants died in 0.3M and 0.4M $MgCl_2$

Table 6.8b Cation concentrations (mg/gram on dry weight basis) of roots and shoots of *Aster tripolium* grown in different concentrations of $MgCl_2$

Concentration	Root				Shoot			
	Na^+	K^+	Mg^{2+}	Ca^{2+}	Na^+	K^+	Mg^{2+}	Ca^{2+}
Control	0.20	10.75	1.13	3.60	2.00	117.50	5.00	12.00
0.005 M	0.20	9.25	2.00	2.25	2.25	110.00	10.50	18.75
0.01 M	0.34	17.25	2.13	2.50	2.75	125.00	13.38	10.75
0.02 M	0.33	17.25	3.50	1.63	2.13	120.00	16.50	8.50
0.05 M	0.15	12.00	4.00	1.25	1.75	127.50	18.75	5.75
0.1 M	0.16	18.75	6.25	0.75	1.75	97.50	30.00	4.25

Standard error of dryweight (Table 6.8a)

	Control	0.005M	0.01M	0.02M	0.05M	0.1M
Shoot	±0.05	±0.02	±0.10	±0.08	±0.07	±0.05
Root	±0.02	±0.01	±0.05	±0.03	±0.01	±0.02

TABLE 6.9.

Series IV : Results of Water Culture experiments on *Puccinellia distans* - NaCl treatments.

Table 6.9a The influence of different concentrations of NaCl on some morphological characteristics of *Puccinellia distans*.

NaCl levels	Total biomass per pot (gram)	Mean dry weight of shoot (gram)	Mean dry weight of root (gram)	Mean No. of tillers	Mean shoot length (cm)	Mean root length (cm)
Control	45.69	1.05	0.161	21	34	26
0.005 M	33.95	0.904	0.156	22	30	28
0.01 M	50.77	1.124	0.153	25	34	27
0.02 M	61.47	1.350	0.174	31	36	25
0.05 M	40.89	1.03	0.151	20	32	26
0.1 M	31.16	0.88	0.136	17	30	26
0.2 M	22.64	0.69	0.106	15	29	31
0.3 M	7.55	0.35	0.069	8	21	29
0.4 M	2.09	0.09	0.016	4	16	24

Table 6.9b Cation concentrations (mg/gram, dry weight) of root and shoot of *Puccinellia distans* grown in different concentrations of NaCl.

Concentration	Root				Shoot			
	Na^+	K^+	Mg^{2+}	Ca^{2+}	Na^+	K^+	Mg^{2+}	Ca^{2+}
Control	0.55	19.87	1.60	11.50	0.37	58.75	4.50	6.37
0.005 M	1.65	10.50	0.95	4.00	5.50	47.50	3.50	4.75
0.01 M	2.85	12.50	1.00	3.85	6.87	57.50	3.00	5.50
0.02 M	6.50	14.00	1.25	6.00	16.00	57.50	3.25	5.62
0.05 M	10.00	13.50	1.26	5.50	19.25	47.50	2.37	4.12
0.1 M	15.25	12.00	1.10	4.75	27.50	28.75	2.75	5.00
0.2 M	13.0	8.50	0.54	2.00	37.50	22.50	2.37	4.25
0.3 M	25.0	10.60	0.67	1.55	30.00	21.25	1.75	3.50
0.4 M	17.50	7.25	0.57	0.97	35.10	23.01	1.56	3.90

Standard error of mean of dryweight (Table 6.9a).

	Control	0.005M	0.01M	0.02M	0.05M	0.1M	0.2M	0.3M	0.4M
Shoot	±0.11	±0.10	±0.09	±0.19	±0.11	±0.13	±0.09	±0.02	±0.01
Root	±0.02	±0.01	±0.01	±0.02	±0.02	±0.02	±0.01	±0.006	±0.001

TABLE 6.10

Series IV : Results of water culture experiments on *Puccinellia distans* - $MgCl_2$ treatments.

Table 6.10a Mean dry weight per plant of *Puccinellia distans* grown in different concentrations of $MgCl_2$.

Concentration	Control	0.005M	0.01M	0.02M	0.05M	0.1M	0.2M	0.3M	0.4M
Total biomass	20.53	16.60	18.67	21.23	24.77	13.66	3.91	1.55	0.35
Shoots (g)	0.993	0.614	0.815	0.844	0.963	0.690	0.224	0.97	0.006
Roots (g)	0.108	0.088	0.100	0.132	0.130	0.094	0.032	0.012	0.006

Table 6.10b Cation concentrations (mg/gram dry weight) of root and shoot of *Puccinellia distans* grown in different concentrations of $MgCl_2$

Concentration	Root				Shoot			
	Na^+	K^+	Mg^{2+}	Ca^{2+}	Na^+	K^+	Mg^{2+}	Ca^{2+}
Control	1.65	45.00	1.55	4.25	0.32	55.00	3.25	6.00
0.005 M	1.20	29.50	1.95	1.45	0.27	43.75	5.25	4.50
0.01 M	1.90	35.00	2.05	1.40	0.25	50.00	5.62	4.75
0.02 M	1.05	33.50	3.50	1.90	0.30	52.50	7.50	3.25
0.05 M	0.85	45.00	3.80	2.25	0.30	50.85	7.50	4.00
0.1 M	0.67	33.50	3.45	1.25	0.17	41.25	10.13	3.50
0.2 M	2.00	37.00	5.86	1.00	0.27	32.50	12.37	1.38
0.3 M	3.9	36.1	6.36	1.33	0.31	32.50	13.75	1.02
0.4 M	2.5	11.87	12.75	1.13	0.70	23.33	28.33	1.58

Standard error of means of dryweight (Table 6.10a).

	Control	0.005M	0.01M	0.02M	0.05M	0.1M	0.2M	0.3M	0.4M
Shoot	±0.08	±0.05	±0.08	±0.13	±0.11	±0.05	±0.02	±0.01	±0.001
Root	±0.01	±0.009	±0.01	±0.02	±0.02	±0.01	±0.002	±0.001	-

CHAPTER 7

DISCUSSIONS AND CONCLUSIONS : A REVIEW OF THE MAIN RESULTS OF THE THESIS

A. The Present Status of Inland Salt Marshes.

a. Nature of Soils.

British inland saline sites fall into three major soil types - saline, saline/alkaline and non-saline/alkaline soils, and the salts in these sites are mainly composed of a mixture of sodium, magnesium and calcium, while sodium chloride is most pronounced in salt marshes. The salinization of such soils is by several methods - small and temporary saline sites have developed in the immediate vicinity of brine pipes, wherever there is brine spillage or leakage; the salt marshes are found around brine springs and have originated by the percolation of water from the wet rock-head of the Keuper Saliferous Beds, to issue at the surface as local brine springs, and the surface horizons of such sites have a very high concentration of sodium ions. The major saline sites have developed due to subsidence. Subsidence, caused by wild brine pumping and solution of rock beds, has resulted in the development of hollows known as flashes, and the existing flashes are either freshwater - with sodium concentrations less than 100 ppm or saline - with sodium concentrations up to 5000 ppm, and alkaline having sodium in low concentrations but very high magnesium concentrations. The details of such sites are described in Chapter 2. Another major type of saline habitat is the industrial waste lagoon, where industrial wastes have been dumped. These waste lagoons are to be found in Cheshire and at Stoke Works, Worcestershire, and are mostly alkaline/saline in nature. The other sources of salinity which have affected small pockets of soils are old brine pits, cisterns and lagoons, and such sites may have a very high concentration of sodium; old saline ponds and salt pans, rotting halite mounds and seepages from coal mines are other minor sources of salinity.

The soils of the industrial waste lagoons are at the earliest stage in the evolutionary sequence of soil formation and are classified as incipient. The soils of the natural salt marshes from Aldersey, Cheshire and Pasturefields, Staffordshire are distinguished by the gleyed Bg and Cg horizons saturated from below by water held by a deeper impermeable horizon. The soils at the two sites are almost the same in horizon description and differentiation and are characterised by a well developed Phragmites peat. The soils of the natural salt marshes are thus classified in -

the major group - Groundwater gley soils,

the group - Alluvial gley soil,

the sub-group - Clayey pelo-alluvial gley soils of river flood plains,

and the Midelney Series, very wet, drought resistant soils supporting a good halophytic vegetation. The soils of the semi-natural salt marshes such as at Upton Warren, Worcestershire also are distinguished by the gleyed Bg and Cg horizons saturated from below by water. The salinity gradient causes a change from salt marsh to pasture accompanied by changes in water table. The soils of the semi-natural salt marshes belong to the same major group, group and sub-group as those of natural salt marshes, except they differ in series and thus belong to the Crompton Series or a variant of this Series.

Thus, the soils associated with natural, semi-natural and colonising salt marshes differ widely in terms of age, structure, horizon differentiation, sodium concentration and cation ratio, and there are few, if any, features which generally characterise soils on which halophytic vegetation grows. However, all the soils described have an annually fluctuating ground-water level which deposits cations throughout most layers of the soil profiles and may result in sodium concentrations as high as 22 mg/gram in the upper horizons.

b. Nature of Vegetation.

Inland salt marshes are generally poorer in species than coastal marshes and a number of common maritime species, such as Salicornia europaea, Spergularia media, Suaeda maritima, Limonium vulgare, Juncus maritimus, Aremeria maritima, Cochlearia anglica and Halimione portulacoides seem to be absentin inland localities of the British Isles. The halophytic species present are grouped into four main vegetation types mainly on the growth form, and the phytosociological methods used in the survey description and classification of the vegetation are those of National Vegetation Classification Project. Of the four associations, Lemnetum salinae sensulato, Potamogetonetum pectinati, Zannichellietum palustris and Myriophylletum salinae of the vegetation type of pioneer, floating communities of static or slow-moving water, the Potamogetonetum pectinati is most widespread. Despite the fact that the four associations seem to have a wide overlap in their ecological conditions, a distinct range of tolerance for sodium ions and almost a clear zonation for each association was shown. Thus Potamogetonetum pectinati can tolerate the highest sodium concentration, followed by Zannichellietum then Lemnetum salinae and finally Myriophylletum salinae.

Five associations from the vegetation type of emergent sedge and reedswamp vegetation at the margins of open water are described. The Scirpetum tabernaemontani seems to be most widespread at the margins of saline pools as compared to others. The associations Scirpetum maritimi and Caricetum otrubae were more localized. Five associations may be arranged in series, according to the sodium concentration tolerance: Scirpetum maritimi > Scirpetum tabernaemontani > Phragmitetum eurosibericum > Typhetum angustifolio-latifoliae > Caricetum otrubae.

Two associations, the Atriplicetum salinae and the Cotuletum coronopifoliae belong to the vegetation type of annual herb communities of periodically inundated saline soils. The association Atriplicetum salinae is widespread in almost all inland saline sites, while Cotuletum coronopifoliae is rare and is localised in two or three places.

Four associations, Juncetum gerardii, Puccinellietum maritimae, Spergularietum salinae and Puccinellietum distantis are described from the inland salt marsh vegetation dominated by perennial rush and grass species. The association Puccinellietum distantis is the most widespread and occurs in more localities than any other association. The association Juncetum gerardii and Puccinellietum maritimi are present only on natural salt marshes. The Puccinellietum distantis is a major association with a number of sub-associations and variants and provides a good example for the study of succession in inland saline sites. The initial colonizer on highly saline soils and in saline depressions is Spergularia marina and Puccinellia distans tends to occupy comparatively less saline places. The succession of this association is shown in Figure 4.5.

c. The Need for Conservation.

The detailed phytosociological and ecological survey presented in the thesis provides a factual background upon which conservation proposals may be based. The site studies provide necessary information about soil characters, water status and analysis and vegetation analysis. The thesis also provides growth characteristics and tolerance of salts of both rare and common species. Reference to the association tables and their comparison with the available data from the coastal site throws some light upon the need to conserve sites. The extensive Nature Conservation Review (Volumes I,II) by Ratcliffe (1977) does not mention any inland saline sites. Referring to Ratcliffe's criteria for key site assessment and selection for the comparative site evaluation some proposal for the selection of sites may be made. In coastal habitats he is of the view that some criteria, such as size of the marsh which includes the extent of habitat and size of populations; diversity - both physiographic diversity per se and ecological diversity in terms of habitat and organisms; bird populations and freedom from disturbance, have been regarded as having paramount importance. If these criteria are taken into consideration for choice of conservation site, then in inland saline localities there are five areas of semi-natural and natural salt marshes which deserve attention. The following communities were recorded from each site and the sites are given in order of preference:-

	Site	Vegetation
1.	Upton Warren, Worcestershire.	association Puccinellietum distantis
		sub-ass. typicum
		sub-ass. hordeetosum
		sub-ass. agropyretosum
		association Atriplicetum salinae
		Association Scirpetum tabernaemontani
		association Caricetum otrubae
2.	Sandbach, Cheshire.	association Puccinellietum distantis
		sub-ass. asteretosum
		Aster tripolium Nodum
		association Scirpetum tabernaemontani
		association Typhetum angustifoliae-latifoliae
3.	Aldersey, Cheshire.	association Spergularietum marinae
		sub-ass. festucetosum
		association Juncetum gerardii
4.	Pasturefields, Staffordshire.	association Puccinellietum maritimae
		association Juncetum gerardii

5. Mickletown West Yorkshire. — association Cotuletum coronopifoliae, Scirpetum tabernaemontani

Other site information, such as concentrations of Na^+, K^+, Mg^{2+} Ca^{2+} and Cl^- in soil and associated water, soil profiles and soil types are given in detail in Chapter 2. There are extensive stands of Cotula coronopifolia present at Mickletown which produce viable seeds. In glasshouse conditions about 95% of the sown seed could germinate. Cotula coronopifolia is rare in this country; therefore, the Mickletown Marsh in West Yorkshire needs immediate attention for conservation purposes.

B. The Problem of Classification of Halophytes.

British inland saline sites are not rich in species as compared to coastal sites; moreover, large areas in the vicinity of the salt extraction and manufacturing industries remain unvegetated. A preliminary investigation into the colonization of alkaline industrial waste at Elton Hall (Mirza & Shimwell 1977) showed that unvegetated areas are characterised by extremely high concentration of magnesium and apparently this element was the limiting factor for vegetative growth. Many other areas analysed showed either an excess of magnesium salts or otherwise an extreme salinity. Therefore, to establish the tolerance ranges of the flowering plants encountered in these habitats, the plants, shoot and associated soils were analysed for the four cations, Na^+, K^+, Mg^{2+}, Ca^{2+}. On the basis of these results about 53 flowering plants were classified in five different ways. i.e. on the basis of concentration of Na^+ in the habitat, maximum concentration of Na^+ in the shoots; a maximum ratio of Na^+ in the shoot to Na^+ in the soil; Na:K ratio in the shoot and a ratio of monovalent to divalent cations, which showed the range of alkalinity and salinity tolerated by each species. Hence the five methods mentioned above, taken together, could clearly define the ecological amplitude of the halophytes commonly encountered in the British inland saline habitats and provide a good basis for defining the eco-physiological affinities of any species. Thereupon, some selected species grown under glasshouse conditions for the tolerance and toxic levels of NaCl and $MgCl_2$ showed almost similar results as obtained from field analysis. The classification of the inland species on the basis of the above mentioned methods provides a base for the selection of principal halophyte colonizers of alkaline and saline industrial waste habitats.

C. Growth and Cation Accumulation Studies in Inland Halophytes.

The importance of species selection has long been recognised for the revegetation of derelict and salt contaminated lands. If the information about the substrates and selected species is available then the choice of species becomes fairly easy and simple. In this context, for the reclamation of salt contaminated soils, growth studies of some common halophytes were undertaken. Thus, it was shown that the growth of Ranunculus sceleratus at median salinity is severely affected under controlled conditions. Cotula coronopifolia is quite clearly capable of tolerating median salt treatments; it produced greater dry weight with added NaCl between 0.005M and 0.05M, the growth decreased by 47% in 0.2M, by 66%, in 0.3M and by 80% in 0.4M NaCl as compared to control. Cotula coronopifolia is tolerant of slightly alkaline conditions, but toxicity of $MgCl_2$ is more apparent at the 0.1M concentration, while levels of 0.3 and 0.4M resulted in death of the plants. The plant has a very high maximum accumulating capacity for Na ions and shoots can accumulate about 17 times more Na^+ than levels in soil. Similarly, Mg^{2+} and K^+ are toxic at higher concentrations only. Hence, the species may be used to revegetate saline sites with median sodium concentrations and low magnesium levels. Aster tripolium is a species capable of tolerating highly saline conditions, producing about 95% more dry weight in 0.01M NaCl as compared to 0 NaCl. The dry weight of shoot was increased with added NaCl between 0.005M and 0.2M NaCl and at very high salt treatments (0.4M NaCl), the growth of shoots was decreased only by 25%. The plant can only tolerate slight alkaline conditions and higher magnesium levels severely damaged the plant's growth. Aster tripolium can also accumulate a high Na^+ concentration up to 87.50 mg/gram in the shoot. It, therefore, is capable of colonizing those inland marshes with high NaCl. Puccinellia distans can tolerate a median NaCl and a median $MgCl_2$ concentration in the external medium. The species is capable of colonizing land with either high NaCl or $MgCl_2$ with reduced growth. Hence, as is already discussed in the details of the growth of those species in Chapter 6, their resistance to different cations is manifested in their ability to colonize those habitats which are otherwise toxic to other glycophytic species.

D. The Need for Further Ecological Studies.

The new industrial sites have provided special habitats which can make a positive contribution towards the understanding of the diversities in nature and the wildlife they support. Thus, any future research should be directed on two lines - that is; the conservation of the already existing marshes and the revegetation and the evolution of new ecotypes on the reclaimed sites. Further work needs to be done on :

1. detailed soil mapping of the natural and semi-natural salt marshes;
2. the collection of further data on other chemical properties of the sites, such as phosphorus and nitrogen status;
3. autecological studies on the evolution and selection of magnesium tolerant ecotypes;
4. comparative studies in the inland and coastal ecotypes of major halophytes found in both areas;
5. transplant experiments of the three species, Cotula coronopifolia, Aster tripolium and Puccinellia distans on a variety of lagoon habitats and their monitoring to define the best method for revegetation of the industrial wastes.

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ECOLOGICAL STUDIES IN THE INLAND HALOPHYTIC VEGETATION OF THE BRITISH ISLES. VOLUME II

by

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MIRZA, R.A. & SHIMWELL, D.W. (1977) Preliminary investigation into the colonization of alkaline industrial waste by bryophytes. J.Bryol. (1977), 9, 565-572

Table 4.1a

Lemnetum sensu lato

Relevé No.	C92	C59A	C90	S2	DWS11	C40
Area of Relevé (m^2)	4	1	4	4	4	4
% cover	100	100	100	80	75	100
Species No.	1	2	2	3	3	3
Lemna gibba	10	8	10	-	-	-
Lemna trisulca	-	-	-	6	8	-
Lemna polyrhiza	-	6	-	-	-	-
Lemna minor	-	-	-	-	-	7
Enteromorpha intestinalis	-	-	4	-	-	-
Callitriche stagnalis	-	-	-	6	4	-
Apium nodiflorum	-	-	-	3	-	-
Potamogeton berchtoldii	-	-	-	-	4	-
Ceratophyllum demersum	-	-	-	-	-	7
Potamogeton natans	-	-	-	-	-	3

Table 4.1b

Ecological Characteristics

Relevé No.	C92	C59A	C90	S2	C40
Water Sample No.	62	43	61	69	42
Water depth (cm)	60	60	25	15	30
Conductivity	4.93	2.46	1.50	6.50	0.46
pH	8.5	7.8	8.5	6.9	8.9
Na^+	500	325	68	925	23
K^+	20	12	12	07	04
Mg^{2+}	21	29	20	24	19
Ca^{2+}	70	90	50	100	48
Cl-	1200	450	65	1450	120

Table 4.2a

Potamogetonetum pectinati (Carstensen 1955)

	Sub-ass. salinetosum											Sub-ass. lemnetosum			
Relevé No.	W27	C39	C84	S1	C59	S24	W26	W20A	C34	DWS9	C58	C1	C3	C7	K
Area of Relevé (m^2)	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
% cover.	100	82	60	80	40	80	100	60	50	100	80	90	95	100	
Species No.	1	1	1	1	1	2	2	3	2	4	2	5	7	10	
Potamogeton pectinatus	10	9	8	9	7	8	7	7	7	9	7	3	8	6	V
Potamogeton crispus	-	-	-	-	-	-	-	4	-	-	-	5	-	4	II
Lemna trisulca	-	-	-	-	-	-	-	-	-	-	-	8	+	-	I
Lemna minor	-	-	-	-	-	-	-	-	-	-	-	-	4	6	I
Cladophora sp.	-	-	-	-	-	4	7	-	-	-	-	-	-	-	I
Myriophyllum spicatum	-	-	-	-	-	-	-	4	-	-	-	4	+	4	II
Enteromorpha intestinalis	-	-	-	-	-	-	-	-	-	-	-	+	5	5	II
Myriophyllum alterniflorum	-	-	-	-	-	-	-	-	4	4	-	-	-	-	I
Ceratophyllum demersum	-	-	-	-	-	-	-	-	-	-	7	-	4	-	I
Callitriche stagnalis	-	-	-	-	-	-	-	-	-	4	-	-	-	3	I

Also:- In Relevé No. (DWS9) Zannichellia palustris 4; (C3) Elodea canadensis 3; (C7) Apium nodiflorum 3; Chara vulgaris 3; Scirpus tabernaemontani 3; Eleocharis palustris 5.

Table 4.2b

Ecological Characteristics

Relevé No.		W27	C39	C84	S1	C59	S24	W26	W20A	C58	C34	C1	C3	C7
Water Sample No.		23	41	60	68	48	73	07	03	47	37	31	32	34
Water depth (cm)		20	10	30	60	50	60	20	27	30	50	45	45	20
Conductivity		2.84	2.78	23.74	1.26	49.13	1.22	4.91	0.45	5.74	25.37	4.44	4.28	1.90
	pH	8.4	8.5	9.0	7.1	8.2	7.4	8.3	8.1	8.3	8.4	8.3	8.8	8.9
	Na^{+}	350	413	3750	88	17000	100	625	20	950	6625	638	650	250
	K^{+}	09	12	33	13	25	15	10	07	04	14	13	12	04
	Mg^{2+}	75	23	43	18	26	24	75	100	43	75	25	23	43
	Ca^{2+}	200	75	83	84	20000	105	225	50	123	475	130	110	68
	Cl^{-}	1000	475	5000	130	18000	130	1200	166	1263	6000	938	1350	475

Table 4.3a

Zannichellietum palustris G. Lang em Oberd. 1957

Relevé No.	W47	W21	S17	C33	C54	DWS 8	K
Area of Relevé (m^2)	4	1	4	1	4	4	
% cover	70	60	50	90	40	100	
Species No.	1	1	2	2	2	3	
Zannichellia palustris	8	8	7	7	6	9	V
Callitriche stagnalis	-	-	3	-	-	-	I
Enteromorpha intestinalis	-	-	-	7	-	-	I
Lemna minor	-	-	-	-	4	-	I
Myriophyllum alterniflorum	-	-	-	-	-	5	I
Potamogeton crispus	-	-	-	-	-	4	I

Table 4.3b

Ecological Characteristics

Relevé No.		W47	W21	S17	C54
Water Sample No.		16	04	72	44
Water depth (cm)		10	7	25	2
Conductivity		9.22	1.57	5.60	2.62
	pH	7.6	8.4	7.2	9.2
	Na^+	165	148	575	275
	K^+	10	14	06	06
	Mg^{2+}	550	63	15	118
	Ca^{2+}	775	125	53	55
	Cl^-	2900	58	800	980

Table 4.4a

Myriophylletum sensu lato.

Relevé No.	L21	L22	W24	C129	DWS 10
Area of Relevé (m^2)	4	4	4	4	4
% cover	100	100	100	100	96
Species No.	1	1	2	2	3
Myriophyllum spicatum	10	10	9	-	-
Myriophyllum alterniflorum	-	-	-	10	9
Cladophora sp.	-	-	5	-	-
Potamogeton crispus	-	-	-	4	2
Potamogeton trichoides	-	-	-	-	4

Table 4.4b

Ecological Characteristics

Relevé No.	L21	L22	W24	C129
Water Sample No.	80	82	05	88
Water depth (cm)	50	60	10	20
Conductivity	4.06	1.57	0.87	1.20
pH	8.6	8.0	8.8	8.7
Na^+	525	200	30	108
K^+	06	05	05	04
Mg^{2+}	13	11	28	25
Ca^{2+}	48	48	38	45
Cl^-	1075	238	25	138

Table 4.5a

Typhetum angustifolio-latifoliae (Eggler 1933) Schmale 1939

Relevé No.	C112	C120	C126	C127	C38	C57	K
Area of Relevé (m^2)	4	4	4	4	4	4	
% cover	100	100	100	100	100	90	
Species No.	1	5	5	5	7	4	
Typha latifolia	10	9	9	9	7	-	V
Typha angustifolia	-	4	-	-	-	9	II
Agrostis stolonifera	-	4	4	4	4	-	IV
Aster tripolium	-	4	+	+	-	-	III
Solanum dulcamara	-	-	+	3	-	-	II
Urtica dioica	-	-	+	+	-	-	II
Lemna trisulca	-	-	-	-	5	+	II
Acrocladium cordifolium	-	-	-	-	8	-	I

Also: In Relevé No. (C120) Ranunculus sceleratus +; (C38) Lemna minor 5: Juncus inflexus 4; Cicuta virosa +; (C57) Potamogeton pectinatus 5: Scirpus tabernaemontani 4.

Table 4.5b

Ecological characteristics

Relevé No.		C112	C120	C126 C127	C38	C57
Water Sample No.		56	86	89	40	45
Water depth (cm)		25	-	-	10	2
Conductivity		1.25	16.80	4.53	2.95	11.46
	pH	7.7	7.7	7.5	7.1	6.5
	Na^+	93	3250	788	375	1750
	K^+	12	23	35	12	01
	Mg^{2+}	24	38	30	68	65
	Ca^{2+}	95	95	149	125	275
	Cl^-	55	4250	-	313	2250

Table 4.6a

Scirpetum maritimi (Br.-Bl.1931), R.Tx. 1937

Relevé No.	C26	C29	C25	C28	C24	C30	C67	C23	K
Area of Relevé (m^2)	4	4	4	4	8	4	4	4	
% cover	100	100	100	100	100	100	100	100	
Species No.	2	5	5	3	5	8	6	9	
Scirpus maritimus	10	8	6	6	9	7	9	6	V
Atriplex hastata	-	5	4	6	4	4	-	4	IV
Puccinellia distans	-	-	8	-	-	-	-	5	II
Spergularia marina	-	-	-	7	3	-	-	3	II
Agrostis stolonifera	-	-	4	-	3	4	-	5	III
Phragmites communis	4	-	-	-	-	4	-	-	II
Carex otrubae	-	-	3	-	-	-	-	4	II
Agropyron repens	-	3	-	-	-	-	-	4	II
Festuca arundinacea	-	-	-	-	-	-	3	4	II

Also: in Relevé No. (C 29) Eupatorium cannabinum 3; Rumex conglomeratus 3; (C24) Ranunculus sceleratus 3; (C30) Rumex hydrolapathum 3; Berula erecta 3; Calystegia sepium 4; Glyceria maxima 4; (C67) Polygonum persicaria 4; Glyceria plicata 3; Epilobium hirsutum 3; Apium graveolens 4; (C23) Arrhenatherum elatius +.

Table 4.6b

Ecological characteristics

Relevé No.	C29	C24	C25
Soil Sample No.	97	98	95
pH	6.9	6.3	6.8
Na^+	9.00	7.00	6.25
K^+	0.05	0.60	0.18
Mg^{2+}	0.30	0.25	0.38
Ca^{2+}	9.00	10.50	12.25
Cl^-	17.76	5.00	15.38

Table 4.7a

Scirpetum tabernaemontani Passarge 1964.

	Sub-ass. typicum									Sub-ass. agrostetosum					
Relevé No.	W61	W46	W66	C32	W65	C4	C11	L20	C131	C37	C119	C56	C52	C55	K
Area of Relevé(m^2)	4	4	4	4	4	4	4	4	4	4	4	4	4	4	
% cover	100	100	80	100	100	80	100	100	100	100	100	90	70	85	
Species No.	1	1	1	3	3	5	3	6	4	3	4	6	8	7	
Scirpus tabernaemontani	10	10	9	10	8	9	9	9	10	9	8	6	7	8	V
Scirpus maritimus	-	-	-	-	5	-	-	-	-	-	-	-	-	-	I
Agrostis stolonifera	-	-	-	-	-	-	-	-	-	4	4	+	3	4	II
Aster tripolium	-	-	-	-	-	-	-	-	4	-	5	6	4	4	II
Atriplex hastata	-	-	-	3	-	-	-	-	3	-	-	-	-	3	II
Typha latifolia	-	-	-	-	-	-	3	4	-	-	4	-	-	-	II
Chenopodium rubrum	-	-	-	-	-	-	-	3	-	-	-	-	4	3	II
Rumex hydrolapathum	-	-	-	-	-	+	4	-	-	-	-	-	-	-	I
Solanum dulcamara	-	-	-	+	-	+	-	-	-	-	-	-	-	-	I
Ranunculus sceleratus	-	-	-	-	-	-	-	+	-	-	-	-	+	-	I
Eleocharis palustris	-	-	-	-	-	-	-	-	-	+	-	-	-	+	I
Juncus bufonius	-	-	-	-	-	-	-	-	-	-	-	-	3	3	I
Acrocladium cordifolium	-	-	-	-	-	-	-	5	-	-	-	7	-	-	I

Also:In Relevé (W65) Phragmites communis 5; (C4) Enteromorpha intestinalis 7; Lemna minor 7; Rumex crispus 3; (C131) Puccinellia distans 3; (C56) Carex otrubae 4; Eupatorium cannabinum 3; (C52) Triglochin maritima 4; Apium nodiflorum + ;

Table 4.7b

Ecological Characteristics

		W61	W46	W66	W65	C4	C32	C11	L20	C131	C119	C52
Relevé No.		W61	W46	W66	W65	C4	C32	C11	L20	C131	C119	C52
Water Sample No.		28	15	28	30	32	-	35	-	-	-	-
Soil Sample No.		-	-	-	-	-	102	-	186	25	26	110
Conductivity		7.03	9.19	7.03	4.71	4.28	-	6.34	-	-	-	-
	pH	8.6	8.0	8.6	8.5	8.8	6.5	9.2	6.8	6.9	6.9	8.6
	Na^{+}	1700	160	1700	1950	650	25.00	1150	0.88	0.83	1.20	0.65
	K^{+}	05	08	05	12	12	0.03	14	0.17	0.09	0.09	0.05
	Mg^{2+}	73	875	73	100	23	0.55	20	0.27	0.25	0.23	1.83
	Ca^{2+}	138	375	138	103	110	10.50	55	4.50	3.25	3.75	3.13
	Cl^{-}	1000	2750	1000	610	1350	14.00	863	0.60	-	-	2.60

Table 4.8a

Phragmitetum eurosibiricum (Gams 1927) Schmale 1939

	Sub-ass. typicum						Sub-ass. plantaginetosum					
	Typical variant		Atriplex variant									
Relevé No.	C104	W25	C106	L16	C105	L1	L19	L15	L17	L6	L18	K
Area of Relevé (m^2)	4	4	4	4	4	4	4	4	4	4	4	
% cover	100	100	100	100	100	100	90	100	100	100	90	
Species No.	1	2	2	2	4	5	5	5	4	5	6	
Phragmites communis	10	6	9	10	10	7	7	8	7	6	6	V
Atriplex hastata	-	-	4	+	4	+	+	-	-	-	4	III
Juncus gerardii	-	-	-	-	-	7	-	-	-	-	-	I
Plantago maritima	-	-	-	-	-	-	6	5	4	6	5	III
Puccinellia maritima	-	-	-	-	-	-	4	4	5	4	6	III
Spergularia marina	-	-	-	-	-	-	+	4	5	-	4	II
Festuca rubra	-	-	-	-	-	-	-	4	-	6	-	I
Agrostis stolonifera	-	-	-	-	+	4	-	-	-	4	-	II

Also:- In Relevé No. (W25) Cladophora sp. 9; (C105) Urtica dioica +; (L1) Plantago lanceolata 3; (L18) Puccinellia distans 4.

Table 4.8b

Ecological Characteristics

Relevé No.		C104	W25	C105	L16	L1	L19	L15	L6
Water Sample No.		63	6	-	-	-	81	-	-
Soil Sample No.		-	-	39	185	177	-	185	182
Conductivity		36.52	0.49	-	-	-	17.88	-	-
	pH	9.0	7.3	7.2	7.4	8.2	8.6	7.9	7.5
	Na^{+}	2250	33	5.00	1.15	0.68	3000	1.15	3.25
	K^{+}	35	10	0.17	0.05	0.03	04	0.05	0.07
	Mg^{2+}	18	23	0.53	0.19	0.05	40	0.19	0.09
	Ca^{2+}	1875	25	11.00	1.25	2.50	225	1.25	1.13
	Cl^{-}	8750	37	3.75	0.50	0.05	2500	0.50	2.50

Table 4.9a

Caricetum otrubae ass. nov. prov.

Relevé No.	W45	W68	C108	W69	C70	C111	C110	C109	K
Area of Relevé (m^2)	4	4	4	4	4	4	4	4	
% cover	80	100	100	90	100	90	85	100	
Species No.	2	4	5	3	3	10	3	7	
Carex otrubae	9	8	9	9	9	8	8	9	V
Atriplex hastata	4	4	5	3	4	5	-	-	IV
Agrostis stolonifera	-	-	-	4	4	4	5	+	IV
Cirsium arvense	-	-	-	-	-	-	+	3	II
Galium palustre	-	-	-	-	-	3	-	+	II

Also: In Relevé No : (W68) Juncus effusus 6; Juncus bulbosus 3; (C108) Chenopodium rubrum, +; Typha latifolia 4; Plantago major +; (C111) Sonchus arvensis +; Brachythecium rutabulum 3; Rumex crispus +; Atriplex patula 3; Juncus bufonius 3; Cirsium palustre +; (C109) Rubus fruticosus 4; Agropyron repens 4; Vicia angustifolia +.

Table 4.9b

Ecological characteristics

		W45	C110	C108	C109	C111
Relevé No.		W45	C110	C108	C109	C111
Water Sample No.		11	66	64	65	67
Conductivity		8.68	12.24	14.34	8.41	7.84
	pH	8.0	7.5	8.5	8.1	8.0
	Na^{+}	80	1300	2250	1150	1175
	K^{+}	13	10	09	12	11
	Mg^{2+}	650	46	29	16	15
	Ca^{2+}	800	850	425	325	263
	Cl-	3500	2020	3500	1650	1400

Table 4.10a. Atriplicetum salinae deviense (Duvigneaud 1967)

	Sub-ass. initial							Sub-ass. ~~ty~~atriplicetosum											Sub-ass agrostetosum									
Relevé No.	C97	C41	C42	C98	C10	C102	C99	C18	C12	W55	S25	W40	W57	W39	C65	C103	W34	C13	C107	C91	C19	C114	C115	C16	C100	C85	C116	K
Area of Relevé (m^2)	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	8	4	4	4	4	4	4	4	4	
% cover	85	80	90	55	70	60	80	70	40	100	50	70	90	60	90	80	75	70	100	100	70	100	100	80	80	95	100	
Species No.	3	3	7	4	7	7	5	3	2	12	4	4	4	4	8	3	4	3	3	3	3	2	2	3	4	4	2	
Atriplex hastata	-	-	4	3	3	7	7	7	7	8	7	7	9	8	8	8	6	8	10	10	8	8	9	8	8	8	7	V
Chenopodium rubrum	9	5	6	7	6	4	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	II
Puccinellia distans	-	-	3	-	-	3	-	5	3	4	3	4	3	3	+	-	4	4	-	+	-	-	-	-	-	-	-	III
Spergularia marina	-	-	3	4	4	4	-	-	-	-	-	3	3	+	4	3	5	-	+	-	-	-	-	-	-	-	-	III
Juncus bufonius	-	-	-	-	5	-	-	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-	-	-	-	-	-	I
Agrostis stolonifera	+	-	-	3	3	-	5	-	-	-	-	-	-	-	-	-	-	+	+	3	2	6	5	4	4	4	8	III
Agropyron repens	-	-	-	-	-	+	-	-	-	-	4	-	4	+	-	3	5	-	-	-	-	-	-	-	-	5	-	II
Funaria hygrometrica	-	5	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	I
Holcus lanatus	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	I
Juncus effusus	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-	I
Tussilago farfara	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	3	-	-	-	I
Tripleurospermum maritimum	-	-	-	-	-	+	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	I

Also: In Relevé No. (C97) Plantago major 4; (C41) Cyanophyceae 7; (C42) Atriplex patula 4; Cyanophyceae 7; (C10) Ranunculus sceleratus 3; Alopecurus geniculatus 4; (C102) Plantago major +; (W55) Poa trivialis 4; Lolium perenne 4; Capsella bursa-pastoris 3; Cirsium vulgare +; Stellaria media +; Sonchus arvensis +; Hordeum murinum +; Matricaria matricarioides + ; Dipsacus fullonum +; (S25) Phragmites communis 3; (W40) Poa annua 4; (C65) Ranunculus sceleratus 3; Typha angustifolia +; Poa annua 3; Polygonum persicaria 3; (C85) Potentilla anserina +.

Table 4.10b Ecological Characteristics

Relevé No.	C97	C41	C42	C98	C10	C102	C99	C18	C12	W55	S25	C103	C13	C107	C91	C114 C115 C116	C16	C100	C85
Soil Sample No.	136	103	104	138	78	143	142	91	83	42	174	143	85	40	132	-	87	142	132
Water Sample No.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	85	-	-	-
pH	7.6	9.0	8.2	7.8	6.3	7.7	8.1	8.0	8.0	6.7	6.5	7.7	8.4	8.8	6.9	6.8	8.5	8.1	6.9
Na^+	15.00	0.55	1.25	1.03	6.75	1.10	1.53	0.55	8.75	1.83	2.50	1.10	0.48	3.25	0.78	750	9.25	1.53	0.38
K^+	0.15	0.90	0.09	0.30	0.15	0.05	0.13	0.06	0.15	0.13	0.25	0.05	0.12	0.38	0.23	15	0.21	0.13	0.23
Mg^{2+}	0.55	2.75	1.75	1.00	0.30	0.29	0.25	5.00	0.53	4.25	0.23	0.29	1.00	0.38	0.38	59	1.05	0.25	0.38
Ca^{2+}	7.50	3.25	4.00	7.75	7.75	6.50	7.75	9.50	12.50	9.75	4.25	6.50	7.75	8.00	1.50	20	14.50	7.75	1.50
Cl-	20.10	0.65	0.80	0.65	8.75	2.00	4.13	8.00	7.40	11.65	0.63	2.00	0.75	1.38	0.10	1190	17.75	4.13	0.10

Table 4.11a

Cotuletum coronopifoliae ass. nov. prov.

	Sub-ass. cotuletosum					Sub-ass. atriplo-juncetosum								
Relevé No.	DWS 4	DWS 5	WY 5	WY 6	WY 4	DWS 3	WY 1	DWS 2	WY 2	WY 3	LM1 1	DWS 6	DWS 7	K
Area of Relevé (m^2)	4	4	2	2	2	4	2	4	2	2	2	4	4	
% cover	80	80	100	60	100	90	100	90	90	80	80	90	80	
Species No.	3	3	2	6	7	6	8	5	7	10	12	7	9	
Cotula coronopifolia	7	8	9	7	9	4	7	6	8	8	3	6	7	V
Atriplex hastata	-	-	-	-	-	8	3	1	3	4	-	-	-	II
Juncus bufonius	-	-	-	-	-	-	7	7	3	3	1	4	3	III
Spergularia marina	-	-	-	-	-	-	-	-	-	-	5	-	-	I
Agrostis stolonifera	-	-	4	4	3	1	-	-	-	3	6	-	-	III
Ranunculus sceleratus	-	-	-	-	-	-	3	4	-	5	-	2	2	II
Rumex sanguineus	-	-	-	-	-	-	3	-	-	3	-	+	1	II
Juncus inflexus	-	-	-	-	-	-	3	-	-	3	-	5	4	II
Juncus articulatus	-	-	-	-	-	-	3	-	-	-	-	3	3	II
Phragmites communis	-	-	-	-	-	-	3	-	3	-	-	-	-	I
Typha latifolia	-	-	-	-	-	-	-	-	2	2	-	-	-	I
Chenopodium rubrum	-	-	-	-	-	4	-	1	-	-	-	-	-	I
Polygonum persicaria	-	-	-	-	-	-	-	-	-	-	-	5	4	II
Rorippa islandica	-	-	-	-	-	-	-	-	-	-	-	-	3	I
Juncus effusus	-	-	-	-	-	-	-	-	2	-	-	-	-	I
Hippuris vulgaris	3	-	-	-	-	-	-	-	-	3	-	-	2	II
Trifolium repens	-	-	-	-	-	-	-	-	-	-	4	-	-	I
Plantago major	-	-	-	-	4	-	-	-	-	-	4	-	-	I
Rumex crispus	-	-	-	-	3	-	-	-	-	-	4	-	-	I

Also: In Relevé No. (DWS 4) Myriophyllum alterniflorum 5; (DWS 5) Callitriche platycarpa 4; Potamogeton pectinatus 3; (WY 6) Plantago lanceolata 4; Bellis perennis 2; Leontodon autumnalis 3; Poa annua 3; (WY 4) Cirsium vulgare 2; Atriplex patula 2; Cirsium palustre 2; (DWS 3) Tussilago farfara 1; Bidens tripartita 1; (WY 2) Scirpus tabernaemontani 3; (WY 3) Carex hirta 3; (LM1) Agropyron repens 5; Ranunculus repens 3; Glaux maritima 3; Plantago coronopus 4; Potentilla anserina 3;

Table 4.11b Ecological Characteristics

		WY1	WY3	WY2	WY5	WY6	LM1
Relevé No.		WY1	WY3	WY2	WY5	WY6	LM1
Soil Sample No.		01	02	-	-	-	03
Water Sample No.		-	-	102	103	104	-
	pH	6.7	3.8	7.1	5.1	5.8	7.2
	Na^{+}	2.49	0.66	300	305	290	0.14
	K^{+}	0.26	0.14	30	23	14	0.13
	Mg^{2+}	1.19	0.37	123	86	51	0.15
	Ca^{2+}	7.26	7.92	578	205	186	1.26

Table 4.12a — *Juncetum gerardii* Warming 1906

	Sub-ass. agrostetosum					Sub-ass. of Festuca and Glaux						Sub-ass. of Leontodon autumnalis					
Relevé No.	W44	S3	C76	C80	C79	S9	C78	S5	S23	S6	C77	L3	L2	W67	W62	W63	K
Area of Relevé (m^2)	4	4	4	4	4	4	4	4	4	4	4	1	1	4	4	4	
% cover	60	100	50	95	90	100	100	100	100	100	100	90	80	60	80	70	
Species No.	4	4	5	9	10	4	5	9	7	6	9	9	10	11	13	9	
Juncus gerardii	7	5	4	6	5	7	8	7	7	4	4	5	-	4	5	5	V
Agrostis stolonifera	4	8	5	7	8	4	6	4	6	4	8	3	4	-	5	4	V
Festuca rubra	-	-	-	-	-	6	-	5	4	7	3	6	4	-	-	-	III
Glaux maritima	-	-	-	-	-	-	+	3	4	3	4	-	-	-	-	-	II
Leontodon autumnalis	-	-	-	-	-	-	-	-	-	-	-	+	+	+	3	+	II
Carex distans	-	-	-	-	-	-	-	-	-	-	-	5	7	-	5	4	II
Festuca arundinacea	-	-	-	+	-	-	-	-	-	-	-	-	-	6	4	5	II
Alopecurus geniculatus	-	-	-	3	-	-	-	-	-	-	-	-	-	5	5	6	II
Plantago maritima	-	-	-	-	-	-	-	3	3	-	-	4	4	-	-	-	II
Lolium perenne	-	4	-	4	-	-	-	3	4	-	-	-	-	-	-	-	II
Atriplex hastata	3	-	4	+	-	-	-	-	-	-	+	-	-	-	-	-	II
Poa pratensis	-	4	-	-	-	-	4	3	-	3	3	-	-	-	-	-	II
Trifolium repens	-	-	-	-	-	3	-	3	-	3	-	-	-	-	-	-	II
Triglochin maritima	-	-	-	3	4	-	-	-	-	-	3	-	-	-	-	-	I
Scirpus maritimus	-	-	-	-	-	-	-	-	-	-	-	-	-	+	3	+	I
Ranunculus sceleratus	-	-	-	-	+	-	-	-	-	-	-	-	-	+	+	3	II
Potentilla anserina	-	-	-	+	-	-	+	-	-	-	-	-	-	-	-	-	I
Juncus bufonius	-	-	-	-	3	-	-	-	-	-	-	-	-	+	-	-	I
Scirpus tabernaemontani	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	3	I
Phragmites communis	-	-	-	-	4	-	-	-	-	-	-	-	3	+	-	-	I

Also: In Relevé No. (W44) Puccinellia distans 4; (C76) Atriplex patula 4; Poa annua 4; (C80) Agropyron repens 3; (C79) Apium nodiflorum +; Samolus valerandi 4; Carex otrubae +; Amblystegium serpens +; (S9) Acrocladium cuspidatum 3; (S23) Cirsium vulgare 3; (C77) Hordeum secalinum 3; Polygonum aviculare +; (L3) Carex panicea 3; Barbula tophacea 3; Pellia endiviifolia 3; (L2) Carex panicea 3; Juncus bulbosus 4; Barbula tophacea +; Trifolium micranthum +; (W67) Pottia heimii 4; Hordeum secalinum +; Bellis perennis 4; (C62) Hordeum murinum +; Eleocharis palustris +; Phleum bertolonii +; Taraxacum laevigatum +.

Table 4.12b Ecological Characteristics

Relevé No.		S3	C76	C80	C79	S9	C77	S5	S6	S23	L3	L2	W67	W62
Water Sample No.		-	-	-	55	-	-	-	-	-	-	-	-	-
Soil Sample No.		146	125	127	-	163	126	162	164	165	179	178	66	65
	pH	5.6	6.0	5.7	7.3	5.0	6.0	4.9	5.5	5.7	8.7	8.8	8.4	7.7
	Na^{+}	4.75	8.50	26.25	3750	6.00	13.00	5.75	3.75	7.13	0.55	0.63	2.00	3.25
	K^{+}	0.14	0.50	0.95	30	0.09	0.38	0.08	0.09	0.17	0.05	0.06	0.50	0.50
	Mg^{2+}	0.35	0.75	1.58	105	0.23	1.05	0.23	0.35	0.30	0.10	0.11	1.13	0.93
	Ca^{2+}	5.00	2.50	4.50	2.25	2.00	3.38	2.50	3.25	2.50	3.00	3.50	7.25	10.50
	Cl^{-}	3.20	6.50	20.00	2750	7.40	12.00	7.50	2.88	5.00	0.28	0.09	0.50	1.00

Table 4.13a

Puccinellietum maritimae Warming (1906) Christiansen 1927.

	Sub-ass. puccinellietosum			Sub-ass. agrostetosum.						Sub-ass. festucetosum								
Relevé No.	S11	S10	S14	L7	S12	S8	S13	S16	S15	S7	L14	L5	L4	L8	L9	L10	L11	K
Area of Relevé (m^2)	4	1	4	4	4	1	4	1	4	1	4	4	4	4	4	4	4	
% cover	9.5	100	100	80	100	100	100	100	90	100	80	90	90	100	100	100	100	
Species No.	1	4	4	3	4	4	4	5	4	6	6	6	4	4	3	3	7	
Puccinellia maritima	10	8	8	8	9	8	8	6	5	8	5	5	7	7	5	4	-	V
Plantago maritima	-	-	-	5	3	5	6	6	7	5	3	3	3	7	9	8	8	V
Spergularia marina	-	3	5	6	3	4	3	6	5	4	7	5	7	4	-	-	+	V
Agrostis stolonifera	-	4	4	-	4	4	4	4	4	3	3	3	-	-	-	-	-	III
Lolium perenne	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	I
Festuca rubra	-	-	-	-	-	-	-	-	-	4	3	7	+	4	4	6	5	III
Juncus gerardii	-	-	4	-	-	-	-	-	-	4	-	-	-	-	-	-	-	I
Glaux maritima	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	I
Phragmites communis	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	I

Also: in Relevé (L14) Puccinellia distans 4; (L11) Cladonia sp. 5; Mnium affine 5; Aira caryophyllea +; Lathyrus pratensis +.

Table 4.13b

Ecological Characteristics

Relevé No.	S10 S11	S14	S12 S13	S15 S16	L5	L4	L9, L10 L11
Soil Sample No.	156	172	171	173	181	180	184
pH	5.9	6.4	5.9	5.8	6.8	7.7	6.8
Na^+	14.25	11.50	9.25	9.75	1.10	2.75	1.48
K^+	0.35	0.19	0.23	0.19	0.05	0.07	0.10
Mg^{2+}	0.39	0.30	0.30	0.26	0.05	0.08	0.12
Ca^{2+}	3.75	2.75	2.50	3.50	0.45	0.80	1.23
Cl^-	12.00	15.00	12.75	9.00	0.60	2.00	0.65

Table 4.14a — Spergularietum marinae ass. nov. prov.

	Monospecific variant		Sub-ass. initial, Atriplex variant								Sub-ass. festucetosum rubrae							
Relevé No.	L13	C27	W15	W17	W18	W11	W12	W1	W3	W4	C69	C72	C71	C73	C74	C75	C68	K
Area of Relevé (m^2)	4	4	4	4	4	1	4	4	0.25	0.25	4	4	4	4	4	4	4	
% cover	80	80	50	40	40	80	70	70	60	75	90	95	70	80	100	98	80	
Species No.	1	1	6	5	6	3	4	5	5	8	5	3	6	5	7	9	8	
Spergularia marina	8	9	7	7	5	9	7	6	5	7	8	9	7	3	7	5	9	V
Atriplex hastata	-	-	+	+	3	3	5	5	5	5	-	-	-	-	-	-	-	III
Agrostis stolonifera	-	-	-	2	4	2	1	4	5	2	-	4	-	7	5	6	-	IV
Tripleurospermum maritimum	-	-	+	3	3	-	-	4	3	1	-	-	-	-	-	-	-	II
Festuca rubra	-	-	-	-	-	-	-	-	-	-	5	4	5	+	3	6	4	II
Lolium perenne	-	-	-	-	-	-	-	-	-	-	3	-	3	-	3	+	+	II
Hordeum secalinum	-	-	-	-	-	-	-	-	-	-	4	-	4	-	4	4	4	II
Festuca arundinacea	-	-	-	-	-	-	-	-	-	-	-	-	3	-	5	3	3	II
Poa annua	-	-	4	3	-	-	-	-	-	4	-	-	-	4	-	-	3	II
Triglochin maritima	-	-	-	-	-	-	-	-	-	-	-	-	4	7	-	+	-	I
Atriplex patula	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	I
Alopecurus geniculatus	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	3	I

Also: In Relevé No. (W15) Bromus sterilis +; Rumex crispus +; (W18) Funaria hygrometrica 7; Cirsium palustre +; (W12) Cirsium vulgare +; (W1) Cirsium arvense +; (W3) Sonchus oleraceus +; (W4) Arrhenatherum elatius 3; Vulpia myuros 3; Holcus lanatus +; Trifolium repens 3; (C75) Polygonum aviculare 3.

Table 4.14b — Ecological Characteristics

Relevé No.	L13	C27	W18 W17	W4	C75 C74	C73
Soil Sample No.	183	96	72	68	128	124
pH	7.8	7.1	8.4	7.6	5.2	5.5
Na^+	2.25	17.75	0.55	6.63	9.50	32.50
K^+	0.04	0.17	0.13	0.35	0.60	0.70
Mg^{2+}	0.08	1.00	1.60	0.45	0.84	1.75
Ca^{2+}	0.58	15.75	7.50	7.25	2.50	4.75
Cl-	1.20	43.00	1.01	7.05	8.00	23.75

Table 4.15a

Puccinellietum distantis Feekes (1934) 1945

Sub-ass. initial

	Typical variant													Agrostis variant											Lolium variant									
Relevé No.	W7	W8	W9	W10	W29	W42	W50	W56	W41	C124	C125	C43	C15	C21	C17	C8	C31	C22	W6	C5	C96	C6	C9	C83	C81	C82	C89	C93	C94	C88	C87	K A	K B	K C
Area of Relevé (m^2)	0.25	0.25	0.25	0.25	4	4	4	1	4	4	4	4	4	4	4	4	4	4	0.25	4	4	4	4	4	4	4	4	4	4	4	4			
% cover	80	100	80	85	90	95	80	60	92	100	100	60	70	80	85	100	70	85	100	60	95	80	95	70	90	80	80	50	40	75	50			
Species No.	2	2	2	2	2	2	2	3	4	4	4	6	5	4	4	5	5	3	5	8	4	5	8	6	4	5	3	4	3	3	4			
Puccinellia distans	5	+	3	4	9	9	7	4	9	6	7	4	8	7	8	4	7	3	8	7	4	4	+	4	6	7	4	5	6	4	5	V	V	V
Spergularia marina	8	10	9	9	4	4	6	7	4	8	7	7	4	7	4	8	5	8	6	+	9	8	3	4	6	5	5	5	4	8	6	V	V	V
Atriplex hastata	-	-	-	-	-	-	-	4	+	+	+	4	+	4	4	-	4	-	4	-	3	-	-	4	-	3	-	+	-	-	-	III	III	II
Juncus bufonius	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	3	7	-	-	-	-	-	-	-	-	-	II	-
Aster tripolium	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	I	-	-
Agrostis stolonifera	-	-	-	-	-	-	-	-	-	-	-	-	-	+	5	4	4	4	3	5	3	4	7	7	5	5	-	-	-	-	-	-	V	II
Lolium perenne	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	4	+	8	3	3	3	3	-	I	V
Triglochin maritima	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	3	+	-	-	-	-	-	-	-	-	II	-
Ranunculus sceleratus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	3	+	-	-	-	-	-	-	-	-	-	II	-
Tripleurospermum maritimum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	I	-
Atriplex patula	-	-	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	I	-	-
Hordeum secalinum	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	I	-	-

Also: In Relevé No. (C43) Funaria hygrometrica 4; Cyanophyceae 7; (C8) Alopecurus geniculatus +; (C15) Sonchus asper +; Holcus lanatus +; (C5) Carex otrubae +; Apium nodiflorum +; Chenopodium rubrum +; (C9) Juncus articulatus 3; Eleocharis palustris 3.

Table 4.15b

Ecological Characteristics

Relevé No.	W7 W10	W41 W42	W29	C43	C21	C17	C8	C31	W6	C5	C9	C44	C81 C82	C87 C88	C93 C94
Soil Sample No.	70	48	45	105	99	89	77	100	70	76	78	145	130	131	133
pH	8.0	6.7	6.4	9.2	7.7	7.5	7.0	7.4	8.0	9.1	6.3	9.1	6.3	5.7	6.7
Na^+	4.75	3.75	3.75	1.08	11.50	10.00	4.00	11.50	4.75	5.75	6.75	2.50	1.90	5.00	1.35
K^+	0.43	0.35	0.35	0.10	0.40	0.23	0.13	0.07	0.43	0.07	0.15	0.10	0.05	0.09	0.07
Mg^{2+}	0.25	2.50	3.50	1.15	0.19	1.68	0.28	0.33	0.25	6.00	0.30	0.41	0.20	0.15	0.10
Ca^{2+}	6.50	8.25	8.75	4.25	1.30	13.75	2.00	3.00	6.50	3.00	7.75	4.00	0.83	0.93	1.13
Cl^-	3.98	12.42	16.50	0.20	28.00	19.25	3.43	13.73	3.98	9.00	9.75	0.50	1.75	4.75	0.75

Table 4.16a

Puccinellietum distantis Feekes (1934) 1945

				Sub-ass. degraded								Sub-ass. asteretosum						Aster tripolium Nodum					
				Monospecific variant				Agrostis variant															
Relevé No.	K A	K B	K C	C133	C132	W58	C159	C44	C14	C48	C47	C49	C51	C156	C157	C155	C160	C154	C113	C121	C128	K D	K E
Area of Relevé (m^2)				4	4	4	0.25	4	4	4	4	4	4	0.25	0.25	0.25	1	0.25	4	4	4		
% cover				70	80	90	100	70	70	100	100	90	100	100	100	90	100	100	100	100	100		
Species No.				1	1	1	1	5	6	9	10	8	9	2	2	4	3	1	2	2	2		
Puccinellia distans	V	V	V	8	8	9	10	4	8	9	9	5	7	7	5	6	3	-	-	-	-	V	V
Spergularia marina	V	V	V	-	-	-	-	-	-	-	-	-	-	-	-	+	7	-	-	-	-	-	II
Aster tripolium	I	-	-	-	-	-	-	-	-	4	+	7	7	7	8	7	6	10	10	10	9	II	V
Atriplex hastata	III	III	I	-	-	-	-	-	4	-	-	3	-	-	-	+	-	-	-	-	-	I	II
Juncus bufonius	-	II	-	-	-	-	-	-	-	-	3	4	4	-	-	-	-	-	-	-	-	II	II
Agrostis stolonifera	-	V	II	-	-	-	-	3	4	3	3	4	+	-	-	-	-	-	+	3	5	III	II
Funaria hygrometrica	I	-	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-	-	I	-
Sonchus arvensis	-	-	-	-	-	-	-	-	-	-	3	-	+	-	-	-	-	-	-	-	-	I	I
Festuca arundinacea	-	-	-	-	-	-	-	-	-	+	-	3	+	-	-	-	-	-	-	-	-	I	II
Triglochin maritima	-	II	-	-	-	-	-	-	-	3	3	5	4	-	-	-	-	-	-	-	-	II	II
Chenopodium rubrum	-	I	-	-	-	-	-	-	-	+	2	2	-	-	-	-	-	-	-	-	-	II	I
Samolus valerandi	-	-	-	-	-	-	-	-	-	+	-	-	3	-	-	-	-	-	-	-	-	I	I
Epilobium hirsutum	-	-	-	-	-	-	-	-	-	3	+	-	-	-	-	-	-	-	-	-	-	II	I
Barbula tophacea	-	-	-	-	-	-	-	7	-	-	3	-	-	-	-	-	-	-	-	-	-	II	-
Pulicaria dysentrica	-	-	-	-	-	-	-	-	-	+	-	-	3	-	-	-	-	-	-	-	-	I	I

Also: In Relevé No. (C44) Sagina nodosa 3; Centaurium erythra ea +; (C14) Rumex crispus +; Brassica oleracea +; Dactylis glomerata +.

Table 4.16b

Ecological Characteristics

Relevé No.	C132 C133	W58	C47	C14	C51 C49	C157	C121	C128
Soil Sample No.	9	42	108	85	109	23	19	16
pH	7.9	6.7	9.9	8.4	8.7	6.9	7.0	7.0
Na^+	0.13	1.83	0.85	0.48	0.77	4.75	14.25	3.30
K^+	0.05	0.13	0.04	0.12	0.03	0.06	0.33	0.04
Mg^{2+}	1.13	4.25	32.50	1.00	2.00	1.16	0.28	0.14
Ca^{2+}	2.00	9.75	0.58	7.75	3.50	3.50	6.00	4.29
Cl^-	-	11.65	1.50	0.75	1.20	-	-	-

Table 4.17a

Puccinellietum distantis Feekes (1934) 1945 Transition type 1.

Relevé No.	K A	K B	K C	W30	W31	W28	W33	S26	S29	C95	S28	C101	K F
				Sub-ass. of Agropyron repens					Agropyron repens Nodum				
Area of Relevé (m^2)				4	4	4	4	4	4	4	4	4	
% cover				100	90	70	100	70	100	100	100	60	
Moss cover				-	-	-	-	-	-	70	-	-	
Species No.				4	5	5	6	7	3	3	6	7	
Puccinellia distans	V	V	V	8	7	5	4	4	-	-	-	-	III
Spergularia marina	V	V	V	5	4	4	4	-	-	-	-	-	III
Agropyron repens	-	-	-	5	7	7	8	4	10	10	9	5	V
Atriplex hastata	III	III	I	+	3	3	5	+	-	-	-	4	IV
Agrostis stolonifera	-	V	I	-	-	4	-	-	-	-	-	6	II
Festuca rubra	-	-	-	-	-	-	-	8	3	-	-	-	II
Holcus lanatus	-	-	-	-	-	-	-	-	-	-	4	3	II
Hordeum secalinum	-	I	-	-	3	-	+	-	-	-	-	-	II
Lolium perenne	-	I	V	-	-	-	-	+	-	-	-	-	I
Cirsium arvense	-	-	-	-	-	-	-	-	-	+	-	3	II
Brachythecium rutabulum	-	-	-	-	-	-	-	-	-	8	-	-	I

Also: In Relevé No. (W33) Poa annua 4; (S26) Cirsium vulgare +; Poa pratensis +; (S29) Arrhenatherum elatius 3; (S28) Pohlia nutans 3; Urtica dioica +; Phragmites communis 4; Vicia angustifolia 3; (C101) Ranunculus repens 3; Chenopodium rubrum +.

Table 4.17b

Ecological Characteristics

Relevé No.	W28 W31	S26	S29 S28	C95	C101
Soil Sample No.	46	175	176	134	142
pH	6.9	6.8	7.3	8.1	8.1
Na^+	0.83	6.50	6.00	3.25	1.53
K^+	0.12	0.20	0.16	0.20	0.13
Mg^{2+}	1.58	0.18	0.18	0.18	0.25
Ca^{2+}	5.25	2.25	2.25	3.13	7.75
Cl^-	2.75	4.80	4.80	2.25	4.13

Table 4.18a

Puccinellietum distantis Feekes (1934) 1945 Transition type 2

Relevé No.	K A	K B	K C	C122	C123	W14	W15	W52	W53	W54	KG
				Sub-ass. vulpietosum		Vulpia-Agrostis Nodum					
Area of Relevé (m^2)				4	4	1	1	4	4	4	
% cover				100	100	80	100	190	80	80	
Moss cover				-	30	-	20	10	-	10	
Species No.				10	11	7	14	15	15	15	
Spergularia marina	V	V	V	4	-	-	-	-	-	-	I
Puccinellia distans	V	V	V	8	6	-	-	-	-	-	II
Aster tripolium	I	-	-	4	3	-	-	-	-	-	II
Vulpia myuros	-	-	-	4	5	5	8	8	8	3	V
Vulpia bromoides	-	-	-	-	-	-	-	-	-	6	I
Agrostis stolonifera	-	V	II	4	5	8	3	4	3	3	V
Atriplex hastata	III	III	I	-	-	3	-	-	-	-	I
Cirsium vulgare	-	-	-	-	+	+	4	-	4	3	IV
Holcus lanatus	I	-	-	3	-	+	-	3	4	-	III
Sonchus oleraceus	-	-	-	-	-	-	+	-	+	+	III
Crepis capillaris	-	-	-	-	-	-	3	+	+	+	III
Funaria hygrometrica	I	-	-	-	6	-	-	3	-	3	III
Cerastium fontanum	-	-	-	-	3	-	-	3	+	-	III
Linaria vulgaris	-	-	-	-	-	-	-	3	-	3	II
Inula conyza	-	-	-	-	-	-	-	3	+	+	III
Achillea millefolium	-	-	-	-	-	-	4	-	-	+	II
Agropyron repens	-	-	-	4	-	4	-	-	-	-	II
Trifolium repens	-	-	-	4	4	-	-	-	-	-	II
Tripleurospermum maritimum	-	I	-	-	-	3	-	-	+	-	II
Ceratodon purpureus	-	-	-	-	-	-	5	4	-	-	II
Cirsium arvense	-	-	-	-	-	-	-	+	+	-	II
Rumex crispus	-	-	-	-	-	-	+	3	-	-	II

Also: In Relevé No. (C122) Juncus bufonius 3; Bellis perennis +; (C123) Vicia angustifolia 3; Festuca arundinacea +; Cyonosurus cristatus 3; (W5) Dipsacus pilosus +; Arrhenatherum elatius 3; Plantago major 3; Epilobium tetragonum +; Sagina nodosa +; Poa annua 4; (W52) Chamaenerion angustifolium 3; Sonchus arvensis 3; Senecio jacobaea 3; Poa pratensis 3; (W53) Plantago lanceolata +; Plantago media +; Taraxacum laevigatum +; Dipsacus fullonum +; (W54) Vicia hirsuta +; Festuca pratensis +; Barbula sp. 4; Arenaria serpyllifolia 6; Vicia sativa +.

Table 4.18b

Ecological Characteristics

Relevé No.	C123 C122	W52 W53
Soil Sample No.	30	69
pH	8.4	7.3
Na^{+}	0.10	0.14
K^{+}	0.05	0.38
Mg^{2+}	0.65	0.40
Ca^{2+}	1.90	6.25
Cl^{-}	0.10	0.50

Table 4.19a   Puccinellietum distantis   Feekes (1934)   1945   Transition Type 3

				Sub-ass. of Hordeum secalinum											
				typical variant					Agrostis variant						
Relevé No.	K A	K B	K C	W37	W38	C70	W36	W32	W59	W48	W51	W43	W49	K H	K I
Area of Relevé (m^2)				4	4	4	4	4	4	4	4	4	4		
% cover				100	100	100	75	90	100	100	100	100	100		
Species No.				14	16	7	4	5	5	6	5	6	13		
Spergularia marina	V	V	V	-	-	4	4	4	-	-	-	-	-	III	-
Puccinellia distans	V	V	V	4	5	-	8	7	-	4	5	5	+	IV	IV
Atriplex hastata	III	III	I	4	+	+	+	+	3	-	-	+	-	V	II
Hordeum secalinum	I	I	-	6	4	5	4	5	7	9	7	6	7	V	V
Agrostis stolonifera	-	V	II	-	-	-	-	-	6	4	4	7	5	-	V
Lolium perenne	-	I	V	6	5	8	-	-	-	4	4	-	4	III	III
Leontodon autumnalis	-	-	-	3	+	-	-	-	-	+	-	-	3	II	II
Festuca pratensis	-	-	-	4	-	3	-	-	3	-	-	3	-	II	II
Agropyron repens	-	-	-	-	-	-	-	5	4	-	4	-	-	I	II
Poa annua	-	-	-	-	4	+	-	-	-	+	-	-	-	II	I
Festuca rubra	-	I	-	3	-	-	-	-	-	-	-	-	4	I	I
Holcus lanatus	I	-	-	-	-	+	-	-	-	-	-	-	+	I	I
Trifolium repens	-	-	-	-	3	-	-	-	-	-	-	-	4	I	I
Agrostis tenuis	-	-	-	+	6	-	-	-	-	-	-	-	-	II	-
Bellis perennis	-	-	-	+	+	-	-	-	-	-	-	-	-	II	-
Cynosurus cristatus	-	-	-	-	4	-	-	-	-	-	-	-	4	II	I
Alopecurus geniculatus	-	-	-	3	3	-	-	-	-	-	-	-	-	I	-
Carex otrubae	-	-	-	3	-	-	-	-	-	-	-	4	-	I	I
Juncus inflexus	-	-	-	3	-	-	-	-	-	-	-	-	3	I	I
Poa trivialis	-	-	-	3	4	-	-	-	-	-	-	-	-	II	I

Also: In Relevé No. (W37) Plantago lanceolata +; (W38) Plantago lanceolata +; Plantago major 4; Cirsium vulgare +; Cirsium arvense 3; (W49) Cirsium vulgare +; Cerastium holosteoides +; Trifolium pratense +.

Table 4.19b

Ecological Characteristics

Relevé No.	W37	W32	C70	W59	W48 W49	W43
Soil Sample No.	49	46	119	43	59	52
pH	6.7	6.9	5.0	6.5	5.2	6.2
Na^{+}	1.00	0.83	12.50	1.80	0.16	0.90
K^{+}	0.23	0.12	1.50	0.15	0.25	0.12
Mg^{2+}	2.00	1.58	0.98	3.25	1.38	3.75
Ca^{2+}	7.50	5.25	3.00	7.75	5.25	8.75
Cl^{-}	8.82	2.75	18.10	11.30	1.30	7.94

Table 4.20a. Puccinellietum distantis Feekes (1934) 1945 Transition Type 4.

Relevé No.	K A	K B	K C	C36	C63	C66	C35	C61	C60	W23	KJ
				Sub-ass. apietosum					Apium-Poa Nodum		
Area of Relevé (m^2)				4	4	4	4	4	4	4	
% cover				100	100	100	90	100	100	100	
Species No.				5	6	8	8	16	10	11	
Puccinellia distans	V	V	V	6	3	5	4	4	-	-	IV
Spergularia marina	V	V	V	6	7	3	4	-	-	-	III
Apium graveolens	-	-	-	3	3	8	6	7	7	7	V
Atriplex hastata	III	III	I	6	7	4	3	4	-	-	IV
Agrostis stolonifera	-	V	II	3	-	3	6	+	3	4	V
Juncus bufonius	-	II	-	-	4	4	4	3	-	-	III
Holcus lanatus	I	-	-	-	-	-	-	3	3	5	III
Poa trivialis	-	-	-	-	-	-	-	4	7	4	III
Cirsium vulgare	-	-	-	-	-	-	-	-	3	+	II
Epilobium hirsutum	-	-	-	-	-	-	-	4	4	4	III
Ranunculus sceleratus	-	II	-	-	3	-	-	3	-	-	II
Tussilago farfara	-	-	-	-	-	3	-	+	-	-	II
Triglochin maritima	-	II	-	-	-	-	3	-	-	-	I
Rumex conglomeratus	-	-	-	-	-	-	-	3	3	-	II

Also: In Relevé No. (C66) Phragmites communis +; (C35) Festuca arundinacea +; (C61) Epilobium obscurum 3; Sonchus oleraceus +; Carex otrubae +; Funaria hygrometrica +; Polygonum aviculare +; (C60) Tripleurospermum maritimum 3; Rumex crispus 3; Juncus inflexus 3; (W23) Urtica dioica 3; Cirsium arvense 3; Galium aparine 4; Alopecurus geniculatus 3; Agropyron repens 4.

Table 4.20b Ecological Characteristics

Relevé No.	C35	C61 C63	C66	C60	W23 W
Soil Sample No.	144	112	113	111	-
Water Sample No.	-	-	-	-	04
pH	8.9	7.9	8.4	7.8	8.4
Na^+	3.00	0.30	0.35	0.50	148
K^+	0.06	0.03	0.07	0.06	14
Mg^{2+}	0.09	0.20	0.50	0.55	63
Ca^{2+}	4.25	5.00	6.25	6.75	125
Cl^-	2.25	0.60	3.40	0.75	58

Table 4.21a — Puccinellietum distantis Feekes (1934) 1945

Relevé No.	K A	K B	K C	C62	C134	W16	W19	W20	C20	C136	C136	C140	C137	C138	C139	C141	C142	C143	C144	C145	C146	C147	C46	C45	C148	C149	C150	C154	C151	C152	C153	K K	K L	K M
				Sub-ass. funaria hygrometrica						Sub-ass. barbuletosum tophaceae															Sub-ass. pohlietosum annotinae: Typical variant				Juncus variant					
Area of Relevé (m^2)				64	0.25	0.1	0.25	0.25	4	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	4	4	0.25	0.25	0.25	0.25	0.25	0.25	0.25			
% cover Phanerogams.				80	20	25	30	30	50	16	20	-	30	20	12	20	40	4	4	4	4	30	70	80	80	80	100	80	100	100	100			
% cover Moss				80	100	50	60	60	20	100	100	100	100	100	100	100	100	100	100	100	100	100	40	20	80	100	100	100	100	80	100			
Species No.				10	2	6	8	12	3	3	3	3	3	3	3	4	4	3	3	3	3	4	5	6	6	4	8	6	8	7	8			
Puccinellia distans	V	V	V	10	5	4	3	3	8	5	5	-	5	4	4	5	7	4	4	4	4	5	7	8	8	8	8	7	5	4	4	V	V	V
Spergularia marina	V	V	V	-	-	5	4	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	-	+	III	-	II
Funaria hygrometrica	I	-	-	8	10	7	8	8	4	9	10	4	4	4	4	3	6	4	4	4	4	5	4	3	-	-	-	-	-	-	-	V	V	-
Barbula tophacea	-	-	-	-	-	-	-	-	-	4	7	10	10	10	10	10	8	9	10	10	10	9	4	3	-	-	-	-	-	-	-	-	V	-
Pottia crinita	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	V
Pohlia annotina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	9	10	10	10	10	9	10	-	II	-
Juncus bufonius	I	-	II	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	7	7	7	I	-	III
Atriplex hastata	I	III	III	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	4	5	-	-	II
Triglochin maritima	II	-	II	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	3	3	7	7	-	-	IV
Juncus articulatus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	5	-	6	5	7	-	-	IV
Agrostis stolonifera	-	V	I	-	-	4	5	5	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	6	-	-	IV	-	II
Poa annua	-	-	-	3	-	4	-	3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	III	-	-
Chenopodium rubrum	-	-	-	-	-	-	3	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	II	-	-
Festuca arundinacea	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	+	-	-	-	-	-	-	-	I	-	I
Tussilago farfara	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	-	3	-	-	-	3	-	-	III
Holcus lanatus	I	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3	4	3	-	-	-	-	-	-	III

Also: In Relevé No. (C62) Cirsium vulgare +; Epilobium hirsutum 3; Epilobium parviflorum 3; Apium graveolens +; Sonchus oleraceus +; (W16) Tripleurospermum maritimum 4; (W19) Sonchus asper +; Aira caryophyllea +; Epilobium hirsutum +; (W20) Tripleurospermum maritimum +; Arenaria serpyllifolia +; Sagina procumbens +; Epilobium hirsutum +; Arabidopsis thaliana +; Sonchus asper +; (C147) Dactylis glomerata 4; (C46) Sonchus arvensis 5; Festuca arundinacea 3; (C45) Cyanophyceae 4; Sonchus arvensis 5; Festuca arundinacea +; (C148) Cirsium vulgare +; (C149) Polygonum persicaria +; (C150) Cirsium vulgare +; (C154) Epilobium sp. +; (C151) Rubus fruticosus agg. +; (C154) Polygonum persicaria +.

Table 4.21b — Ecological Characteristics

Soil Sample No.	73	12	13	14	15
pH	9.0	8.5	8.6	8.4	8.8
Na^+	0.06	0.12	0.15	0.08	0.07
K^+	0.10	0.11	0.07	0.02	0.01
Mg^{2+}	9.50	1.26	3.63	4.75	11.75
Ca^{2+}	3.25	3.97	2.64	3.86	1.50

Table 4.22 Constancy Table (K) of the Sub-associations of the Association Puccinellietum distantis Feekes (1934) 1945

	A	B	C	D	E	F	G	H	I	J	K	L	M
Number of Relevés	13	11	7	8	6	5	2	5	5	5	6	16	7
Association Species													
Puccinellia distans	V	V	V	V	V	III	II	IV	IV	IV	V	V	V
Spergularia marina	V	V	V	-	II	III	I	III	-	III	II	-	II
Sub-association and variant species													
Agrostis stolonifera	-	V	II	III	II	II	V	-	V	V	IV	-	I
Lolium perenne	-	I	V	-	-	-	-	III	III	-	-	-	-
Aster tripolium	I	-	-	II	V	-	II	-	-	-	-	-	-
Agropyron repens	-	-	-	-	-	V	-	II	I	-	-	-	-
Vulpia myuros	-	-	-	-	-	-	V	-	-	-	-	-	-
Hordeum secalinum	-	I	-	-	-	II	-	V	V	-	-	-	-
Apium graveolens	-	-	-	-	-	-	-	-	-	V	-	-	-
Funaria hygrometrica	I	-	-	I	-	-	III	-	-	-	V	-	-
Barbula tophacea	-	-	-	-	-	-	I	-	-	-	-	V	-
Pohlia annotina	-	-	-	-	-	-	-	-	-	-	-	-	V
Companion Species. (Constancy II)													
Atriplex hastata	III	III	II	I	II	IV	I	V	II	IV	-	-	III
Holcus lanatus	I	-	-	-	-	II	III	I	I	III	-	-	III
Juncus bufonius	-	II	I	II	II	-	I	-	-	III	-	-	III
Triglochin maritima	-	II	-	II	II	-	-	-	-	I	-	-	IV
Cirsium vulgare	-	-	-	I	-	I	IV	I	I	-	II	-	-
Poa annua	-	I	-	I	-	I	-	II	I	-	III	-	-
Festuca arundinacea	-	I	-	I	II	-	I	-	-	I	-	-	-
Festuca rubra	-	-	-	-	-	II	-	I	I	-	-	-	-
Sonchus oleraceus	-	-	-	I	-	-	III	-	-	-	-	-	-
Ranunculus sceleratus	-	II	-	-	-	-	-	-	-	II	-	-	-
Leontodon autumnalis	-	-	-	-	-	-	-	II	II	-	-	-	-

Table 4.23a

Saline Agrostis stolonifera Noda

	Typical Nodum					Agrostis-Lolium Nodum				
Relevé No.	W2	C117	C118	S4	W13	S18	S19	S22	S21	S20
Area of Relevé (m^2)	4	4	4	4	1	4	4	4	4	4
% cover	100	100	100	100	100	100	100	100	100	100
Species No.	1	2	4	2	6	6	6	5	4	7
Agrostis stolonifera	10	10	7	10	9	7	8	9	9	7
Lolium perenne	-	-	-	-	-	7	5	4	4	6
Poa pratensis	-	-	-	-	-	4	4	3	4	5
Deschampsia cespitosa	-	-	-	-	-	4	3	-	+	3
Atriplex hastata	-	+	4	-	-	-	-	-	-	-
Trifolium repens	-	-	-	-	-	-	3	3	-	3
Triglochin maritima	-	-	7	-	-	-	3	-	-	-
Cirsium vulgare	-	-	-	-	-	3	-	-	-	3
Potentilla anserina	-	-	-	-	-	3	-	+	-	-

Also: in Relevé No. (C118) Ranunculus sceleratus +; (S4) Plantago maritima 3; (W13) Poa annua 4; Agropyron repens +; Cirsium palustre 4; Sonchus oleraceus 4; Leontodon autumnalis +; (S20) Potentilla anserina 3.

Table 4.23b

Ecological Characteristics

Relevé No.		W2	S4	W13	S18	S19	S20	S21,S22
Soil Sample No.		67	151	71	166	167	168	169
	pH	8.0	5.1	8.4	4.9	4.5	4.3	5.4
	Na^{+}	1.75	3.50	0.35	8.00	7.50	4.25	2.25
	K^{+}	0.14	0.38	0.15	0.13	0.10	0.15	0.07
	Mg^{2+}	0.28	0.25	1.45	0.35	0.30	0.23	0.28
	Ca^{2+}	5.75	2.88	7.50	4.75	2.75	2.50	2.25
	Cl^{-}	0.94	3.75	0.78	8.00	8.75	5.25	1.40

Table 4.24a

Saline Ranunculus sceleratus Nodum

Relevé No.	W22	W60	W64
Area of Relevé (m^2)	1	4	4
% cover	90	100	60
Species No.	5	5	5
Ranunculus sceleratus	8	8	7
Ranunculus baudotii	-	-	3
Zannichellia palustris	5	-	+
Alopecurus geniculatus	4	4	-
Festuca arundinacea	-	5	-
Juncus gerardii	-	-	3
Juncus inflexus	-	+	-
Juncus bufonius	-	-	+
Poa trivialis	4	-	-
Phragmites communis	4	-	-
Agrostis stolonifera	-	4	-

Table 4.24b

Ecological Characteristics

Relevé No.	W22	W60	W64
Water Sample No.	4	26	27
Conductivity	1.57	6.60	5.93
pH	8.4	8.6	8.5
Na^+	148	1100	1050
K^+	14	05	09
Mg^{2+}	63	63	75
Ca^{2+}	125	168	28
Cl-	58	950	830

Table 4.25 Miscellaneous Stands

Relevé No.	C53	C64	C2	C130	S27
Area of relevé (m^2)	4	4	4	4	4
% cover	100	100	90	100	100
Species No.	2	5	7	2	1
Eleocharis palustris	10	5	4		
Atriplex hastata	3	7			
Scirpus lacustris		7			
Holcus lanatus		1			
Polygonum persicaria		1			
Rumex hydrolapathum			9		
Scirpus tabernaemontani			+		
Triglochin maritima			+		
Lemna trisulca			7		
Lemna minor			4		
Enteromorpha intestinalis			7		
Sparganium erectum				7	
Elodea canadensis				8	
Rorippa nasturtium-aquaticum					10

Localities for Relevés

Association Lemnetum sensu lato

C90, C92	Shrew bridge, Nantwich, Cheshire. (33/651509).
C59a	River Weaver, Winsford, Cheshire. (33/655684).
C40	Billingegreen Pool, Cheshire. (33/681715).
DWS11	Mickletown, West Yorkshire (44/402276).

Association Potamogetonetum pectinati

W26,W27	River Salwarpe (Ladywood Bridge), Droitwich,Worcestershire. (32/864619).
W20	Worcester and Birmingham Canal, Stoke Works, Worcestershire. (32/943662).
C34	Anderton, Cheshire. (33/662750)
C39	Trent and Mersey Canal, Cheshire. (33/683714).
C58	Winsford, Cheshire. (33/655684).
C59	River Weaver near Silverwell lagoon, Cheshire. (33/566768)
C84	Boating lake, Nantwich, Cheshire. (33/651509)
C1,C3,C7	Marston Pool, Northwich, Cheshire. (33/671754-7).
S1	River Trent, Pasturefields, Staffordshire. (33/992247)
S24	River Trent, Shirleywich, Staffordshire. (33/984254)
DWS9	Mickletown, West Yorkshire (44/402276)

Association Zannichellietum palustris

W47	Upton Warren pools, Worcestershire. (32/934665)
W21	Droitwich canal, Worcestershire .(32/975622)
S17	Pasturefields (ditch) Staffordshire. (33/992248)
C33	Anderton pool, Cheshire, (33/662750)
C54	Winsford Pool, Cheshire. (33/655684)
DWS8	Mickletown, West Yorkshire. (44/402276)

Association Myriophylletum sensu lato

L21,L22	Preesall, (lake II,III),Lancashire. (34/361468-9)
W24	Droitwich canal, Worcestershire (32/876623)
DWS10	Mickletown, West Yorkshire (44/402276)
C129	Watch Lane Pond, Sandbach, Cheshire. (33/730608)

Association Typhetum angustifolio-latifoliae

C112 Bottom Flash, Winsford, Cheshire. (33/665654)
C120 Watch Lane, Sandbach, Cheshire. (33/726604)
C126,C127 Watch Lane, Sandbach, Cheshire (33/726606)
C38 Marsh near Trent and Mersey Canal, Cheshire.(33/683714)
C57 Winsford pool, Cheshire. (33/655684)

Association Scirpetum maritimi

C23,C24,C25,C26,C28,C29,C30 - Dairy House Farm, Marston, Middlewich, Cheshire. (33/662753)
C67 Silver Well, Cheshire. (33/566767)

Association Scirpetum tabernaemontani

Sub-ass. typicum

W61,W65,W66 - Southam Salt Spring, Warwickshire (24/444602)
W46 Upton Warren Pool, Worcestershire. (32/934665)
C4 Marston Pool, Northwich, Cheshire. (33/671757)
C11 Marston Pool, Northwich, Cheshire. (33/671754)
C131 Watch Lane, Sandbach, Cheshire.(33/726604)
L20 Preesall, Lancashire. (34/361468)
C32 Anderton Cistern, Cheshire (33/662750)

Sub-ass. agrostetosum

C37 Anderton, Cheshire. (33/652754)
C52,C55,C56 Winsford, Cheshire (33/655684)
C119 Watch Lane, Sandbach, Cheshire. (33/726606)

Association Phragmitetum eurosibricum

Sub-ass. typicum

W25 Opposite Chawson Farm, Droitwich, Worcestershire,(32/881624)
C104 Lock bridge, River Weaver, Dutton, Cheshire. (33/58770)
C105,C106 Plumley, Cheshire. (33/708751)
L1,L16 Preesall, Lancashire. (34/361467)

Sub-ass. plantaginetosum

L6,L15,L17-L19 -Preesall Marsh, Lancashire. (34/361467)

Association Caricetum otrubae

C108-C111, Plumley, Cheshire (33/708751)

W45,W68-W70 - Upton Warren, Worcestershire. (32/934665)

Association Atriplicetum salinae deviense

Sub-ass. initial

C97-C99 Middlewich, Cheshire. (33/712652)

C41,C42 Winsford Lagoon,1,Cheshire. (33/656682)

C10 Marston pool, Cheshire (33/671754)

C102 Dutton Lagoon, Cheshire (33/583767)

Sub-ass. atriplicetosum

C12,C13 Neumann's Flash. Cheshire. (33/665749)

C18 Ashton Flash. Cheshire (33/666758)

C65 Silver Well, Cheshire. (33/566767)

C103 Dutton, Cheshire (33/583767)

W34,W39,W40,W55,W57. - Upton Warren, Worcestershire. (32/934665)

S25 Shirleywich, Staffordshire (33/984259)

Sub-ass. agrostetosum

C107 Plumley, Cheshire. (33/708751)

C16 Neumann's Flash. Cheshire (33/665749)

C19 Ashton Flash, Cheshire. (33/666748)

C100 Dutton, Cheshire (33/583767)

C85,C91 Nantwich, Cheshire. (33/651510)

C114,C115,C116 - Watch Lane, Sandbach, Cheshire. (33/730605)

Association Cotuletum coronopifoliae

WY1-WY6 Mickletown, West Yorkshire. (44/402276)

DWS1-DWS7 Mickletown, West Yorkshire (44/402276)

LM1 Leasowe, Merseyside. (33/252914)

Association Juncetum gerardii

Sub-ass. agrostetosum

W44 Upton Warren, Worcestershire. (32/934665)

S3 Pasturefield, Staffordshire. (33/992248)

C79,C76,C80 - Aldersey, Cheshire. (33/457567)

Sub-ass. of Festuca and Glaux

C77,C78 Aldersey, Cheshire. (33/457567)

S5,S6,S9,S23 - Pasturefields, Staffordshire. (33/992248)

Sub-ass. of Leontodon autumnalis

L2,L3 Preesall, Lancashire. (34/361467)

W62,W63,W67 - Southam Salt Spring, Warwickshire (24/444602)

Association Puccinellietum maritimae

Sub-ass. puccinellietosum

S10,S11,S14 - Pasturefields, Staffordshire. (33/992248)

Sub-ass. agrostetosum

S8,S12,S13,S15,S16 - Pasturefields, Staffordshire (33/992248)

L7 Preesall, Lancashire (34/361467)

Sub-ass. festucetosum

S7 Pasturefields, Staffordshire. (33/992248)

L4,L5,L8-L11, L14 - Preesall, Lancashire. (34/361467)

Association Spergularietum marinae

Sub-ass. initial

L13 Preesall, Lancashire. (34/361467)

C27 Dairy House Farm, Marston, Middlewich, Cheshire. (33/662753)

W1,W3,W4,W11,W12, W15,W17,W18 - Stoke Works, Worcestershire (32/943663)

Sub-ass. festucetosum

C68,C69,C71-C75 - Aldersey, Cheshire. (33/457567)

Association Puccinellietum distantis

Sub-ass. initial

W6,W10, Stoke Work, Worcestershire (32/943663)

W29,W41,W42,W50,W56 - Upton Warren, Worcestershire (32/934665)

C15,C17 Neumann's Flash, Cheshire (33/665749)

C43 Winsford, Cheshire. (33/656682)

C124,C125 Watch Lane, Sandbach, Cheshire. (33/730605)

C21,C22 Dairy House Farm, Marston,Cheshire (33/662753)

C5,C6,C9,C8 - Marston, Cheshire. (33/671754)

C31 Anderton, Cheshire (33/652750)

C96 Middlewich Lagoon, Cheshire (33/712652)

C81,C82,C83,C87-C89,C93,C94 - Shrew bridge, Nantwich, Cheshire (33/651510)

Sub-ass. degraded

C132,C133,C159 - Elton Hall Flash, Cheshire (33/717596)

W58 Upton Warren, Worcestershire. (32/934665)

C44,C48,C47 - Winsford,Cheshire. (33/654684)

C14 Neumann's Flash, Cheshire. (33/665749)

Sub-ass. asteretosum

C49,C51 Winsford, Cheshire. (33/654684)

C155-C157,C160. - Watch Lane, Sandbach, Cheshire. (33/730605)

Sub-ass. Agropyron repens

W28,W30,W32,W33. - Upton Warren,Worcestershire (32/934665)

S26 Amerton Brook, Shirleywich,Staffordshire.(33/984259)

Sub-ass. vulpietosum

C122,C123 Watch Lane, Sandbach, Cheshire (33/730605)

Sub-ass. hordeetosum

W32,W36-W38,W43,W48,W49,W51,W59 - Upton Warren,Worcestershire. (32/934665)

C70 Aldersey, Cheshire. (33/457567)

Sub-ass. apietosum

C35,C36 Anderton, Cheshire (33/655750)

C61,C63,C66 - Silver Well, Cheshire. (33/566767)

Sub-ass. funerietosum

C62 Silverwell, Cheshire (33/566767)

C134 Elton Hall Flash, Cheshire (33/717596)

W16,W20,W19 .-Stoke Works,Worcestershire (32/943663)

C20 Ashton Flash, Cheshire. (33/666748)

Sub-ass. barbuletosum

C135-C147 Elton Hall Flash, Cheshire (33/717596)

C46,C45. Winsford, Cheshire (33/654684)

Sub-ass. pohlietosum

C148-C154 Elton Hall Flash, Cheshire (33/717596)

Saline Agrostis stolonifera Noda

W2,W13 Stoke Works, Worcestershire (32/943662)

C117,C118 Watch Lane, Sandbach, Cheshire (33/730605)

S4,S18-S22 Pasturefields,Staffordshire (33/992248)

Saline Ranunculus sceleratus Nodum

W22 Droitwich Canal, Worcestershire (32/975622)

W60,W64 Southam Salt Spring, Warwickshire (24/444602)

Agropyron repens Nodum

C95 Middlewich, Cheshire, (33/712652)

C101 Dutton,Cheshire (33/583767)

S28,S29 Amerton Brook, Shirleywich, Staffordshire. (33/984259)

Vulpia-Agrostis stolonifera Nodum

W14,W15,W52,W53,W54 - Stoke Works, Worcestershire (32/943662)

Aster tripolium Nodum

C113,C121,C128,C154 - Watch Lane, Sandbach, Cheshire. (33/730605)

Apium-Poa Nodum

C60	SilverWell, Cheshire. (33/566767)
W23	Droitwich Canal, Worcestershire (32/876623)

Miscellaneous Stands

C53	Winsford, Cheshire. (33/654684)
C64	Silver Well, Cheshire. (33/566767)
C2	Marston, Cheshire (33/671757)
C130	Bottom Flash, Winsford, Cheshire (33/665654)
S27	Amerton Brook, Shirleywich, Staffordshire (33/984259)

APPENDIX I

a. Atomic absorption spectrophotometer procedure.

For the analysis of ecological materials, two techniques, flame spectroscopy (emission spectra) and atomic absorption spectrophotometry (absorption spectra) are well known. More recently, the atomic absorption method has almost replaced the flame emission technique for the analysis of most elements. The use of flame absorption spectra was first proposed and developed by Walsh (1955) and the principles underlying the technique, as given by Allen (1974) are as follows: "Atomic absorption spectra are formed by the absorption of radiation of certain wavelengths by atoms whose electrons are in the ground state. On absorbing this energy the atoms become excited. The extent of absorption is dependent on the number of atoms in the ground state in the path of the radiation beam at any one time and can thus be used as a quantitative method of determining this number."

What actually happens is that a solution of the element is sprayed into a relatively cool flame and the atoms tend to remain in ground state. Then radiation of a characteristic wavelength (e.g. Na^+. 589 nm) from the hollow cathode discharge lamp set on a particular continuous mA reading (e.g. 12 for Na^+) is passed through the flame and the decrease in intensity is measured using a monochromater and detection system. This decrease is related to the concentration of the element in solution and thus the measurement system is recorded on the chart.

A Perkin-Elmer 360 Atomic Absorption Spectrophotometer was used for the four cations, sodium, potassium, magnesium, calcium analysis. Basically, this consists of a source of radiation, burner plus sampler compartment, monochromator and a detection and measurement system in the form of a chart recorder. The equipment was prepared for operation according to the operating conditions specified in the Manual (Perkin-Elmer, Model 360 Atomic Absorption Spectrophotometer, 1974). For greater accuracy, the spectrophotometer was calibrated to a 0-2 ppm range and the test samples diluted the appropriate number of times.

b. Auto-Analyser Method.

Water and soil chloride was analysed on the Technicon II Autoanalyzer.

Auto-analysis was first developed by Technicon Instruments (1957) and is based on an automatic continuous flow analysis technique. The instrument consists of separate modules, linked to form one flow system. The Sampler, Proportioning pump, Colorimeter constitute the basic modules of the system, while an appropriate Cartridge/Manifold is used for the element being analysed. The proportioning pump draws the liquid sample into the manifold from the sampler, at the same time the reagents from the reagent containers are drawn into system on a correct proportion due to the bores of the tube used and unit time. An air bubble is introduced into the liquid stream at two second intervals. This air segmentation acts as a barrier to prevent sample interaction and cross-contamination (Allen 1974). Samples enter the Cartridge/Manifold as segmented, but continuously flowing streams, then are mixed with reagents and this stream then passes into the colorimeter. In the colorimeter, through a photo-tube, an electrical output is produced, which is measured against the output of a blank channel (Technical Publication No. TSO-0170-20, 1975). The differences between the two outputs is the test result which is recorded by a chart recorder. The chloride analysis method depends upon the liberation of thiocyanate ions from mercuric thiocyanate by the formation of un-ionised but soluble mercuric chloride. In the presence of ferric ions the liberated thiocyanate forms highly coloured ferric thiocyanate proportional to the original chloride (Allen 1974).

c. The pH Meter.

The 291 Pye Unicam Model was used. The pH meter and electrodes were set up according to the makers' instruction. An adequate time was allowed for the meter to stabilize and the asymmetry and temperature adjustments were done. The two buffer solutions with pH 4.0 and 9.2 were prepared from BDH buffer tablets and the meter was checked against these two buffers. The electrode was immersed in the suspensions and water samples and approximately one minute was allowed for the needle drift to cease and then the reading was taken. The pH of every sample was recorded to one decimal place. The electrodes were thoroughly washed with deionised water after every determination.

d. Conductivity.

The Conductivity is the reciprocal of the resistance offered by a solution with platinum electrodes immersed in it, each 1cm square and 1cm apart (Allen 1974) and commonly it indicates the total concentration of the ionised constituents of solutions (Richards 1969). The Conductivity of natural waters generally falls in the range of 0.085 mmhos/Cm to 0.12 mmhos/Cm (Allen 1974). The Conductivity was determined to estimate the salinity of waters and soils under investigation.

The Conductivity was determined using a WPA.25 cm Conductivity meter. The value of the cell constant provided by the makers was 1.57, and the temperature of the samples was taken while determining the resistance value from the meter dial. The results were corrected to $25^{\circ}C$, applying the appropriate temperature conversion factor obtained from Richards (table 15, 1969).

e. Calculations.

If $C = mgl^{-1}$ (ppm) element is obtained from the calibration curve then for

Plant material:

$$\text{total element mg/gram} = \frac{C \times \text{sample volume}}{10^3 \times \text{sample weight}}$$

Soil:

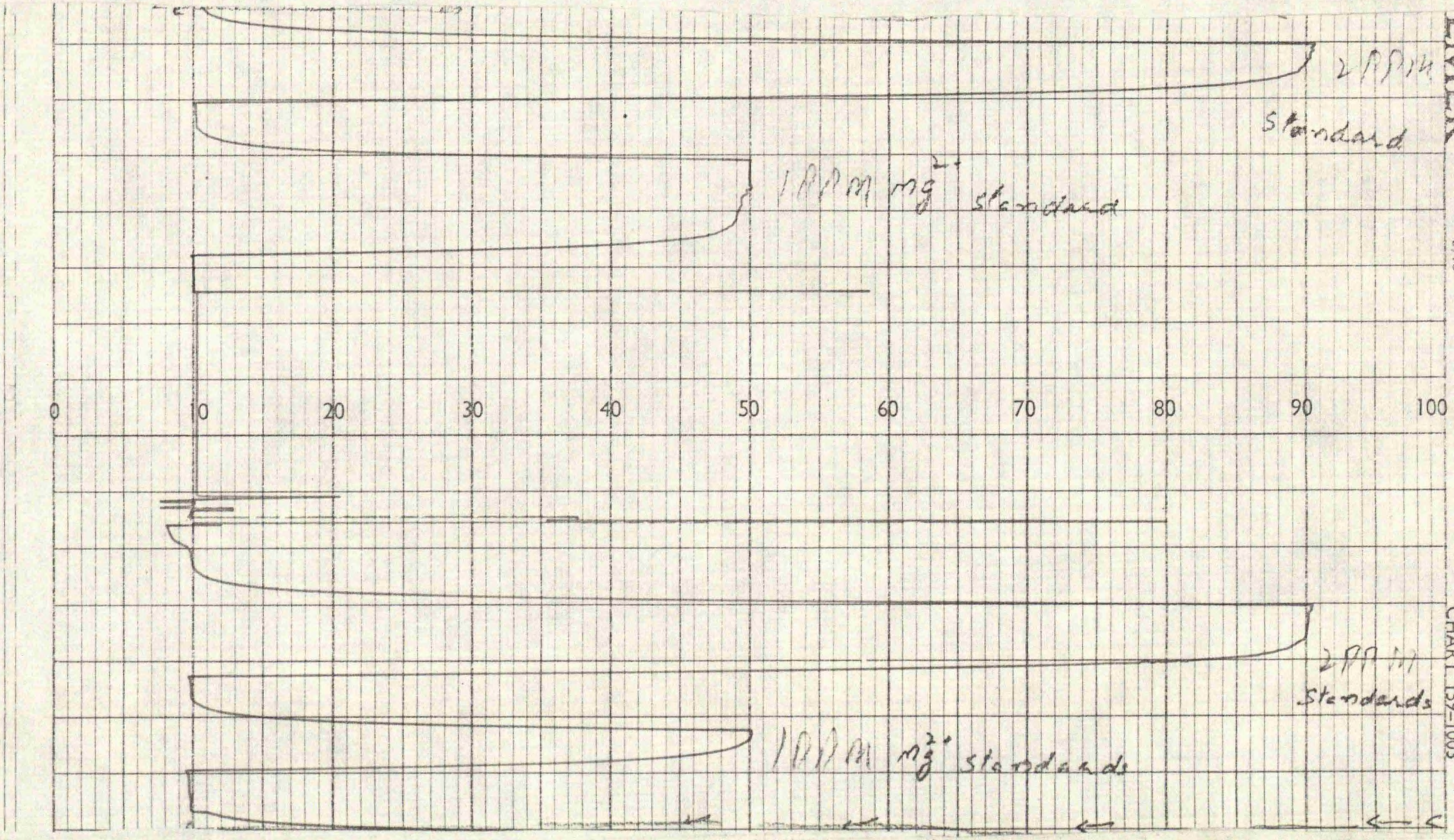
$$\text{mg/gram} = \frac{C \times \text{sample volume}}{10^3 \times \text{sample weight}}$$

Water:

$$\text{ppm} = mgl^{-1} = C$$

f. Examples of print out from Atomic Absorption Spectrophotometer (a) Magnesium standards (b) Test solutions.

a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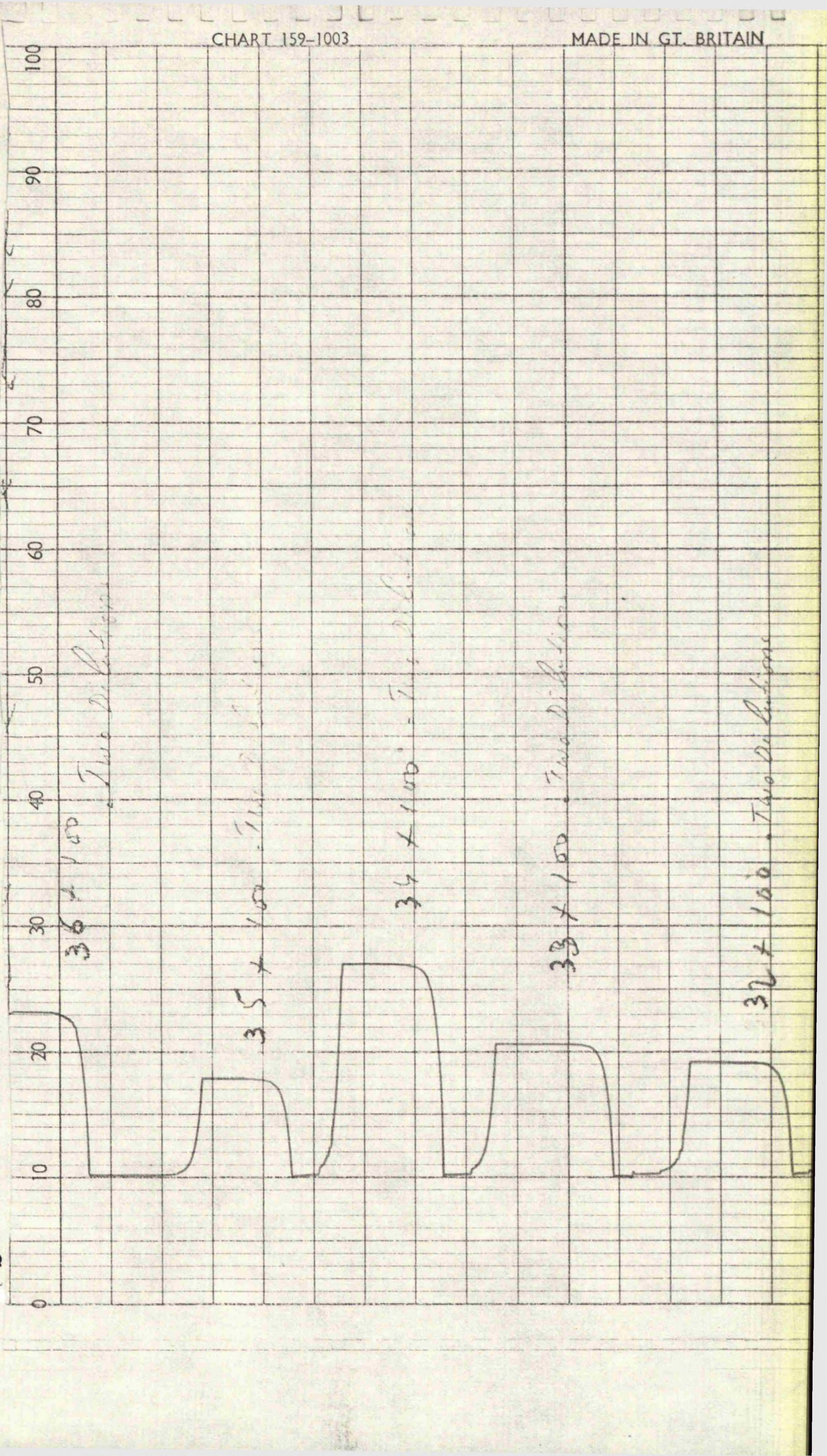
10
20
30
40
50
60
70
80
90
100
2 PPM Standard
1 PPM Mg^{2+} standard
2 PPM Standards
1 PPM Mg^{2+} standards
LMER
5/75
CHART 159–1003

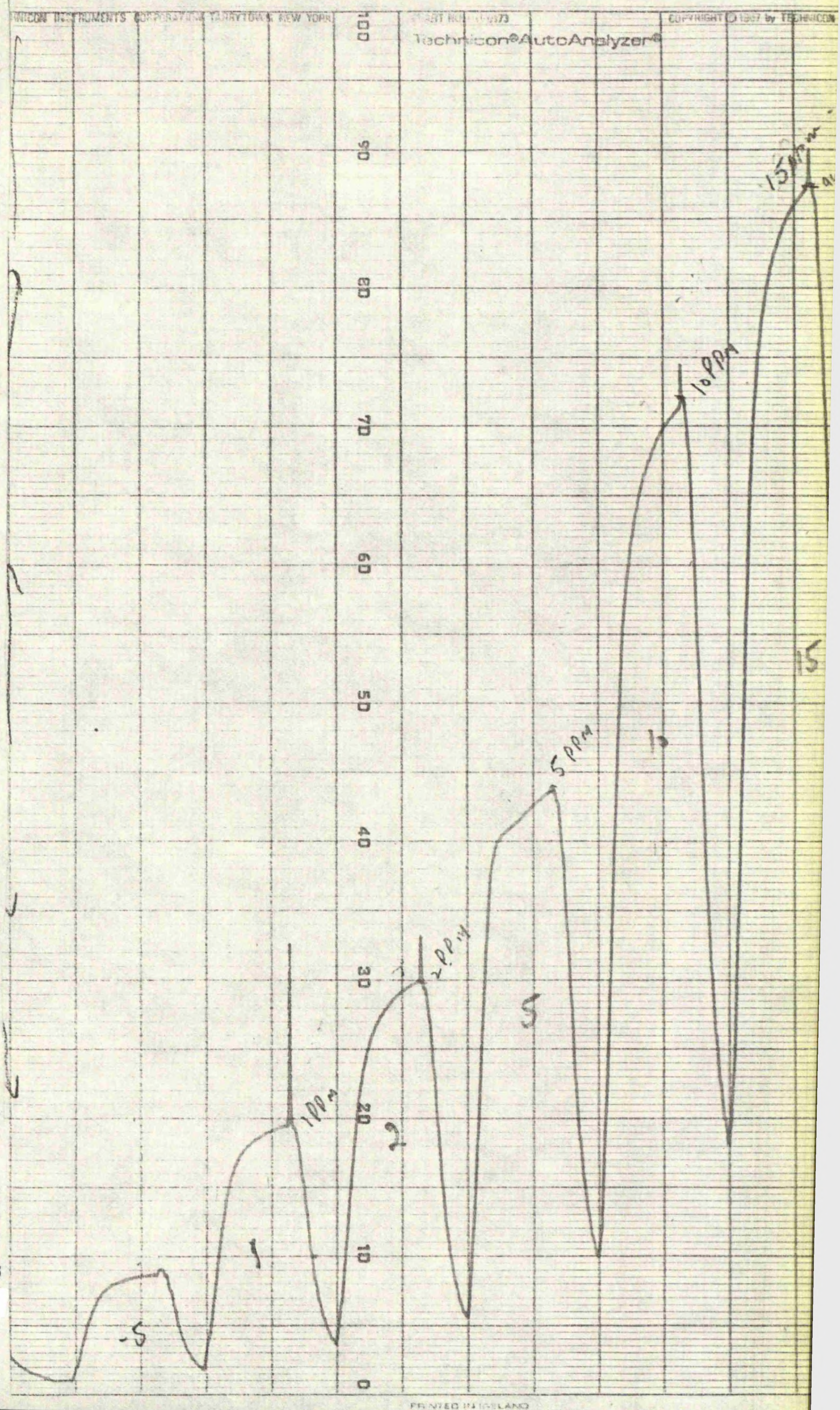


b

9. Examples of print out from

Auto-analyzer (a) Chloride standards

(b) Test sõlutions



TECHNICON INSTRUMENTS CORPORATION TARRYTOWN, NEW YORK
Technicon® AutoAnalyzer®
COPYRIGHT © 1967 by TECHNICON
100
90
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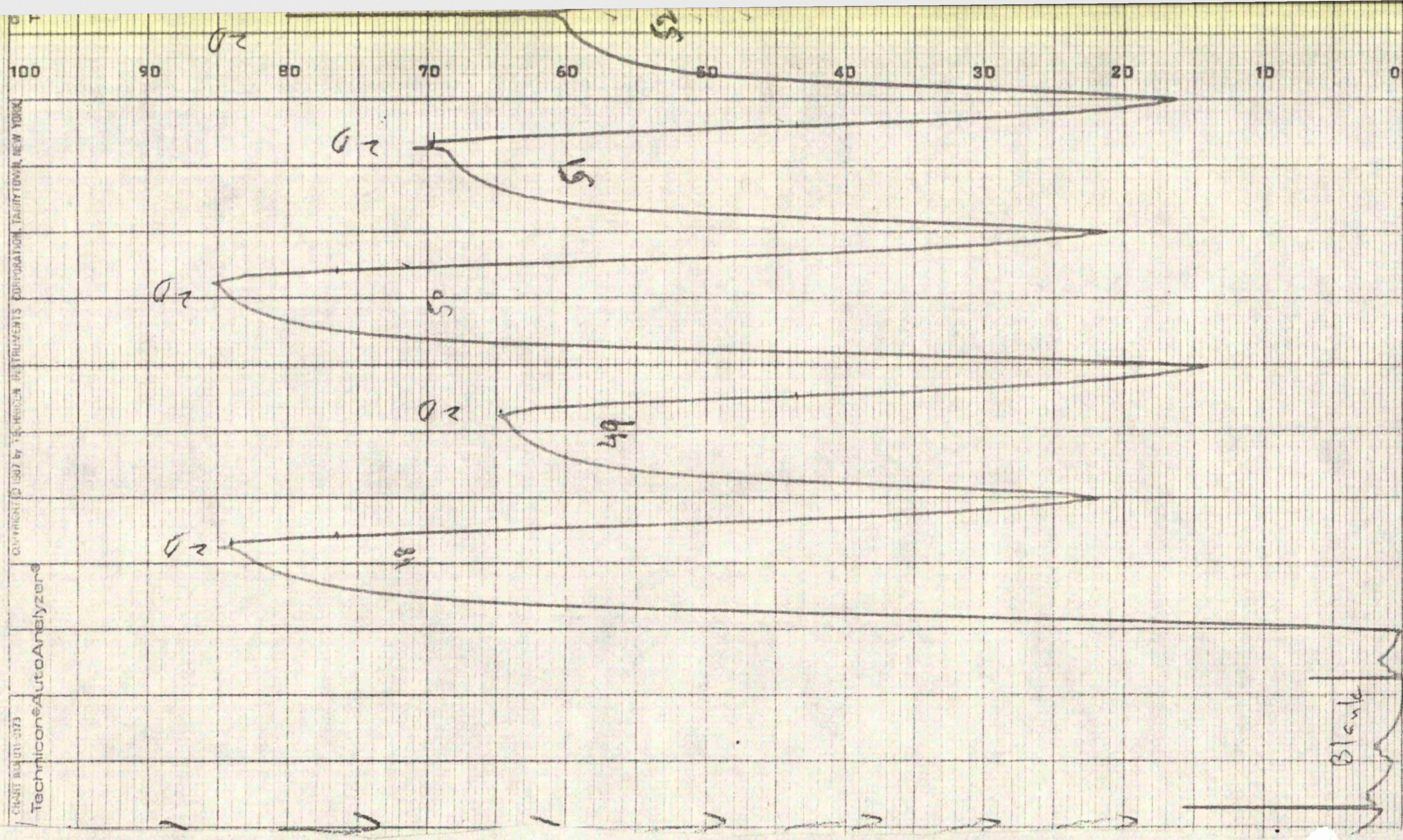
a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O2
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Technicon®AutoAnalyzer®
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9

APPENDIX IIa

pH, Concentrations of Cations and Chloride in Soils (mg. per gram)

All results (except pH given on dry weight basis). Extractions carried out using M ammonium acetate pH.7.0.

Sample No.	pH	Na^{+}	K^{+}	Mg^{2+}	Ca^{2+}	Cl-
01	6.7	2.49	0.26	1.19	7.26	-
02	3.8	0.66	0.14	0.33	7.92	-
03	7.2	0.14	0.13	0.15	1.26	-
04	7.0	0.26	0.19	0.26	7.26	-
05	8.5	0.38	0.03	3.38	4.25	-
06	9.3	0.11	0.02	10.66	0.56	-
07	9.5	0.58	0.02	20.00	1.00	-
08	9.8	6.38	0.04	28.50	1.28	-
09	7.9	0.13	0.05	1.33	2.00	-
10	8.5	0.19	0.05	13.00	2.00	-
11	9.3	0.23	0.01	35.00	1.25	-
12	8.5	0.12	0.11	1.26	3.96	-
13	8.6	0.15	0.07	3.63	2.64	-
14	8.4	0.08	0.02	4.75	3.88	-
15	8.8	0.07	0.01	11.75	1.50	-
16	7.0	3.30	0.04	0.14	4.29	-
17	7.2	1.93	6.06	6.23	5.25	-
18	7.2	2.50	0.05	0.18	6.25	-
19	7.0	14.25	0.33	0.28	6.00	-
20	7.3	27.50	0.30	0.33	7.50	-
21	6.2	0.73	0.05	0.08	2.50	-
22	6.2	0.80	0.05	0.09	2.75	-
23	6.9	4.75	0.06	1.16	3.50	-
24	6.9	4.75	0.05	0.16	3.50	-
25	6.9	0.83	0.09	0.25	3.25	-
26	6.9	1.20	0.09	0.23	3.75	-
27	6.7	0.35	0.03	0.06	0.75	-
28	6.4	5.25	0.09	0.18	1.45	-
29	6.4	5.00	0.04	0.19	1.33	-
30	8.4	0.10	0.05	0.65	1.90	0.10
31	7.9	0.03	0.12	0.18	5.50	-
32	8.1	0.04	0.13	0.23	5.75	-
33	7.8	0.02	0.04	0.09	4.75	-

Sample No.	pH	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-
34	7.2	1.21	0.06	0.18	5.75	-
35	7.7	0.06	0.09	0.20	4.50	-
36	7.6	0.03	0.04	0.07	4.00	-
37	7.1	0.03	0.09	0.30	1.75	-
38	7.1	0.03	0.08	0.20	1.90	-
39	7.2	5.00	0.17	0.53	11.00	3.75
40	8.8	3.25	0.38	0.38	8.00	1.38
41	6.8	3.50	0.16	5.00	13.00	20.20
42	6.7	1.83	0.13	4.25	9.75	11.65
43	6.5	1.80	0.15	3.25	7.75	11.30
44	6.8	4.00	0.33	3.50	10.75	20.00
45	6.4	3.75	0.35	3.50	8.75	16.50
46	6.9	0.83	0.12	1.58	5.25	2.75
47	7.1	2.25	0.14	5.25	12.75	10.00
48	6.7	3.75	0.35	2.50	8.25	12.42
49	6.7	1.00	0.23	2.00	7.50	8.82
50	8.5	3.50	0.25	3.25	13.00	14.38
51	6.8	1.25	0.12	1.90	10.00	9.72
52	6.2	0.90	0.12	3.75	8.75	7.94
53	5.3	0.85	0.15	3.13	8.00	6.07
54	5.1	0.63	0.10	2.00	6.00	5.53
55	6.2	0.80	0.11	3.00	6.75	6.16
56	5.7	1.08	0.09	1.75	8.75	7.05
57	5.5	0.83	0.09	1.78	7.25	5.89
58	6.2	0.70	0.09	1.43	6.25	6.34
59	5.2	0.16	0.25	1.38	5.25	1.20
60	6.5	0.30	0.14	1.50	4.63	0.63
61	6.5	0.33	0.1i	1.58	5.75	2.89
62	7.8	7.50	0.35	1.28	12.00	1.60
63	7.9	6.25	0.30	0.85	15.25	0.62
64	8.2	4.63	0.23	1.05	12.24	0.64
65	7.7	3.25	0.50	0.93	10.50	1.00
66	8.4	2.00	0.50	1.13	7.25	0.50
67	8.0	1.75	0.14	0.28	5.75	0.94
68	7.6	6.63	0.35	0.45	7.25	7.05
69	7.3	0.14	0.38	0.40	6.25	0.50
70	8.0	4.75	0.43	0.25	6.50	3.98
71	8.4	0.35	0.15	1.45	7.50	0.78

Sample No.	pH	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl-
72	8.4	0.55	0.13	1.60	7.50	1.01
73	9.0	0.06	0.10	9.50	3.25	0.25
74	9.2	0.06	0.40	8.25	3.25	0.50
75	9.3	0.08	0.01	16.00	1.18	0.65
76	9.1	5.75	0.07	6.00	3.00	9.00
77	7.0	4.00	0.13	0.28	2.00	3.43
78	6.3	6.75	0.15	0.30	7.75	8.75
79	7.9	37.50	0.11	0.04	0.58	42.00
80	7.3	16.25	0.7	0.03	0.38	17.75
81	6.2	27.50	0.11	0.03	0.48	36.50
82	6.7	14.38	0.09	0.02	0.43	18.00
83	8.0	8.75	0.15	0.53	12.50	7.40
84	8.9	4.75	0.05	6.75	17.25	13.50
85	8.4	0.48	0.12	1.00	7.75	0.75
86	8.6	0.88	0.04	4.25	15.00	6.50
87	8.5	9.25	0.21	1.05	14.50	17.75
88	8.6	6.00	0.05	8.75	19.50	15.00
89	7.5	10.00	0.23	1.68	13.75	19.25
90	7.6	2.50	0.05	7.00	17.50	12.38
91	8.0	0.55	0.06	5.00	9.50	8.00
92	8.2	12.25	0.10	5.50	15.50	15.00
93	8.8	0.43	0.06	4.00	12.50	0.75
94	8.2	1.35	0.06	2.50	12.25	7.75
95	6.8	6.25	0.18	0.38	12.25	15.38
96	7.1	17.75	0.17	1.00	15.75	43.00
97	6.9	9.00	0.05	0.30	9.00	17.75
98	6.3	7.00	0.60	0.25	10.50	5.00
99	7.7	11.50	0.40	0.19	1.30	28.00
100	7.4	11.50	0.07	0.33	3.00	13.73
101	7.9	57.50	0.03	0.17	3.25	17.50
102	6.5	25.00	0.03	0.55	10.5	14.00
103	9.0	0.55	0.09	2.75	3.25	0.65
104	8.2	1.25	0.09	1.75	4.00	0.80
105	9.2	1.08	0.10	1.15	4.25	0.20
106	9.3	5.75	0.04	4.00	2.00	5.50
107	9.4	3.25	0.04	3.55	2.25	4.75
108	9.9	0.85	0.04	32.50	0.58	1.50
109	8.7	0.77	0.03	2.00	3.50	1.20
110	8.5	0.65	0.05	1.83	3.13	2.60

Sample No.	pH	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl-
111	7.8	0.50	0.06	0.55	6.75	0.75
112	7.9	0.30	0.03	0.20	5.00	0.60
113	8.4	0.35	0.07	0.50	6.25	3.40
114	5.7	22.50	0.62	1.66	5.50	22.50
115	5.5	14.25	0.30	1.00	3.75	14.40
115A	5.7	9.25	0.20	0.68	2.50	10.40
116	6.0	32.50	0.22	1.00	3.38	18.60
117	4.6	16.75	0.52	1.07	3.75	14.75
118	3.6	37.50	0.27	0.41	6.50	47.50
119	5.0	12.50	1.50	0.95	3.00	18.10
121	4.6	1.38	0.13	0.47	1.73	1.50
122	5.5	7.50	1.4	0.9	3.38	8.50
123	6.4	16.25	0.25	1.53	4.50	20.00
124	5.5	32.50	0.70	1.75	4.75	23.75
125	6.0	8.50	0.50	0.75	2.50	6.50
126	6.0	13.00	0.38	1.05	3.38	12.00
127	5.7	26.25	0.95	1.58	4.50	20.00
128	5.2	9.50	0.60	0.84	2.50	8.00
129	6.3	2.75	0.13	0.40	1.75	2.75
130	6.3	1.90	0.05	0.20	0.83	1.75
131	5.7	5.00	0.09	0.15	0.93	4.75
132	6.9	0.78	0.23	0.38	1.50	0.10
133	6.7	1.35	0.07	0.10	1.13	0.75
134	8.1	3.25	0.20	0.18	3.13	2.25
135	7.5	6.00	0.10	0.23	5.50	10.00
136	7.6	15.00	0.15	0.55	7.50	20.10
137	8.2	4.50	0.18	0.40	7.75	7.20
138	7.8	1.03	0.30	1.00	7.75	0.65
139	7.5	0.60	0.27	0.83	6.00	0.40
140	8.4	8.50	0.09	0.83	19.38	5.87
141	7.9	2.50	0.06	0.43	7.75	2.67
142	8.1	1.53	0.13	0.25	7.75	4.13
143	7.7	1.10	0.05	0.29	6.50	2.00
144	8.9	3.00	0.06	0.09	4.25	2.25
145	9.1	2.50	0.10	0.41	4.00	0.50
146	5.6	4.75	0.14	0.35	5.00	3.20
147	4.5	8.13	0.10	0.28	3.75	8.30
148	3.0	10.50	0.10	0.25	5.75	13.40
149	3.2	9.75	0.18	6.34	2.50	8.00

Sample No.	pH.	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-
150	4.7	21.25	0.14	0.59	4.75	18.20
151	5.1	3.50	0.38	0.25	2.88	3.75
152	5.2	4.75	0.13	0.25	2.50	2.50
153	4.4	7.50	0.16	0.30	3.00	6.50
154	3.3	15.38	0.20	0.40	3.75	17.25
155	3.9	20.75	0.13	0.68	5.25	27.50
156	5.9	14.25	0.35	0.39	3.75	12.00
157	5.2	16.25	0.20	0.38	5.00	10.75
158	5.7	13.50	0.15	0.21	6.50	8.50
159	4.1	19.50	0.18	0.33	2.75	17.50
160	2.8	18.00	0.23	0.28	2.50	17.20
161	5.1	14.75	0.15	0.28	2.13	12.38
162	4.9	5.75	0.08	0.23	2.50	7.50
163	5.0	6.00	0.09	0.23	2.00	7.40
164	5.5	3.75	0.09	0.35	3.25	2.88
165	5.7	7.13	0.17	0.30	2.50	5.00
166	4.9	8.00	0.13	0.35	4.75	8.00
167	4.5	7.50	0.10	0.30	2.75	8.75
168	4.3	4.25	0.15	0.23	2.50	5.25
169	5.4	2.25	0.07	0.28	2.25	1.40
170	6.1	14.50	0.16	0.34	2.25	13.13
171	5.9	9.25	0.23	0.30	2.50	12.75
172	6.4	11.50	0.19	0.30	2.75	15.00
173	5.8	9.75	0.19	0.26	3.50	9.00
174	6.5	2.50	0.25	0.23	4.25	0.63
175	6.8	6.50	0.20	0.18	2.25	4.80
176	7.3	6.00	0.16	0.18	2.25	4.80
177	8.2	0.68	0.03	0.05	2.50	0.05
178	8.8	0.63	0.06	0.11	3.50	0.09
179	8.7	0.55	0.05	0.10	3.00	0.28
180	7.7	2.75	0.07	0.08	0.80	2.00
181	6.8	1.10	0.05	0.05	0.45	0.60
182	7.5	3.25	0.07	0.09	1.13	2.50
183	7.8	2.25	0.04	0.08	0.58	1.20
184	6.8	1.48	0.10	0.12	1.23	0.65
185	7.9	1.15	0.05	0.19	1.25	0.50
186	6.8	0.88	0.17	0.27	4.50	0.60
187	9.3	0.09	0.03	6.25	1.60	0.20

APPENDIX IIb

Localities for Soil Samples (S.S.)

Sample 01,02	Mickletown, West Yorkshire, (44/402276)
03	Leasowe, Merseyside (33/252914)
04	Ainsdale, Merseyside (34/290110)
05-15	Elton Hall, Cheshire (33/717596)
16-30	Watch Lane, Sandbach, Cheshire. (33/730605)
31-40	Plumley, Cheshire. (33/708751)
41-61	Upton Warren, Worcestershire. (32/934665)
62-66	Southam Salt Spring, Warwickshire. (24/444602)
67-72.	Stoke Works, Worcestershire. (32/943662)
73-75	Stoke Works, Lagoon, Worcestershire (32/943663)
76	Marston, Salt Pan, Cheshire. (33/671754)
77,78	Marston Pools, 3, 2, Northwich, Cheshire (33/671757)
79-82	Marston Hall Field Farm, Northwich, Cheshire. (33/670761)
83-90, 92	Neumann's Flash, Northwich, Cheshire. (33/665749)
91,93,94	Ashton Flash, Northwich, Cheshire. (33/666748)
95-99	Dairy House Farm, Cheshire. (33/662753)
100-102, 144.	Anderton, Cheshire (33/652750)
103-105, 145	Winsford Lagoon 1. Cheshire. (33/656682)
106-110	Winsford Lagoon II, Cheshire. (33/654684)
111-113	Silver Well, Cheshire. (33/566767)
114-129	Aldersey, Cheshire. (33/457567)
130-113	Nantwich, Shrewbridge, Cheshire. (33/651510)
134-140	Middlewich, Cheshire. (33/712652)
141-143	Dutton, Cheshire. (33/583767)
146-173	Pasturefields, Staffordshire (33/992248)
174-176	Shirleywich, Staffordshire. (33/984259)
177-187	Preesall, Lancashire. (34/361467)

APPENDIX IIIa

Water Analyses (Conductivity mmhos/cm; elements-ppm).

Sample No.	pH	Conductivity	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-
01	8.0	11.99	1725	23	35	58	2600
02	7.5	19.92	5750	17	58	125	7800
03	8.1	0. 45	20	07	100	50	166
04	8.4	1.57	148	14	63	125	58
05	8.8	0.87	30	05	28	38	25
06	7.3	0.49	33	10	23	25	37
07	8.3	4.91	625	10	75	225	1200
08	7.7	2.60	1625	14	1450	3750	5400
09	8.0	13.65	525	12	1100	1600	3200
10	8.3	7.04	550	13	200	675	1000
11	8.0	8.68	80	13	650	800	3500
12	7.9	2.35	48	03	168	275	610
13	7.8	7.53	110	04	650	1750	11000
14	7.0	36.03	1775	11	2000	11250	20000
15	8.1	9.19	160	8	875	375	2750
16	7.6	9.22	165	10	550	775	2900
17	8.5	0.84	19	01	1000	103	80
18	8.4	0.93	45	09	68	128	56
19	8.0	1.07	48	12	30	230	130
20	8.3	0.71	35	07	45	93	133
21	8.4	4.85	725	11	145	550	600
22	8.3	1.34	100	11	50	180	260
23	8.4	2.84	350	09	75	200	1000
24	7.9	1.27	28	05	88	143	67
25	7.8	0.55	15	09	18	95	31
26	8.6	6.60	1100	05	63	168	950
27	8.5	5.93	1050	09	75	28	830
28	8.6	7.03	1700	05	73	138	1000
29	8.5	7.26	1625	10	88	187	1800
30	8.5	4.71	1950	12	100	103	610
31	8.3	4.44	638	13	25	130	938
32	8.8	4.28	650	12	23	110	1330
33	8.9	3.81	625	13	26	78	450
34	8.9	1.90	250	04	43	68	475
35	9.2	6.34	1150	14	20	55	863
36	7.5	63.43	7125	38	33	20000	15000

Sample No.	pH	Conductivity	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-
37	8.4	25.37	6625	14	75	475	6000
38	7.9	221.99	262500	50	68	4000	480000
39	7.8	0.66	113	04	10	63	700
40	7.1	2.95	375	12	68	125	313
41	8.5	2.78	413	12	23	75	475
42	8.9	0.46	23	04	19	48	120
43	7.8	2.46	325	12	29	90	450
44	9.2	2.62	275	06	118	55	980
45	6.5	11.46	1750	01	65	275	2250
46	7.5	0.62	18	06	18	50	15
47	8.3	5.74	950	04	43	123	1263
48	8.2	49.13	17000	25	26	20000	18000
49	9.9	393.00	1300000000	148	01	5	1350000000
50	7.4	40.96	13250	55	400	750	6600
51	7.0	34.13	11000	40	263	475	9500
52	7.2	39.25	8250	30	225	500	12750
53	7.6	23.89	5125	23	158	325	3500
54	8.4	1.50	193	10	23	73	400
55	7.3	12.53	3750	30	105	225	2750
56	7.7	1.25	93	12	24	95	55
57	7.2	3.68	975	07	45	95	562
58	7.6	0.62	33	35	28	40	113
59	7.5	1.84	275	07	30	75	763
60	9.0	23.74	3750	33	43	83	5000
61	8.5	1.50	68	12	20	50	65
62	8.5	4.93	500	20	21	70	1206
63	9.0	36.52	2250	35	18	1875	8750
64	8.5	14.34	2250	09	29	425	3500
65	8.1	8.41	1150	12	16	325	1650
66	7.5	12.24	1300	10	46	850	2020
67	8.0	7.84	1175	11	15	263	1400
68	7.1	1.26	88	13	18	84	130
69	6.9	6.50	925	07	24	100	1450
70	6.3	43.82	7500	153	100	575	6200
71	7.5	25.56	4000	15	45	300	4000
72	7.2	5.60	575	06	15	53	800
73	7.4	1.22	100	15	24	105	130
74	7.2	0.82	45	17	25	68	65
75	7.9	0.68	23	13	18	56	15

Sample No.	pH.	Conductivity	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-
76	7.6	14.50	3000	16	65	175	4500
77	8.0	1.01	103	15	24	108	138
78	8.3	15.92	3500	11	13	85	3000
79	7.3	102.17	16250	13	125	875	62500
80	8.6	4.06	525	06	13	48	1075
81	8.6	17.88	3000	04	40	225	2500
82	8.0	1.57	200	05	11	48	238
83	-	25.62	6250	25	108	462	-
84	-	4.44	775	15	43	152	-
85	6.8	5.04	750	15	59	20	1190
86	7.7	16.80	3250	23	38	95	4250
87	8.3	22.40	4500	25	50	105	6500
88	8.7	1.12	108	04	25	45	138
89	7.5	4.53	788	35	30	149	-
90	-	5.6	812	14	28	155	-
91	-	4.20	763	14	95	297	-
93	-	1.12	73	10	20	142	-
94	-	6.59	1300	08	25	726	-
95	-	3.32	400	08	18	528	-
96	-	3.10	400	06	43	396	-
97	-	6.26	1000	08	18	528	-
98	-	9.93	58	33	0.1	925	-
99	-	2.80	500	06	18	561	-
100	-	0.85	23	11	19	96	-
101	-	1.25	108	14	23	119	-
102	-	-	300	30	123	578	-
103	-	-	305	23	86	205	-
104	-	-	290	14	51	186	-
105	-	-	880	31	54	136	-
106	-	-	89	16	22	76	-
107	-	-	40	02	11	173	-
108	-	-	37	02	12	173	-
109	-	-	38	02	10	107	-
110	-	-	53	02	12	117	-
111	-	-	33	02	11	103	-

Appendix IIIb

Localities for Water Samples; (W.S.)

W.S. 01,02	North,South,Railway Line Pools, Stoke Works, Worcestershire, (32/943662).
03	Worcester and Birmingham Canal, Stoke Works, Worcestershire, (32/943662).
04,	Droitwich Canal, Worcestershire (32/975622).
05	Droitwich Canal, Worcestershire (32/876623).
06	Droitwich Canal, opposite Chawson Farm,Worcestershire. (32/881624).
07	River Salwarpe, Worcestershire (32/880626).
08-10	Upton Warren pools D.E. Worcestershire (32/934665).
11-16	Upton Warren pool F, Worcestershire.(32/934664).
17	Upton Warren pool A, Worcestershire (32/938677).
18	Upton Warren pool B, Worcestershire (32/937674).
19	Upton Warren bridge on river Salwarpe, Worcestershire (32/933674).
20,	Upton Warren Pool C, Worcestershire. (32/935670).
21	Upton Warren, Henbrook outflow from Flash Pools, Worcestershire (32/933668).
22	River Salwarpe at Wychbold bridge, Worcestershire (32/919664).
23	River Salwarpe at Ladywood bridge, Worcestershire (32/864619).
24	Oakleypool,Worcestershire, (32/893607).
25	Oxford Canal, Napton Hall bridge, Warwickshire.(24/458599).
26-30	Southam Salt Spring, Warwickshire (24/446605).
31,32	Marston Pool 1, Northwich, Cheshire (33/671757).
33	Trent and Mersey Canal, Northwich, Cheshire (33/671757).
34,35	Marston pool 3,2, Northwich Cheshire (33/671754) and (33/671757).
36	Dairy House Farm brine flow, Northwich, Cheshire.(33/662753).
37,38	Anderton, Old brine cistern and ground seepage, Northwich Cheshire. (33/662751)

W.S. 39 Anderton, Rifle Range pool, Cheshire (33/652754).

40 Marsh near Trent and Mersey Canal,Cheshire. (33/683714).

41 Trent and Mersey Canal, Cheshire (33/683714).

42 BillingeGreen pool, Cheshire. (33/681715).

43. River Weaver, Winsford, Cheshire (33/655684).

44,45,47. Winsford Marsh pools, Cheshire. (33/655684).

46 Boggart Brook Flash, Cheshire. (33/632683).

48. River Weaver, Silver Well, Cheshire. (33/566768).

49. Brine pipe leakage. Silverwell, Cheshire (33/566768).

50 Aldersey brine pit, Cheshire (33/457565).

51 Aldersey Field (Water table). Cheshire (33/457565)

52. Aldersey, (ditch near Brine pit), Cheshire (33/457565)

53,54 Aldersey (northern and southern ditches) Cheshire (33/457565).

55. Aldersey field, (Upwelling) Cheshire, (33/457565).

56. Winsford, Bottom Flash, Cheshire. (33/665654).

57 Aldersey, (Upwelling) Cheshire (33/457565)

58 Aldersey Field (pond,)Cheshire (33/457562)

59 Aldersey Field (Glyceria fluitans - Lemna Community)
Cheshire (33/457563)

60 Nantwich, Shrewbridge, boat lake, Cheshire. (33/651509)

61,62. Nantwich, Shrewsbridge pools, I,II, Cheshire.(33/651509)

63 Dutton, River Weaver, Lock Bridge, (Phragmites Communis Community)
(33/58770).

64-67 Plumley (Carex otrubae Community) Cheshire (33/708751).

68 Pasturefields , river Trent, Staffordshire.(33/992247)

69 Pasturefields , (ditch) Staffordshire. (33/992248).

70 Pasturefields (bare area seepage) Staffordshire (33/992248)

71 Pasturefields, (Well) Staffordshire (33/992248)

72 Pasturefields (ditch) Staffordshire)(33/992248)

73 Shirleywich, River Trent, Staffordshire (33/984254)

74,75 Shirleywich, Staffordshire (33/984255)

76 Shirleywich, Amerton Brook, Staffordshire, (33/982267).

W.S. 77 Salt, River Trent, Staffordshire. (33/958279).

78 Preesall (lake I) Lancashire (34/361467)

79 Preesall, (seepage) Lancashire. (34/361467).

80. Preesall, (Lake II) Lancashire (34/361468)

81 Preesall (Puccinellia maritima Community) Lancashire (34/361467)

82 Preesall, (lake III), Lancashire (34/361469)

83,86,87. Sandbach, Watch Lane, (Lake) Cheshire. (33/726606)

84,89. Sandbach, Watch Lane, (Main lake) Cheshire. (33/726604).

85. Sandbach, Watch Lane, (pool) Cheshire. (33/730608)

90. Elton Hall (inflow from chemical works). Cheshire (33/717586)

91 Elton Hall, (Fresh water inflow), Cheshire (33/717586)

92 Elton Hall (Lake towards chemical works), Cheshire (33/717586)

93 Elton Hall (Lake Railway Side) Cheshire /(33/717586)

94 Plumley (pipe leakage) Cheshire (33/708751)

95,96. Plumley (Lake) Cheshire (33/708751)

97 Plumley (Phragmites communis Community) Cheshire (33/708751)

98 Plumley (Lime flooded tract) Cheshire (33/708751)

99 Plumley (Typha Community) Cheshire (33/708751)

100,101 Fodens Flash, Sandbach, Cheshire. (33/726608)

102,103,104. Mickletown, (Cotula coronopifolia Community) West Yorkshire (44/402276)

105, Mickletown (Mine inflow) West Yorkshire. (44/402276)

106 Leasowe, Merseyside, (33/252914)

107-111 Ainsdale (pools) Merseyside (34/290110)

Appendix IVa

Concentrations of Cations in Vegetation (Shoots only). Results expressed as mgram per gram on dry weight basis.

Sample No.	Name of Plant.	Na^+	k^+	Mg^{2+}	Ca^{2+}
01	Atriplex hastata	75.00	11.50	6.00	17.50
02	Agrostis stononifera	3.00	13.25	1.28	3.50
03	Spergularia marina	57.50	12.75	5.25	19.75
04	Vulpia myuros	3.00	5.25	0.88	3.75
05	Puccinellia distans	11.25	19.00	1.95	13.00
06	Tripleurospermum maritimum	15.50	14.75	4.50	15.50
07	Cirsium vulgare	14.75	3.50	4.75	22.50
08	Ranunculus sceleratus	3.50	18.00	5.00	13.00
09	Agropyron repens	2.50	19.75	3.25	11.50
10	Juncus acutiflorus	7.50	14.25	7.00	13.25
11	Spergularia marina	50.50	25.00	7.50	16.25
12	Atriplex hastata	40.50	16.00	13.00	32.50
13	Puccinellia distans	4.25	35.00	4.25	11.75
14	Hordeum secalinum	5.00	17.25	3.75	11.50
15	Juncus inflexus	0.59	15.00	2.50	3.00
16	Carex otrubae	1.63	25.00	4.25	8.50
17	Scirpus tabernaemontani	10.50	14.75	5.75	16.00
18	Puccinellia distans	3.75	13.25	3.50	8.75
19	Juncus gerardii	5.00	22.50	9.50	27.50
19A	Juncus effusus	5.50	15.00	4.25	3.50
20	Zannichellia palustris	2.25	7.00	7.75	75.00
21	Potamogeton crispus	8.50	30.00	6.50	65.00
22	Myriophyllum spicatum	8.25	15.75	10.25	27.50
23	Scirpus tabernaemontani	8.00	47.50	2.25	12.50
24	Zannichellia palustris	6.75	22.50	7.75	32.50
25	Ranunculus sceleratus	12.50	32.50	4.50	15.00
26	Apium graveolens	12.50	40.00	5.00	15.00
27	Phragmites communis	0.46	32.50	1.20	1.00
28	Myriophyllum spicatum	6.50	14.50	9.00	80.00
29	Carex distans	5.25	17.50	2.75	5.00
30	Hordeum secalinum	13.50	9.25	0.45	1.50
31	Juncus gerardii	4.00	40.00	1.38	2.25
32	Phragmites communis	5.75	16.00	1.38	1.75
33	Scirpus maritimus	22.50	10.75	2.25	4.25

Sample No.	Name of Plant	Na^{+}	k^{+}	Mg^{2+}	Ca^{2+}
34	Ranunculus scereratus	4.50	15.25	3.00	19.25
35	Potamogeton pectinatus	3.00	7.00	10.20	5.25
36	Potamogeton pectinatus	4.50	16.50	9.25	37.50
37	Scirpus tabernaemontani	37.50	18.75	3.25	6.00
38	Potamogeton pectinatus	4.60	6.80	3.25	42.50
39	Potamogeton crispus	16.50	12.00	1.88	52.50
40	Myriophyllum spicatum	7.20	8.40	2.50	68.75
41	Ceratophyllum demersum	6.25	14.25	6.75	17.50
42	Scirpus tabernaemontani	27.50	22.50	2.25	16.75
43	Eleocharis palustris	15.50	27.50	1.68	3.75
44	Rumex hydrolapathum	25.00	52.50	8.50	27.50
45	Carex otrubae	17.50	22.50	1.10	4.00
46	Elodea canadensis	16.50	7.00	2.50	55.26
47	Potamogeton pectinatus	13.00	11.00	5.88	32.50
48	Ceratophyllum demersum	8.00	15.00	6.75	37.50
49	Potamogeton pectinatus	4.13	5.50	5.25	117.50
50	Agrostis stolonifera	7.38	10.00	1.58	9.00
51	Puccinellia distans	6.25	12.75	4.25	5.75
52	Apium nodiflorum	22.50	27.50	6.88	25.00
53	Spergularia marina	80.00	25.00	3.88	11.50
54	Puccinellia distans	15.50	25.00	1.00	6.50
55	Juncus bufonius	22.50	12.75	3.25	8.75
56	Myriophyllum spicatum	3.19	3.75	3.75	62.50
57	Potamogeton pectinatus	3.33	7.00	2.13	22.50
58	Spergularia marina	52.50	27.50	3.13	6.50
59	Ranunculus sceleratus	8.50	22.50	2.88	13.50
60	Puccinellia distans	8.75	18.50	1.00	2.25
61	Chenopodium rubrum	40.00	35.00	3.13	5.50
62	Atriplex hastata	52.50	50.00	5.50	7.75
63	Hordeum vulgare	40.00	11.75	0.60	8.63
64	Hordeum vulgare	35.00	25.00	0.53	4.25
65	Poa annua	3.50	27.50	1.03	6.50
66	Atriplex hastata	62.50	13.75	6.75	18.00
67	Puccinellia distans	1.00	16.00	1.40	2.00
68	Atriplex hastata	47.50	25.00	10.00	18.75
69	Puccinellia distans	1.08	11.75	1.58	4.00
70	Chenopodium rubrum	35.00	6.75	12.50	9.25
71	Tussilago farfara	1.60	12.50	14.50	30.00
72	Puccinellia distans	1.38	10.25	0.75	2.63

Sample No.	Name of plant	Na^+	K^+	Mg^{2+}	Ca^{2+}
73	Puccinellia distans	1.05	10.25	0.83	1.50
74	Chenopodium album	0.43	30.00	30.00	23.75
75	Carex otrubae	8.75	18.00	2.00	6.75
76	Scirpus maritimus	8.63	22.50	0.25	4.50
77	Atriplex hastata	45.00	35.00	2.75	25.00
78	Puccinellia distans	7.00	27.50	0.43	5.50
79	Spergularia marina	40.00	30.00	2.25	19.00
80	Spergularia marina	50.00	19.75	2.13	17.50
81	Puccinellia distans	8.25	22.50	0.68	6.00
82	Apium graveolens	27.50	14.75	5.00	18.75
83	Spergularia marina	57.50	17.50	2.25	4.00
84	Puccinellia distans	12.75	17.00	1.26	3.75
85	Scirpus tabernaemontani	20.00	9.75	1.45	9.75
86	Potamogeton pectinatus	18.75	11.50	2.88	115.00
87	Zannichellia palustris	28.00	15.50	3.25	75.00
88	Typha latifolia	8.00	12.50	3.50	15.50
89	Sonchus arvensis	28.75	40.00	13.25	7.00
90	Potamogeton pectinatus	12.50	17.50	3.88	20.00
91	Ceratophyllum demersum	11.25	50.00	9.25	10.25
92	Atriplex patula	18.75	20.00	19.75	6.75
93	Atriplex hastata	62.50	15.75	19.75	7.50
94	Chenopodium rubrum	35.00	25.00	17.25	6.75
95	Sonchus arvensis	37.50	6.25	15.00	6.25
96	Puccinellia distans	3.00	4.75	2.00	4.75
97	Samolus valerandi	20.00	15.50	10.00	4.25
98	Triglochin maritima	4.50	11.50	3.38	1.65
99	Aster tripolium	25.00	17.25	5.00	6.75
100	Agrostis stolonifera	1.50	7.25	1.48	8.75
101	Samolus valerandi	20.00	15.25	10.25	3.75
102	Festuca arundinacea	4.75	6.50	3.88	2.50
103	Chenopodium rubrum	37.50	45.00	18.75	8.25
104	Scirpus tabernaemontani	8.50	14.25	3.50	0.75
105	Eleocharis palustris	9.50	14.00	3.00	23.75
106	Zannichellia palustris	13.33	27.50	7.50	41.50
107	Atriplex hastata	50.00	9.00	3.75	3.50
108	Typha angustifolia	32.50	40.00	12.00	18.25
109	Potamogeton pectinatus	47.50	6.00	4.88	16.50
110	Apium graveolens	25.00	27.50	3.75	35.00
111	Potamogeton pectinatus	22.50	16.25	1.50	53.75

Sample No.	Name of Plants	Na^+	K^+	Mg^{2+}	Ca^{2+}
112	Scirpus maritimus	11.75	19.50	1.58	3.00
113 *	Acrocladium cordifolium	4.00	5.50	2.50	11.50
114	Tussilago farfara	2.50	37.50	4.25	50.00
115	Apium graveolens	12.00	35.00	5.25	42.50
116	Scirpus lacustris	13.75	25.00	2.75	7.75
117	Atriplex hastata	26.25	42.50	12.75	17.50
118	Festuca rubra	9.50	32.50	2.00	4.63
119	Hordeum secalinum	17.50	10.00	1.00	3.00
120	Triglochin maritima	30.00	37.50	2.25	6.00
121	Festuca arundinacea	5.13	32.50	2.00	4.00
122	Samolus valerandi	37.50	11.50	7.00	15.00
123	Atriplex hastata	62.50	22.50	6.00	7.00
124	Atriplex hastata	67.50	32.50	5.75	6.25
125	Spergularia marina	45.00	32.50	3.00	2.50
126	Glaux maritima	37.00	8.50	4.75	8.38
127	Spergularia marina	32.50	27.50	3.50	4.25
128	Potamogeton pectinatus	62.50	14.00	7.00	2.25
129	Atriplex hastata	20.00	20.00	5.00	6.50
130	Agropyron repens	1.00	14.25	1.00	2.38
131	Lemna gibba	4.25	19.50	6.25	45.00
132 *	Acrocladium cordifolium	6.50	10.00	1.50	12.50
133	Potamogeton pectinatus	8.25	32.50	2.25	16.25
134	Atriplex hastata	35.00	8.13	7.50	16.25
135	Phragmites communis	6.25	1.50	1.88	3.25
136	Atriplex hastata	32.50	40.00	4.13	27.50
137	Atriplex hastata	42.50	20.00	6.25	22.50
138	Agropyron repens	3.75	15.50	0.80	9.75
139	Spergularia marina	27.50	20.00	4.00	30.00
140	Carex otrubae	7.63	11.00	1.00	3.13
141	Carex otrubae	8.75	20.00	0.85	5.25
142	Carex otrubae	5.50	15.75	1.03	6.25
143	Carex otrubae	6.50	10.75	0.95	3.75
144	Atriplex hastata	15.00	20.00	3.50	6.50
145	Spergularia marina	45.00	15.50	3.50	5.75
146	Puccinellia maritima	15.00	16.25	1.25	4.25
147	Juncus gerardii	6.50	13.00	17.50	6.38
148	Potamogeton pectinatus	8.50	32.50	3.13	16.25
149	Atriplex hastata	50.00	25.00	8.38	7.00
150	Phragmites communis	4.25	3.75	0.63	3.25

Sample No.	Name of Plant.	Na^+	K^+	Mg^{2+}	Ca^{2+}
151	Scirpus tabernaemontani	16.50	4.00	2.75	3.88
152	Carex distans	1.50	8.75	1.50	5.00
153	Juncus gerardii	6.50	13.75	1.25	3.75
154	Plantago maritima	32.50	6.00	1.78	13.50
155	Spergularia marina	35.00	17.75	3.00	6.50
156	Puccinellia maritima	3.75	5.75	1.00	5.00
157	Myriophyllum spicatum	11.25	9.25	2.50	22.50
158	Plantago maritima	27.50	5.50	2.00	14.50
159	Juncus inflexus	4.80	24.00	1.04	0.89
160	Scirpus tabernaemontani	16.60	5.78	1.64	4.73
161	Carex hirta	7.80	17.70	1.53	3.19
162	Rumex crispus	19.50	12.25	3.13	4.49
163	Ranunculus sceleratus	20.00	17.41	3.58	5.28
164	Myriophyllum alterniflorum	14.22	12.00	3.25	13.98
165	Callitriche intermedia	18.00	11.50	2.50	14.30
166	Cotula coronopifolia	42.90	37.90	3.97	10.33
167	Aster tripolium	42.90	16.60	2.31	7.26
168	Puccinellia distans	0.96	3.30	4.12	29.70
169	Prunella vulgaris	2.50	12.25	5.38	125.00
Cryptogams					
170	Peltigera sp.	0.40	2.77	2.68	141.66
171	Barbula tophacea	0.66	0.46	12.64	75.90
172	Funaria hygrometrica	0.71	0.43	15.28	51.28
173	Pohlia annotina	0.57	0.59	3.35	10.99
174	Pohlia annotina	2.50	2.75	1.25	9.25
175	Funaria hygrometrica	0.93	3.57	0.93	9.30
176	Camptothecium lutescens	0.83	11.00	1.73	15.00
177	Bryum microerythrocarpum	0.93	1.75	2.90	156.00
178	Barbula convoluta	0.50	2.60	3.09	143.00
179	Campt othecium lutescens	0.74	5.17	2.36	13.15
180	Hylocomi um splendens	0.54	4.17	1.39	37.12
181	Drapanocladus fluitans	0.50	3.50	3.13	25.00
182	Pleurozium schreberi	0.27	5.00	2.50	17.00
183	Bryum pallens	0.28	4.50	2.62	22.50
184	Encalypta vulgaris	0.14	1.5	2.25	82.50
185	Bryum pallens	0.50	0.85	1.25	143.10
186	Bryum pallens (external)	0.50	0.25	0.13	9.50
187	Ceratodon purpureus	0.55	3.00	2.50	162.50
188	Funaria hygrometrica	1.23	19.75	8.00	77.50

Sample No.	Name of Plant		Na^+	K^+	Mg^{2+}	Ca^{2+}
189	Funaria hygrometrica		0.63	2.75	11.80	87.50
190	-	-	0.70	1.75	12.00	112.50
191	-	-	0.88	3.00	15.50	100.00
192	-	-	0.95	4.25	12.55	105.00
193	Acrocladium cordifolium		6.25	12.50	3.50	37.50
194	Chara vulgare		1.30	1.50	6.00	500.00
195	Peltigera sp.		0.40	2.77	2.68	141.66

APPENDIX IVb

Localities for Vegetation Samples (V.S.)

V.S.01-07,187,188	Stoke Works, Worcestershire (32/943662)
189-192	Stoke Works, Lagoon, Worcestershire, (32/943662)
08-20	Upton Warren, Worcestershire (32/934665)
21,28,36	Worcester and Birmingham Canal, Stoke Works ,Worcester, (32/943662)
22,23	Droitwich Canal, Worcestershire (32/876623)
24-26	Droitwich Canal, Worcestershire (32/875622)
27	Droitwich Canal, Worcestershire (32/881624)
29-34, 37.	Southam Salt Spring, Warwickshire (24/444602)
35	River Salwarpe, Worcestershire (32/880626)
38-48	Marston Pool 1, Northwich, Cheshire (33/671757)
49	Marston, Trent & Mersey Canal,Northwich,Cheshire, (33/671757)
50-52	Marston, Saltpan, Cheshire (33/671754)
53-60, 194	Marston Pool 3, Northwich, Cheshire (33/671754)
61,62	Marston Pool 2, Northwich, Cheshire (33/671757)
63-65	Marston Hall Field Farm, Northwich, Cheshire (33/670761)
66-69	Neumann's Flash, Northwich, Cheshire. (33/665749)
70-74	Ashton Flash, Northwich, Cheshire. (33/666748)
75-82	Dairy House Farm, Cheshire (33/662753)
83-87	Anderton, Cheshire. (33/652750)
88	Marsh near Trent and Mersey Canal.Cheshire. (33/683417)
90	Trent and Mersey Canal, Cheshire. (33/683714)
91	Billinge Green Pool.Cheshire. (33/681715)
92-94	Winsford Lagoon 1. Cheshire. (33/656682)
89,95-109,113, 193.	Winsford Lagoon 2, Cheshire (33/654584)
111	SilverWell, Cheshire, River Weaver, (33/566758)
110,112,114-117	SilverWell, Lagoon, Cheshire, (33/566767)
118-126	Aldersey, Cheshire. (33/457567)
127-133	Nantwich, Shrewbridge, Cheshire. (33/651510)

134,135,140-144,169-170, 177-186	Plumley, Cheshire (33/708751)
136-139	Dutton, Cheshire (33/583767)
145-149	Pasturefields, Staffordshire, (33/992248)
150-158	Preesall, Lancashire (34/361467)
159-166	Mickletown, West Yorkshire, (44/402276)
167,174-176	Sandbach, Watch Lane, Cheshire. (33/730605)
168,171-173	Elton Hall, Cheshire (33/717596)

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Preliminary investigation into the colonization of alkaline industrial waste by bryophytes

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INTRODUCTION

The salt extraction and manufacturing industries of Cheshire have resulted in two distinct ecological types of subsidence hollow, known locally as flashes—a saline type caused by natural brine-pumping and colonized by halophytic phanerogams, such as *Aster tripolium, Spergularia marina* and *Puccinellia distans* (Lee, 1975, 1977) and an alkaline type, caused mainly by the surface deposition of residues from the ammonia-soda process of alkali manufacture and sparsely colonized by both halophyte and glycophyte phanerogams and several species of tolerant bryophyte. In the former situation, the saltmarsh vegetation is well-established but in the latter, extensive areas of alkaline waste remain unvegetated except for sparse *Puccinellia distans* stands and local zones of bryophyte-dominated vegetation where there is some surface irrigation by fresh water from land drains. As part of a programme of research into the chemical characteristics of the alkaline residues and problems associated with management and reclamation at Elton Hall Flash, investigations into the ecology of the bryophyte vegetation were undertaken. The preliminary results of the study are presented in this paper and interpreted in the light of knowledge of the sociology and ecology of bryophytes of extreme habitats.

FIELD AND LABORATORY METHODS OF ANALYSIS

The fieldwork was based at Elton Hall Flash (National grid ref. 33/717596), a local nature reserve managed by the Cheshire Conservation Trust as a wildfowl reserve. The flash comprises two areas of standing water, one with extensive marginal expanses of periodically inundated alkaline waste and sparse vegetation. Fig. 1 shows the distribution of the main vegetation types investigated, their relation to surface freshwater flow and the location of quadrats and plant and soil samples. Vegetation analysis involved the calculation of rooted frequency for all species using both transect and random sampling with a 0.25 m^2 quadrat. Samples of bryophyte material and soil from the top 5 cm were collected from each quadrat for laboratory analysis of calcium, magnesium, potassium and sodium. The pH of fresh soil samples were measured prior to the extraction of 10-g oven-dried samples for 24 h with 100 ml of N ammonium acetate. The bryophyte samples were teased into individual shoots to remove adhering soil and washed five times with deionized water to remove extracellular cations, so that remaining cations were exchangeable and intracellular (Bates & Brown, 1974). One-gram oven-dried samples were ashed at 450°C and extracted with 100 ml of equal volumes of N hydrochloric and nitric acid. Analysis for the four cations was performed using a Perkin-Elmer 360 atomic absorption spectrophotometer and, in the determination of calcium and magnesium, lanthanum chloride was added to the extracts to suppress phosphate interference.

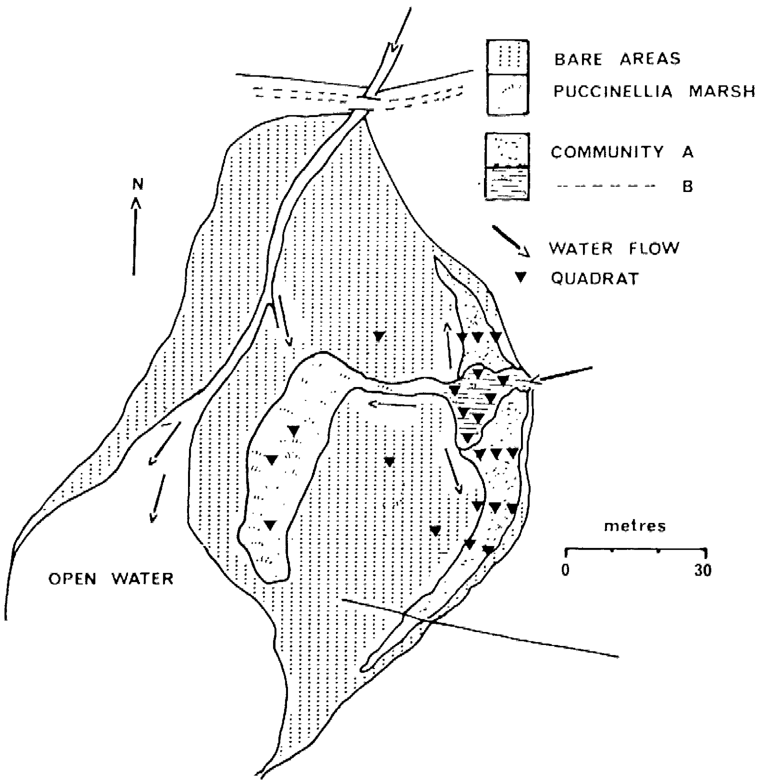

Fig. 1. Map of distribution of vegetation types and quadrats at Elton Hall Flash.

RESULTS AND DISCUSSION

Sociology and ecology of plant communities

Details of the specific composition of the two main vegetation types are given in Table 1, from which it can be seen that community A is essentially a community dominated, in terms of species numbers and frequency, by the mosses

Barbula tophacea and *Funaria hygrometrica* with *Puccinellia distans* of low frequency and vitality. Conversely, *P. distans* assumes much greater importance in community B where it is co-dominant with *Pohlia annotina* and where the presence of other glycophytic and halophytic phanerogams is also a distinguishing feature. The *Barbula-Funaria* community shows affinities to the association Funarietum hygrometricae Gams 1927, which is a characteristic pioneer vegetation of sparse soils on sites rich in potassium, sodium, calcium and nitrates throughout central and western Europe (Hübschmann, 1957) and North America (Hoffmann, 1966a). Other species of high constancy in this association are *Marchantia polymorpha, Ceratodon purpureus* and *Bryum argenteum*, the typical components of many familiar moss communities of derelict land, footpaths and disturbed waste ground, particularly after fire. *Barbula tophacea* has not been previously recorded as a component of the association and it seems that the pioneer vegetation at the Cheshire site could represent a distinct variant. Similar stands dominated by *Funaria* and *Barbula* are quite common in the damper areas of chalk quarries in East Yorkshire and elsewhere and, although *B. tophacea* does have quite a pronounced calcicole tendency (Watson, 1918), it also occurs on a variety of substrates similar to *Funaria* (cf. Proctor, 1956), and rarely in coastal salt marshes (Adam, 1976). The community may therefore be quite widespread. Although *Funaria* has been recorded as occurring on saline soils in North America (Flowers, 1933; Parker, 1931), and is also found occasionally as a ruderal in salt marshes, it is not generally regarded as a salt-tolerant species, unlike a third moss, *Pottia crinita* (Gams, 1932), which was present in only one quadrat. Unfortunately, the small quantities of this latter species precluded analysis of plant material, but the habitat details do provide some autecological data.

The *Pohlia-Puccinellia* community is closely related to the association Puccinellietum distantis Feekes (1934) 1945, sub-association juncetosum, described by Lee (1977) from saline flashes at Winsford and Sandbach in Cheshire, wherein *Puccinellia distans* and *Juncus bufonius* are co-dominant. Bryophytes are absent in Lee's data and it seems that the community at Elton Hall Flash is a distinct structural variant of the sub-association. For *Pohlia annotina*, this represents a rather unusual habitat, it being a moss which prefers damp, sandy earth, usually of a non-calcareous nature. In terms of syntaxonomy, this community is classified in the alliance Puccinellio-Spergularion salinae Beeftink 1965 of the order Glauco-Puccinellietalia Beeftink & Westhoff 1962 and the class Asteretea tripolium Westhoff & Beeftink 1962 and is rather unusual in that, apart from Pottietum heimii Hübschmann 1957, is one of the few saltmarsh vegetation types in which mosses occur.

The type of soil on which both communities grow is similar to the non-saline/alkali group, characterized by exchangeable sodium percentages greater than 15, a pH range of 8.5–10 and a conductivity of saturated soil extracts of less than 4 mmhos/cm at 25°C (Richards, 1969; Waisel, 1972). The Elton Hall soils are similar in terms of pH (7.9–9.3) and conductivity (1.29–4.81 mmhos/cm), but their industrial origin has resulted in lower sodium levels and much

Table 1. *Specific composition of plant communities (Mean % rooted frequency)*

	A	B
Number of quadrats:	14	7
pH range:	8·4–9·3	7·9–8·8
Species number:	5	14
Barbula tophacea	94	–
Funaria hygrometrica	34	–
Pottia crinita	+	–
Pohlia annotina	–	91
Puccinellia distans	21	74
Dactylis glomerata	2	–
Juncus bufonius	–	39
J. articulatus	–	36
Triglochin maritima	–	36
Atriplex hastata	–	12
Agrostis stolonifera	–	10
Holcus lanatus	–	3
Spergularia marina	–	2
Tussilago farfara	–	2
Cirsium vulgare	–	1
Polygonum persicaria	–	1
Epilobium sp.	–	+
Rubus fruticosus agg.	–	+

A. *Barbula-Funaria* community
B. *Pohlia-Puccinellia* community

(Phanerogam nomenclature: Clapham, A. R., Tutin, T. G. & Warburg, E. F. (1962) *Flora of the British Isles*, 2nd. ed., Cambridge.)

higher magnesium levels. The pH values and magnesium concentrations are extreme and both are certainly important limiting factors in the growth of phanerogamic vegetation. The upper limits at which mosses will grow and reproduce are fairly well known. Armentano & Caponetti (1972) have shown that the growth of protonemata of *Funaria hygrometrica* increases significantly at each succeeding pH from 3.5 to 7.8 and Woollon (1975) has demonstrated that the calcicolous moss, *Fissidens cristatus*, has optimum growth at a pH of 8.0. Hoffmann (1966a, b) recorded *Funaria hygrometrica* growing on soils of pH 8.4, while Segal (1969) reports several mosses growing on mortar with an alkalinity in excess of 8.5 and occasional plantules of *Grimmia pulvinata* and *Ceratodon purpureus* above pH 10. The values reported in Table 1 are thus not unusual for bryophyte growth and it appears that pH is not the factor limiting distribution and revegetation.

It seems more probable that it is magnesium which is the major limiting factor, for reference to Table 2 shows that the areas devoid of vegetation are extremely rich in magnesium. It is interesting to arrange the vegetation types in a series relative to the mean values for the ratio [Mg]/[K], thus: bare soils (Mg/K 400/1); *Barbula-Funaria* community (Mg/K 52/1); *Puccinellia* community (Mg/K 27/1); *Pohlia-Puccinellia* community (Mg/K 11/1)—for the sequence also reflects the differing frequency of freshwater irrigation, from little or no water movement in the bare soil areas through to a regular irrigation in the *Pohlia-Puccinellia* areas. The magnesium concentrations may, therefore, reflect the greater solubility of magnesium salts and different degrees of lateral leaching. Unfortunately, there is a lack of information on the nature of magnesium toxicity in mosses, but there are general indications that high concentrations are frequently more toxic than are isosmotic concentrations of other neutral salts (Richards, 1969) and that toxicity may be alleviated by the presence of high concentrations of calcium in such situations as revegetated quarry spoil-heaps of Magnesian limestone (Shimwell, 1968). The relatively high concentration of calcium is clearly an important factor at Elton Hall Flash in enabling vegetation development but, nevertheless, there is a definite suggestion that both *Funaria hygrometrica* and *Barbula tophacea* can withstand high concentrations of magnesium and a reversal of the normal Ca > Mg ratios found in the soils associated with the other vegetation at the site and most other types of vegetated alkaline soils.

Table 2. *Concentrations of cations in soils and plants*

	Number of analyses	Mean values (mg/g) Na^+	K^+	Mg^{++}	Ca^{++}	Cation Ratios K = 1
(a) Soils						
Bare areas	3	0·11	0·026	10·66	0·56	Mg400>Ca22>Na4>K1
Barbula-Funaria community	11	0·15	0·07	3·63	2·64	Mg52>Ca38>Na2>K1
Puccinellia community	3	0·13	0·05	1·33	2·00	Ca40>Mg27>Na2·6>K1
Pohlia-Puccinellia community	7	0·12	0·11	1·26	3·96	Ca36>Mg11>Na=K1
(b) Plants						
Barbula tophacea	11	0·66	0·46	12·64	75·90	Ca165>Mg27>Na1·4>K1
Funaria hygrometrica	6	0·71	0·43	15·28	51·28	Ca119>Mg34>Na2>K1
Pohlia annotina	6	0·57	0·59	3·35	10·99	Ca19>Mg6>Na=K1
Puccinellia distans	3	0·96	3·30	4·12	29·70	Ca31>Mg4>K3>Na1

The relative concentrations of the major cations, expressed in terms of ratios to the least abundant ion, are also of interest in the determination of the ecological affinities of the habitat. Lee (1975) has shown that the soils of inland salt marshes have a cation series Na > Ca > Mg > K unlike coastal salt marshes where the order usually runs Na > Mg > Ca > K. Similarly, Gorham (1958) indicated that Ca > Na ⩾ Mg > K was a common feature of various types of exposed dune and Willis *et al.* (1959) have shown that Ca > Mg > Na ⩾ K is the expected situation in a variety of calcareous dune and dune slack habitats. Although direct quantitative comparisons are impossible, the alkaline marshes at Elton Hall seem to be more closely related, both in terms of major cation concentrations, ratios and hydrology to the dune slack habitats, rather than to other inland saline marshes.

Cation content of mosses

There is a considerable literature on the exchangeable and intracellular cation content of mosses (Shacklette, 1965; Streeter, 1965; Allen *et al.*, 1967; Beaumont, 1968; Bates & Brown, 1974, *inter alia*) which indicates that there is a wide variation in the absorptive capacity of different moss species for the four cations, Ca, Mg, Na, and K, which varies with ecological habitat. The general pattern emerging is that mosses from calcareous habitats have cation contents according to the series Ca > Mg > K ⩾ Na, whereas, in maritime mosses, Na and Mg levels are greatest, uptake being stimulated by external Ca concentration. Bates & Brown (1974) suggest that there are specific cation uptake mechanisms in mosses and moss ecotypes, and the results for the three mosses, presented in Table 2(b), tend to vindicate this suggestion; for whether the ratio of divalent cations in the soil is Ca > Mg or Mg > Ca the mosses, without exception, have a content where Ca > Mg > Na > K. The figures suggest that magnesium toxicity is prevented by selective uptake of calcium in preference to magnesium, but a more detailed analysis of the reduction of toxicity and of mechanisms of selected ion uptake awaits further research.

There are two other features of interest in the data in Table 2(b): (i) *Barbula tophacea* and *Funaria hygrometrica* absorb much greater concentrations of divalent cations than *Pohlia annotina*, whereas concentrations of monovalent cations remain similar; (ii) when cation concentrations in *P. annotina* are compared with those in *Puccinellia distans* they can be seen to be similar, but levels of potassium in the grass are much higher than those for sodium and the concentration of both monovalent cations are higher than in all mosses.

SUMMARY

Preliminary studies on the colonization of alkaline waste by bryophytes indicate that there are two distinct vegetation types in which mosses dominate or play an important role in community structure: (i) *Barbula tophacea–Funaria hygrometrica* community, characterized by the high frquency of both mosses, low vitality of phanerogams, on sites whrere there is a slow throughflow of fresh water, a soil pH range of 8.4–9.3 and concentrations of magnesium exceeding those of calcium; (ii) *Pohlia annotina–Puccinellia distans* community, in which *Pohlia annotina* comprises the bryophyte layer and *Puccinellia distans* is predominant in the herb layer, on sites where there is a greater freshwater throughflow, a soil pH range of 7.9–8.8 and concentrations of calcium exceeding

those of magnesium. Unvegetated areas are characterized by extremely high concentrations of magnesium and it is apparently this element which is the factor limiting vegetative growth. Although the external concentrations of magnesium may exceed calcium, in the three moss species analysed there was always more calcium present and evidence suggests selective uptake of this latter divalent cation, and hence the ability to colonize otherwise toxic habitats.

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