RELATIONSHIP OF VEGETATION TO SALINITY AND SODICITY IN WETLAND MEADOWS OF THE CHILCOTIN REGION OF BRITISH COLUMBIA

By

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Abstract

This study investigates the relationships between vegetation and salinity and sodicity in wetland meadows in the Chilcotin region of British Columbia.

Eleven vegetation communities and one group of releves with no vegetation were identified using cluster analysis. An exchangeable sodium per cent of 15 and an electrical conductivity of 4 mmhos/cm were found to be appropriate boundaries for distinguishing between saline and sodic tolerant and intolerant vegetation communities. Some salt tolerant species and communities occurred in fresh conditions; however, intolerant species and communities were rarely found in saline or sodic conditions. Most meadows have soils that are low in salts, but 20 per cent had a high electrical conductivity and 18 per cent had a high exchangeable sodium per cent.

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1 Introduction

Within the dry grasslands and lodgepole pine (*Pinus contorta*) forests of the Chilcotin region of British Columbia, wetlands are oases of floral and faunal productivity. As such they are in demand by a variety of resource users.

The Chilcotin ranching industry, since its inception in 1863 (McLean pers. comm.), has depended heavily upon wetlands for hay plus summer and fall grazing (Morton 1979). Improvement of wetlands for ranching purposes can involve drainage and removal of shrubs to plant better forage such as reed canary grass (*Phalaris arundinaceae*). The wetlands also provide summer breeding grounds for waterfowl and, in shrub areas, winter browse for moose and deer. As well, wetlands function as natural water storage areas.

In the Canadian and American prairies, wetlands have long been the subject of considerable research, but Chilcotin wetlands have only recently been studied. Water regime, nutrient regime, disturbance, salinity, sodicity and pH have all been identified as factors that are important in controlling the distribution of both prairie and Chilcotin wetland vegetation.

1.1 Factors affecting vegetation distribution in wetlands

1.1.1 Water regime

The overriding influence of the water regime on species distributions has been well documented (Dix and Smeins 1967, Walker and Coupland 1968, Boyd and Hess 1970, van der Valk and Bliss 1971, Walker and Wehrhahn 1971, Millar 1973). Wetland vegetation is highly influenced by the initial depth of water, the rate of water loss and the degree to which the water level fluctuates both within and between seasons.

The moisture gradient is largely responsible for the distinctive banded pattern of vegetation in Chilcotin wetlands (Jones 1981). In a study that looked at soil parameters related to vegetation distribution in Chilcotin wetlands, Selby and Moon (1981) found that depth to mineral soil, humus form, depth of the surface organic horizon, depth to carbonates and microtopography were the only parameters required to predict more than 90 per cent of the variation in vegetation. Depth to mineral soil, humus form and depth of the surface organic horizon are largely controlled by the moisture regime. The presence of carbonates depends on the geology and groundwater flow patterns of the surrounding area, but their depth depends on moisture regime. Though moisture regime is not necessarily responsible for the development of microtopographic features such as hummocks and hollows, it is certainly responsible for the resulting vegetation patterns.

1.1.2 Nutrient regime

Studies indicating the importance of the nutrient regime to plant species distributions in wetlands have been carried out by Heinselman (1970), Walker and Wehrhahn (1971) and Schwintzer (1978). Based on water chemistry, two main types of wetlands have been recognized: ombrotrophic and minerotrophic (Moore and Bellamy 1974). Ombrotrophic wetlands depend on precipitation for water and minerals and consequently are deficient in nutrients and generally have a pH less than 7. In contrast, a large part of the waters of minerotrophic wetlands have percolated through mineral soils and bedrock. Thus pH and nutrient regime are dependent on the geology of the surrounding area. Most Chilcotin wetlands appear to be of the minerotrophic type and, because much of the Chilcotin is underlain by Tertiary lava beds, are well fertilized by nutrient rich groundwaters (van Ryswyk 1971).

1.1.3 Disturbance

Disturbance by man has been found to be a major influence on wetland vegetation in the Canadian prairies (Walker and Coupland 1970). Walker and Wehrhahn (1971) stated that in relatively undisturbed, shallow, non- to slightly saline prairie sloughs, disturbance in the form of grazing or mowing was the most important factor affecting variation in the vegetation. Chilcotin wetlands are virtually all disturbed to some degree - by mowing, grazing, drainage, cultivation or a combination of these activities.

1.1.4 pH

Sjors (1950) stated that pH is an indicator of the complicated soil conditions controlling vegetation, but other environmental factors are generally more significant. According to Walker and Coupland (1968), vegetation changes along a pH gradient, but the same community response was also observed along a salinity gradient. In Chilcotin wetlands, pH rarely falls below 7 (Mayall 1983).

1.1.5 Salinity and sodicity

The salinity of a soil depends both on the amount of soluble salts and the amount of moisture the soil contains. Saline soils are defined as those for which the conductivity of a saturation extract is more than 4 mmhos/cm at 25°C (United States Salinity Laboratory Staff 1954). The pH of these soils is usually less than 8.5. In sodic or alkali soils the percentage of exchangeable sodium (ESP) is greater than 15 and the pH is generally greater than 8.5.

Salts affect vegetation by decreasing the availability of water, by toxicity and nutritional imbalances and, in the case of sodium, by the deterioration of soil structure. The decrease in water availability is caused by the increased osmotic pressure of the soil solution which results in a decrease of the diffusion pressure gradient between the medium and the plant (Bernstein and Hayward 1958, Hayward and Bernstein 1958). Because of this fact it is important to determine the soluble salt content of the soil.

In saline and sodic soils, calcium, magnesium and sodium are generally the dominant cations, although potassium is usually present in smaller amounts. Chloride, sulphate, carbonate and bicarbonate are the dominant anions. Proportions may vary considerably among different soils. An excess of a particular ion may result in toxic accumulations of that ion or in decreased absorption of some other essential ion resulting in nutrient deficiency (Hayward and Bernstein 1958). Sodium in excess of approximately 15 per cent on the exchange complex has a deleterious effect on soil structure. Sodic soils tend to absorb water slowly, to crust when dry and to become sticky when wet (Pearson 1960).

Both salinity and sodicity can vary considerably both seasonally and spatially through the soil profile. During dry periods salts have been observed to move upward by capillary action, concentrating in the upper few centimetres, as water is evaporated from the surface and transpired (Jackson et al. 1956, Bolen 1964). During rainy periods or spring snow-melt salts may be leached downward again

Research has been carried out on relationships between native vegetation and salinity in Utah, North Dakota and the Canadian prairies. In 1934, Flowers described the vegetation of the Great Salt Lake region. He noted that salt concentration is more important than total salt content and that moist periods thus allow the establishment of seedlings. Gates et al. (1956), studying shrub vegetation on salt deserts in Utah, found that 'soil analysis showed some significant edaphic differences between soils occupied by various species. However, no species was restricted in distribution to a narrow tolerance for any specific soil factor!. This was corroborated by Keith (1958) for native herbaceous vegetation in southeastern Alberta. In North Dakota, species have been used as indicators of high or low salinity by Worcester and Seelig (1976). Such indicator species are useful to give a general idea of conditions in which they are growing, to obtain in the field a preliminary assessment of potential productivity.

The relationship of vegetation communities and species to salinity on the Canadian prairies has been investigated by several researchers. Dodd and Coupland (1966) found that salinity decreased from the wet centres to the dry margins of depressions. A sequence of vegetation types corresponded to the sequence of soil types. Walker and Coupland (1968, 1970) stated that after water regime, salinity is the most important factor controlling vegetation distribution. A few species were restricted to a narrow range of salinity while others flourished in a broad range of conditions. Millar (1976) identified dominant wetland species and the salinities in which they occur for a classification system for prairie wetlands.

Salt tolerance ranges of a wide variety of forage crops have been identified (Forsberg 1953, Bernstein 1958, Pearson 1960, Dewey 1960, Moxley et al. 1978, Rauser and Crowle 1963) and it has been found that saline areas may become relatively productive if planted with appropriate species, such as tall wheatgrass, crested wheatgrass and Russian wild rye.

1.2 Wetland classification in the Chilcotin

The potential for resource use conflicts arising among ranchers, Ducks Unlimited, the Canadian Wildlife Service and the Fish and Wildlife Branch of the Ministry of Environment was identified by the Cariboo Wetland Working Group in 1978 (Beets, pers. comm.). To assist in their objectives of facilitating wetland description and compiling a wetland registry, a wetland classification system was developed by Runka and Lewis (1981) for the Resource Analysis Branch of the Ministry of Environment. This classification scheme defines wetlands as 'lands that are wet enough or inundated frequently enough to develop and support a distinctive natural vegetative cover that is in strong contrast to the adjacent matrix of better drained lands' (Runka and Lewis 1981). Because existing research concerning Cariboo-Chilcotin wetlands was limited, the manual 'was intended as an open-ended guide to be field verified, altered and added to' as knowledge of wetland systems increased.

A second classification system for Cariboo-Chilcotin wetlands was independently developed in 1982 by Moon and Selby. The authors of both classification systems suggested that further research was required to elucidate relationships between vegetation and salinity in those areas where mineral soils support water-tolerant grasses, forbs, low sedges and rushes. These ecosystems are called meadows by Runka and Lewis (1981). In Runka and Lewis's (1981) classification system, salinity and sodicity of the soil are used as one basis for the subdivision of the meadow class. Lewis (pers. comm.) stated that this subdivision was appropriated from Diagnosis and Improvement of Saline and Alkali Soils (United States Salinity Laboratory Staff 1954) and, being based on research in the United States, might not be valid for Chilcotin meadows.

Selby and Moon (1981) stated that their water-tolerant grass/forb vegetation group might require subdivision on the basis of salinity and sodicity. A subsequent paper by Moon and Selby (1982) subdivided this vegetation group into alkaline and nonalkaline subgroups.

1.3 Research hypotheses

Meadows provide excellent grazing and native hay for ranchers, as well as nesting sites for several species of water fowl. Although some waterfowl thrive in saline or sodic ponds (Savard pers. comm.), the vegetative productivity which is of concern to ranchers may be limited by salinity (Selby pers. comm., Lewis pers. comm.). A better understanding of relationships between vegetation and salinity and sodicity in wet meadows will facilitate management decision-making in these areas. The identification of indicator species could provide managers with a useful tool for assessment of salinity and sodicity in the field.

In order to fulfill these objectives the following four null hypotheses will be tested:

1. Distribution of wet meadow vegetation communities is not significantly affected by electrical conductivity of the soil,
2. Distribution of wet meadow vegetation communities is not significantly affected by exchangeable sodium per cent of the soil,
3. Distribution of individual wet meadow species is not significantly affected by electrical conductivity of the soil,
4. Distribution of individual wet meadow species is not significantly affected by exchangeable sodium per cent of the soil.

If the null hypotheses are rejected, the tolerance ranges of important species and communities will be described, appropriate salinity and sodicity boundaries for the meadow component of Runka and Lewis's (1981) classification system will be suggested and these findings will be compared with those of Moon and Selby (1982).

2. Description of the study area

2.1 Location

Field work was carried out in 72 wetland meadows of the Chilcotin, a 35,000 square kilometre region west of Williams Lake in south-central British Columbia (Figure 1).

2.2 Physiography

Holland (1976) included the Chilcotin in the Fraser Plateau, a gently rolling upland underlain by late Miocene or Pliocene olivine basalt flows. Much of the Plateau is blanketed with glacial drift comprised of till and glacio-fluvial deposits. During the last glaciation, which ended about 10,000 years ago, ice flowed in a northeasterly to easterly direction from the Coast Mountains. Thus glacial till close to the Coast Mountains is generally comprised of coarse-grained igneous materials, while till farther from this source is derived from the basaltic rock of the Plateau and is finer-grained (Annas and Coupe 1979). Late in the glacial period, a temporary readvance westward from the Cariboo Mountains entered the eastern fringe of the study area. Drumlins and eskers provide much of the low relief on the Plateau surface (Tipper 1971).

The general elevation range of the Plateau is 1,200 to 1,500 metres, rising gradually to 1,800 metres along the margin of the Chilcotin Ranges to the west. Several mountain ranges project above this level to elevations of approximately 2,400 metres.

The Plateau is drained largely by Chilcotin River which flows east into Fraser River. Upper portions of Dean, Klinaklini and Homathko Rivers drain the southwest and west portions of the region through the Coast Mountains to the Pacific Ocean.

Figure 1. Location of the study area in British Columbia

2.3 Climate

Within the Chilcotin the general climate trends are governed by latitude, elevation and position in relation to the regional mountains. The Chilcotin is located in the rain shadow of the Coast Mountains and thus enjoys a relatively dry climate. Annual precipitation varies from approximately 290 mm (Puntzi Mountain) to 420 mm (Alexis Creek/Tautri Creek) (Annas and Coupe 1979). In the eastern portion of the region 50 to 60 per cent of the precipitation occurs from May to September. Closer to the Coast Range, the influence of coastal weather systems decreases the proportion of summer precipitation to approximately 40 per cent.

The high elevation of the Plateau results in relatively cool temperatures. Thus the average frost free period ranges from 12 days at Tautri Creek to 44 at Big Creek (Annas and Coupe 1979).

2.4 Vegetation

Samples were collected from within the sub boreal spruce (a) and Ponderosa pine bunchgrass (e) biogeoclimatic subzones as well as an undifferentiated subzone of the interior Douglas-fir zone as defined by the Ministry of Forests (Annas and Coupe 1979).

The sub boreal spruce (a) subzone is dominantly *Pinus contorta* with an understory of shrubs - *Arctostaphylos uva-ursi*, *Shepherdia canadensis*, *Juniperus communis* and *Rosa acicularis*. The herb layer is generally poorly developed in all but the wetter sites resulting in rather unproductive forage for livestock. *Calamagrostis rubescens* is sparse, and less productive species such as *Festuca ovina* and *Oryzopsis asperifolia* are often the dominant forage species.

The ponderosa pine bunchgrass (PPBG) (e) subzone is too cold for ponderosa pine; otherwise vegetation resembles other PPBG subzones. Common shrubs are *Chrysothamnus nauseosus* and *Artemisia tridentata*. A variety of grasses, including *Agropyron spicatum* and *Stipa* spp., occur on mesic sites. *Opuntia fragilis* and *Calochortus macrocarpus* are found on drier sites. Because of the low elevation and low winter precipitation, this area is used largely for spring range.

Vegetation in the undifferentiated subzone of the interior Douglas-fir biogeoclimatic zone has not yet been described by the Ministry of Forests.

2.5 Wetlands

Wetlands are found in depressions throughout the Chilcotin. Wetland soils include Regosols, Gleyed Brunisols, Gleysols and Organic soils (Moon and Selby 1982). Deposits of marl occur in localized areas throughout the region.

The following vegetation cover types have been identified in Chilcotin wetlands (Runka and Lewis 1981, Moon and Selby 1982):

1. Floating aquatic - e.g. *Sparganium* spp., *Lemna* spp., *Nuphar polysepalum*, *Potamogeton* spp.
2. Submerged aquatic - e.g. *Utricularia vulgaris*, *Myriophyllum* spp.
3. Nonvegetated - barren mudflats or saltflats
4. Moss - mosses other than *Sphagnum* spp., e.g. *Tomenthypnum nitens*, *Drepanocladus* spp.
5. *Sphagnum* spp.
6. Cattail - *Typha latifolia*
7. Bulrush - *Scirpus* spp.
8. Horsetail - *Equisetum* spp.
9. Emergent grasses - e.g. *Alopecurus aequalis*, *Beckmannia syzigachne*, *Scolochloa festucacea*, *Glyceria* spp.
10. Spike rush - *Eleocharis palustris*
11. Sedge - e.g. *Carex aquatilis*, *C. rostrata*, *C. atherodes*

12. Water tolerant grass/forb - a mixture of grasses, herbaceous plants and dryland rushes and sedges

13. Low shrub in combination with either sedge or water tolerant grass/forb - e.g. *Betula glandulosa*, *Salix* spp.

14. Tall shrub in combination with either sedge or water tolerant grass/forb - e.g. *Salix* spp.

15. Treed - over 10 per cent tree cover, usually *Picea* spp.

Runka and Lewis (1981) identified seven wetland classes: fen, marsh, bog, swamp, shallow open water, meadow and shrub carr. Each of these classes represents a type of system and nutrient cycling that is generally characterized by specific combinations of soils and vegetation. Meadows, the class selected for study, are defined by Runka and Lewis as 'herbaceous wetlands developed on mineral materials that are periodically saturated but rarely inundated'. Meadow vegetation may be composed of various mixtures of water tolerant grasses, low sedges, rushes (*Juncus* spp.) and forbs. Soils are mineral, but occasionally have an organic capping. At the second level of the classification system, the subclass, meadows are subdivided into those with and those without an organic capping. At the third level, the variant, mineral meadows are further subdivided on the basis of salinity and sodicity. In Moon and Selby's (1982) wetland classification system, the approximate equivalent to meadow is water tolerant grass/forb on Shallow-peaty, Humic, Rego-humic or Orthic Gleysols, carbonate deposits or Gleyed Brunisols.

3 Methods

The major environmental factor controlling wetland vegetation is moisture regime. Meadows occur in a restricted range of moisture regimes: where the soil may be saturated during some portion of the year, but is rarely inundated. By looking at meadows alone, and thereby limiting the variation in vegetation resulting from variations in moisture regime, the effects of salinity and sodicity may be more apparent.

3.1 Site selection

One hundred and thirty-four sites in 72 different meadows (Figure 2) in the sub boreal spruce (a), Ponderosa pine bunchgrass (e) and undifferentiated interior Douglas-fir biogeoclimatic subzones of the Cariboo Forest District were sampled during the summer of 1980.

Meadows were selected by driving as many roads in the Chilcotin as possible during the field season and sampling all meadows encountered. Roads were chosen to cover the greatest geographical distance north to south and east to west. Each meadow was stratified subjectively to produce visually similar botanical composition and foliar cover and within each stratum one site was selected using two random numbers from a random numbers table. The first number indicated the number of paces to walk around the perimeter of the meadow from the point of access. The second number denoted the number of paces to walk towards the centre of the meadow.

To ascertain the variability in salinity through the season the soils of 3 sites in each of four meadows were sampled every two weeks from June 22 until September 1 (Figure 2). These four meadows - at Horseshoe meadow and Suds, Patterson and Moores Lakes - were selected to provide a range of conditions of salinity within a short distance from the base station. They were chosen after a reconnaissance survey of nearby meadows.

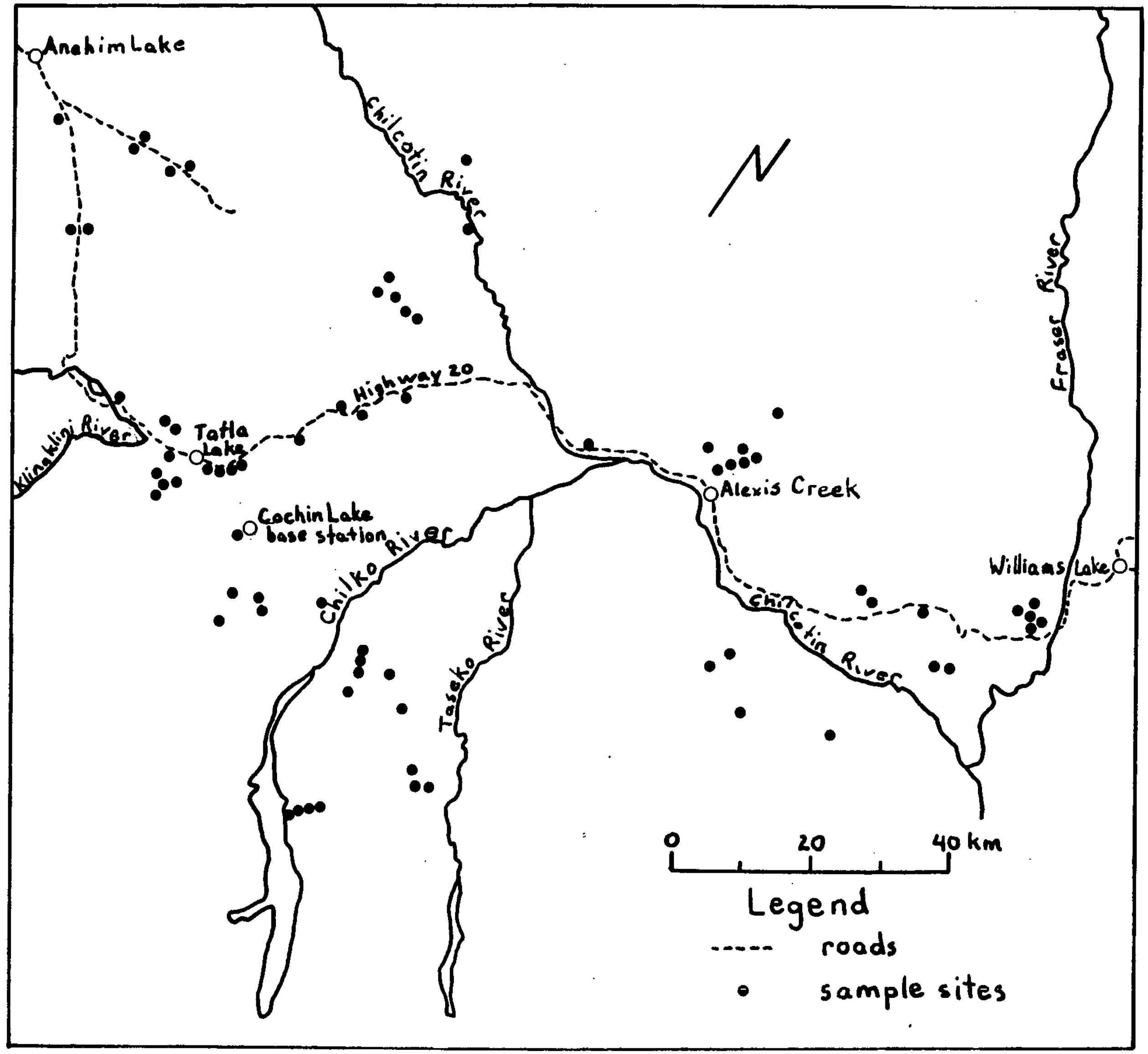

Figure 2. Location of sample sites

3.2 Vegetation

At each site vegetation was sampled by listing the species present in a one square metre quadrat and visually estimating per cent cover of each species to the nearest percentage point. Cover of each species was also recorded according to the Domin-Krajina cover-abundance scale (Table 1). Mosses were identified by T. McIntosh of the Department of Botany, University of British Columbia. Grass species were identified according to Hitchcock (1971) and, where required, Roberts (unpubl.). Hitchcock and Cronquist (1973) served as the authority for all other botanical groups. Fourteen specimens were insufficiently developed to be positively identified, but were included in the analyses as 'unidentified 1' to 'unidentified 14'. Specimens are deposited in the University of British Columbia herbarium.

3.3 Soils

At each of the 134 sample sites a composite soil sample of 5 cores was taken for the 0 to 25 cm depth. The samples were stored in plastic soil sample bags. Within a week, a portion of each sample was oven-dried at 105°C until two successive weighings 12 hours apart were the same to determine moisture content. The remaining portion of each sample was air-dried for two weeks. Samples were crushed to pass through a 2 mm sieve using a motorized grinder (Lavkulich 1981).

All soil samples were analyzed for electrical conductivity and, for those for which there was sufficient extract, for soluble cations to provide an estimate of exchangeable sodium per cent. After these analyses, remaining extract was used to determine soluble anions to further characterize the soil. All of these analyses were carried out by the author according to procedures set out by Lavkulich (1981). The extract for the first run of 23 samples was made using a 1:2 soil:water ratio, but it

Table 1. Foliar cover scale adapted from Domin-Krajina Cover-Abundance scale

Scale	Description	Cover (%)
9	any number, with complete cover	100
8	any number, with more than 3/4 but less than complete cover	75
7	any number, with 1/2 to 3/4 cover	50-75
6	any number, with 1/3 to 1/2 cover	33-50
5	any number, with 1/4 to 1/3 cover	25-33
4	any number, with 1/10 to 1/4 cover	10-25
3	any number, with 1/20 to 1/10 cover	5-10
2	scattered, with cover under 1/20	1-5
1	very scattered, with small cover	1

was realized that an extract more representative of the soil solution to which the plants are exposed would be obtained by using the extract from a saturated soil paste (U.S. Salinity Lab. Staff 1954). The data from the first 23 samples were not included in the statistical analyses. The saturated soil paste was allowed to equilibrate for 16 hours before extraction of the soil solution under suction using a Buchner funnel fitted with Whatman No. 42 filter paper.

The rate of extraction varied considerably among the samples; from 15 minutes to 8 hours were required to produce sufficient extract for the analyses. Attempts to hasten the process for the slow samples were made by adding filter pulp and by processing only small amounts of the paste at a time, but to no avail. Eight samples refused to yield any extract under suction. Five of these samples did yield an extract using the centrifuge followed by vacuum filtration. Two of these five samples yielded sufficient extract only for the analysis of electrical conductivity; the remaining three yielded an amount adequate for the analysis of all parameters investigated. The three samples that did not yield any extract, even in the centrifuge, were discarded. The rate of extraction may be significant because during the extraction the liquid which has already been extracted is subject to a vacuum and therefore may evaporate relatively rapidly (Lowe pers. comm.). Equipment has been designed to minimize the evaporation under suction and it has been found that the average overestimate of electrical conductivity using normal suction is approximately 0.68 mmhos/cm.

Carbonate and bicarbonate were determined within 24 hours of the extraction by titration with acid. Three drops of toluene were placed in the remaining portion of each sample and these were kept under refrigeration until all extracts had been prepared. Electrical conductivity was measured using the Radiometer Type CDM2e conductivity meter and the CDC104 conductivity cell. Calcium, magnesium, sodium and potassium were determined using atomic absorption spectrophotometry. Chloride was measured by titration with silver nitrate using the Radiometer Titration Apparatus T1T1. Sulphate was determined by turbidimetry.

The exchangeable sodium per cent (ESP) is the standard parameter used to describe the amount of sodium in relation to other cations in the soil. ESP can be estimated from the sodium absorption ratio (SAR) by use of the equation $ESP = \frac{100(-.0126 + .01475SAR)}{1 + (-.0126 + .01475SAR)}$ (United States Salinity Lab. Staff 1954). SAR is defined as $\frac{Na}{(Ca + Mg)/2}$ where Ca, Mg and Na refer to the concentrations of the designated soluble cations in milliequivalents per litre.

Nine of the white, saline appearing samples were further analyzed by the Soils Laboratory at the University of British Columbia. pH in H_2O and $CaCl_2$ were measured and a rough estimate of constituent salts was made by X-ray diffraction.

3.4 Precipitation

Precipitation was recorded at the base station at Cochin Lake from May 7 until September 28. An Atmospheric Environment Service standard rain gauge was used. The base station was located within 1 kilometre of the Horseshoe meadow and within 15 kilometres of Suds, Moores and Patterson Lakes.

3.5 Data analysis

To determine seasonal trends in salt content of the soil the electrical conductivity and per cent moisture of the twelve sites sampled through the season were plotted against time.

Relationships between salinity and sodicity parameters and both individual species and vegetation communities were examined. Linear regression was used to determine whether simple linear relationships existed between foliar cover of individual species occurring in more than 10 releves and electrical conductivity and exchangeable sodium per cent. The $\log_{10}$ of the recorded data for both these parameters was used for this analysis. Whittaker and Fairbanks (1958) stated 'The biological effect of salinity increments is proportional not to absolute magnitudes but to the increment in relation to the salinity to which it is added'. Walker and Coupland (1968) found that the relationship of the $\log_{10}$ of the recorded salinity value to wetland vegetation closely approached linearity. As well, per cent foliar cover of individual species occurring in more than 10 releves was plotted against electrical conductivity and exchangeable sodium per cent.

For computer work the Domin-Krajina foliar cover values for vegetation were used. Vegetation communities were identified by cluster analysis (Fox and Guire 1976). The cluster analysis is based on a hierarchical grouping method which successively groups releves. At each stage an objective function (the sum of the within group sum of squares) is calculated to determine the similarity of species compositions of releves. Unlike some techniques for identification of communities, this method uses species cover values, not just presence or absence. The product is a dendrogram linking releves which exhibit the greatest similarity. The number of final groupings selected is subjective. It is based on the desire to produce the smallest number of classes possible while minimizing within group variation and maximizing between group variation (Jones 1981). The dendrogram is intercepted at the appropriate level and the intercepted stems are used to delineate vegetation types (Orloci 1975).

After vegetation communities were identified, analysis of variance (ANOVA) was used to find significant differences between the groups on the basis of soil parameters. Homogeneity of variance, a requirement of ANOVA, was determined using Scheffe's test. It is not as rigorous as the more commonly used Bartlett's test, but there is evidence that Bartlett's test is 'overly sensitive to departures from normality of the basic observations' (Winer 1971). Moderate departures from homogeneity of variance do not seriously affect the ANOVA. Transformation of all data to natural logarithms was required to homogenize the variations sufficiently for the ANOVA. The Student-Newman-Keuls test was used to determine differences in salinity and sodicity among the population means following rejection of the null hypotheses (Zar 1974, Larkin 1979).

4 Results and discussion

4.1 Vegetation communities

Thirteen vegetation groups were identified using cluster analysis (Figure 3 and Table 2). Eleven of the groups are characterized by an abundance of one or more species, indicating communities. In group 6 there is no single dominant species and the group appears to be composed of residual releves that did not fit into any other group. In releves comprising group 1 the dominant species is *Carex praegracilis*; in group 2 it is *Juncus balticus*; in group 3 dominant species are *Carex praegracilis*, *Taraxacum officinale* and frequently *Juncus balticus*; in group 4 it is *Potentilla anserina*; in group 5 it is *Hordeum jubatum*; in group 7 it is *Suaeda depressa*; in group 8 it is *Deschampsia caespitosa*; group 9 has no vegetation; and in group 10 the dominant species is *Puccinellia distans*. In groups 11, 12 and 13 the moss *Drepanocladus aduncus* is always present. In group 13 *Juncus balticus* and often *Deschampsia caespitosa* are also present. In both groups 11 and 12 there is no other single dominant species. Group 12 is composed of releves with either *Sium suave* and *Agrostis scabra* or *Calamagrostis inexpansa* and *Carex rostrata* as dominant species. Group 11 is formed of all other releves containing an abundance of *Drepanocladus aduncus*. In this group dominants include *Poa pratensis*, *Hordeum brachyantherum*, *Deschampsia caespitosa*, *Carex praegracilis*, *C. aquatilis*, and *Juncus balticus*. Group 6 contains all other releves that did not fit into the 12 groups described above. It contains subgroups with dominants of *Distichlis stricta*, *Scirpus nevadensis*, *Alopecurus pratense*, *A. aequalis*, *Beckmannia sizygachne*, *Juncus balticus*, *Potentilla anserina*, and *Hordeum jubatum*. *Alopecurus aequalis*, *A. pratense*, *Scirpus nevadensis* and *Beckmannia syzigachne* generally occur in moister conditions than are

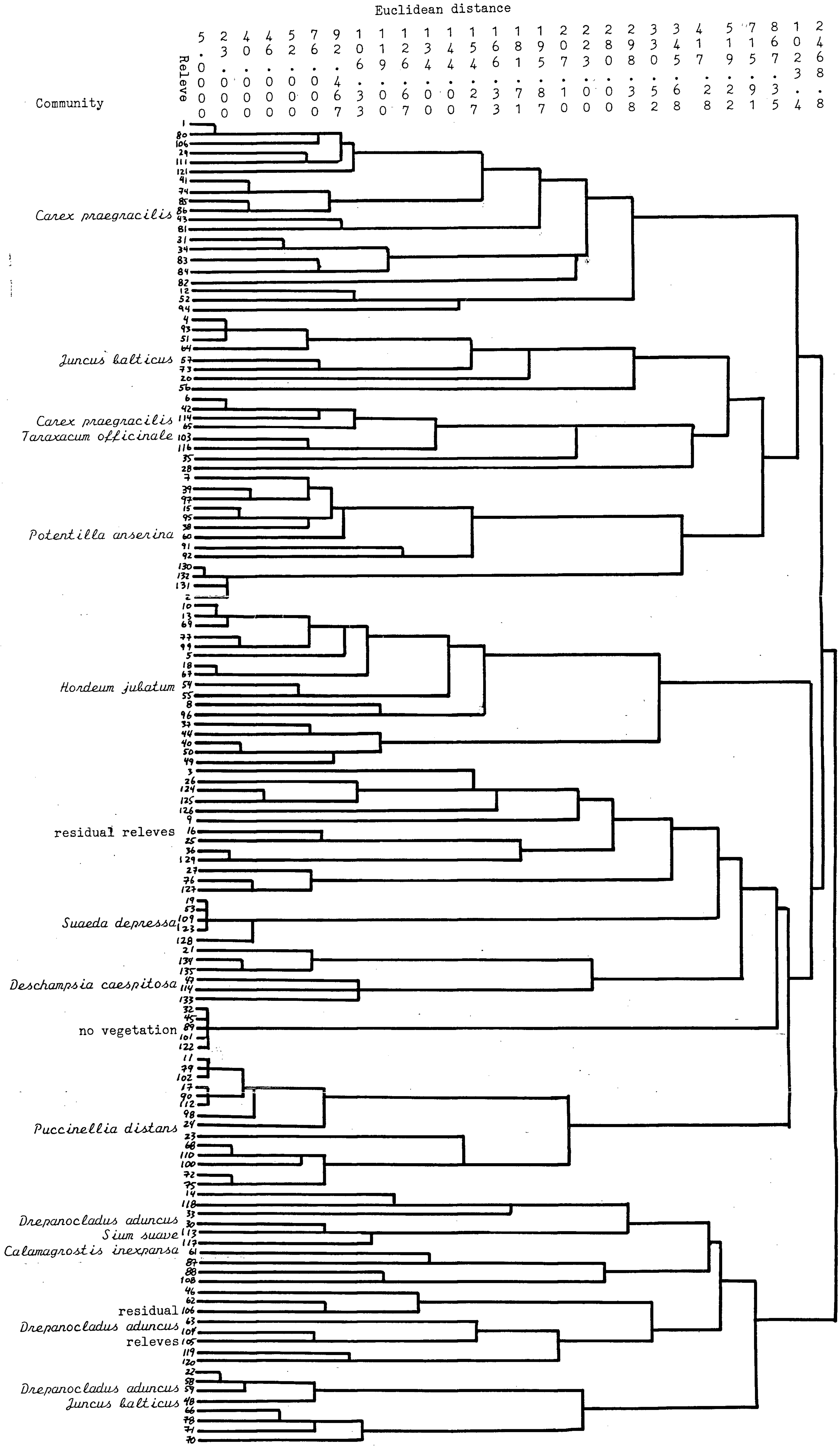

Figure 3. Cluster analysis dendrogram

Table 2. Per cent frequency of species in vegetation groups identified by cluster analysis.

Species	Vegetation group												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Achillea millefolium											11		
Agropyron repens	7			8	6								
Agropyron smithii													17
Agropyron subsecundum	7		17									14	
Agropyron trachycaulum var. *novae-angliae*	21	14									33		
Agropyron trachycaulum var. *trachycaulum*	14			8		15					11		
Agropyron trachycaulum var. *unilaterale*			33								11		
Agropyron violaceum	14		17			15					11		
Agrostis scabra		14	17									57	
Alopecurus aequalis						8						14	
Alopecurus pratense						8							
Amblystegium riparium						8							
Amblystegium serpens	14	14											
Antennaria spp.				8									
Arnica chamissonis													17
Aster campestris var. *campestris*	7		17								22		
Aster pansus	29			15	6	15		60			22		17
Aster spp.					6								
Beckmannia sysigachne						8						14	
Bryum spp.				23									
Calamagrostis inexpansa		29	17	8	6			40			22	28	17
Carex aquatilis					6			60			33		
Carex atherodes												28	
Carex athrostachya			17	8							22		
Carex aurea								20					
Carex disperma	7											14	
Carex lasiocarpa			17									14	
Carex parryana	7												
Carex praegracilis	93	14	100	46		8				8	56	14	17
Carex rostrata								60			11	14	
Carex sartwellii			17										
Carex spp.			17										
Chenopodium rubrum										15			
Danthonia intermedia			17										

Table 2. continued

Species	Vegetation group 1	2	3	4	5	6	7	8	9	10	11	12	13
Deschampsia caespitosa	14	29	33	15	6			100			44	28	66
Desmatodon cernuus	7												
Diaduncus spp.			17										
Dicranella spp.				8									
Distichlis stricta					12	23							
Drepanocladus aduncus	7	14		8	6						100	100	100
Eleocharis palustris					6					8			17
Epilobium watsonii var. *occidentale*											22		
Erigeron lonchophyllus		14	50	8	6						11		
Fragaria vesca var. *bracteata*											11	14	
Galium trifidum											11		
Glyceria grandis												29	
Glyceria striata													17
Hierochloe odorata													17
Hippurus vulgaris										15			
Hordeum brachyantherum	21		17								44		
Hordeum jubatum	21	57		15	100	31				38			17
Juncus balticus	29	100	83	46	25	23		20			22	28	100
Machaeranthera canescens						15							
Menthe arvensis													17
Muhlenbergia richardsonis	14					8							
Penstemon procerus var. *procerus*												28	
Plagiomnium spp.			17										
Plantago major var. *major*		14			6	8							
Poa juncifolia	7										11		
Poa palustris				15		8							
Poa pratensis	7	43	17	15	12			20			44		17
Polygonum ramossimum										8			
Potentilla anserina	21	43	17	92	38	31				15		14	50
Potentilla biennis												14	
Potentilla gracilis var. *gracilis*	14	14	50	23				20			22		17
Potentilla pensylvanica													17
Potentilla spp.		14				8						28	
Puccinellia distans	7				31	31	7			100			

Table 2. continued

Species	Vegetation group 1	2	3	4	5	6	7	8	9	10	11	12	13
Puccinellia nuttalliana										28			
Ranunculus cymbalaria	43	14		31	31	23				8			17
Ranunculus macounii													17
Ranunculus occidentale											22		
Ranunculus sceleratus				8						15			
Rumex maritimus										15			
Scirpus nevadensis					12	23							
Senecio pauperculus					6								
Sisyrinchium angustifolium	14					15							
Sium suave												29	
Smilacina stellata				8									14
Solidago canadensis												11	
Stellaria longipes var. *longipes*			17		12			20		8		14	
Suaeda depressa					12	23	100			8			
Taraxacum officinale	14	71	100	31	12	15		60			44		66
Thalictrum venulosum			17								22		
Trifolium hybridum								20					
Trifolium repens		29											
Triglochin maritimum				15	25								
Viola adunca var. *adunca*			17	8							11		
Viola spp.		14											
Veronica scutellata			17					20					

found in meadows. Their presence may result from a higher water table in previous years. More extensive sampling might distinguish a *Distichlis stricta* community in meadows.

In most cases, species are relatively widely dispersed throughout the groups. All species found in more than two releves occur in more than one community. The dominant species *Juncus balticus*, *Potentilla anserina*, *Carex praegracilis*, *Hordeum jubatum*, *Taraxacum officinale*, and *Deschampsia caespitosa* are found in 10, 9, 9, 7, 9, and 9 groups respectively. Communities appear to grade into one another as different species become dominant. Except for groups 7 and 9 (*Suaeda depressa* and no vegetation) there is a large number of species in all groups. Apart from these last two groups, the minimum is 13 species in group 10.

4.2 Soils

The range median and mean of all soil parameters tested for the 116 sample plots that yielded a testable extract are presented in Table 3. The distributions of all of these parameters are skewed to the right. One hundred and five of the samples had an electrical conductivity less than 4 mmhos/cm. One hundred and eight of the samples had an exchangeable sodium percentage less than 15.

In 54 per cent of samples, sodium dominates the soluble cations. Magnesium dominates 37 per cent of samples, while calcium is the dominant soluble cation in 9 per cent of samples. Potassium occurs in much smaller amounts than the other cations.

Fifty-five samples yielded sufficient extract to determine soluble anions. Bicarbonate is the dominant soluble anion in 52 per cent of samples, sulphate dominates in 33 per cent of samples, carbonate is dominant in 14 per cent and chloride in only 1 per cent. Sulphate and bicarbonate are widespread, but chloride is present in 75 per cent of

Table 3. Range, median, mean and standard deviation of soluble cations, soluble anions, electrical conductivity (EC) and exchangeable sodium per cent (ESP) of soils.

	(meq/100 g soil)								mmhos/cm	
	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	$SO_4^{=}$	$CO_3^{=}$	HCO_3^{-}	EC	ESP
High	9.01	13.00	9.04	.89	.56	17.30	14.10	6.2	16.50	71.10
Low	.00	.00	.01	.00	.00	.00	.00	.00	.17	.00
Median	.05	.22	.45	.03	.03	.16	.00	.27	1.60	3.30
Mean	.49	.69	1.06	.07	.05	.77	.34	.46	.30	.46
Standard deviation	1.31	1.82	1.65	.11	.10	2.28	1.43	.84	1.38	.84

samples and carbonate in only 43 per cent.

All samples with electrical conductivity over 4 mmhos/cm and/or exchangeable sodium percentage over 15 were greyish to white, but not all samples in that colour range tested were high in salts.(Appendix III). Nine of the greyish to white samples were tested for constituent salts and eight of these samples were tested for pH. Calcium carbonate was relatively abundant in all of these samples, but abundance of other salts varied widely even among samples from sites that were relatively close together. The high levels of calcium were not revealed by the tests for soluble cations. This may have resulted from at least two factors. Calcium carbonate is relatively insoluble so the extract probably contained little of this salt. As well, calcium carbonate in the solution may have precipitated between the time of extraction and the time of analysis. The latter problem could have been prevented by the addition of one drop of 0.1 per cent sodium hexametaphosphate solution for each 25 ml of extract.

The nine samples showed a range of electrical conductivity from 1.3 to 16.5 mmhos/cm, of exchangeable sodium percentage from 3.7 to 69.0 and of pH from 8.82 to 10.3. A pH greater than 8.5 generally indicates an exchangeable sodium percentage greater than 15. However, although pH of all samples exceeded 8.5, 4 of the 8 samples tested for pH had an exchangeable sodium percentage of much less than 15. This may reflect dilution of the soil samples to a 1:1 (and in one case 1:1.5) soil:water ratio for this test. The standard method for this analysis is to determine pH on the extract of a saturated soil paste. The soil:water ratio of these samples for soluble cation content, from which exchangeable sodium percentage was derived, was determined by saturated soil paste and varied from 1:.3 to 1:1 with an average of 1:.56. Since a rise in moisture content tends to increase pH readings, pH estimates are somewhat high.

4.3 Seasonal variations in soil salinity and moisture content

Electrical conductivity and per cent moisture through the summer at three sites at each of four wetlands are shown in Figures 4 to 7. Precipitation for the period is shown in Figure 8. Showers in the region are often very localized, hence small amounts of precipitation recorded may not reflect the amount received at the more distant sites. The larger storms producing more than several millimetres of precipitation affect larger areas. The fact that soil moisture did not necessarily increase shortly after the heavy rains in late August indicates that earlier high moisture levels are more strongly affected by groundwater levels. Since 60 per cent of precipitation occurs from October to April, spring smowmelt generally produces the highest water levels of the year. Consequently, decreasing moisture and increasing conductivity were expected with time. However, neither electrical conductivity nor soil moisture showed any distinctive similar trend between June 22 and August 31 at the twelve sites. Even at different sites within wetlands, seasonal variations in the two parameters did not follow the same trends. An examination of the date of the maximum value for each parameter at each site shows that maxima occurred on all sample dates with the exception of July 20. The average range from maximum to minimum electrical conductivity recorded at each site was 1.67 mmhos/cm. At 4 sites the range was over 2.5 mmhos/cm and at one site the range was 7 mmhos/cm.

Other research on seasonal wetland salinity trends shows a negative correlation between soil salinity and moisture content (Jackson et al. 1956, Bolen 1964). In this study 42 of the 51 increases or decreases in moisture content of the soil from one visit to the next were accompanied

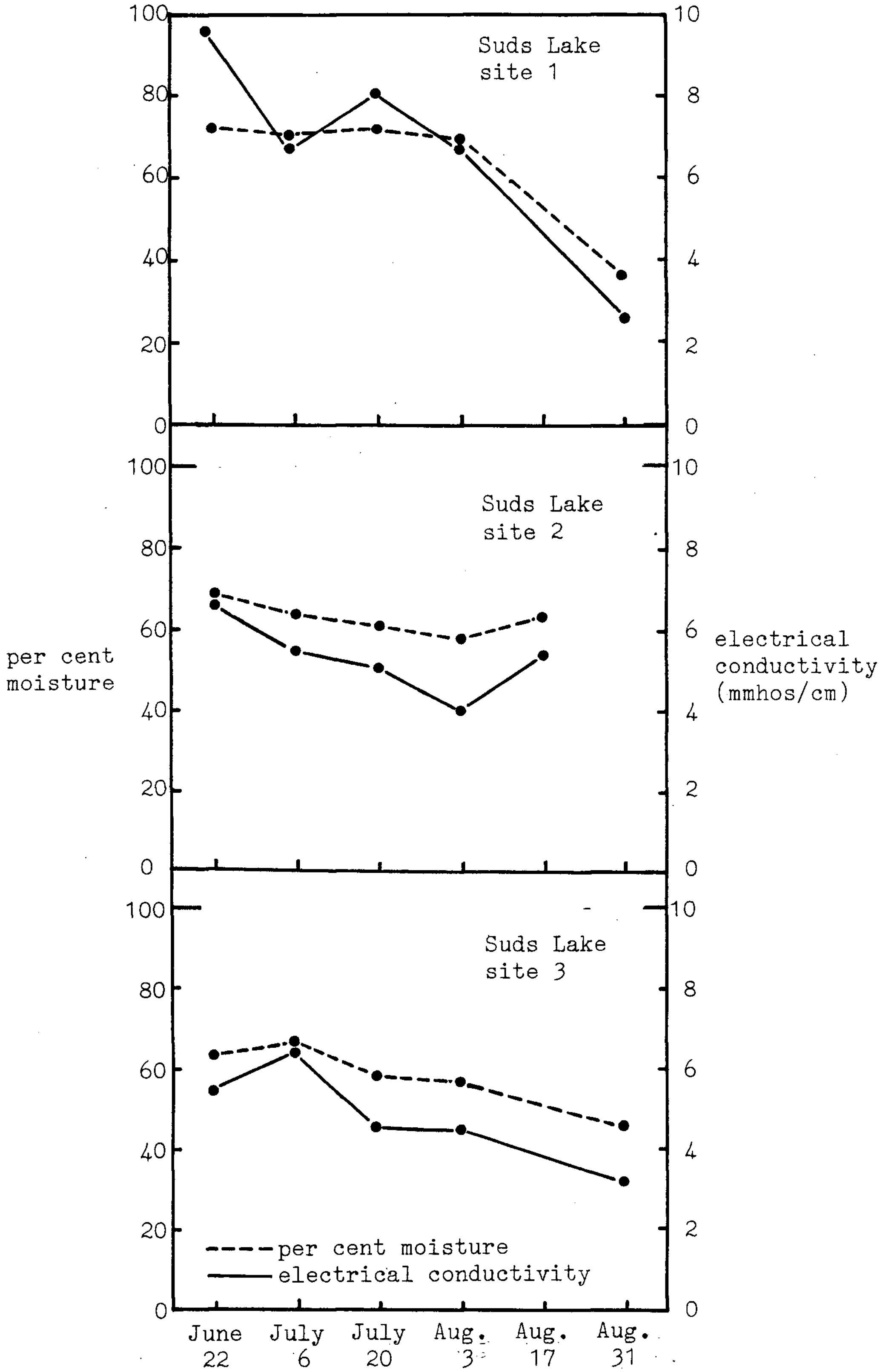

Figure 4. Electrical conductivity and per cent moisture at Suds Lake.

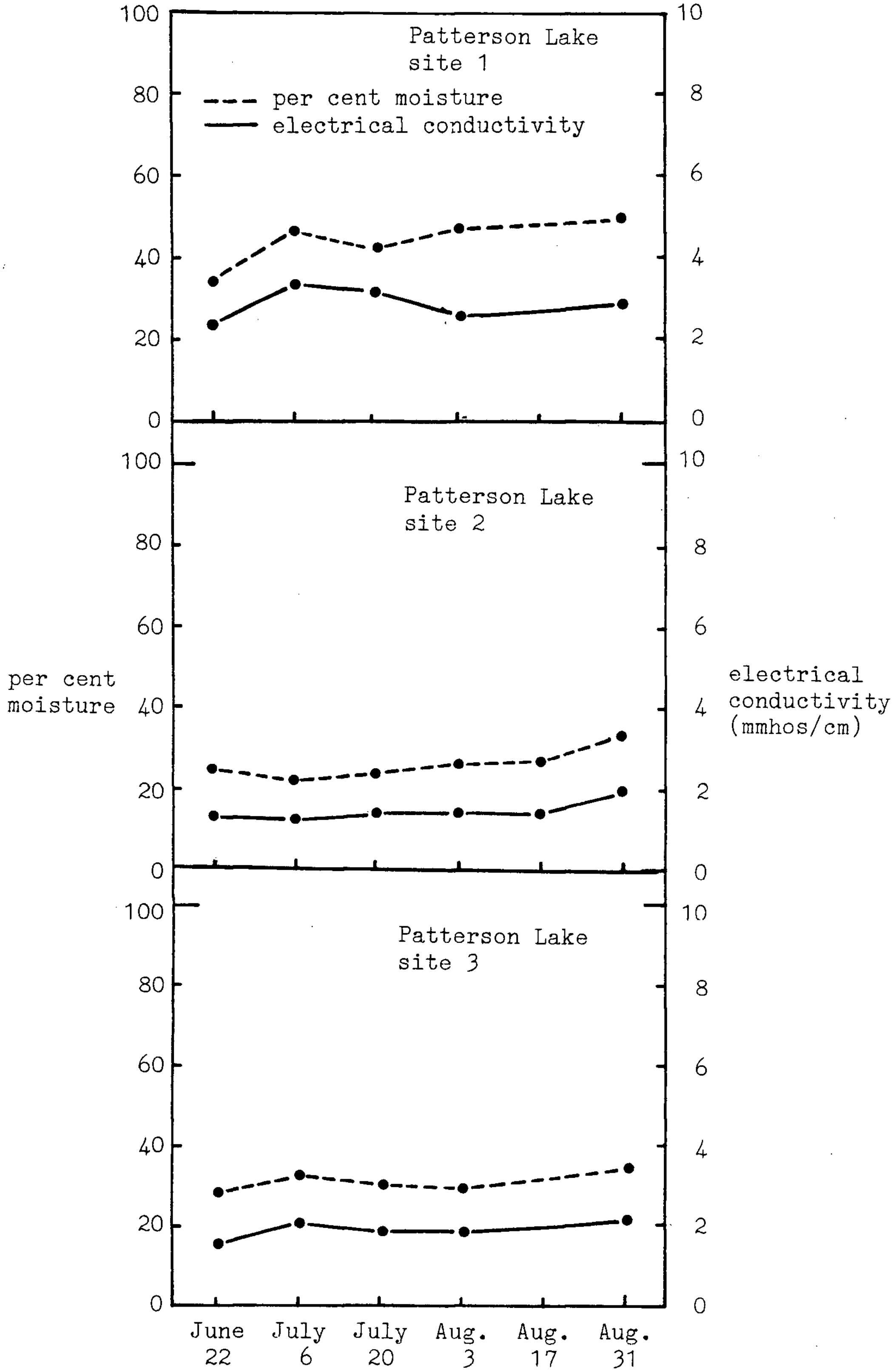

Figure 5. Electrical conductivity and per cent moisture at Patterson Lake.

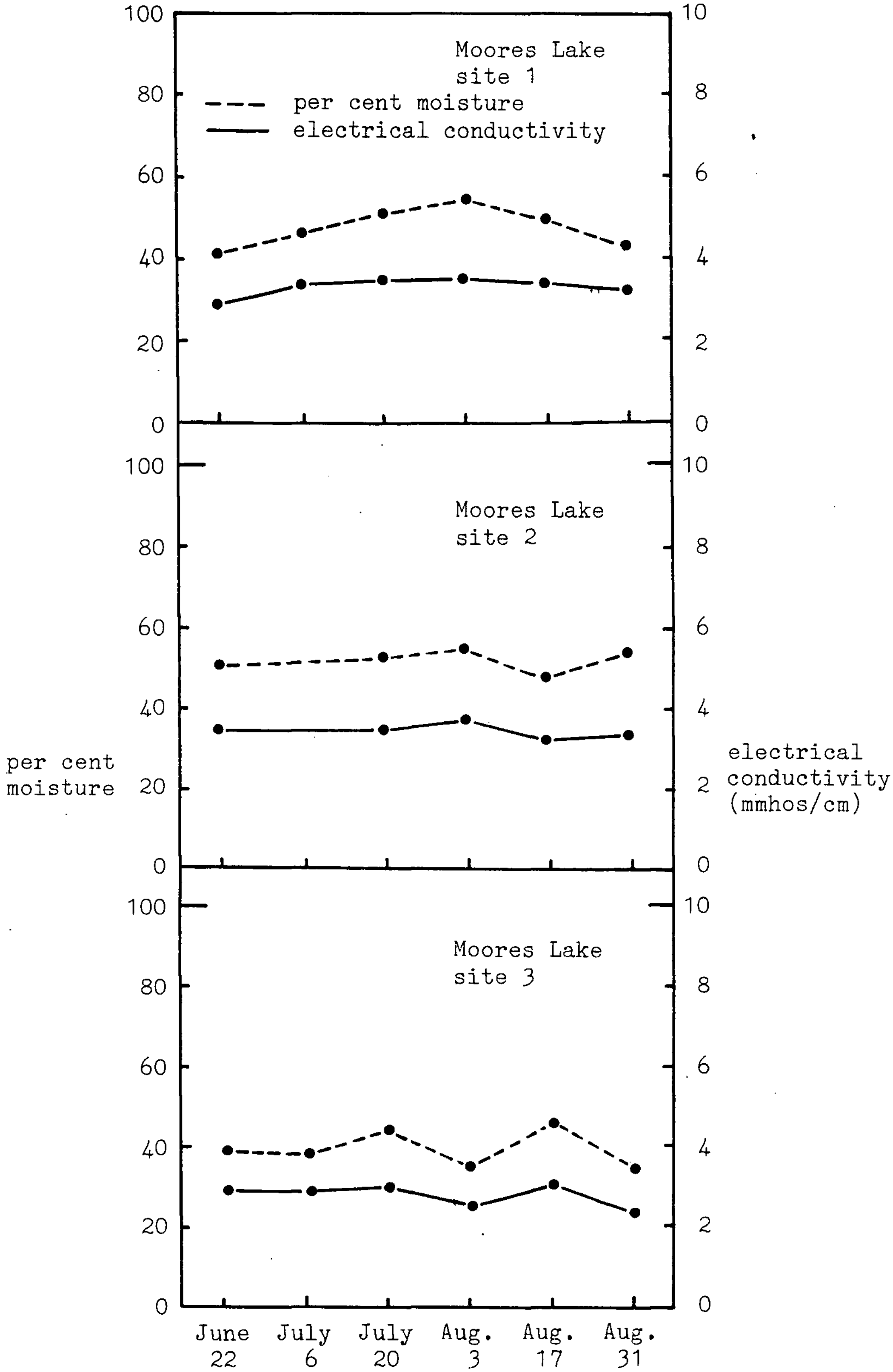

Figure 6. Electrical conductivity and per cent moisture at Moores Lake.

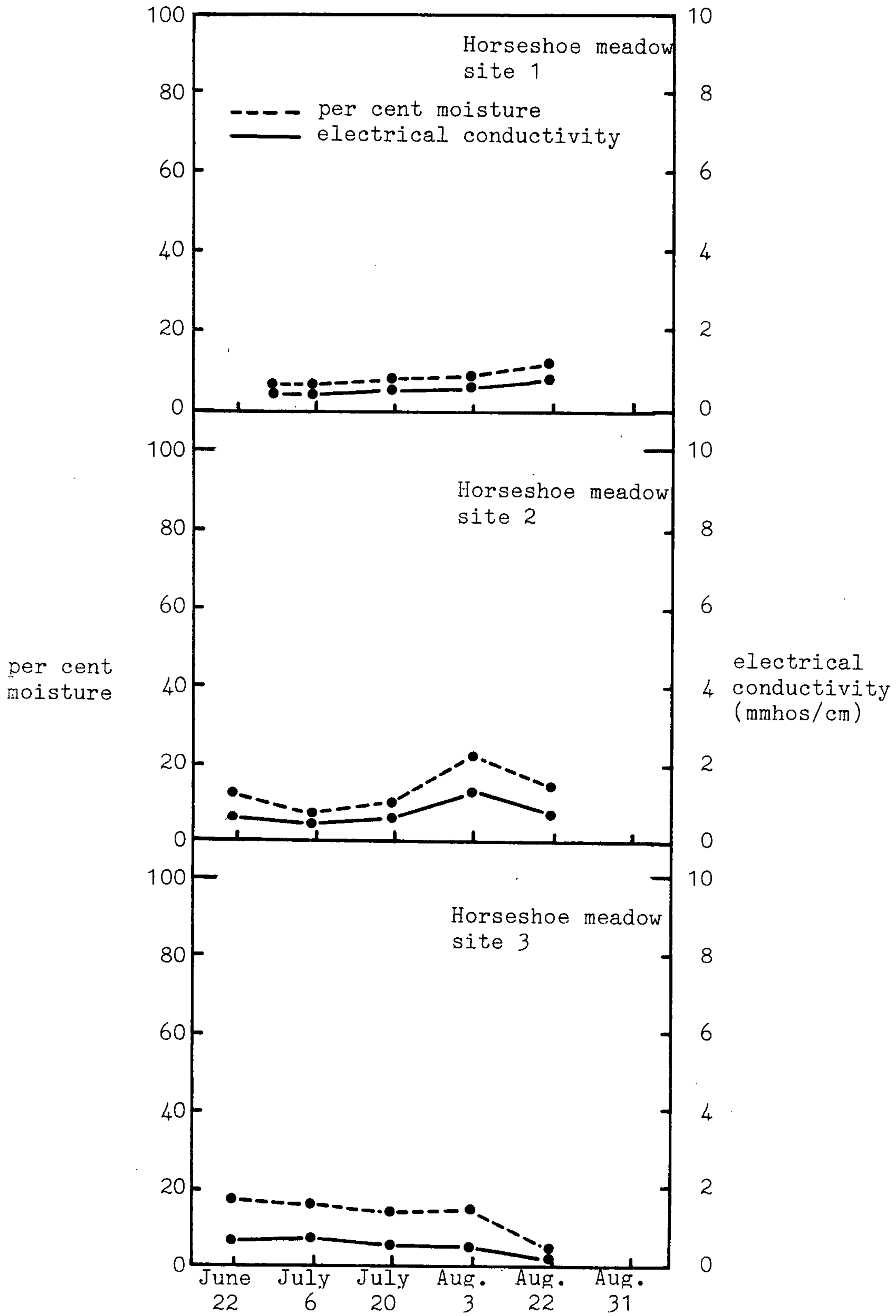

Figure 7. Electrical conductivity and per cent moisture at Horseshoe meadow.

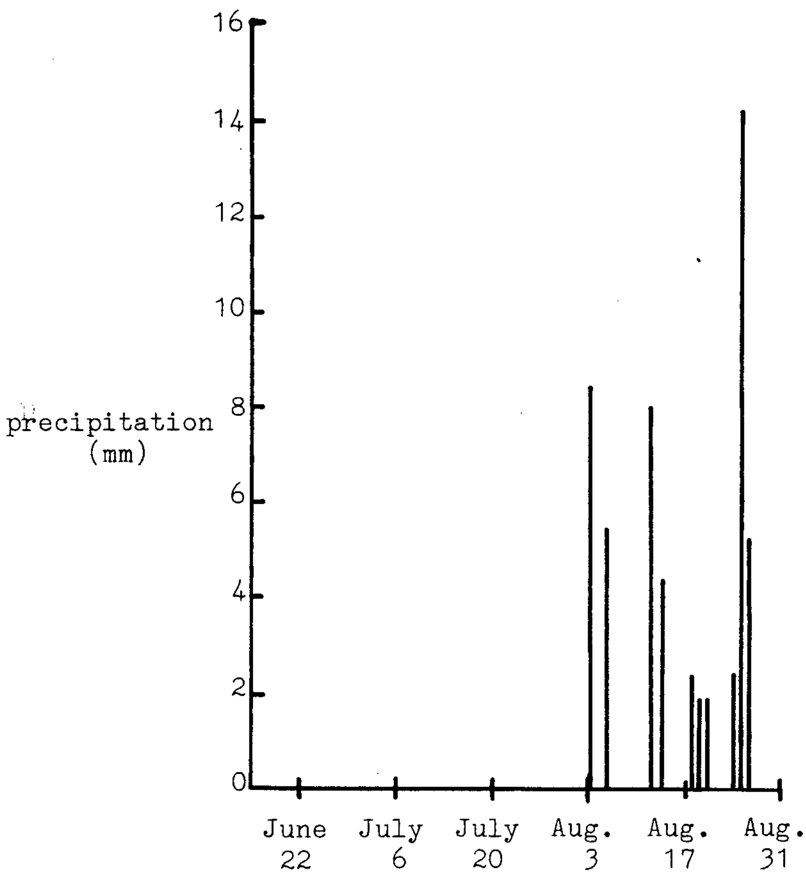

Figure 8. Precipitation from June 22 to August 31 at Cochin Lake base station.

by a change in electrical conductivity in the same direction. In the remaining 9, the per cent moisture changed by only one percentage point while the electrical conductivity remained the same. A possible mechanism for the results obtained here is as follows. Soil moisture is controlled largely by groundwater table. When soil moisture is high the concentration of salts in solution may be relatively low. As soil moisture decreases the salts become more concentrated and may diffuse to areas of lower concentration deeper in the soil. Thus when soil moisture is high the total salt content may be higher than when soil moisture is low.

The implications of these results and explanation are significant. First, the possibility of variations of as much as 7.0 mmhos/cm in electrical conductivity through the season means that samples must be taken in varying moisture conditions to adequately characterize a site. Second, it must be understood that the measurement of salinity on the extract of a saturated soil paste gives an indication of total salts that may be useful for comparative purposes, but it is not necessarily indicative of the range of conditions to which the plants are exposed. To determine the osmotic pressures to which the plants are being subjected it would be necessary to test the salinity of an extract of soil moisture taken at field conditions. Furthermore, if salinity increases and decreases with moisture the effects of high salinity are ameliorated. One of the main problems of high salinity is moisture stress. However, if salinity is highest when soil moisture is also highest this problem would be reduced. Thus salinity should be examined in relation to field moisture.

The large differences in electrical conductivity recorded through the season at some sites must be borne in mind in interpretation of the results of the soils analysis and vegetation soil relationships in this study.

The limiting factor to some species may be maximum electrical conductivity through the growing season which may or may not be the same as the electrical conductivity at the time of sampling.

4.4 Relationships between individual species and salinity and sodicity

Regression analysis indicates, at the 5 per cent level of significance, that *Ranunculus cymbalaria* decreases with increasing exchangeable sodium per cent and that foliar cover of *Carex praegracilis* increases with both electrical conductivity and exchangeable sodium per cent. These findings for *Carex praegracilis* are somewhat misleading for the species is rarely found at electrical conductivities over 4 mmhos/cm or exchangeable sodium per cents over 15. However these absences were not included in the regression. The null hypotheses were accepted for all other regressions.

The scattergrams (Figures 9 to 13) showing species abundance as related to exchangeable sodium per cent and electrical conductivity, demonstrate that, at the salinity where each species thrives best, it may occur in almost any amount up to its maximum. *Deschampsia caespitosa*, *Poa pratensis*, *Potentilla gracilis*, *Drepanocladus aduncus*, and *Calamagrostis inexpansa*, are all restricted to electrical conductivities less than 3.6 mmhos/cm. *Suaeda depressa* is the only species that does not occur on the freshest sites, but it does occur from 2 mmhos/cm to 10 mmhos/cm. The rest of the species, *Puccinellia distans*, *Juncus balticus*, *Hordeum jubatum*, *Potentilla anserina*, *Ranunculus cymbalaria*, *Taraxacum officinale*, *Carex praegracilis*, and *Aster pansus* occur in a relatively broad range of conditions. All are found on the freshest sites and their maximum tolerable electrical conductivity ranges from 5.5 for *Aster pansus* to 9 mmhos/cm for *Puccinellia distans*, *Juncus balticus*, *Potentilla anserina*, and

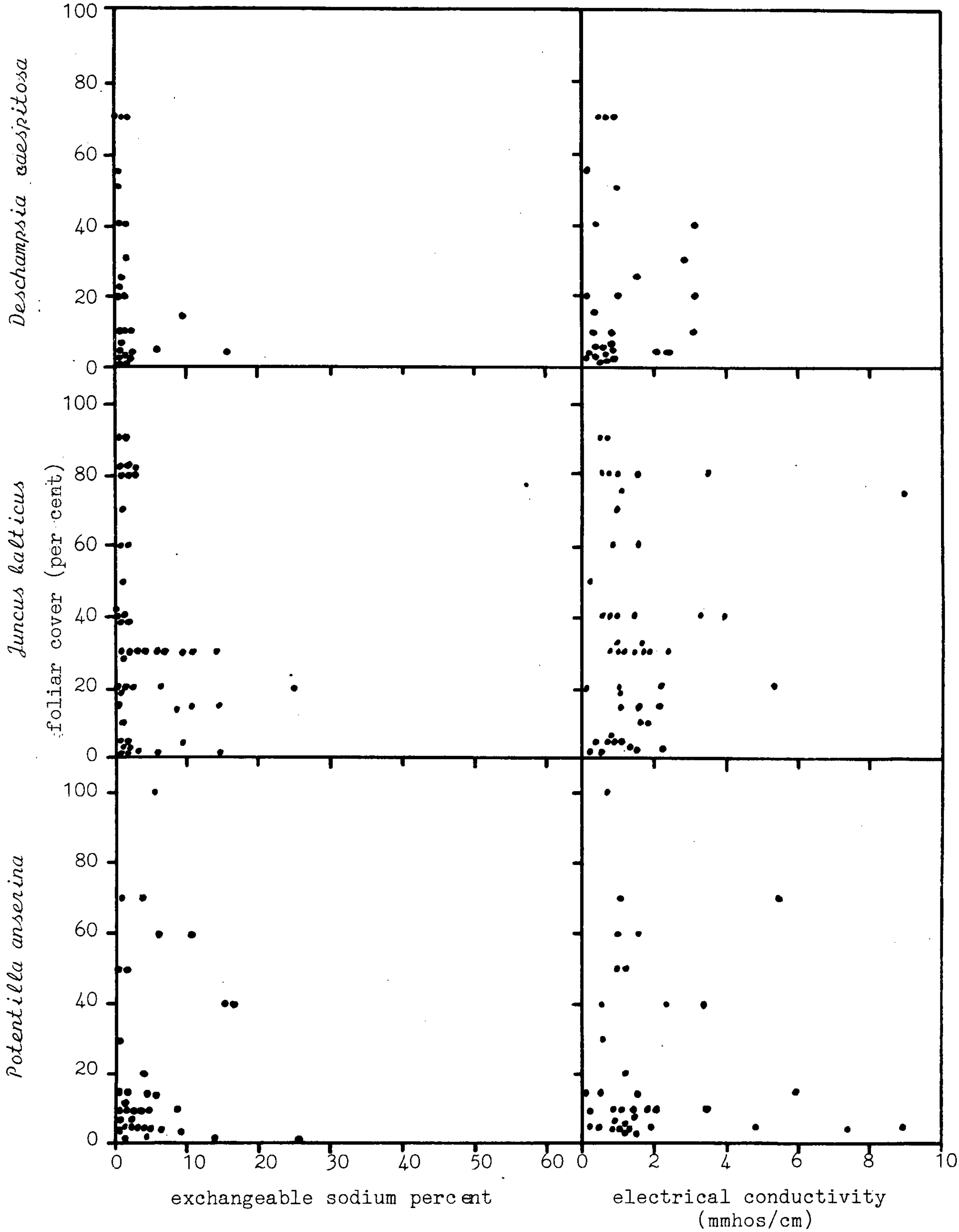

Figure 9. Foliar cover of *Potentilla anserina*, *Juncus balticus* and *Deschampsia caespitosa* versus exchangeable sodium per cent and electrical conductivity.

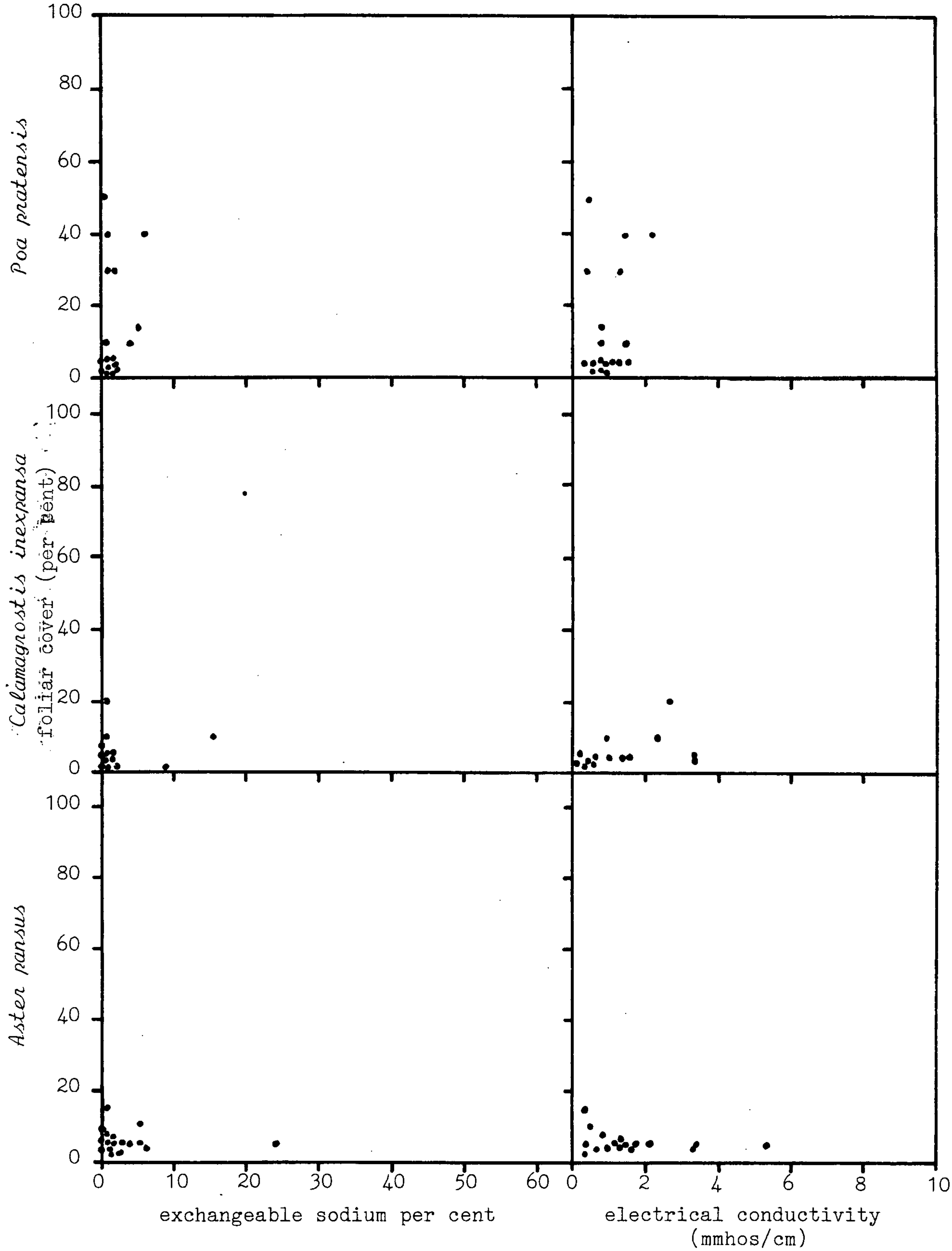

Figure 10. Foliar cover of *Poa pratensis*, *Calamagrostis inexpansa* and *Aster pansus* versus exchangeable sodium percent and electrical conductivity.

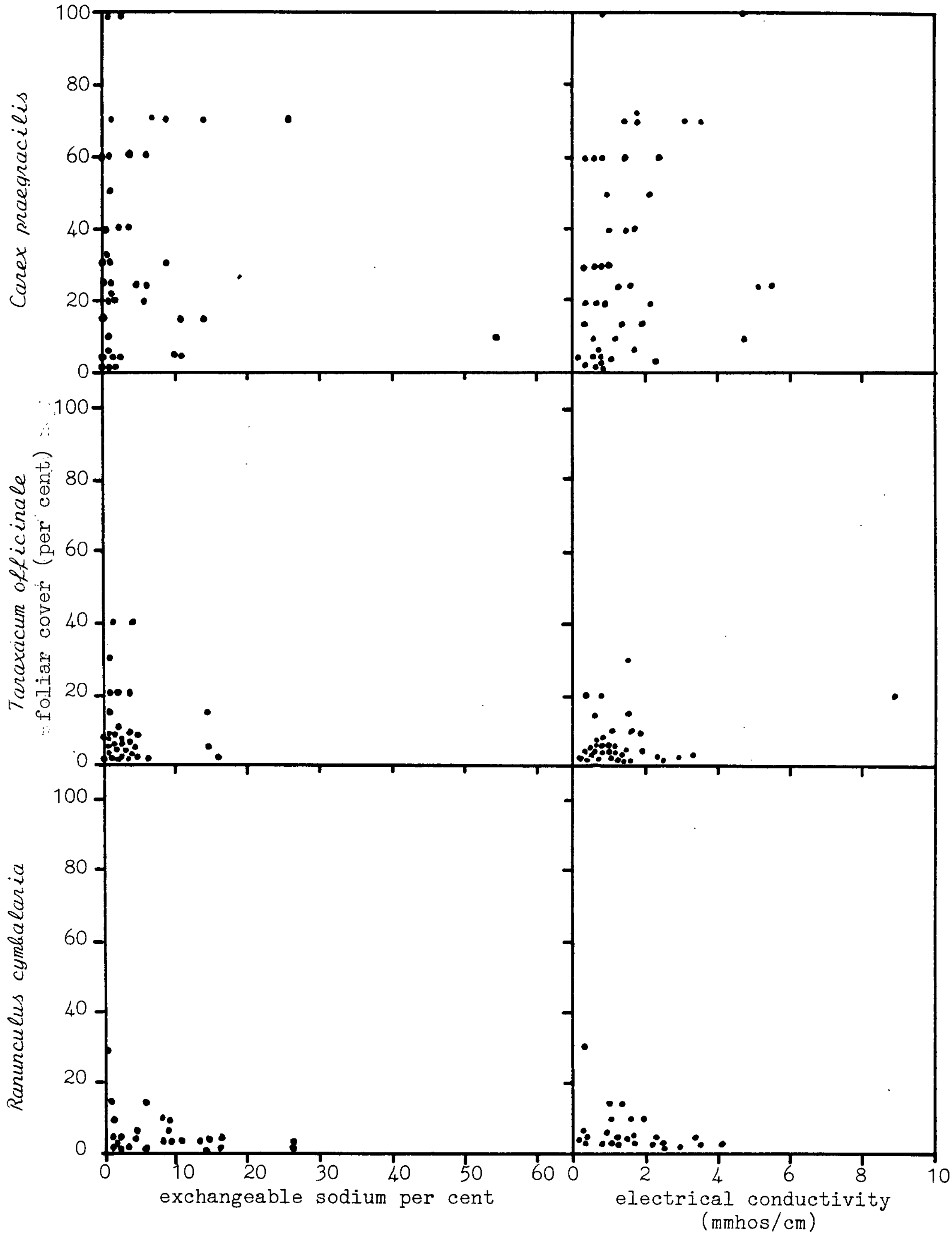

Figure 11. Foliar cover of *Carex praegracilis*, *Taraxacum officinale* and *Ranunculus cymbalaria* versus exchangeable sodium percent and electrical conductivity.

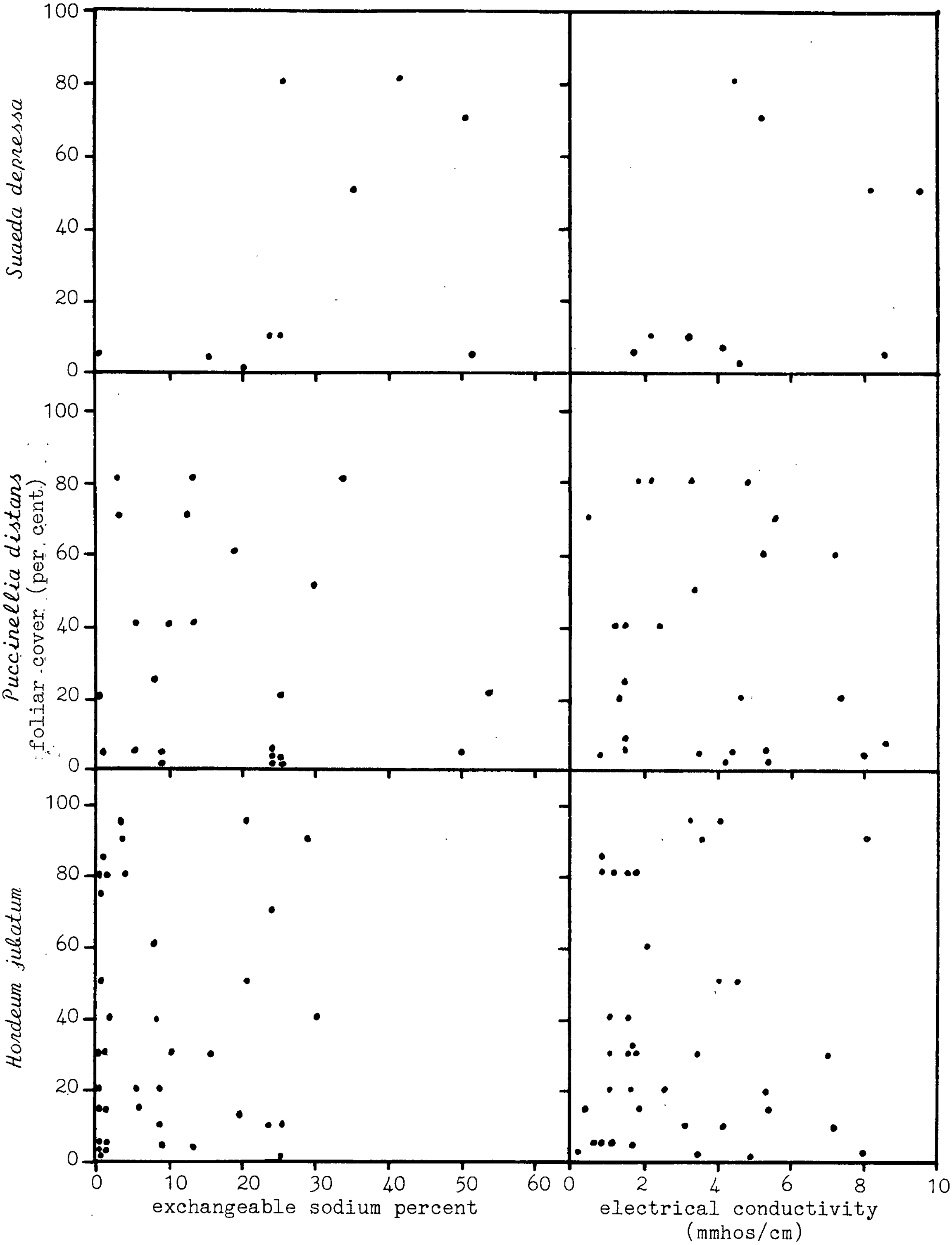

Figure 12. Foliar cover of *Suaeda depressa*, *Puccinellia distans* and *Hordeum jubatum* versus exchangeable sodium percent and electrical conductivity.

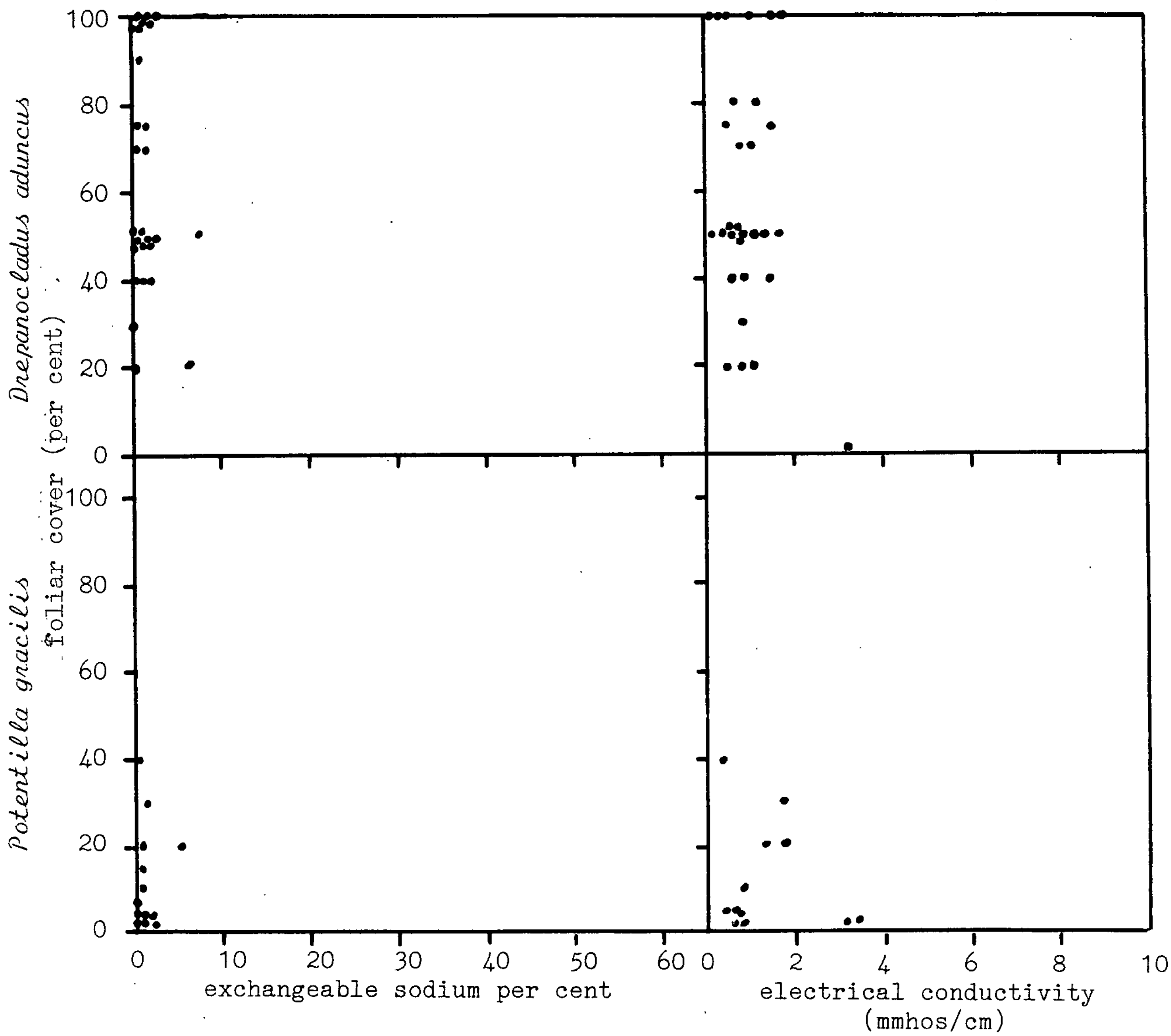

Figure 13. Foliar cover of *Drepanocladus aduncus* and *Potentilla gracilis* versus exchangeable sodium percent and electrical conductivity.

Taraxacum officinale.

Poa pratensis, *Potentilla gracilis* and *Drepanocladus aduncus* occurred where exchangeable sodium per cent was less than 10. Except for occasional occurrences at higher values, *Taraxacum officinale*, *Calamagrostis inexpansa*, *Aster pansus*, *Deschampsia caespitosa*, *Juncus balticus*, *Potentilla anserina*, *Ranunculus cymbalaria*, and *Carex praegracilis* were found where exchangeable sodium per cent did not exceed 16. *Hordeum jubatum* and *Puccinellia distans* were widespread to exchangeable sodium percentages of 30 and 55, respectively. *Suaeda depressa* generally occurred where exchangeable sodium percentage was greater than 15, though it occurred in a small amount (5 per cent foliar cover) at one site where the exchangeable sodium per cent was 0.

4.5 Relationships between vegetation communities and salinity and sodicity

The results of the Analysis of Variance and Student-Newman-Keuls tests show that there are in fact significant differences in soil salinity and sodicity parameters among vegetation communities (Tables 4-10, Appendix V). An examination of these tables reveals that exchangeable sodium per cent is the most important parameter for differentiating among communities (significant in 39 of a possible 78 pairs of groups), however electrical conductivity and soluble potassium and sodium are significant in 20, 21 and 15 comparisons respectively. Although soluble potassium occurs in much smaller amounts than other cations it is significantly different in 21 pairs of groups, indicating that it is important in small quantities.

Soluble magnesium and calcium, though generally present in large amounts, rarely affect the vegetation significantly. Magnesium does not appear significant in any comparisons, while calcium is only significant by its paucity where there is no vegetation.

Table 4. Analysis of variance and Student-Newman-Keuls tests for differences in soluble magnesium content of the soil among vegetation groups.

Dominant species	*Suaeda depressa*	*Drepanocladus aduncus*, residual releves	residual releves	no vegetation	*Potentilla anserina*	*Drepanocladus aduncus*, *Sium suave* *Calamagrostis inexpansa*	*Deschampsia caespitosa*	*Puccinellia distans*	*Juncus balticus*	*Hordeum jubatum*	*Carex praegracilis*	*Drepanocladus aduncus*, *Juncus balticus*	*Carex praegracilis*, *Taraxacum officinale*
Community number	7	12	6	9	4	13	8	10	2	5	1	13	3
n	5	7	12	4	12	9	5	12	7	17	14	6	6
$\bar{x}$ ($\log_e$)	-3.25	-2.43	-2.41	-1.85	-1.55	-1.45	-1.37	-1.23	-1.23	-1.05	-1.04	-1.00	-.90
$\bar{x}$ (untransformed data)	.09	.15	.43	.18	.50	.38	.42	1.50	1.25	1.42	.88	.39	.48

*continuous lines indicate vegetation groups that are not significantly different at the 95 per cent confidence level in soluble magnesium content of the soil.

Table 5. Analysis of variance and Student-Newman-Keuls tests for differences in soluble calcium content of the soil among vegetation groups.

Dominant species	no vegetation	*Suaeda depressa*	*Carex praegracilis*	residual releves	*Puccinellia distans*	*Potentilla anserina*	*Drepanocladus aduncus* residual releves	*Hordeum jubatum*	*Drepanocladus aduncus, Juncus balticus*	*Juncus balticus*	*Drepanocladus aduncus, Sium suave, Calamagrostis inexpansa*	*Carex praegracilis, Taraxacum officinale*	*Deschampsia caespitosa*
Community number	9	7	1	6	10	4	12	5	13	2	11	3	8
n	4	5	14	12	12	12	7	17	6	7	9	6	5
$\bar{x}$ ($\log_e$)	-5.18	-4.11	-3.10	-3.09	-2.82	-2.59	-2.59	-2.58	-2.22	-2.17	-1.90	-1.75	-.54
$\bar{x}$ (untransformed data)	.008	.02	.38	1.44	1.24	.36	.12	.59	.20	.69	.25	.20	1.72

*continuous lines indicate vegetation groups that are not significantly different at the 95 per cent confidence level

Table 6. Analysis of variance and Student-Newman-Keuls tests for differences in soluble sodium content of the soil among vegetation groups.

Dominant species	*Drepanocladus aduncus* residual releves	*Juncus balticus*	*Deschampsia caespitosa*	*Drepanocladus aduncus, Juncus balticus*	*Potentilla anserina*	*Drepanocladus aduncus, Sium suave Calamagrostis inexpansa*	*Carex praegracilis, Taraxacum officinale*	residual releves	*Carex praegracilis*	*Puccinellia distans*	*Hordeum jubatum*	no vegetation	*Suaeda depressa*
Community number	12	2	8	13	4	11	3	6	1	10	5	9	7
n	7	7	5	6	12	9	6	12	14	12	17	4	5
$\bar{x}$ ($\log_e$)	-2.95	-1.81	-1.65	-1.64	-1.56	-1.45	-1.00	-.49	-.48	-.01	.02	.74	.84
$\bar{x}$ (untransformed data) *	.08	.62	.46	.24	.49	.31	.56	.76	.92	2.19	1.57	2.76	3.01

*continuous lines indicate vegetation groups that are not significantly different at the 95 per cent confidence level

Table 7. Analysis of variance and Student-Newman-Keuls tests for differences in soluble potassium of the soil among vegetation among vegetation groups.

Dominant species	*Deschampsia caespitosa*	*Juncus balticus*	*Drepanocladus aduncus* residual releves	*Drepanocladus aduncus, Sium suave Calamagrostis inexpansa*	residual releves	*Carex praegracilis, Taraxacum officinale*	*Drepanocladus aduncus, Juncus balticus*	*Potentilla anserina*	*Carex praegracilis*	*Puccinellia distans*	*Hordeum jubatum*	*Suaeda depressa*	no vegetation
Community number	8	2	12	11	6	3	13	4	1	10	5	7	9
n	5	7	7	9	12	6	6	12	14	12	17	5	4
$\bar{x}$ ($\log_e$)	-5.85	-4.75	-4.73	-4.48	-3.97	-3.53	-3.58	-3.25	-3.03	-2.95	-2.86	-2.26	-1.80
$\bar{x}$ (untransformed data) *	.006	.02	.02	.02	.03	.04	.04	.06	.06	.08	.09	.24	.20

*continuous lines indicate vegetation groups that are not significantly different at the 95 per cent confidence level

Table 8. Analysis of variance and Student-Newman-Keuls tests for differences in electrical conductivity of the soil among vegetation groups.

Dominant species	*Drepanocladus aduncus* residual releves	*Carex praegracilis* *Taraxacum officinale*	*Drepanocladus aduncus* *Juncus balticus*	*Drepanocladus aduncus*, *Sium suave* *Calamagrostis inexpansa*	*Potentilla anserina*	*Deschampsia caespitosa*	*Juncus balticus*	*Carex praegracilis*	*Hordeum jubatum*	residual releves	*Puccinellia distans*	no vegetation	*Suaeda depressa*
Community number	12	3	13	11	4	8	2	1	5	6	10	9	7
n	7	6	6	9	13	5	7	14	16	13	13	4	5
$\bar{x}$ ($\log_e$)	-.74	-.03	-.01	.03	.32	.33	.55	.71	.99	.99	1.07	1.50	2.08
$\bar{x}$ (untransformed data)*	.64	1.2	1.0	1.1	1.9	2.0	2.6	2.2	3.2	3.6	3.5	6.5	8.8

*continuous lines indicate vegetation groups that are not significantly different at the 95 per cent confidence level in electrical conductivity of the soil

Table 9. Analysis of variance and Student-Newman-Keuls tests for differences in exchangeable sodium per cent of the soil among vegetation groups.

Dominant species	*Drepanocladus aduncus* residual releves	*Deschampsia caespitosa*	*Drepanocladus aduncus*, *Juncus balticus*	*Juncus balticus*	*Drepanocladus aduncus*, *Sium suave* *Calamagrostis inexpansa*	*Potentilla anserina*	*Carex praegracilis*, *Taraxacum officinale*	*Carex praegracilis*	*Puccinellia distans*	*Hordeum jubatum*	residual releves	no vegetation	*Suaeda depressa*
Community number	12	8	13	2	11	4	3	1	10	5	6	9	7
n	7	5	6	7	9	13	6	14	12	16	12	4	5
$\bar{x}$ ($\log_e$)	-2.00	-1.23	-.68	-.54	-.49	-.25	.51	1.65	1.96	2.01	2.03	3.17	3.76
$\bar{x}$ (untransformed data) *	.08	.6	.87	1.2	2.3	3.6	3.5	7.0	12.5	13.2	15.7	30.0	45.6

*continuous lines indicate vegetation groups that are not significantly different at the 95 per cent confidence level in exchangeable sodium per cent of the soil

Table 10. Summarized results of analysis of variance and Student-Newman-Keuls tests.

Community number	1	2	3	4	5	6	7	8	9	10	11	12
2	*K ESP											
3												
4	ESP											
5		Na ESP K		ESP								
6		ESP		ESP								
7	EC	ESP EC Na K	EC ESP	ESP EC Na	EC	EC						
8	ESP K		K	K	ESP K	ESP K	ESP EC Na K					
9		ESP K Na	EC	ESP EC				ESP K Ca				
10		ESP K Na		ESP			EC	ESP K				
11	ESP				ESP K	ESP	ESP EC Na K		ESP EC K	ESP		
12	ESP EC Na K		Na		ESP EC Na K	ESP EC Na	ESP EC Na K		ESP EC Na K	ESP EC Na K		
13	ESP				ESP	ESP	ESP EC Na	K	ESP EC	ESP		

*Parameters that are significantly different between pairs of communities are shown. K is soluble potassium, Na is soluble sodium, Ca is soluble calcium, ESP is exchangeable sodium per cent, and EC is electrical conductivity.

Table 11. Untransformed mean values for soil parameters in each vegetation group.

Community number	Dominant species	exchangeable sodium per cent	electrical conductivity (mmhos/cm)	soluble calcium (meq/100 g soil)	soluble magnesium (meq/100 g soil)	soluble sodium (meq/100 g soil)	soluble potassium (meq/100 g soil)
1	*Carex praegracilis*	7.0	2.2	.38	.88	.92	.06
2	*Juncus balticus*	1.2	2.6	.69	1.25	.62	.02
3	*Carex praegracilis* *Taraxacum officinale*	3.5	1.2	.20	.48	.56	.04
4	*Potentilla anserina*	3.6	1.9	.36	.50	.49	.06
5	*Hordeum jubatum*	13.2	3.2	.59	1.42	1.57	.09
6	residual releves	15.7	3.6	1.44	.43	.76	.03
7	*Suaeda depressa*	45.6	8.8	.02	.09	3.01	.24
8	*Deschampsia caespitosa*	.6	2.0	1.72	.42	.46	.006
9	no vegetation	30.0	6.5	.008	.18	2.76	.20
10	*Puccinellia distans*	12.5	3.5	1.24	1.50	2.19	.08
11	*Drepanocladus aduncus* *Sium suave* *Calamagrostis inexpansa*	2.3	1.1	.25	.38	.31	.02
12	*Drepanocladus aduncus* residual releves	.08	.64	.12	.15	.08	.02
13	*Drepanocladus aduncus* *Juncus balticus*	.87	1.0	.20	.39	.24	.04

Average exchangeable sodium per cent, electrical conductivity and soluble calcium, magnesium, sodium and potassium for each vegetation group are shown in Table 11. The *Suaeda depressa* community and the releves with no vegetation had the highest exchangeable sodium per cent, electrical conductivity, sodium and potassium and the lowest calcium and magnesium. The three vegetation groups with *Drepanocladus aduncus* were in the lowest half for all parameters.

5 Conclusions

5.1 Vegetation communities

Eleven vegetation communities were identified in Chilcotin wetland meadows using cluster analysis. The communities grade into one another as different species become dominant. No dominant species is restricted to one community only. A further group consisted of residual releves that were not sufficiently similar to any community to fit into one of those groups. With more data some of these releves might form new communities. A thirteenth group of releves was characterized by an absence of vegetation.

5.2 Soils

The majority of meadows have soils that are low in salts according to the United States Salinity Laboratory Staff (1954), but of the 116 soils tested, 26 had an electrical conductivity over 4 mmhos/cm and 23 had an exchangeable sodium per cent over 15. The median electrical conductivity and exchangeable sodium per cent are 1.6 mmhos/cm and 3.3, respectively, but their maximum values are 16.5 mmhos/cm and 71.1. The dominant soluble cation is generally sodium, but magnesium and calcium are often almost as abundant. Potassium occurs in much smaller amounts than the other cations.

Soils that appear saline or sodic, that are greyish to white, vary considerably in their chemical constitution. Both electrical conductivity and exchangeable sodium per cent range from low, 1.3 mmhos/cm and 3.7, to high, 16.5 mmhos/cm and 69.0. Calcium carbonate is always abundant, but other salts are quite variable even in sites that are relatively close together.

A knowledge of soluble salt content is important in possibly saline wetlands because it is the soluble salts that affect the osmotic potential of the plant. But in the Chilcotin, where alkaline-earth carbonates appear to be the dominant salts, it must be recognized that a test of soluble salts will not truly reflect the salt composition.

Seasonal variability in electrical conductivity may be high, ranging to as much as 7.0 mmhos/cm between June and September at individual sites. This large range must be borne in mind when wetlands are being classified on the basis of a single field check.

5.3 Relationships between vegetation and soils

The results showed that all four null hypotheses were rejected; thus vegetation distribution does appear to be affected by salinity and sodicity.

Linear regression analysis proved to be an inappropriate technique for determining relationships between individual species and salinity and sodicity. At least three factors may be responsible for this finding. The effects of other factors affecting vegetation distribution cannot be entirely removed, hence at a given electrical conductivity species may occur in any amount up to their maximum possible. Seasonal variability in salinity and sodicity would also adversely affect the development of a linear relationship. Thirdly, according to Whittaker (1967) species populations are generally distributed along single environmental gradients in the form of bell-shaped binomial curves. For species with their maximum abundance at an electrical conductivity of 0 mmhos/cm (*Ranunculus cymbalaria*) or for salt-tolerant species from a conductivity of 0 to conductivities at which they attain maximum productivity (*Carex praegracilis*) the linear relationship described by Walker and Coupland (1968) may be valid. But, for species that attain their maximum productivities at conductivities greater than 0 the $\log_{10}$ of the conductivity cannot be related linearly to foliar cover over the full range of conductivities at which the species are found. In terms of the theoretical distributions described by Whittaker, this simply means that the $\log_{10}$ of a bell-shaped curve is not a straight line.

A graphic representation of species abundance versus salinity and sodicity showed that *Deschampsia caespitosa*, *Poa pratensis*, *Potentilla gracilis*, *Drepanocladus aduncus* and *Calamagrostis inexpansa* were restricted to electrical conductivities less than 3.6 mmhos/cm and *Poa pratensis*, *Potentilla gracilis* and *Drepanocladus aduncus* were restricted to an exchangeable sodium per cent less than 10. Except for occasional occurences at higher values, *Taraxacum officinale*, *Calamagrostis inexpansa*, *Aster pansus*, *Deschampsia caespitosa*, *Juncus balticus*, *Potentilla anserina*, *Ranunculus cymbalaria*, and *Carex praegracilis* were found where exchangeable sodium per cent was less than 16. *Suaeda depressa* was the only species that did not occur at the lowest electrical conductivities and only rarely occurs at the lowest exchangeable sodium per cents. Eight species occur in a relatively broad range of electrical conductivities while only two species were widespread from the lowest to the highest exchangeable sodium per cents. This may be because high electrical conductivities can be circumvented by plants by establishing opportunistically, when conditions are favourable, and by completing their life cycles early in the season when the ground is still moist and soluble salts are less concentrated. Salt tolerance of mature plants is often greater than that of seedlings. The deterioration of soil structure caused by a high proportion of sodium on the cation exchange complex may be more stable seasonally and thus more difficult to avoid.

Unlike individual species, some of the most salt tolerant and intolerant communities are relatively restricted in their tolerance ranges. Other communities occur in a broader range of conditions. The *Suaeda* *depressa* community, which is identified by *S. depressa* in excess of 50 per cent, occurs only where electrical conductivity is greater than 4.7 mmhos/cm and exchangeable sodium per cent is greater than 26.5. The *Deschampsia caespitosa* community and all three communities with *Drepanocladus aduncus* are restricted to an exchangeable sodium per cent less than 10 and electrical conductivity less than 4 mmhos/cm. The *Juncus balticus* community is restricted to an exchangeable sodium per cent less than 3.7 and the *Carex praegracilis-Taraxacum officinale* community is restricted to an electrical conductivity less than 2.4. The *Carex praegracilis*, *Hordeum jubatum* and *Puccinellia distans* communities, though tolerant of high salinity and sodicity, also occur in fresh conditions.

Although the releves without vegetation generally occur at either or both high salinity and sodicity, there were two releves in which electrical conductivity was below 1.7 mmhos/cm and exchangeable sodium per cent was less than 10.7. Many wetlands show high water marks as much as two or three metres higher than their present levels and, over at least the last five years, have shown a consistent drying trend. Vegetation may occasionally be absent in areas where ponds have recently evaporated and there has been insufficient time for vegetation to become established. This is certainly the case at sample site 101, which in 1977 was a shallow pond, in 1979 had no water and also no vegetation, but in 1983 had a 70 per cent cover of *Puccinellia distans*. This was a site which appeared saline owing to the greyish-white soil colour, but which had an exchangeable sodium per cent of 8.6 and an electrical conductivity of 1.7. Appearance of soil and absence of vegetation can therefore not be used as a definitive indication of potential productivity.

5.4 Implications for classification

In Runka and Lewis' (1981) classification system, meadows are classified as saline if the electrical conductivity of a saturated soil paste extract is greater than 4 mmhos/cm and sodic if the exchangeable sodium per cent is greater than 15. Relationships between electrical conductivity and both vegetation species and communities indicate that retention of the 4 mmhos/cm boundary would be useful. The average electrical conductivity in the *Suaeda depressa* community and the releves without vegetation is 6.5 mmhos/cm, whereas the average electrical conductivity in all other vegetation communities is less than 3.5 mmhos/cm. Individual species also indicate that 4 mmhos/cm is an appropriate boundary. Species restricted to low salinities are all found only where electrical conductivity is less than 3.6 mmhos/cm. *Suaeda depressa*, the only species not found on the freshest sites, is found in only small amounts (less than 10 per cent foliar cover) at conductivities less than 4 mmhos/cm.

An appropriate boundary for exchangeable sodium per cent is not as clear. For individual species 15 per cent does appear to be appropriate. Except for occasional occurrences at higher values, 11 species are found only where exchangeable sodium per cent is less than 15 or 16. *Suaeda depressa* is the only species that is found mainly at high sodicity. Except for one occurrence at less than 10 per cent foliar cover at an exchangeable sodium per cent of 0, it only occurs where this parameter is greater than 15. The occurrence of communities tolerant of sodic conditions on relatively fresh soils lowers the average exchangeable sodium per cent of these communities. These averages range from 45.6 for the *Suaeda depressa* community to 7.0 for the *Carex praegracilis* community. Average exchangeable sodium per cent of communities intolerant of high sodicity ranges from .08 to 3.6. A better method to establish the boundary might be to determine at what sodicity the intolerant species begin to die out. The maximum sodicity in the 7 moderately tolerant and intolerant communities is 15.8. This indicates that 15 should be retained as the significant exchangeable sodium per cent boundary for Chilcotin wetland meadows.

Electrical conductivity and exchangeable sodium per cent do not adequately characterize the alkaline-earth carbonates that are so abundant and widespread in Chilcotin wetlands. Some indication of these salts should be included in the classification system. The method adopted by the British Columbia Ministry of Environment for indication of carbonates using four degrees of effervescence on application of 10 per cent HCl (Walmsley et al 1980) is simple and appropriate for use in the field, and would provide at least a rough estimate of these salts.

The results obtained herein generally agree with those obtained by Moon and Selby (1982). They identified *Distichlis stricta, Puccinellia* spp., *Spartina gracilis*, and *Suaeda depressa* as dominants and *Triglochin maritimum* and *Hordeum jubatum* as associated species in alkaline conditions. Non-alkaline dominants include *Juncus arcticus (balticus), Carex praegracilis, Hordeum jubatum, Poa pratensis, Muhlenbergia richardsonis, Potentilla anserina* and *Taraxacum officinale*. The present study found *Suaeda depressa, Hordeum jubatum* and *Puccinellia distans* to be salt tolerant and *Poa pratensis, Juncus balticus* and *Taraxacum officinale* intolerant, although *Poa pratensis* rarely occurred as a dominant. *Carex praegracilis* and *Potentilla anserina* occurred in a broad range of conditions. There were insufficient data to categorize *Spartina gracilis, Muhlenbergia richardsonis, Distichlis stricta* and *Triglochin maritimum*. In the few places where the latter two were found soils were generally saline or sodic, but occasionally were not. *Muhlenbergia richardsonis* was found on 4 sites, none of which were saline or sodic.

Literature cited

Annas, R.M. and R. Coupe (ed.) 1979. Biogeoclimatic zones and subzones of the Cariboo Forest Region. Research Branch, Ministry of Forests, Victoria, B.C. 15BN 0-7719-8134-1. 103 p.

Bernstein, L. 1958. Salt tolerance of grasses and forage legumes. U.S.Gov't. Printing Off., Wash., D.C. USDA Agr. Inf. Bull. no. 194. 7 p.

____________ and H.E. Hayward. 1958. Physiology of salt tolerance. Ann. Rev. of Plant Physiol. 9:25-46.

Bolen, E.G. 1964. Plant ecology of spring fed salt marshes in western Utah. Ecol. Monogr. 34:143-166.

Boyd, C.E. and L.W. Hess. 1970. Factors influencing shoot production and mineral levels in *Typha latifolia*. Ecol. 51:296-300.

Dewey, D.R. 1960. Salt tolerance of 25 strains of *Agropyron*. Agron. J. 52:621-625.

Dix, R.L. and F.E. Smeins. 1967. The Prairie, meadow and marsh vegetation of Nelson County, North Dakota. Can. J. Bot. 45:21-58.

Dodd, T.D. and R.T. Coupland. 1966. Vegetation of saline areas in Saskatchewan. Ecol. 47:958-968.

Flowers, S. 1934. Vegetation of the Great Salt Lake region. Bot. Gaz. 95:353-418.

Forsberg, D.E. 1953. Response of various crops to saline soils. Can. J. Agric. Sci. 33:542-549.

Fox, D.J. and K.E. Guire. 1976. Documentation for Midas. 3rd ed. Statistical Research Lab. Univ. of Michigan, Ann Arbor, Mich. 203 p.

Gates, D.H., L.A. Stoddart and C.W. Cook. 1956. Soils as a factor influencing plant distribution on salt deserts of Utah. Ecol. Monogr. 26:155-175.

Hayward,H.E. and L Bernstein. 1958. Plant growth relationships on salt-affected soils. Bot. Rev. 24:584-635.

Heinselman, M.L. 1970. Landscape evolution, peatland types and the environment of the Lake Agassiz Peatlands Natural Area, Minnesota. Ecol. Monogr. 40:235-261.

Hitchcock, A.S. 1971. Manual of the Grasses of the United States. 2nd ed. revised. Dover Publications, Inc. New York. 1051 p.

Hitchcock, C.L. and A. Cronquist. 1973. Flora of the Pacific Northwest. University of Washington Press. Seattle, Wash. 730 p.

Holland, S.S. 1976. Landforms of British Columbia. A Physiographic Outline. B.C. Dept. of Mines and Petroleum Resources Bull. No. 48. 138 p.

Jackson, E.A., G. Blackburn and A.R.P. Clarke. 1956. Seasonal changes in soil salinity at Tintinara, South Australia. Aust. J. Agr. Res. 7:20-44.

Jones, C.E. 1981. Analysis and integration of soil parameters and vegetation of a Cariboo-Chilcotin wetland in British Columbia. MSc. thesis. Faculty of Agriculture, University of British Columbia. 66 p.

Keith, L.B. 1958. Some effects of increasing soil salinity on plant communities. Can. J. Bot. 36:79-89.

Larkin, P.A. 1979. A handbook of elementary statistical tests designed for use in Biology 300 (Biometrics). Univ. of British Columbia. 161 p.

Lavkulich, L.M. 1981. Methods manual. Pedology Laboratory. Dept. of Soil Science, Univ. of British Columbia. 197 p.

Mayall, A.C. 1983. Preliminary assessment of wetland classification systems and wetland variability for the Cariboo-Chilcotin region, British Columbia. Canadian Wildlife Service Report. File No. 9462. 49 p.

Millar, J.B. 1973. Vegetation changes in shallow marsh wetlands under improving moisture regime. Can. J. Bot. 51:1443-1457.

__________ 1976. Wetland classification in Western Canada. Canadian Wildlife Service Report. Series No. 37.

Moon, D.E. and C.J. Selby. 1982. Wetland systems of the Cariboo-Chilcotin region of B.C. Unpubl. B.C. Pedology Unit., Ag. Can., Vancouver, B.C. 28 p.

Moore, P.D. and D.J. Bellamy. 1974. Peatlands. Springer-Verlag. New York. 221 p.

Morton, J.W. 1979. Chilcotin meadowlands: livestock range and culture. Rangelands. 1:183-185.

Moxley, M.G., W.A. Berg and E.M. Barrau. 1978. Salt tolerance of 5 varieties of wheatgrass during seedling growth. J. Range Manage. 31:54-55.

Orloci, L. 1975. Multivariate analysis in vegetation research. Dr. W. Junk Publishers, The Hague, Netherlands.

Pearson, G.A. 1960. Tolerance of crops to exchangeable sodium. U.S. Govt. Printing Off., Wash., D.C. USDA Agr. Inf. Bull. No. 216. 4 p.

Rauser, W.E. and W.L. Crowle. 1963. Salt tolerance of Russian wild rye grass in relation to tall wheatgrass and slender wheatgrass. Can. J. Plant Sci. 43:397-407.

Roberts, A. Unpubl. Common grasses of the Cariboo Forest Region. Ministry of Forests, Williams Lake, B.C. mimeo, 29 p.

Runka, G.G. and T. Lewis. 1981. Preliminary Wetland Managers Manual. Cariboo Resource Management Region. APD Technical Paper No. 5. Ministry of Environment, Victoria, B.C. 112 p.

Schwintzer, C.A. 1978. Vegetation and nutrient status of northern Michigan fens. Can. J. Bot. 56:3044-3051.

Selby, C.J. and D.E. Moon. 1981. Soil and vegetation sequences as wetland mapping units: Computer assisted definition. Proc. of a workshop on organic soil mapping and interpretation in New Brunswick.

Sjors, H. 1950. On the relation between vegetation and electrolytes in North Sweden waters. Oikos 2:241-258.

Tipper, H.W. 1971. Glacial geomorphology and pleistocene history of central British Columbia. Geol. Surv. Can. Bull. No. 196. Ottawa. 89 p., 8 maps.

United States Salinity Laboratory Staff. 1954. Diagnosis and Improvement of Saline and Alkali Soils. USDA Handbook 60. Govt. Printing Off., Wash., D.C. 160 p.

van der Valk, A.G. and L.C. Bliss. 1971. Hydrarch succession and net primary production of oxbow lakes in Central Alberta. Can. J. Bot. 49: 1177-1199.

van Ryswyk, A.L. 1971. Native meadows of the Cariboo. unpubl.

Waisel, Y. 1972. Biology of Halophytes. Academic Press. New York. 395 p.

Walker, B.H. and R.T. Coupland. 1968. An analysis of vegetation environment relationships in Saskatchewan sloughs. Can. J. Bot. 46:509-522.

______________________________ 1970. Herbaceous wetland vegetation in the aspen grove and grassland regions of Saskatchewan. Can. J. Bot. 48: 1861-1878.

Walker, B.H. and C.F. Wehrhahn. 1971. Relationships between derived vegetation gradients and measured environmental variables in Saskatchewan wetlands. Ecol. 52:85-95.

Walmsley, M., G. Utzig, T. Vold, D. Moon and J. van Barneveld. (ed.) 1980 Describing Ecosystems in the Field. RAB Technical Report No. 2. Ministry of Environment. Victoria, B.C. 224 p.

Whittaker, R.H. 1967. Gradient analysis of vegetation. Biol. Rev. 42: 207-264.

Whittaker, R.H. and C.W. Fairbanks. 1958. A study of plankton copepod communities in the Columbia Basin, southeastern Washington. Ecol. 39:46-65.

Winer, B.J. 1971. Statistical Principles in Experimental Design. 2nd ed. Mcgraw-Hill. New York.

Worcester, B.K. and B.D. Seelig. 1976. Plant indicators of saline seep. N.D. Farm Research 34:18-20.

Zar, J.H. 1974. Biostatistical analysis. Prentice-Hall, Inc. Englewood Cliffs, N.J. 620 p.

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Beets, Mr. M. Fish and Wildlife Branch, Ministry of Environment, Williams Lake, B.C.

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Appendix I

Species List

Achillea millefolium L.	Yarrow
Agropyron repens (L.) Beauv.	Couchgrass
Agropyron smithii Rydb.	Bluestem wheatgrass
Agropyron subsecundum (Link) Hitchc.	Bearded wheatgrass
Agropyron trachycaulum var. *novae-angelicae* (Scribn.) Fern.	Slender wheatgrass
Agropyron trachycaulum var. *trachycaulum* (Link)Malte.	Slender wheatgrass
Agropyron trachycaulum var. *unilaterale* (Cassidy)Malte.	Slender wheatgrass
Agropyron violaceum (Hornem.)Lange	
Agrostis scabra Willd.	Winter bentgrass
Alopecurus aequalis Sobol.	Little meadow foxtail
Alopecurus pratensis L.	Meadow foxtail
Amblystegium riparium	
Amblystegium serpens (Hedw.)B.S.G.	
Antennaria sp.	Pussytoes
Arnica chamissonis Less.	Arnica
Aster campestris var. *campestris* Nutt.	White meadow aster
Aster pansus (Blake) Cronq.	Tufted white prairie aster
Aster sp.	Aster
Beckmannia syzigachne (Steud.) Fern.	Sloughgrass
Bryum sp.	
Calamagrostis inexpansa Gray	Narrow-spiked reedgrass
Carex aquatilis Wahl.	Water sedge
Carex atherodes Spreng.	Awned sedge
Carex athrostachya Olney	Slender-beaked sedge
Carex aurea Nutt.	Golden sedge
Carex disperma Dewey	Soft-leaved sedge
Carex lasiocarpa Ehrh.	Slender sedge
Carex parryana Dewey	Parry sedge
Carex praegracilis W. Boott.	Clustered field sedge
Carex rostrata Stokes	Beaked sedge
Carex sartwellii Dewey	Sartwell's sedge
Carex sp.	Sedge
Chenopodium rubrum L.	Red goosefoot
Danthonia intermedia Vasey	Timber oatgrass
Deschampsia caespitosa (L.)Beauv.	Tufted hairgrass
Desmatodon cernuus	
Diaduncus sp.	
Dicranella sp.	
Distichlis stricta (Torr.)Rydb.	Alkali saltgrass
Drepanocladus aduncus	
Eleocharis palustris (L.)R.&S.	Common spike rush
Epilobium watsonii var. *occidentale* (Trel.)Hitchc.	Watson's willow weed
Erigeron lonchophyllus Hook.	Spear-leaf fleabane
Fragaria vesca var. *bracteata* (Heller) Davis	Woods strawberry
Galium trifidum L.	Small bedstraw
Glyceria grandis Wats.	Reed mannagrass
Glyceria striata (Lam.)Hitchc.	Fowl mannagrass

Hierochloe odorata (L.) Beauv.	Sweetgrass
Hippurus vulgaris (L.)	Common mare's-tail
Hordeum brachyantherum Nevski	Meadow barley
Hordeum jubatum L.	Foxtail barley
Juncus balticus Willd.	Baltic rush
Machaeranthera canescens (Pursh.) Gray	Hoary aster
Menthe arvensis L.	Field mint
Muhlenbergia richardsonis (Trin.) Rydb.	Mat muhly
Penstemon procerus var. *procerus* Dougl.	Small-flowered penstemon
Plagiomnium spp.	
Plantago major var. *major* L.	Plantain
Poa juncifolia Scribn.	Alkali bluegrass
Poa palustris L.	Fowl bluegrass
Poa pratensis L.	Kentucky bluegrass
Polygonum ramossimum Michx.	Bushy knotweed
Potentilla anserina L.	Common silverweed
Potentilla biennis Greene	Biennial cinquefoil
Potentilla gracilis var. *gracilis* Dougl.	Slender cinquefoil
Potentilla pensylvanica L.	Prairie cinquefoil
Potentilla spp.	Cinquefoil
Puccinellia distans (L.) Parl.	Weeping alkaligrass
Puccinellia nuttalliana (Schult.) Hitchc.	Nuttall's alkaligrass
Ranunculus cymbalaria Pursh.	Shore buttercup
Ranunculus macounii Britt.	Mocoun's buttercup
Ranunculus occidentalis Nutt.	Western buttercup
Ranunculus scleratus L.	Blister buttercup
Ranunculus spp.	Buttercup
Rumex maritimus L.	Golden dock
Scirpus nevadensis Wats.	Nevada bulrush
Senecio pauperculus Michx.	Balsam groundsel
Sisyrinchium angustifolium Mill.	Blue-eyed grass
Sium suave Walt.	Hemlock water parsnip
Smilacina stellata (L.) Pesf.	Starry solomon-plume
Solidago canadensis L.	Canadian goldenrod
Stellaria longipes var. *longipes* Goldie	Longstalk starwort
Suaeda depressa (Pursh.) Wats.	Pahute weed
Taraxacum officinale Weber	Common dandelion
Thalictrum venulosum Trel.	Veiny meadow rue
Trifolium hybridum L.	Alsike clover
Trifolium repens L.	Dutch clover
Triglochin maritimum L.	Seaside arrowgrass
Viola adunca var. *adunca* Sm.	Early blue violet
Viola spp.	Violet
Veronica scutellata L.	Marsh speedwell

Appendix II

Soils data

Plot no.	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	$SO_4^{=}$	$CO_3^{=}$	HCO_3^{-}	EC	ESP
				meq/100 g soil					mmhos/cm	
1	4.10	7.72	4.29	.03	0	17.3	0	.40	4.8	3.3
2	5.30	13.0	6.92	.03	-	-			8.1	4.5
3	4.56	3.44	1.43	.02	.02	-	0	.48	4.1	1.1
4	4.29	7.40	3.68	.02	0	-	0	.35	9.0	3.7
5	3.36	2.51	1.34	.02	-	-	0	.31	4.1	1.6
6	.13	.67	2.0	.09	0	-	0	.78	1.5	4.0
7	.02	.30	.09	.06	-	-	0	.52	1.0	.1
8	.04	.38	.12	.03	.01	.06	0	.68	1.5	.2
9	.03	.08	.72	.01	0	.26	0	.52	1.2	13.6
10	.02	.48	.24	.05	-	-	0	.47	1.2	1.6
11	.01	,13	.45	.02	.01	.1	.15	.43	1.5	8.5
12	.05	.71	1.18	.05	.03	.25	.06	1.46	1.9	7.1
13	.70	4.77	3.14	.11	0	2.24	0	-	3.2	4.6
14	.44	1.13	.35	.01	-	-	0	.06	1.4	.3
15	3.69	4.25	3.11	.26	-	-	0	.34	5.6	4.1
16	.01	.02	.31	.09	.03	.07	.10	.29	1.8	16.5
17	.01	.02	.83	.14	.06	-	.10	.25	4.9	34.4
18	.03	.09	1.17	.20	.08	1.19	.01	.31	4.6	22.4
19	.01	.02	.77	.07	-	-	.07	.38	9.6	35.9
20	.11	.13	.07	0	.04	-	-	-	.8	0
21	.16	.13	.05	0	.03	.05	0	.13	.6	0
22	.34	.34	.41	.04	0	.11	0	.58	1.2	2.0
23	1.39	1.62	1.66	0	-	-	0	1.04	1.6	1.9
24	9.01	11.47	8.34	.04	-	-	0	5.75	6.0	4.5
25	.03	.17	.41	.03	.04	.29	.03	.35	1.7	5.6
26	.32	.40	.19	.03	-	-	0	.16	1.4	.2
27	.04	.10	.52	.03	.09	.26	.01	.23	.9	9.6
28	.08	.27	.23	.01	-	-	0	.13	.6	1.1
29	.14	.55	.55	.04	-	-	.03	.58	2.3	3.8
30	.19	.21	.12	.04	-	-	0	.21	.7	.3
31	.02	.53	.8	.04	-	-	.03	.54	2.3	6.3
32	0	.22	6.6	.32	-	-	.22	.80	16.5	53.2
33	.02	.14	.69	.08	-	-	-	-	2.3	11.6
34	.79	.95	.67	.10	-	-	0	6.2	3.1	2.1
35	.43	.38	.20	.01	.03	.05	0	.87	.28	.3
36	.01	.04	.74	.01	.07	.92	.31	-	8.0	26.9
37	.06	.29	2.17	.22	.04	1.88	.05	1.06	7.4	26.5
38	.02	.11	.76	.07	.05	.53	-	-	2.5	15.8
39	.02	.23	.88	.12	-	-	.10	.30	1.7	10.8
40	.02	.19	1.26	.09	.05	1.10	.08	.25	3.5	16.8
41	.02	.20	.51	.03	-	-	.02	.15	1.9	7.8
42	.12	.13	.21	.03	-	-	0	.15	1.1	2.4
43	.03	.07	.57	.07	.02	.30	0	.18	2.0	14.3
44	.12	.86	1.52	.36	.03	1.61	0	.13	4.2	9.4

Soils data (continued)

Plot no.	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	$Cl^{=}$	$SO_4^{=}$	$CO_3^{=}$	HCO_3^{-}	EC mmhos/cm	ESP
			meq/100 g soil							
45	.01	.13	1.68	.19	.26	.13	1.67	.54	3.2	23.5
46	.21	.31	.06	.07	-	-	0	.12	.8	0
47	.02	.04	.02	.02	.01	0	0	.10	.28	0
48*	.10	.15	.34	.05	-	-	0	.23	.34	1.9
49*	.06	.10	.96	.05	-	-	0	.06	.40	9.0
50	.07	.25	.74	.01	.04	.77	.26	.26	2.0	8.4
51	0	.03	.06	.01	-	.01	-	-	3.5	2.0
52*	.01	.21	1.13	.10	0	.39	.96	.55	1.0	8.8
53	.02	.02	5.32	.14	-	-	-	-	8.3	71.1
54	.01	.08	1.23	.07	0	.16	-	-	2.2	24.1
55	.02	.18	1.03	.07	0	0	-	-	2.5	13.8
56	.16	.44	.15	0	-	-	0	.37	1.1	.3
57	.12	.32	.14	.02	-	-	0	.27	1.5	.7
58	.03	.24	.09	.04	0	.03	.07	.29	.9	.1
59	.04	.26	.13	.02	.01	.05	.29	.33	1.0	.5
60	.01	.16	.10	.04	-	-	.17	.42	1.2	.4
61	1.03	1.26	.41	.02	-	-	0	.24	1.5	0
62	.03	.04	.01	.01	0	0	0	.08	.39	0
63	.02	.02	.04	.02	.06	.06	0	.03	.33	.1
64	.09	.14	.05	.03	.02	0	0	.14	.72	0
65*	.08	.35	.28	.06	.06	0	0	.53	-	.7
66	.10	.34	.08	.04	.03	.04	0	.33	.6	0
67	.03	.03	1.20	.07	-	-	-	-	3.5	29.1
68	.02	.12	1.62	.08	.03	.03	-	-	3.0	26.3
69	.04	.06	1.04	.03	-	-	-	-	4.0	22.5
70	.65	.58	.42	.09	-	-	0	.21	1.7	1.1
71*	.32	.28	.34	.05	-	-	0	.23	1.0	.8
72*	.02	.5	2.0	.15	0	.45	.96	1.1	1.6	10.5
73*	.03	.14	.11	.02	0	.21	0	.23	.41	.1
74	.02	.15	.21	.02	-	.1	.06	.21	1.0	2.8
75	-	-	-	-	-	-	-	-	5.3	-
76	-	-	-	-	-	-	-	-	8.7	-
77	.02	.54	.36	.02	-	-	.24	.33	.9	2.2
78	.06	.59	.32	.01	0	.11	.16	.38	.87	1.5
79	.01	.04	.03	.02	-	-	.37	.10	1.3	0
80	.02	.50	.24	.10	0	.02	.23	.37	1.0	1.2
81	.02	.24	.41	.05	-	-	.10	.09	1.3	5.1
82	.02	.24	.66	.06	-	-	-	-	1.9	8.5
83	.05	.20	2.18	.09	-	-	-	-	3.6	25.4
84*	.06	.28	.10	.05	0	.16	0	.29	.4	0
85*	.03	.08	9.04	.1	.14	.31	14.1	3.05	4.8	54.6
86	.006	.16	.24	.07	-	-	.59	.35	1.6	3.7
87	.16	.13	.70	.01	.01	.31	0	.45	.8	5.5
88	.14	.13	.09	0	.08	.12	0	.13	.8	.1
89	.01	.07	1.86	.24	-	-	2.44	.73	4.6	36.0
90	.03	.16	.28	.05	.04	.15	.30	.09	1.9	3.8
91	.05	.24	.10	.04	-	-	0	.07	1.2	.1
92	.04	.21	.07	.03	.04	-	.15	.22	1.0	0

Soils data (continued)

Plot no.	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	$SO_4^{=}$	$CO_3^{=}$	HCO_3^{-}	EC mmhos/cm	ESP
			meq/100 g soil							
93	.03	.31	.19	.03	-	-	-	-	1.6	1.5
94*	.04	.21	.07	.03	.01	0	0	.44	.4	.1
95	.07	.10	.33	.03	-	-	0	.06	.83	5.1
96	.07	.09	.26	.03	.03	.05	.10	.17	.9	4.3
97	.04	.10	.33	.03	-	-	0	.16	1.0	6.3
98	.06	1.17	2.35	.13	.06	-	0	.22	5.4	13.1
99	.08	.43	2.89	.09	-	-	-	-	5.3	24.6
100	4.29	2.55	7.82	.60	-	-	0	.17	7.2	19.5
101	.01	.31	.92	.05	.02	-	1.35	.25	1.7	8.6
102	.01	.20	.41	.02	.02	-	.46	.15	1.4	6.3
103*	.12	.23	.24	.05	.01	-	0	.36	.39	.6
104	.03	.03	.03	.01	.02	.02	0	.03	.17	0
105	.06	.07	.05	.03	-	-	-	-	.2	0
106*	.09	.55	1.39	.25	.08	.87	.95	.89	1.5	6.3
107	.06	.14	.16	.05	-	-	0	.22	.8	1.8
108	.02	.31	5.56	.89	-	-	-	-	16.0	42.8
109	.01	.04	1.19	.26	-	-	-	-	3.4	30.8
110*	.07	.53	1.16	.2	.56	-	.57	.8	.6	5.4
111	.01	.44	1.34	.12	-	-	0	.17	2.1	13.4
112	.14	.13	.09	.01	-	-	0	.02	.9	0
113*	.24	.47	.16	.04	-	-	0	.32	.5	0
114	.18	.66	.42	.03	.05	.30	-	.29	1.8	2.1
115	.29	.74	.31	.08	.03	.10	0	-	1.7	.9
116	.11	.16	.19	0	.02	-	0	.15	.83	1.2
117*	.09	.17	.12	.01	0	0	0	.38	.4	0
118	.31	.35	.21	0	.20	.20	0	.43	1.6	.4
119	.19	.22	.14	0	0	.68	.06	.19	1.0	.1
120	.01	.16	.40	.02	.04	.13	0	.39	2.2	6.2
121*	.01	.28	.54	.1	0	0	2.28	.70	.83	10.7
122	.03	.07	1.67	.02	-	-	-	-	4.7	26.5
123	.01	.24	.52	.02	.05	.74	.13	.12	3.3	8.1
124	.05	.12	.32	.01	.05	.40	.06	.10	1.3	4.7
125	.29	.54	.71	.01	.03	1.32	.06	.20	1.8	3.7
126	.01	.003	1.82	.003	.40	.42	1.52	.12	6.8	69.0
127	.01	.01	1.72	.07	.41	.24	.85	.43	5.4	51.6
128	.01	.004	1.42	.07	.40	.26	.83	.42	6.7	53.8
129	.22	.10	.05	.01	.01	-	0	.09	.61	0
130	.19	.14	.07	.02	.01	.05	0	.05	.56	0
131	.46	.22	.14	.01	.03	.36	0	.11	.72	0
132	2.49	.72	.92	.01	.05	3.15	0	.14	3.0	1.5
133	2.47	.32	.27	0	.05	3.48	0	.16	3.5	0
134	3.48	.87	1.05	0	.03	5.76	0	.11	2.9	1.4

* samples extracted using 1:2 soil:water ratio

Appendix III

Constituent salts, pH, exchangeable sodium per cent, electrical conductivity and soluble cations of nine saline appearing soils.

	Suds Lake site 1	Suds Lake site 2	Suds Lake site 3	Patterson Lake site 1	Patterson Lake site 2	Patterson Lake site 3	Morrison meadow site 1	Morrison meadow site 2	Big B Corner
calcium carbonate	4*	3	3	3	3	3	3	2	2
calcium chloride	3	1	2	2		2	1	1	
calcium sulphate	2		1	2					
magnesium sulphate	2		1			2			
sodium bicarbonate	1								
silica dioxide	1	2				2			
barium chloride			2						
sodium bisulphite			2		2		3	3	3
pH (H_2O)	10.3	9.92	9.62	9.36	8.82	9.39	9.63		10.0
exchangeable sodium per cent	69.0	51.6	53.8	8.1	4.7	3.7	53.2		8.6
electrical conductivity (mmhos/cm)	6.7	5.4	5.4	3.3	1.3	2.0	16.5		1.7
soluble calcium	.01**	.01	.01	.01	.05	.29	0.0		.01
soluble magnesium	.003	.01	.004	.24	.12	.54	.22		.31
soluble sodium	1.82	1.72	1.42	.52	.32	.71	6.6		.92
soluble potassium	.003	.07	.07	.02	.01	.01	.32		.05

* 4-very high, 3-high, 2-moderate, 1-low.

** for soluble salts numbers indicate meq/100 g soil of each cation

Appendix IV

Linear regression of 13 vegetation species on electrical conductivity (EC) and exchangeable sodium per cent (ESP)

Species	n	Intercept	Slope	r	Significant r for df = n-2	Decision
Aster pansus						
ESP $\log_{10}$	18	5.50	0	..002	.468	accept
EC $\log_{10}$	18	5.94	-3.27	.4	.468	accept
Calamagrostis inexpansa						
ESP $\log_{10}$	14	5.98	1.39	.28	.532	accept
EC $\log_{10}$	14	5.13	4.28	.3	.532	accept
Carex praegracilis						
ESP $\log_{10}$	46	32.44	7.96	.3	.288	reject
EC $\log_{10}$	46	30.34	30.04	.37	.288	reject
Deschampsia caespitosa						
ESP $\log_{10}$	27	21.84	1.87	.07	.381	accept
EC $\log_{10}$	27	20.79	-3.70	.11	.381	accept
Drepanocladus aduncus						
ESP $\log_{10}$	29	59.67	-.49	.01	.367	accept
EC $\log_{10}$	29	59.78	-10.55	.17	.367	accept
Hordeum jubatum						
ESP $\log_{10}$	41	33.12	2.52	.07	.304	accept
EC $\log_{10}$	41	31.05	13.29	.17	.304	accept
Juncus balticus						
ESP $\log_{10}$	49	32.57	6.36	.08	.288	accept
EC $\log_{10}$	49	32.05	-5.19	.2	.288	accept
Poa pratensis						
ESP $\log_{10}$	19	13.49	-1.47	.09	.456	accept
EC $\log_{10}$	19	14.06	-3.67	.06	.456	accept
Potentilla anserina						
ESP $\log_{10}$	36	22.74	-.80	.03	.325	accept
EC $\log_{10}$	36	22.68	-.48	.01	.325	accept
Potentilla gracilis						
ESP $\log_{10}$	12	14.74	5.21	.40	.576	accept
EC $\log_{10}$	12	12.37	-6.90	.17	.576	accept
Puccinellia distans						
ESP $\log_{10}$	25	51.49	-29.71	.24	.396	accept
EC $\log_{10}$	25	38.22	-2.05	.06	.396	accept
Ranunculus cymbalaria						
ESP $\log_{10}$	25	8.10	-3.74	.46	.396	reject
EC $\log_{10}$	25	7.11	-4.65	.26	.396	accept
Suaeda depressa						
ESP $\log_{10}$	10	-78.6	75.1	.46	.632	accept
EC $\log_{10}$	11	-12.63	64.53	.56	.602	accept
Taraxacum officinale						
ESP $\log_{10}$	36	7.40	1.07	.1	.325	accept
EC $\log_{10}$	36	7.03	2.80	.1	.325	accept

Appendix V

Summary of Analyses of Variance of Six Soil Parameters Among Vegetation Groups

	Degrees of Freedom	Sums of Squares	Mean Square	F ratio	F tab	Decision
Exchangeable sodium per cent ($\log_e$)						
Source of variation						
Total	115	484.2				
Treatment	12	264.8	22.1	10.4	2.04	reject
Error	103	219.4	2.1			
Electrical conductivity ($\log_e$)						
Source of variation						
Total	117	94.2				
Treatment	12	43.1	3.6	7.4	2.04	reject
Error	105	51.1	.5			
Calcium ($\log_e$)						
Source of variation						
Total	115	387.0				
Treatment	12	76.9	6.4	2.1	2.04	reject
Error	103	310.0	3.0			
Magnesium ($\log_e$)						
Source of variation						
Total	115	248.2				
Treatment	12	43.2	3.6	1.8	2.04	accept
Error	103	205	2.0			
Sodium ($\log_e$)						
Source of variation						
Total	115	225.3				
Treatment	12	102.7	8.6	7.2	2.04	reject
Error	103	112.6	1.2			
Potassium ($\log_e$)						
Source of variation						
Total	115	237.0				
Treatment	12	93.8	7.8	5.6	2.04	reject
Error	103	143.2	1.4			