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The vegetation, water chemistry and peat chemistry of fens in the Lesser Slave-Athabasca area, and their relationships to other peatland types in Alberta, Canada.

BY

WAI-LIN CHEE

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

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UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled The vegetation, water chemistry and peat chemistry of fens in the Lesser Slave-Athabasca area, and their relationships to other peatland types in Alberta, Canada

submitted by Wai-Lin CHEE

in partial fulfilment of the requirements for the degree of Masters of Science in Plant Ecology.

Dale H. Vitt
supervisor

Victor Lieffers

S. C. Zoltai

Michael Hickman

Date: June 3, 1988

To the friendships that have come my way through the course of this endeavour.

ABSTRACT.

The vegetation, surface water chemistry and peat chemistry of fourteen fens in the Lesser Slave-Athabasca area are described. A total of nine stand groups characterized by *Drepanocladus vernicosus*, *Brachythecium mildeanum*, *Drepanocladus aduncus* and *Drepanocladus polycarpus* are described. In addition to the species mentioned above, these stand groups are further distinguished on the basis of additional characteristic species such as *Drepanocladus lapponicus*, *Sphagnum subsecundum*, *Andromeda polifolia*, *Carex lasiocarpa*, *Drepanocladus sendtneri*, *Chamaedaphne calyculata*, *Sphagnum warnstorfii*, *Caltha palustris*, *Calliergon giganteum*, *Calliergonella cuspidata*, *Drepanocladus exannulatus* and *Myrica gale*.

The fen waters in this study are in the 5.3-7.1 pH range, with specific conductance of 18-240 µS. The mean calcium content of the waters in the spring and fall are 19.5 and 22.1 mg/l, while that of magnesium are 4.26 and 5.27 mg/l respectively. The fen peats are characterized by a calcium content of 17426 g/kg and magnesium content of 1791 g/kg at the 30 cm depth. Mean organic nitrogen, nitrate and ammonium content in the spring and fall waters ranged from 1967-2395 µg/l, 3.1-9.8 µg/l and 16.8-88.9 µg/l respectively.

The primary vegetation gradient is from stands dominated by *Drepanocladus vernicosus*, *Meesia triquetra*, *Menyanthes trifoliata* and *Carex chordorrhiza* to those dominated by *Brachythecium mildeanum*, *Drepanocladus aduncus*, *Carex aquatilis* and *Drepanocladus polycarpus*. This vegetation gradient reflects an ionic and nutrient gradient of increasing pH, magnesium, sodium,

sulphur, organic nitrogen, and phosphorus in the fen waters, as well as increasing magnesium, iron, and phosphorus in the fen peats. A secondary gradient from shrub-moss vegetation to sedge-moss vegetation is significantly correlated with an increase in moisture and nitrate content in the spring waters. The Lesser Slave-Athabasca fens are classified as moderately rich fens. The abundance of the *Drepanocladus* species mentioned above are believed to be characteristic of moderately rich fens in continental areas.

Together with data from poor fens and rich fens that have previously been described in Alberta, the vegetation-chemistry relationships over a broad range of fen types are examined. Indirect gradient analyses show the bryophyte vegetation gradient to reflect an ionic gradient. Specific conductance and pH of the water, and calcium and magnesium contents in both water and peat are highest in extreme rich fens, intermediate in moderately rich fens, and lowest in poor fens. The vascular vegetation gradient, on the other hand, reflects a nutrient gradient. Organic nitrogen and ammonium in the fall, and phosphorus in the peat are highest in moderately rich fens, while nitrate, ammonium and iron in the spring are highest in extreme rich fens.

Water chemistry values in the spring and in the fall are significantly different. Acidity, calcium, magnesium and iron are higher in the fall, while phosphorus in poor fens, organic nitrogen and ammonium in extreme rich fens are lower in the fall. Peat chemistry variables also show significant differences between surface and subsurface values. Magnesium, sodium, potassium, sulphur and phosphorus are higher in the surface peats.

I would like to thank Dale H. Vitt for his patience and guidance throughout the course of this thesis. Also, many thanks to Vic Lieffers for his critical comments, and Steve Zoltai for his lively discussions.

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Water chemistry variables			Mean values	(Standard deviations)
pH	spring	s	6.70	(0.37)
	fall	f	6.18	(0.41)
Con	(µS)	s	67.5	(43.7)
		f	69.8	(47.5)
Ca	(mg/l)	s	19.5	(20.5)
		f	22.1	(20.3)
Mg	(mg/l)	s	4.26	(3.58)
		f	5.27	(4.93)
Na	(mg/l)	s	4.28	(5.12)
		f	6.87	(8.86)
K	(mg/l)	s	1.60	(1.42)
		f	1.70	(3.21)
S	(mg/l)	s	0.45	(0.65)
		f	0.44	(0.43)
Fe	(mg/l)	s	0.20	(0.24)
		f	0.49	(0.58)
P	(mg/l)	s	0.12	(0.30)
		f	0.05	(0.14)
Org.N	(µg/l)	s	1967	(786.)
		f	2395	(644.)
NO_3	(µg/l)	s	3.10	(1.90)
		f	9.80	(17.6)
NH_4	(µg/l)	s	16.8	(15.3)
		f	88.9	(114.)

Table 2-3a. Mean values and standard deviations of water chemistry variables. N=60. s=spring values. f=fall values.

Peat chemistry variables		Mean values (Standard deviations)	
Ash(%)	0	12.1	(5.2)
	30	10.3	([illegible].1)
Ca (g/kg)	0	14018	(6341)
	30	17426	(6369)
Mg (g/kg)	0	2222	(760)
	30	1791	(857)
Na (g/kg)	0	737	(447)
	30	214	(161)
K (g/kg)	0	1597	(873)
	30	403	(374)
S (g/kg)	0	8267	(12618)
	30	3348	(4939)
Fe (g/kg)	0	1074	(729)
	30	880	(458)
P (g/kg)	0	1916	(1132)
	30	1263	(384)

Table 2-3b. Mean values and standard deviations of peat chemistry variables. N=60. 0(cm)=surface. 30(cm)=subsurface.

Variables		Significant differences
SPRING vs FALL water chemistry	pH	S>F
	Con	-
	Ca	-
	Mg	S<F
	Na	S<F
	K	-
	Fe	S<F
	P	-
	Org.N	S<F
	NO_3	S<F
	NH_3	S<F
SURFACE vs SUBSURFACE peat chemistry	Ash	0>30
	Ca	0<30
	Mg	0>30
	Na	0>30
	K	0>30
	S	0>30
	Fe	0<30
	P	0>30

Table 2-4. Significant differences between spring & fall water values, and between surface & subsurface peat values, based on Wilcoxon's matched pair rank sum test (significant at the 0.05 level).

Water chemistry variables		Correlation with DECORANA scores Ax 1	Ax 2
pH spring	s	.29*	−.06
fall	f	.35*	−.10
Con	s	.27	−.14
	f	.37*	−.07
Ca	s	.23	−.13
	f	.24	−.17
Mg	s	.43*	−.06
	f	.46*	−.10
Na	s	.42*	−.07
	f	.34*	−.01
K	s	.23	−.04
	f	−.01	.30
S	s	.57*	.19
	f	.61*	.24
Fe	s	−.18	−.09
	f	.30	.04
P	s	.31*	.14
	f	.10	−.18
Org. N	s	.35*	−.10
	f	.19	.04
NO_3	s	−.18	−.35*
	f	−.12	−.10
NH_4	s	−.02	−.25
	f	−.21	−.10

Table 2-5a. Spearman's rank order correlation of water chemistry variables with DCA stand scores. Level of significance = 0.05. N=52. s=spring values. f=fall values.

Peat chemistry variables		Correlation with DECORANA scores Ax 1	Ax 2
Ash	0	.06	.06
	30	.37*	.33*
Ca	0	.07	-.18
	30	.21	-.09
Mg	0	.42*	-.16
	30	.55*	.11
Na	0	.05	-.08
	30	-.28*	.13
K	0	-.29*	-.16
	30	-.52*	.02
S	0	-.07	-.07
	30	-.09	-.07
Fe	0	.67*	.03
	30	.76*	.03
P	0	.37*	-.10
	30	.04	-.21

Table 2-5b. Spearman's rank order correlation of peat chemistry variables with DCA stand scores. N=60. Level of significance = 0.05. 0=surface peat, 30=subsurface peat.

In the fen waters, sulphur, magnesium, sodium, pH, phosphorus in the spring and organic nitrogen in the spring are significantly correlated with the first axis of variation of the stand vegetation. Nitrate content in the spring water is negatively correlated to the second axis of variation. In the fen peats, iron, potassium, magnesium, phosphorus in the surface peat and sodium in the subsurface peat are correlated with the axis 1 scores.

There was no correlation between calcium and the stand vegetation as represented by the DCA scores. Although calcium is one of the major cations underlying the variation in the vegetation of different peatland types (Persson 1962; Gorham 1967; Horton *et al.* 1979, Karlin & Bliss 1984), it could not be used to distinguish between the different stand groups found within the narrow chemical range of the peatland type of this study.

Of the water chemistry variables that were significantly correlated to the axes scores, the ions (Mg, Na, H) were correlated to the vegetation both in the spring and in the fall. The nutrients (P, organic nitrogen, NO_3), on the other hand, were only correlated in the spring values. In the fall, the nutrients are generally lower.

In the peat chemistry, correlations of the ions (Fe, Mg, K, Na) to the axes scores were higher for the subsurface (30 cm) peat values. Phosphorus, the exception, was significantly correlated only for the surface (0 cm) peat value.

Axis 2 is also significantly correlated ($r=0.66^*$) to the microtopographic category, an indirect determination of water level. A plot of the microtopographic categories onto the DCA stand ordination is shown in Fig. 2-9.

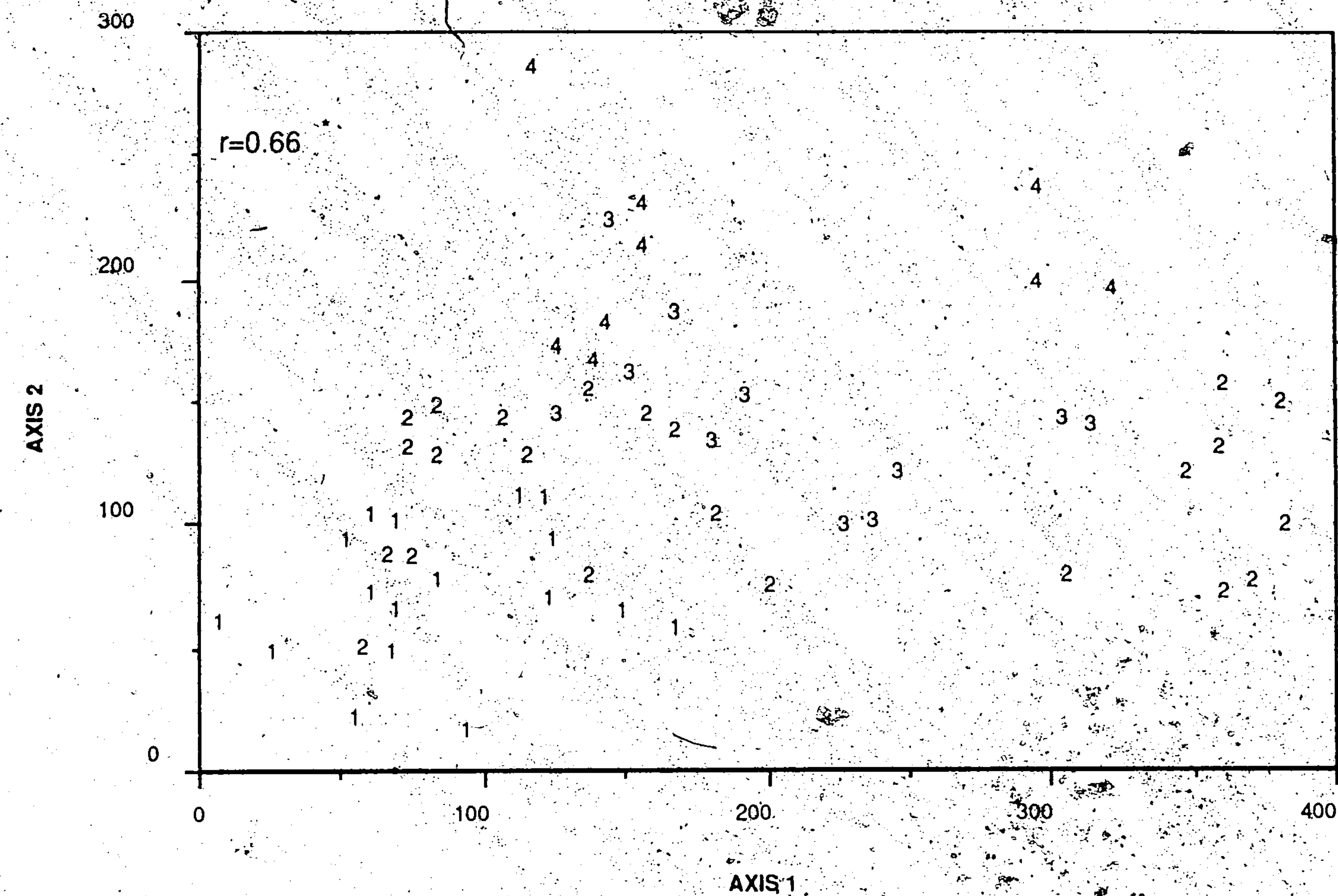

Fig. 2-9. Microtopographic categories superimposed onto the DCA ordination. 1:wet hollow, 2:wet-moist carpet, 3:moist lawn, 4:dry hummock. The categories are significantly correlated to axis 2 scores, r=0.66.

E. DISCUSSION.

Relationhsips between vegetation and environmental factors.

Relationships between vegetation and environmental factors can be ascertained by examining the vegetation gradients described in Fig. 2-7, together with the significant correlations obtained. A summary of the significant correlations of surface water chemistry variables and peat chemistry variables in relation to the DCA axes is graphically represented in Figs. 2-10 and 2-11 respectively. As shown by the correlation vectors, axis 1 reflects a gradient of increasing sulphur, magnesium, phosphorus and organic nitrogen in the water (Fig. 2-10), as well as increasing iron, magnesium and phosphorus in the peat, accompanied by decreasing potassium, sodium and hydrogen in the peat (Fig. 2-11). This gradient is largely a nutrient gradient, and is associated with the vegetation gradient from *Drepanocladus vernicosus, Meesia triquetra, Menyanthes trifoliata* and *Carex chordorrhiza* dominated stands to *Brachythecium mildeanum, Drepanocladus aduncus, Carex aquatilis* and *Drepanocladus polycarpus* dominated stands along axis 1. On the other hand, the vegetation gradient from sedge moss stands to shrub dominated stands along axis 2 reflects a gradient in decreasing nitrate content in the water, as well as a decreasing moisture content.

Within the vegetational and chemical gradients of this study, stand group 2 lies at one extreme. Extremely wet throughout the growing season, and having the lowest pH, specific conductance ionic and nutrient content, it has the lowest species diversity. It is

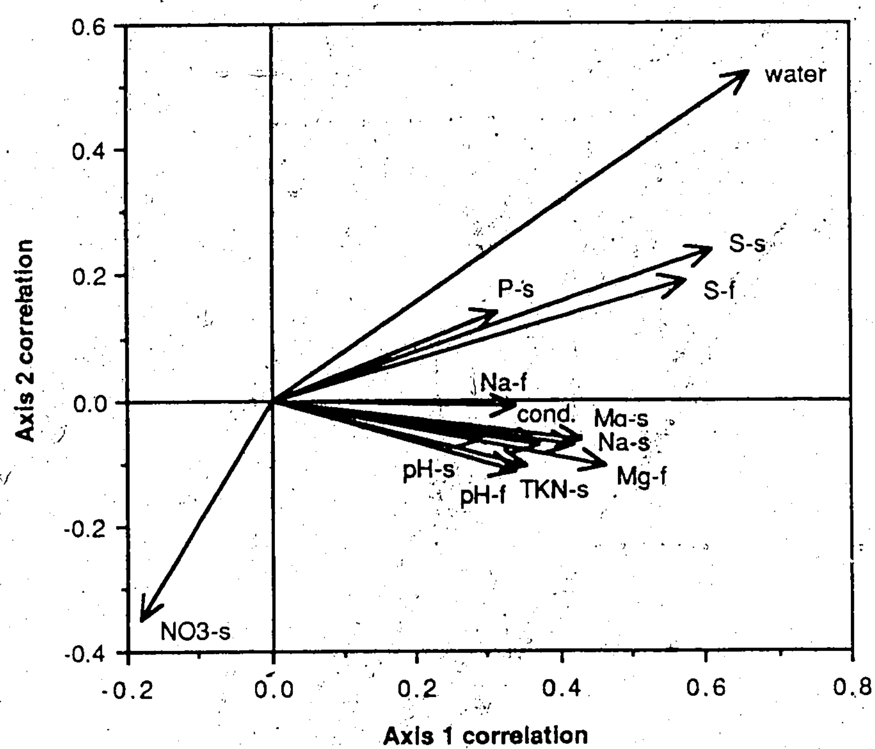

Fig. 2-10. Correlation vectors of water chemistry variables that are significantly correlated to DCA axes scores. s=spring, f=fall.

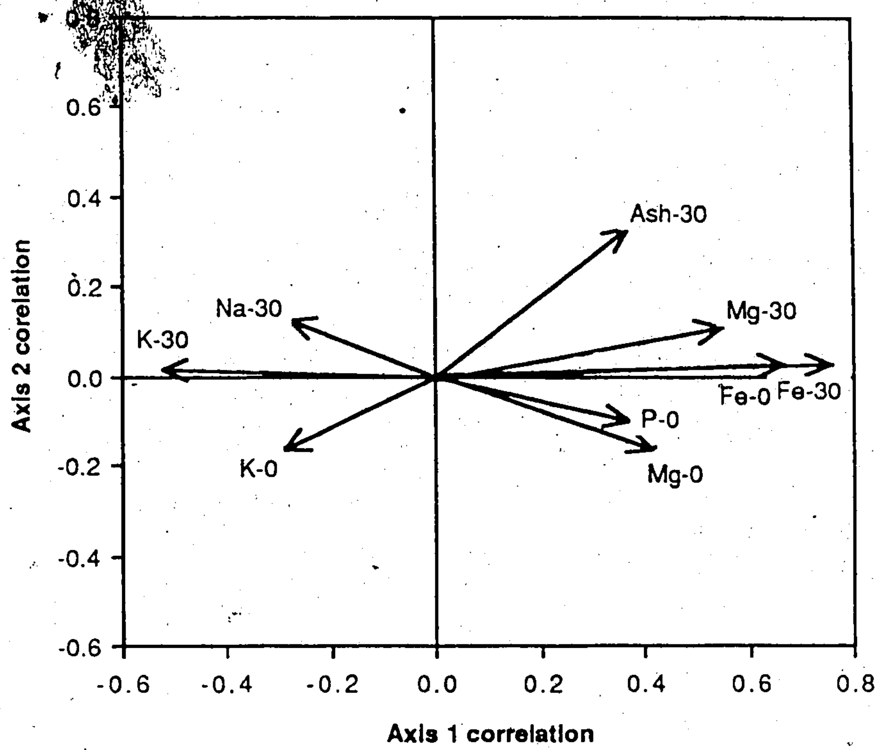

Fig. 2-11. Correlation vectors of peat chemistry variables that are significantly correlated to DCA axes scores. 0=surface, 30=subsurface.

characterized by *Sphagnum subsecundum*, and dominated by *Drepanocladus lapponicus* and *Drepanocladus vernicosus*. *Sphagnum subsecundum* is characteristic of fens that are "transitional" between *Sphagnum* dominated poor fens and brown moss dominated rich fens with pH around 5.5 (Vitt, personal communication). At the other extreme lies stand group 8. With high pH, specific conductance, ionic and nutrient content (with the exception of potassium and sodium in peat), these stands are characterized by *Drepanocladus polycarpus* and *Myrica gale*, with abundant *Carex aquatilis* and *Drepanocladus aduncus*. The wetter stands within this group are further characterized by *Calliergonella cuspidata* and *Drepanocladus exannulatus*.

The vegetation gradient (along axis 2) from sedge-moss to shrub dominated stands reflects primarily a moisture gradient from wet to dry conditions. With drier conditions, there is also a higher species diversity. Nitrate content, the only significant correlation obtained in relation to axis 2, was found to decrease from wet sedge-moss stands to dry shrub dominated stands. Drier stands presumably have higher nitrogen content made available to them through greater decomposition rates as a result of having a larger aerobic zone. However, rapid uptake by plants may reduce the measurable amount of nitrogen in the water. This then suggests that the significantly lower amount of nitrate in the waters of drier stands may be due to a more rapid uptake by the hummock species.

Similar peatland communities in the literature.

The relevant literature for continental areas similar to Alberta is sparse. Kulczynski (1949) described a peatland community with *Drepanocladus aduncus, Calliergon giganteum, Aulacomnium palustre, Bryum pseudotriquetrum* and various carices in Polesie (now partly in Poland). This species group is common in stand groups 7, 8 and 9 of this study. Kulczynski (1949) classified this community as a "uniform transition bog", a ground water influenced peatland consisting of a mixture of bog and valley bog (=fen) species. Bradis and Andrienko (1972) described communities with *Drepanocladus vernicosus, D. aduncus, Calliergon giganteum, Calliergonella cuspidata, Tomenthypnum nitens* and various sedges in Polesye and the Forecarpathians (Russian Ukraine). These species are common in stand groups 7 and 8 of this study. They also described a community with *Drepanocladus sendtneri* and various sedges, which may be similar to stand group 4 of this study. All of these communities were classified as "eutrophic fens" which is equivalent to the use of rich fens here.

Similar communities have also been described elsewhere. In Ireland, O'Connell *et al.* (1984) described peatland communities with *Calliergon giganteum, Calliergonella cuspidata, Potentilla palustris* and various carices, which are similar to stand group 8 of this study. These communities were not classified to fen type. In Finland, Ruuhijarvi (1960) described a *Birkenbraunmoore* (birch rich fen) with *Betula nana, Drepanocladus vernicosus, Sphagnum warnstorfii, Tomenthypnum nitens* and sedges, which is similar to stand group 6. He also described a *Rimpibraunmoore* (string rich fen) with *Drepanocladus vernicosus, Drepanocladus exannulatus, Calliergon giganteum, Carex chordorrhiza, C. limosa, C. diandra, C. heleonastes, C. aquatilis* as well as *Calliergon richardsonii*, which is similar to stand group 8.

The above studies of similar peatland communities did not classify the fens precisely. The communities have been called transition fens in the sense that they have a vegetation and/or water chemistry that is transitional between that of a bog and that of a rich fen, and not because they have characteristic species that identify them as a fen type. They have also been called rich fens, but no distinction has been made between extreme rich fens and moderately rich fens, unlike Sjors (1952).

Comparison of the Lesser Slave-Athabasca fens with other fen types.

The water chemistry data of this study compares favourably to other studies that have been done on "transitional" fens, especially in terms of pH, calcium and magnesium content (Table 2-6a). With a few exceptions, most of the studies done on poor fens were lower in pH, calcium and magnesium content, while most of the rich fen studied showed higher values for these ions. Relatively few studies have looked at nutrient (N,P) content in these transitional fen waters, although Yefimov and Yefimova's (1973) work in continental USSR showed considerably higher values in nitrate (490 ug/l) and ammonium (660 ug/l) than in this study (10 ug/l NO_3, 89 ug/l NH_4). Peat chemistry data for non-forested fens is sparse, making comparisons difficult (Table 2-6b). Based on calcium content in peat, the Lesser

Table 2-6a. A comparison of macronutrient values found in fen waters.

	REFERENCE	STUDY AREA	pH	Con (µS)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	S (mg/l)	Fe (mg/l)	P (mg/l)
POOR FENS	Comeau & Bellamy (1986)	Eastern Canada	4.3	-	7	2	4	0.4	77	-	
	Wilson & Fitter (1986)	England	-	-	-	-	-			-	3-10
	Karlin & Bliss (1984)	Alberta	3.5-6.1	-	2-12	1-3	-	-	-	-	-
	Bellamy (1968)	Western Europe	4.5	-	20	5	7	2	86	-	
	Sjors (1963)	Ontario	4.1-5.4	16-22	2	0.5	0.3	0.1	-	-	-
	Persson (1962)	Sweden	4.3-5.0	-	60-950	10-330	68-130	7-79	-	-	-
	Tolpa & Gorham (1960)	Poland	3.8	-	.4-.9	-	.4-.7	.1-.7	10-11	-	-
	Sjors (1948)	Sweden	4.2	-	6	2	2	0.4	12	-	-
	Zoltai & Johnson (1987)	Alberta	4.7	45	2	0.8	4	0.9	1	0.9	0.24
TRANSITIONAL	Comeau & Bellamy (1986)	[illegible]nada	5.5	-	15	6	7	1	12	-	
	Karlin & Bliss (19[illegible]	[illegible]	4.6-7.1	-	4-51	2-12	-	-	-		
	Schwintzer (1981)	Michigan	5.7-7.0	-	11-75	-	-	-	-	-	-
	Yefimov & Yefimova (1973)	U.S.S.R.	6.1	-	18	8	1	0.3	32	0.4	0.3
	Persson (1961)	Sweden	5.4-7.0	-	40-50	30	85-93	5-16	-		-
	Sjors (1948)	Sweden	6.0	-	68	12	2	0.4	25	-	-
	Zoltai & Johnson (1987)	Alberta	6.0	249	28	11	5	1	1.8	0.5	0.1
RICH FENS	Karlin & Bliss (1984)	Alberta	7.2-8.2	-	31-120	10-53	-	-	-		-
	Bellamy (1968)	Western Europe	[illegible]6	-	183	19	11	2	216	-	
	Sjors (1963)	Ontario	5.8-7.4	48	9	2	1	0.3	-	-	-
	Sjors (1961)	Ontario	7.9	207	32	7	5	0.6	-	-	-
	Persson (1961)	Sweden	5.7-7.9	-	100-1380	50-1690	47-144	4-36	-	-	-
	Zoltai & Johnson (1987)	Alberta	6	374	54	17	6	0.8	1.8	0.04	0.09

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CHAPTER I Introduction and Historical Review.

A. INTRODUCTION.

In the Lesser Slave-Athabasca area of Alberta, there are peatlands that do not meet the historical definition of bog, poor fen nor rich fen in that they do not have the corresponding indicator species or water chemistry. Unlike bogs, these flat peatlands occupying depressional areas appear to be influenced by ground water from the surrounding uplands which is moderately rich in minerals. Their vegetation is not *Sphagnum* dominated as in the case of poor fens, nor are they rich fens, since they do not have the classic indicator species such as *Scorpidium scorpioides* and *Drepanocladus revolvens*.

The pH range of these peatlands is approximately 5.5-7.0, which is higher than that of poor fens (3.8-6.1), but generally lower than that of rich fens (5.8-8.4, see Table 1-2). The vegetation is dominated by brown mosses of the genus *Drepanocladus*, and sedges are also common. Based upon the bryophyte layer, these peatlands are superficially different from both poor and rich fens.

A study was undertaken to characterize these peatlands in terms of their vegetation, water chemistry and peat chemistry. The fen type represented by these peatlands was then identified. This study is documented in chapter 2. The relationship of these Lesser Slave-Athabasca fens to other non-forested fens in Alberta was then examined in terms of vegetation-chemistry relationships over a broad range of fen types. This study is documented in chapter 3.

B. HISTORICAL REVIEW.

Peatlands are characterized by wet organic soils called peats, which are partially decomposed plant materials that accumulate as a result of slow decomposition in wet, anaerobic conditions. Under the Canadian System of Soil Classification, organic layers must be at least 40–60 cm deep to be recognized as peatlands (Anon 1978). This effectively excludes areas with predominantly shallow peat deposits, where the vegetation is often rooted in the underlying mineral soil, as is the case with marshes and swamps. Peatlands are abundant in the boreal and subarctic zones (Moore and Bellamy 1974), occupying sites with an excess of water. Within these two large areas, there are three main peatland regions: a colder, northern Arctic or Subarctic region; a wetter maritime or oceanic region; and a drier inland or continental region (Zoltai & Pollett 1983).

Peatlands are unique in that they build up their own substrate, and thus create their own environment, regardless of the climatic zone that they are found in. The accumulation of peat raises the peatland surface above the influence of the original mineral-rich substrate, so that the system is fed mainly by ground water flowing or seeping in. Further accumulation of peat can raise the entire system above the influence of ground water, so that it is fed only by mineral-poor rain water. Weber (1908) was one of the first to describe this hydrotopographical development in peatlands from *Niedermoore* (low bogs) to *Hochmoore* (raised bogs).

Another feature that makes peatlands difficult to classify, is the great variability that can be found at different scales within and between peatlands. The variation in peatland vegetation has long been described by Swedish researchers in terms of four major vegetational gradients that reflect physical gradients (Tuomikoski 1942; DuRietz 1949; Sjors 1952). The hummock to hollow gradient reflects microtopo- graphical variation within short distances, and is related to water levels. The mire (peatland) expanse to mire margin gradient is related to a physiognomic or shade gradient from an open, non-forested centre to a forested margin. The poor-rich (also called ombrotrophic to minerotrophic) gradient represents a nutrient gradient related to the type of water supply within or between peatlands. The oceanic to continental gradient is related to climatic differences between moist maritime conditions and drier inland conditions. Together, these four vegetational gradients reflect the great variability that can be found within and between peatlands, and suggest that peatland types may be distinguished on the basis of many physical criteria as well.

Historically, peatlands have been distinguished by three main criteria : vegetation, hydrotopography and chemistry.

Vegetation.

Vegetational studies assume that the vegetation is the best integrator and thus indicator of the environment. The vegetation is intimately related to the physical and chemical environment from which it derives its resources. Some species have strict requirements and a narrow range of environmental tolerance which limits their distribution to specific sites. Those species that are exclusive to a certain site type are good indicator species of that environment. Those that show a marked preference for a certain site type, although they may also be present to a smaller extent in other environments are labelled characteristic species. A major problem exists in that many peatland plants have broad limits of tolerances with respect to different physical gradients, possibly as a consequence of having developed physiological races (Longton 1974; Pakarinen 1979), and therefore, they have limited value as indicator species. A more general approach, is to use the physiognomy of the vegetation to distinguish between the peatland types. The effect of stratification in the vegetation has a strong effect on the micro- climate within the community, and can be considered an important feature in peatland classification. Many of the early classifications of peatlands distinguished between forest, shrub, sedge and moss peatlands. In addition, one of the most basic divisions in peatland vegetation is between *Sphagnum* dominated peatlands which are relatively acidic, and brown moss (Bryopsida) dominated peatlands which are more calcareous.

Hydrotopography.

As mentioned before, the surface topograhy and the hydrology of a peatland are intricately related. Weber's (1908) morphological division of peatlands into *Hochmoore, Ubergangsmoore* and *Niedermoore* was modified by Kulczynski (1949) to give corresponding ombrophilous, transitional and rheophilous hydrologic types. One of the most fundamental hydrologic divisions in peatlands is that between ombrophilous or rain-fed peatlands, and rheophilous or ground water fed peatlands. These two terms also correspond to the ombrogenous and geogenous peatlands of von Post and Granlund (1926). In addition, topogenous peatlands, with stagnant or slow moving waters showing mainly vertical oscillations in the water table, are distinguished from soligenous ones with flowing or horizontal water movements . A complication arises when vertical water movements can sometimes have similar effects on the vegetation as flowing water at a constant level (Malmer 1986). Thus, classifications based on hydrotopography (Radforth 1952; Bellamy 1968; Goode 1973) do not necessarily correspond with those based on the vegetation. In addition, the hydrotopography affects the vegetation in two different ways that are often difficult to distinguish, i.e. directly through water availability, as opposed to indirectly through nutrient availability in the water.

Chemistry.

Peatlands, as a whole, are considered nutrient-poor in comparison to upland sites where the vegetation is rooted in a more nutrient-rich mineral soil. The supply of nutrients in a peatland depends on the quality and flow rate of the water entering the peatland (Sjors 1952). The quality of nutrients in the water depends on the chemical nature of its origin, and whether it is through atmospheric deposition or contact with the surficial and/or bedrock geology of the area. The fundamental division of peatlands into ombrotrophic (rain-fed) and minerotrophic (ground water origin) has often been studied with reference to pH, conductivity, calcium, magnesium, potassium and sodium content in the water. Calcium, magnesium and sodium are by far the most abundant cations present in the ground water. Nutrients present in much smaller and often limited amounts, such as nitrogen and phosphorus, are actively taken up by plants and are key elements in the fertility status of any ecosystem. In this study, the term limited nutrient will refer to nitrogen and phosphorus content, while mineral or ionic content will refer to major ions such as calcium, magnesium and sodium.

Correlation between vegetation and environmental factors.

The correlation between peatland vegetation and nutrient content in water has been extensively studied (Kivinen 1935; Witting 1949; DuRietz 1949; Sjors 1952, 1959, 1961a, 1961b, 1963; Gorham 1956; Ritchie 1957; Henoch 1960; Jeglum 1971, 1972; Vitt *et al.* 1975; Horton *et al.* 1979; Slack *et al.* 1980; Sims *et al.* 1982; Karlin & Bliss 1983), but the terminology is not clear. The poor-rich vegetation gradient (DuRietz 1949) in peatlands refers to the low number of indicator species present in *Sphagnum* dominated peatlands as opposed to the high number of indicator species found in brown moss dominated peatlands. This poor-rich vegetation gradient reflects an underlying hydrotopographical and chemical gradient often refered to as the ombrotrophic-minerotrophic gradient (Sjors 1952), from ombrogenous (rain-fed) mineral-poor conditions, to geogenous (ground water-fed) mineral-rich conditions. The bog-fen concept represents a composite of vegetational, chemical and hydrotopographical gradients. Bogs are poor in the number of indicator species, usually *Sphagnum* dominated, and ombrotrophic, while fens are rich in the number of indicator species, often brown moss dominated and minerotrophic.

Although the water chemistry *per se*, is a major factor in determining the type of vegetation, it is often difficult to separate its effects from hydrologic events. Sites with similar water chemistry may support very different plant communities as a result of different hydrotopographic developments which control the flow rate of water, and indirectly, the amount of minerals and nutrients available. The use of water chemistry as a basis for classification is hampered by its seasonal variation in water supply, and it is therefore necessary to couple such studies with flow rates and annual water budgets to produce a complete picture (Moore 1984).

Peat chemistry, on the other hand, is less subject to seasonal variation. Seasonal variations in the water supply do not greatly affect the macronutrient content of the peat which is several orders of magnitude larger than that of the water. The chemical analysis of peat (Malmer & Sjors 1955; Olenin 1951) has been used in supplementary descriptions of peatlands. More recently, attempts have been made to use peat chemistry to characterize peatland types (Zoltai & Tarnocai 1971; Pollett 1972; Stanek & Jeglum 1977). These studies generally showed ombrotrophic peats to have lower mineral and nutrient contents than minerotrophic peats, a trend that is found in the water chemistry as well.

Classification.

As can be seen, it is not the lack of criteria that makes peatland classification difficult. Rather, it is a question of which criteria are considered more important, and whether an agglomerative or divisive approach to classification is taken. The Zurich-Montpelier (Braun-Blanquet 1932) approach which stresses the vegetation, has a strong tradition in central Europe. The basic unit is the plant community association defined by its own indicator and characteristic species. This is an agglomerative approach whereby similar associations are grouped together into larger units, regardless of any spatial relations. For example, string communities in a patterned peatland may be grouped with forested peatlands, although they are an intergral part of patterned peatlands.

The Finnish aproach (Cajander 1913; Ruuhijarvi 1960; Eurola 1962) is based on the site-type concept, where habitats which are ecologically similar are held to support a similar vegetation. Using a divisive approach, seven main units of peatland vegetation are distinguished, each defined by its indicator species and four physical parameters : the trophic status, the water level associated with the hummock to hollow gradient, the source and flow of water, and the physiognomy of the vegetation (Eurola *et al* 1984). One problem, as mentioned before, is the lack of perfect correspondence between vegetational, hydrotopographical and chemical criteria, such that the defining physical parameters may each cover more than one category. This type of approach, nevertheless, serves to compartmentalize peatlands into distinct types based on important criteria, and can be practical for broader-based studies and non-specialists (Allington 1961; Jeglum *et al.* 1974; Wells 1980).

Other approaches have been based on one or two criteria deemed to be more important than others. In most of these studies, three basic peatland types have been recognized :

Peatland Types			Reference
Hochmoore	**Ubergangsmoore**	**Niedermoore**	Weber 1907
Oligotrophic	**Mesotrophic**	**Eutrophic**	Tsinzerling 1938
Ombrophilous	**Transitional**	**Rheophilous**	Kulczynski 1949
Bog	**Poor Fen**	**Rich Fen**	DuRietz 1949

At this basic level of differentiation, the above terms all describe the same three types of peatlands. A more detailed description of these three basic types is given below, following DuRietz's (1949) bog-fen concept.

The bog-poor fen-rich fen concept.

DuRietz's (1949) original division of peatlands into bogs, poor fens and rich fens was based on the vegetation, and more precisely, the number of indicator species. The poor-rich gradient in peatland vegetation refers to the variation from *Sphagnum* dominated communities with a poor or low number of indicator species, to brown moss (Bryopsida) dominated communities with a rich or large number of indicator species. A summary of indicator and characteristic species that have been used by various researchers to define these peatland types is given in Table 1-1.

Table 1-1a. Distribution of common vascular plant species along the bog-fen gradient.

VASCULAR PLANTS	BOG	POOR FEN	INTER. FEN	MODERATELY RICH FEN	EXTREME RICH FEN
Calluna vulgaris	———	–			
Rubus chamaemorus	———	———	–		
Chamaedaphne calyculata	———	———	–		
Carex oligosperma	———	———			
Carex exilis	———	–			
Eriophorum vaginatum	———	———	———	– –	– –
Scheuchzeria palustris	———	———	———	—— –	
Scirpus caespitosus	———	———	———	———	———
Andromeda polifolia	———	———	———	———	———
Carex limosa	———	———	———	———	———
Eriophorum angustifolium	–	———	———	———	———
Menyanthes trifoliata		———	———	———	———
Equisetum fluviatile		———	———	———	———
Carex rostrata		———	———	———	———
Carex lasiocarpa		———	———	———	———
Carex chordorrhiza		———	———	———	———
Juncus stygius		–	———	———	– –
Utricularia intermedia		–	———	———	– –
Potentilla palustris		–	———	———	———
Scirpus hudsonianus		–	———	———	———
Pinguicula vulgaris		–	———	———	———
Carex flava			———	———	———
Epilobium palustre			—— ——	———	———
Tofieldia pulsatilla			–	———	———
Tofieldia glutinosa				——	———
Parnassia palustris				——	———
Carex heleonastes				——	———
Carex diandra				——	———
Carex atrofusca				——	———
Triglochin maritima				–	———
Triglochin palustre				–	———
Carex microglochin					———
Muhlenbergia glomerata					———
Habenaria hyperborea					———
Schoenus ferrugineus					———
Epipactis palustris					———
Liparis loeselii					———

Species selected from DuRietz (1949), Sjors (1950, 1952, 1961a, 1963, 1982), *Ruuhijarvi (1960), Persson (1961, 1962), **Eurola (1962), Vitt & Slack (1975), Vitt et al. (1975), Horton et al. (1975), Slack et al. (1980), Malmer (1986).

* Minerotrophe Weissmoore = poor fen.

** Scorpidium, Drepanocladus revolvens and Campylium stellatum Braunmoore = rich fen.

Table 1-1b. Distribution of common bryophyte species along the bog-fen gradient.

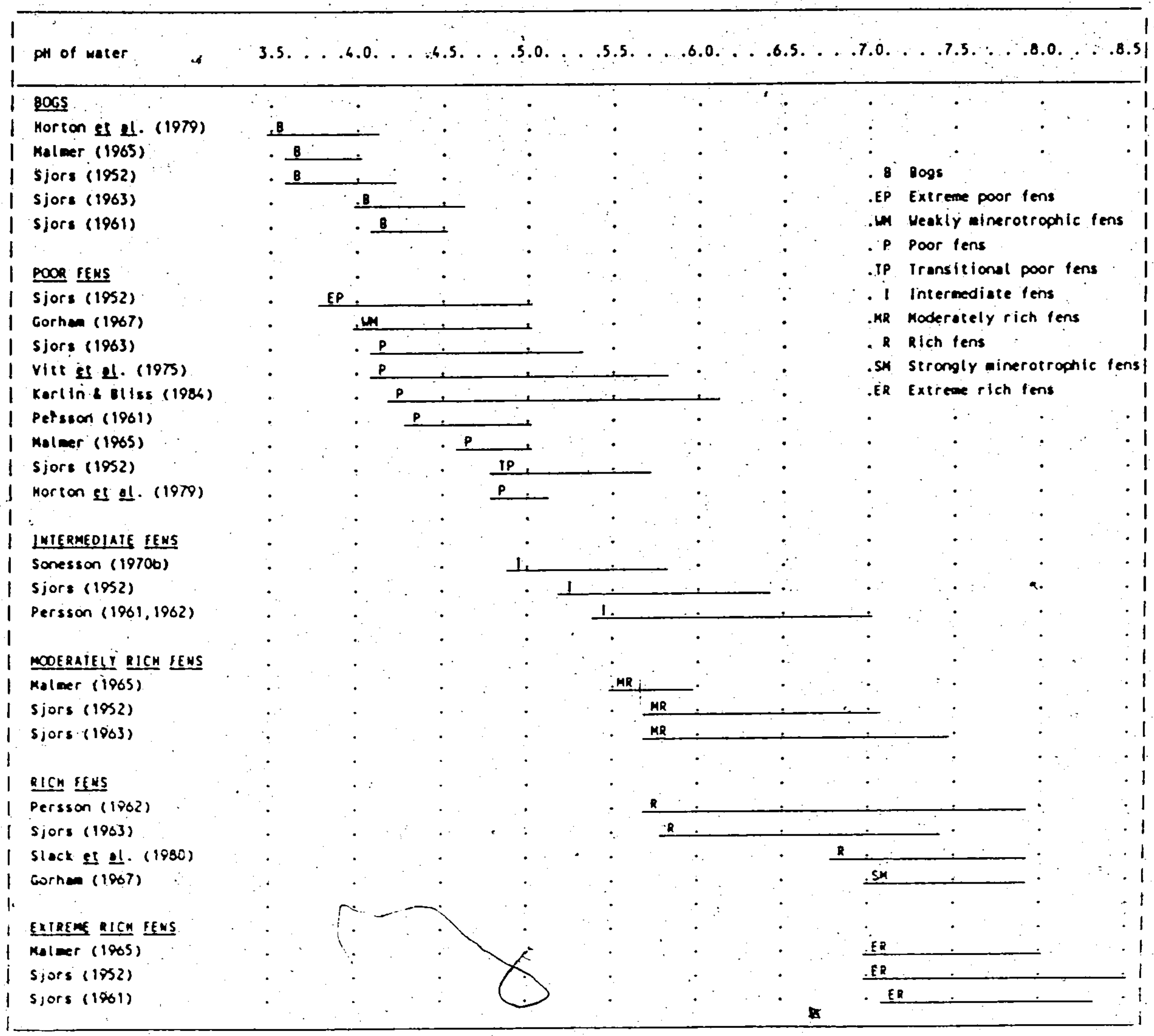
BRYOPHYTES	BOG	POOR FEN	INTER. FEN	MODERATELY RICH FEN	EXTREME RICH FEN
Mylia anomala	———				
Spahgnum cuspidatum	———	———			
Sphagnum balticum	———	———			
Sphagnum rubrum	———	– –	–		
Sphagnum tenellum	———	———			
Drepanocladus fluitans	———	———			
Gymnocolea inflata	———	———			
Cladopodiella fluitans	———	———	———	———	
Sphagnum fuscum	———	———	———	———	–
Sphagnum magellanicum	———	———	———	———	–
Sphagnum angustifolium	———	———	———	———	–
Sphagnum lindbergii	———	———	———		
Sphagnum majus	———	———	——— –		
Sphagnum riparium	–	———			
Sphagnum jensenii		———			
Sphagnum pulchrum		———			
Sphagnum fallax		———			
Sphagnum papillosum	–	———	———	–	
Sphagnum subsecundum		———	———	–	
Drepanocladus exannulatus		———	———	– –	–
Calliergon stramineum		———	———	———	–
Scapania paludicola		–	———		
Calliergon sarmentosum		–	———		
Odontoschisma elongatum			———	–	
Sphagnum subfulvum			———	——— –	
Cinclidium subrotundum			———	——— –	
Paludella squarrosa			———	———	——— –
Aneura pinguis		–	———	———	———
Tomenthypnum nitens			———	———	———
Drepanocladus badius			———	———	——— –
Sphagnum warnstorfii			———	———	——— –
Sphagnum teres			———	———	———
Sphagnum contortum			–	———	–
Sphagnum subnitens				———	
Bryum pseudotriquetrum			———	———	———
Calliergon giganteum				———	———
Campylium stellatum				———	———
Drepanocladus revolvens				———	———
Meesia triquetra				———	———
Scorpidium scorpioides				———	———
Meesia uliginosa				———	———
Cinclidium stygium					———
Calliergon trifarium					———
Catoscopium nigritum					———
Calliergon turgescens					———

Sjors (1952) arranged these peatland types along a water chemistry gradient, specifically, a pH and mineral content gradient. He found the poor-rich vegetation gradient to correspond well with a pH and mineral gradient. Because the poor-rich vegetation gradient parallels the ombrotrophic-minerotrophic gradient, the two sets of terms have often been used synonymously. Other researchers have followed this vegetation/chemistry approach, and a summary of their distributions of peatland communities along a pH gradient is shown in Table 1-2. Referring to Tables 1-1 and 1-2, the following peatland types are defined :

Bogs.

Bogs are *Sphagnum* dominated peatlands with a small number of indicator species such as *Sphagnum cuspidatum, S. balticum, Mylia anomala* and ground lichens (DuRietz 1949; Sjors 1950, 1961a, 1982; Vitt & Slack 1975; Malmer 1986). They are ombrotrophic in that they receive water from precipitation only. Bogs are usually raised or otherwise isolated from the influence of ground water which is more mineral rich. Consequently, the mineral content is extremely low (Sjors 1952; Malmer 1965; Vitt & Slack 1975, Horton *et al.* 1979). As such, minerotrophic fen plants, those requiring a higher mineral content, such as *Menyanthes trifoliata, Carex rostrata, Carex lasiocarpa* and *Sphagnum fallax* are absent. In Alberta, ombrotrophic peatlands in the Caribou Mountains with *Picea mariana* and *Sphagnum* dominated vegetation, especially *S. fuscum, S. magellanicum* and ground lichens of the genera *Cladina, Cetraria* and *Cladonia* have been described as bogs (Horton *et al.* 1979).

Table 1-2. Distribution of peatland communities along a pH (water) gradient.



Black spruce bog islands dominated by *Sphagnum angustifolium*, *Sphagnum fuscum* and *Sphagnum magellanicum* have also been described at Mariana Lakes (Nicholson 1987)

Fens.

Fens have a higher number of indicator species, and generally a greater diversity. Ubiquitous species include *Menyanthes trifoliata*, *Carex rostrata*, *C. lasiocarpa*, *C. chordorrhiza* and *Potentilla palustris*. In addition, each fen type has its own indicator and characteristic species. Fens are minerotrophic and influenced by ground water that is higher in mineral content than precipitation. The pH is usually greater than 4.0. The different fen types cannot easily be distinguished by their hydrotopography alone. Their waters may be topogenous (stagnant) or soligenous (flowing) depending on ther slope. These fens may be patterned with a network of drier "strings" with wet "flarks" or pools in between, or they may be non-patterned and uniform. The different fen types are furth distinguished by their vegetation and the water chemistry.

Poor Fens.

Poor fens are *Sphagnum* dominated, minerotrophic peatlands. Indicator species include *S. lindbergii*, *S. majus*, *S. jensenii*, *S. riparium*, *S. fallax* and *S. pulchrum* (DuRietz 1949; Sjors 1950, 1982; Ruuhijarvi 1960; Persson 1961; Malmer 1986). Other species such as *Drepanocladus exannulatus* and *S. subsecundum* may also be present (Sjors 1963; Vitt *et al.* 1975). The ground waters flowing into these peatlands have a pH of 4.0-~~5.5~~ (Sjors 1952, 1963; Persson 1961; Malmer 1965; Gorham 1967; Vitt *et al.* 1975; Karlin & Bliss 1984). In the Swan Hills of Alberta, non-forested minerotrophic peatlands dominated by *S. jensenii, S. majus* and *Drepanocladus exannulatus*, and with pH of 4.2-5.8 were identified as poor fens (Vitt *et al.* 1975). Nicholson (1988) also reported *Sphagnum angustifolium* and *Sphagnum jensenii* dominated poor fens at Mariana Lakes.

Rich Fens.

Rich fens are brown moss dominated, minerotrophic peatlands. The basic indicator species include *Drepanocladus revolvens, Campylium stellatum, Bryum pseudotriquetrum, Tomenthypnum nitens*, along with *Tofieldia glutinosa, Triglochin maritima* and *T. palustre* (Sjors 1961a,1963; Ruuhijarvi 1960; Persson 1961; Malmer 1986). Ground water has a pH in the range of 5.7-7.8. Two types of rich fens have been recognized : moderately rich fens and extreme rich fens.

Extreme rich fens have additional indicator species of highly calcareous conditions. These include *Scorpidium scorpioides, Calliergon trifarium, Meesia uliginosa, Catoscopium nigritum, Calliergon turgescens* and vascular plants such as *Muhlenbergia glomerata, Carex microglochin, Habenaria hyperborea, Schoenus ferrugineus, Epipactis palustris* and *Liparis loesellii* (Sjors 1950, 1961a, 1963, 1982; Slack *et al.* 1980; Malmer 1986). The highly calcareous ground water, often with marl (precipitated calcium carbonate) present, has a pH in the 7.0-8.4 or higher range (Sjors 1952, 1961a; Malmer 1965; Gorham 1967).

Moderately rich fens, also called transitional rich fens, are less well-defined than extreme rich fens. They have the basic rich fen indicator species as mentioned before, but not the indicator species of the highly calcareous conditions in extreme rich fens. Other species of importance that have been noted in these communities include *Sphagnum warnstorfii, S. teres, S. contortum, S. subnitens* and *Drepanocladus exannulatus* (Sjors 1961, 1982; Malmer 1965, 1986). These species are not particularly exclusive nor most abundant in moderately rich fens. Reported pH's of these communities range from 5.5–7.3.

Rich fen studies do not always make a distinction between extreme rich fens and moderately rich fens. In the Rocky Mountain Foothills of Alberta, non-forested minerotrophic fens with an abundance of *Scorpidium scorpioides, Campylium stellatum, Calliergon trifarium, Catoscopium nigritum, Meesia triquetra* and *Triglochin palustre*, along with high pH's of 6.8-7.4 were identified as rich fens (Slack *et al.* 1980). These were extreme rich fens, judging from the abundance of *Scorpidium scorpioides*.

Sjors (1952) pointed out that the three main peatland types are not compartments with strict boundaries, but regarded the variation from bog-poor fen-rich fen as gradual. This continuum approach has also been favoured in British studies (Bellamy 1968; Daniels 1978; Slater 1984). Sjors recognized intermediates between the three basic types (Table 1-2), especially moderately rich fens, as described above, and intermediate fens.

<u>Intermediate fens</u>.

DuRietz's (1949) original division of peatlands into bogs, poor fens and rich fens has been amended by Sjors (1952) and Persson (1961,1962) to include intermediate fens as well. Sjors originally described these fens as having the less exclusive species of rich fens, mixed with species of poor fens, but Persson believed them to have characteristic species as well. At present, intermediate fens are described as distinct entities with *Scapania paludicola, Calliergon sarmentosum, Odontoschisma elongatum, Cinclidium subrotundum*, and *Sphagnum subfulvum* as the characteristic species (Sjors 1952, 1982; Persson 1961; Sonneson 1970; Malmer 1986). Also present are poor fen species such as *Sphagnum papillosum, S. subsecundum, Drepanocladus exannulatus*, and rich fen species such as *Paludella squarrosa, Drepanocladus badius, Sphagnum warnstorfii, S. teres, Bryum pseudotriquetrum* and *Campylium stellatum*. The water chemistry of these fens have a pH range of 5.2-7.0 (Sjors 1952; Persson 1961, 1962), which is approximately the same range as that described for moderately rich fens. Fens such as these have not been described in Alberta, nor North America.

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CHAPTER II The vegetation, surface water chemistry and peat chemistry of fens in the Lesser Slave-Athabasca area of central Alberta, Canada.

A. INTRODUCTION.

Much of Alberta lies in the Boreal Forest Zone (Rowe 1972), where peatlands cover 21% of the province (Anon. 1986). In the southeast, warm, dry prairie conditions with excessive evapotranspiration limit the distribution of peatlands. To the southwest, steep slopes and the higher elevations of the Rocky Mountains restrict peatlands to late snowmelt areas and to the lowest valleys.

Within the Boreal Forest Zone, Zoltai & Pollett (1983) recognized two major wetland regions. The Mid-Boreal Wetland Region across the central part of the province is characterized by forested flat bogs and basin bogs associated with patterned fens, as well as flat fens and basin fens in the absence of permafrost. The High Boreal Wetland Zone in the northern part of the province is colder and characterized by patterned fens, small wooded peat plateaux and palsas, flat bogs and fens.

Peatland classifications in Canada have been devised for specific practical purposes, as well as for general use in broad-based studies. Most of them have borrowed ideas from Scandanavia and Europe. Radforth's (1952) Muskeg Classification, which stressed the appearance of the peatland from the air, is an example of a system devised for engineering purposes. More recently, there has been interest in peatlands as potential forestry sites in Alberta, and a site classification for drainage and growth potential has been considered by Harkonen (1985) and Makitalo (1985), following the pioneering work of Finnish researchers (Cajander 1913; Heikurainen 1979). Other studies have followed the Braun-Blanquet (1932) approach, which stressed the vegetation component (Dansereau & Segadas-Vianna 1952; Segadas-Vianna 1955; Railton & Sparling 1973; Gauthier & Grandtner 1975). The site-type concept (Cajander 1913), which combined aspects of hydrotopography with physiognomy of the vegetation was found to be more practical for broader-based studies and non-specialists (Allington 1961; Tarnocai 1970; Jeglum *et al.* 1974; Wells 1981). To the above combination, the Zoltai *et al.* (1973) wetland classification included the concept of bog and fen based on the vegetation physiognomy.

The Zoltai *et al.* (1973) wetland classification is a user-oriented classification based on criteria important to many disciplines. Hierarchical in structure, the early divisions are based on the bog-fen concept, hydrotopography and physiognomy of the vegetation, while the lower levels are flexible and subject to modification depending on the purpose of the study.

Most of the peatland studies in Alberta have been done on forested peatlands or muskeg, as they are most abundant. Black spruce bogs have been described in the Caribou Mountains of northern Alberta (Horton *et al.* 1979), and in central Alberta (Nicholson 1987; Zoltai & Johnson 1987). Dominated by *Picea mariana, Sphagnum fuscum, S. magellanicum, S. angustifolium* and lichens in the genera *Cladina, Cetraria,* and *Cladonia*, and with extremely low water pH (3.3-4.1 at Mariana Lakes). Many of these compare favourably to the ombrotrophic bogs described by Swedish researchers (see Tables 2-1 and

2-2). Few studies have been done on open, non-forested peatlands. Non-forested poor fens have been described in the Swan Hills (Vitt *et al.* 1975), and at Mariana Lakes (Nicholson 1987). Dominated by *Sphagnum jensenii, S. majus, S. angustifolium* and *Drepanocladus exannulatus, they have water pH of 4.2-5.8. In the Rocky Mountain Foothills, non-forested minerotrophic fens with an abundance of Scorpidium scorpioides, Drepanocladus revolvens, Campylium stellatum, Tomenthypnum nitens, Calliergon trifarium, Catoscopium nigritum, Meesia triquetra* and *Triglochin maritima*, along with high pH of 6.8-7.4 were identified as rich fens (Slack *et al.* 1980). It is apparent that the bogs, poor fens and rich fens as defined by the Scandinavians have their equivalents here in Alberta.

Peatlands in the Lesser Slave-Athabasca area.

In the Lesser Slave-Athabasca area of Alberta, there are non-forested peatlands that do not meet the historical definition of bog, poor fen or rich fen in that they do not have the corresponding indicator species (Table 2-1) or water chemistry (Table 2-2). These peatlands are minerotrophic in that they are influenced by ground water from the surrounding uplands, and hence, they are not bogs. Their vegetation is not *Sphagnum* dominated, and their waters are moderately rich in minerals, with pH generally above 5.5, and hence, they are not poor fens. Nor are they rich fens, since they do not have the indicator species *Scorpidium scorpioides* and *Drepanocladus revolvens*, and the mineral content of their waters is not as high, usually with pH's below 7.0.

The pH range of these peatlands is approximately 5.5-7.0, which is higher than that of poor fens (3.8-6.1), but generally lower

Table 2-1a. Distribution of common vascular plant species along the bog-fen gradient.

VASCULAR PLANTS	BOG	POOR FEN	INTER. FEN	MODERATELY RICH FEN	EXTREME RICH FEN
Calluna vulgaris	———	–			
Rubus chamaemorus	———	———			
Chamaedaphne calyculata	———	———	–		
Carex oligosperma	———	———			
Carex exilis	———	–			
Eriophorum vaginatum	———	———	———	– –	– –
Scheuchzeria palustris	———	———	———	——— –	
Scirpus caespitosus	———	———	———	———	———
Andromeda polifolia	———	———	———	———	———
Carex limosa	———	———	———	———	———
Eriophorum angustifolium	–	———	———	———	———
Menyanthes trifoliata		———	———	———	———
Equisetum fluviatile		———	———	———	———
Carex rostrata		———	———	———	———
Carex lasiocarpa		———	———	———	———
Carex chordorrhiza		———	———	———	———
Juncus stygius		–	———	———	– –
Utricularia intermedia		–	———	———	– –
Potentilla palustris		–	———	———	———
Scirpus hudsonianus		–	———	———	———
Pinguicula vulgaris		–	———	———	———
Carex flava			———	———	———
Epilobium palustre			– –	———	———
Tofieldia pulsatilla			–	———	———
Tofieldia glutinosa				———	———
Parnassia palustris				———	———
Carex heleonastes				———	———
Carex diandra				———	———
Carex atrofusca				———	———
Triglochin maritima				–	———
Triglochin palustre				–	———
Carex microglochin					———
Muhlenbergia glomerata					———
Habenaria hyperborea					———
Schoenus ferrugineus					———
Epipactis palustris					———
Liparis loeselii					———

Species selected from DuRietz (1949), Sjors (1950, 1952, 1961, 1963, 1982), *Ruuhijarvi (1960), Persson (1961, 1962), **Eurola (1962), Vitt & Slack (1975), Vitt et al. (1975), Horton et al. (1975), Slack et al. (1980), Malmer (1986).

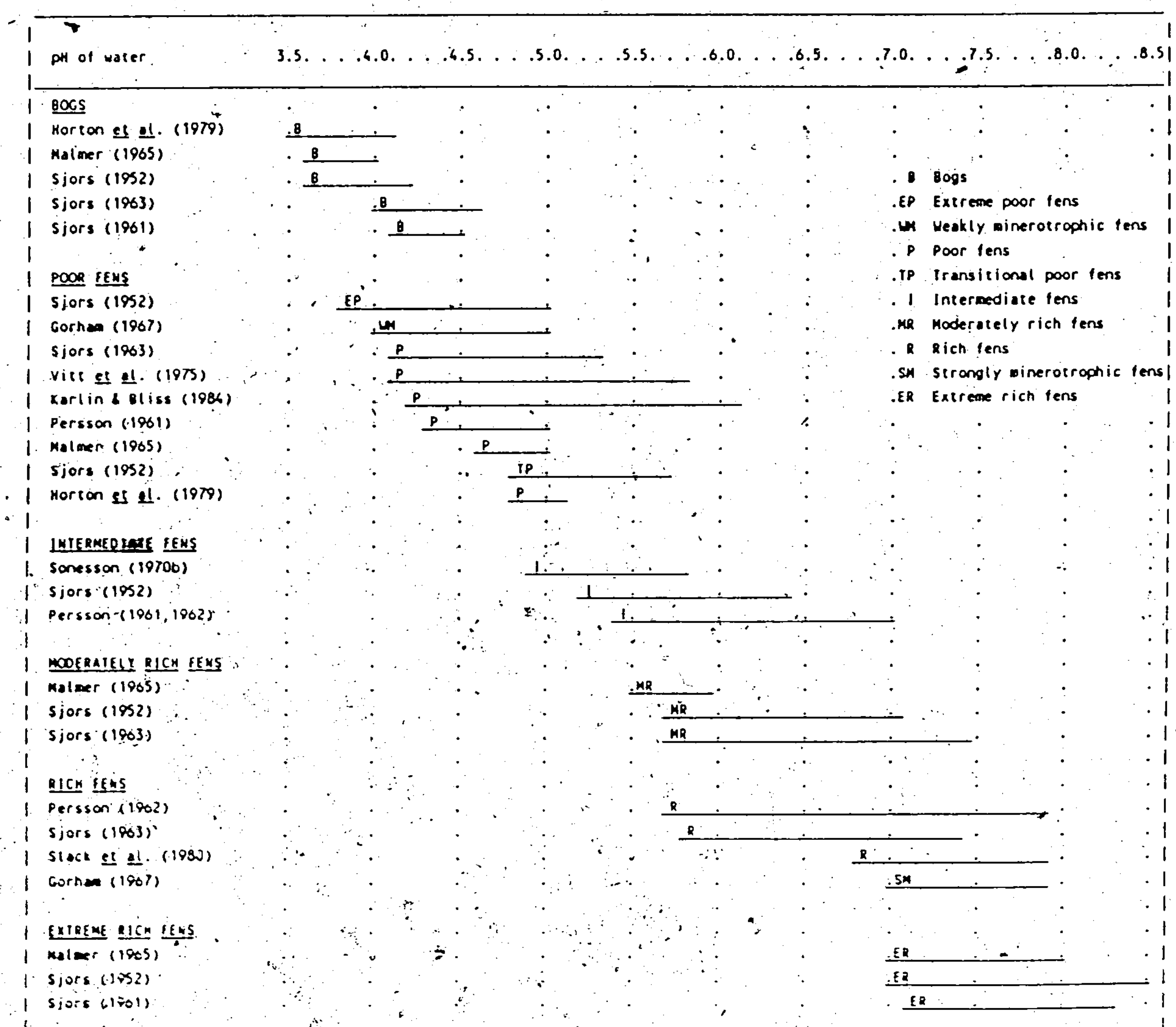
* Minerotrophe Weissmoore = poor fen.

** Scorpidium, Drepanocladus revolvens and Campylium stellatum Braunmoore = rich fen.

Table 2-1b. Distribution of common bryophyte species along the bog-fen gradient.

BRYOPHYTES	BOG	POOR FEN	INTER. FEN	MODERATELY RICH FEN	EXTREME RICH FEN
Mylia anomala	———				
Spahgnum cuspidatum	———	———			
Sphagnum balticum	———	———			
Sphagnum rubrum	———	– –	–		
Sphagnum tenellum	———	———			
Drepanocladus fluitans	———	———			
Gymnocolea inflata	———	———			
Cladopodiella fluitans	———	———	———	———	
Sphagnum fuscum	———	———	———	———	–
Sphagnum magellanicum	———	———	———	———	–
Sphagnum angustifolium	———	———	———	———	–
Sphagnum lindbergii	———	———	———		
Sphagnum majus	———	———	——— –		
Sphagnum riparium	–	———			
Sphagnum jensenii		———			
Sphagnum pulchrum		———			
Sphagnum fallax		———			
Sphagnum papillosum	–	———	———	–	
Sphagnum subsecundum		———	———	–	
Drepanocladus exannulatus		———	———	– –	–
Calliergon stramineum		———	———	———	–
Scapania paludicola		–	———		
Calliergon sarmentosum		–	———		
Odontoschisma elongatum			———	–	
Sphagnum subfulvum			———	——— –	
Cinclidium subrotundum			———	——— –	
Paludella squarrosa			———	———	——— –
Aneura pinguis		–	———	———	———
Tomenthypnum nitens			———	———	———
Drepanocladus badius			———	———	——— –
Sphagnum warnstorfii			———	———	——— –
Sphagnum teres			———	———	———
Sphagnum contortum			–	———	–
Sphagnum subnitens				———	
Bryum pseudotriquetrum			———	———	———
Calliergon giganteum				———	———
Campylium stellatum				———	———
Drepanocladus revolvens				———	———
Meesia triquetra				———	———
Scorpidium scorpioides				———	———
Meesia uliginosa				———	———
Cinclidium stygium					———
Calliergon trifarium					———
Catoscopium nigritum					———
Calliergon turgescens					———

Table 2-2. Distribution of peatland communities along a pH (water) gradient.



than that of rich fens (6.8-8.4). The vegetation is dominated by brown mosses of the genus *Drepanocladus*, but *Drepanocladus revolvens* is rare. Based upon the bryophyte layer, these peatlands are superficially different from poor and rich fens.

Objectives.

The main objective of this study is to characterize the peatlands of the Lesser Slave-Athabasca area in terms of their vegetation, water and peat chemistry : stand groups (plant communities) along with their indicator species are identified; the calcium, magnesium, sodium, potassium, iron, sulphur and phosphorus content of the water and peat are determined, in addition to the pH, specific conductance, organic nitrogen, ammonium and nitrate content of the surface water. Based on the assumption that the vegetation is often a good indicator of the environment, correlations are then examined to identify important environmental parameters underlying the distribution of plant communities. On the basis of the vegetation and water chemistry, a comparison to previously described peatland types is discussed, in an attempt to fit these peatlands into an existing classification.

B. STUDY AREA.

The study area consists of fourteen peatlands in central Alberta. They range from Mitsue Lake in the west to LaBiche River in the east, and from Rock Island Lake in the north to Flatbush in the south (Fig. 2-1). Located in the Lesser Slave Lowlands and the Eastern Alberta High Plains physiographic subzones (Anon 1969), these peatlands occur at elevations of 580-640 m. The gently rolling topography of the area is underlain by marine and continental Upper Cretaceous grey shales and sandstones (Feniak 1944; Borneuf 1973; Campbell 1972; Vogwill 1978). The surficial deposits are predominantly sands, sands and gravels, and gravels, the result of till, glacial outwash, post-glacial lacustrine and aeolian deposition. Glaciated by Laurentide Ice in the Pleistocene, the area became ice-free approximately 12,000-11,800 years ago (Prest 1969). Moderately well-drained, medium textured soils are common in this area. Gray Luvisols developed from clay-rich tills, while Eutric Brunisols and Podsols developed from sandy aeolian deposits (Strong 1984).

All sites are located within the Mixedwood section of the Boreal Forest Zone (Rowe 1972). The upland forests are dominated by *Pinus banksiana, Populus tremuloides, Picea glauca* and *Abies balsamea*. Peatlands occupy depressional areas between the surrounding uplands. Forested peatlands have *Larix laricina* and *Picea mariana* as the dominant trees. Open non-forested peatlands are less common, and are dominated by shrubs such as *Betula pumila* and *Salix* species, as well as sedges and brown mosses (Class Bryopsida). *Sphagnum* dominated peatlands are not common.

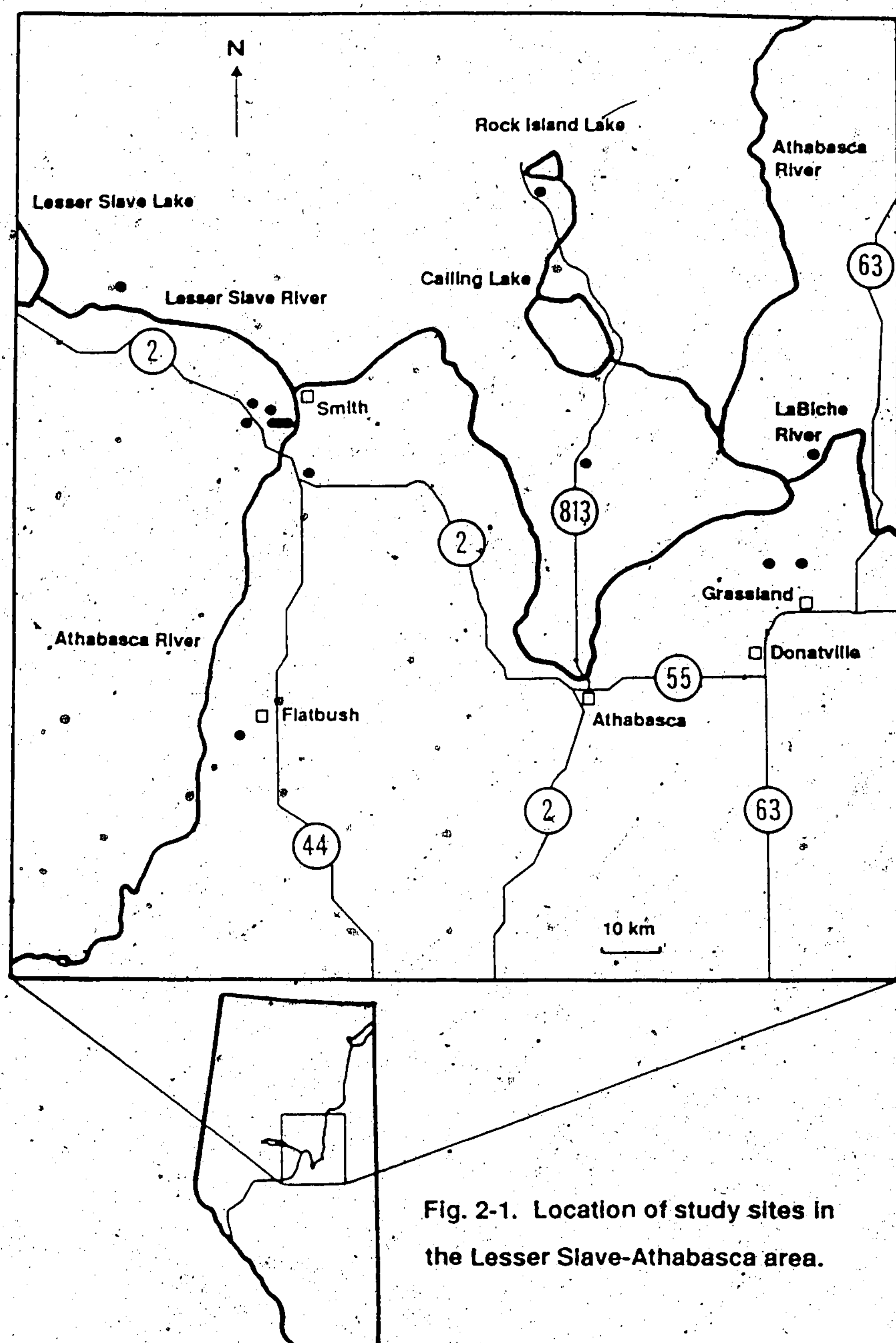


Fig. 2-1. Location of study sites in the Lesser Slave-Athabasca area.

The climate is boreal cold temperate with cold winters and short cool summers (climate type VIII, Walter & Lieth 1960, Fig. 2-2). This climate type is also typical of the aapamire or patterned fen zone in Asia (Moore and Bellamy 1974). During the growing season of May to September, mean monthly temperature is 12°C, and total precipitation is 340 mm.

Site locations.

Site 1 : stands 1-3, 55° 02′ N, 112° 42′ W, 550 m; 17 km due SW of Breynat; a lagg fen between a raised bog and Aspen upland.

Site 2 : stands 4-12, 54° 05′ N, 112° 48′ W, 595 m; 18.3 km north of Donatville on Spruce Valley Road; a patterned fen with shrub-dominated strings.

Site 3 : stands 13-15, 52° 55′ N, 112° 41′ W, 575 m; 10 km north of Grassland; a non-patterned shrub fen.

Site 4 : stands 16-18, 55° 27′ N, 113° 22′ W, 680 m; 32.8 km NW of Calling Lake on Hwy 813; a non-patterned fen in a recharge zone.

Site 5 : stands 19-21, 55° 05′ N, 113° 17′ W, 660 m; on Hwy 813, 46.6 km north of Athabasca River; a non-patterned fen with *Larix laricina* around the margin.

Site 6 : stands 22-31, 55° 19′ N, 114° 35′ W, 580 m; 7.2 km north of Mitsue Lake; a patterned fen with *Larix laricina* on well developed strings.

Site 7 : stands 32-34, 55° 07′ N, 114° 05′ W, 585 m; north of Hwy 2, 11.5 km NW of junction 2A, then 5.6 km east on a Norcen well-site road; a non-patterned fen along a narrow water track next to a sand dune.

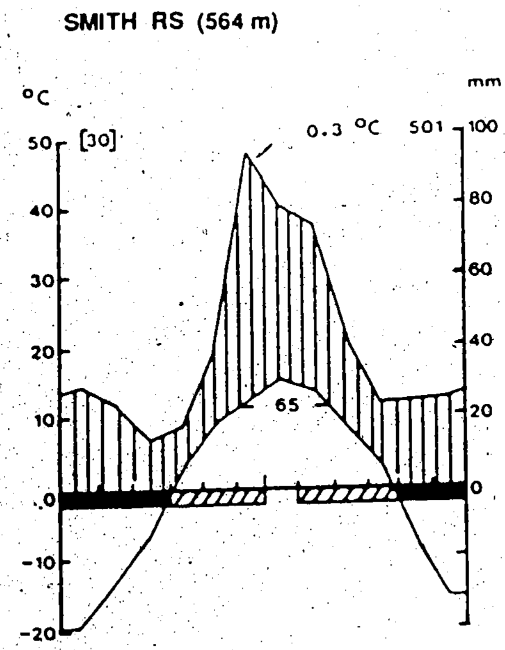


Fig. 2-2. Climate diagram for the Lesser Slave - Athabasca area, after Walter & Lieth (1960); upper line is monthly precipitation; lower line is mean monthly temperature; solid bar is months with mean temp. below 10°C; diagonally hatched bar is months with absolute minimum temp. below 0°C; mean annual temperature and annual precipitation is in top right corner; number of frost free days in middle. Data obtained from meteorological records (Anon. 1984).

Site 8 : stands 35-37, 55^{o} 08′ N, 114^{o} 09′ W, 600 m; up Hwy 2, 11.5 km NW of junction 2A, then 2 km east and north on a Norcen well-site road; a non-patterned fen at the outlet of a small lake between two bog islands.

Site 9 : stands 38-40, 55^{o} 07′ N, 114_{o} 07′ W, 585 m; up Hwy 2, 11.5 km NW of junction 2A, then 3.2 km east on a Norcen well-site road; a non-patterned fen in a depression within a sand dune complex.

Site 10 : stands 41-43, 55^{o} 07′ N, 114^{o} 09′ W, 585 m; up Hwy 2, 11.5 km NW of junction 2A, then 1.5 km east on a Norcen well-site road; a non-patterned fen with *Larix laricina* invading.

Site 11 : stands 44-49, 55^{o} 08′ N, 114^{o} 12′ W, 590 m; off Hwy 2 13.4 km NW of junction 2A; a non-patterned fen in a depression within a sand dune complex.

Site 12 : stands 50-54, 55^{o} 07′ N, 114^{o} 11′ W, 590 m; off Hwy 2, 12.2 km NW of junction 2A; a non-patterned fen in a depression within a sand dune complex.

Site 13 : stands 55-58, 55^{o} 02′ N, 114^{o} 02′ N, 610 m; 3 km south of Hondo, on NE corner of junction 2 and 2A; a non-patterned fen within a sand dune complex.

Site 14 : stands 59-60, 54^{o} 30′ N, 114^{o} 08′ W, 610 m; 8 km south of Flatbush on road parallelling Hwy 44, then west 0.4 km up old cutline.

C. METHODS.

Site selection.

The fourteen sites in the Lesser Slave - Athabasca area were selected in May 1984, using the following criteria : pH of water 5.5-7.0; absence of *Scorpidium scorpioides* and *Drepanocladus revolvens*; not *Sphagnum* dominated; with rich fen and poor fen indicator species (Table 2-1) absent or negligible. These are basically default criteria for fens that are neither poor fens nor extreme rich fens.

Vegetation sampling.

The vegetation of the fourteen Lesser Slave-Athabasca peatland sites were sampled from June to August of 1984. A restricted random sampling technique (Daubenmire 1968) was used. Three to ten stands were sampled at each site, depending on the complexity and number of visually distinct communities in the peatland. In patterned peatlands, strings and flarks were sampled separately. In each stand, a base line was laid out (medially along the long axis of flarks in patterned peatlands). At random intervals along the baseline, a 25x25cm quadrat or subplot was placed randomly within 5 metres perpendicular to the baseline, on an undisturbed patch of vegetation. A minimum of ten quadrats were sampled per stand. Additional quadrats were sampled until no new species were encountered. Each quadrat was assigned a microtopographic category (wet hollow, soft wet-moist carpet, firm moist lawn or high dry hummock), an indirect measure of water level. Additional quadrats were added until a representative ratio of hollow to hummock subplots was obtained. A rough average of the subplot categories was assigned to the stand. Vegetation data was taken in the form of percent canopy cover (Daubenmire 1959). Voucher specimens were collected and deposited in the University of Alberta Herbarium. Nomenclature follows Moss (1983) for vascular plants, Ireland (1982) and Nyholm (1954-1969) for mosses, Stotler and Crandall-Stotler (1977) for hepatics, and Hale and Culberson (1970) for lichens.

Chemical analyses.

Samples of fen water from natural pools, surface water table or water seeping into dugout holes were collected in spring 1985 (May 18-21), and again in fall 1985 (September 10-15) for all stands with the exception of those on strings. Specific conductance (adjusted to 25°C and corrected for $[H^+]$ following Sjors (1950)) and pH were also measured in the field at these times. The samples were stored at 4°C, filtered through a Whatman 42 filter, acidified with 1 part 4N HCl to 24 parts sample, and analyzed for cation content (Ca, Mg, Na, K, P, S, Fe) on an inductively coupled argon plasma spectrometer at the Northern Forestry Centre, Edmonton, Alberta.

Three other water samples taken for determination of nitrogen content were analyzed within 48 hours at either the Limnology Lab or the Meanook Field Station of the Department of Zoology, University of Alberta. All lab analyses were done on triplicate subsamples, which were then averaged. Organic nitrogen plus ammonium was analyzed using the total Kjeldahl nitrogen method (D'Elia 1976). Nitrate content was obtained using the cadmium reduction method (Strickland & Parsons 1968) after filtration of the field sample through a 0.45 millipore filter. Ammonium content was obtained using the phenolhypochlorite method (Weatherburn 1967).

Peat samples were collected in fall (September 3-5) 1984. In each stand, samples were collected from the aerobic surface portion (0-5 cm), and from the anaerobic subsurface portion (30-35 cm). Total calcium, magnesium, sodium, potassium, sulphur, iron and phosphorus were analyzed by dry ashing 0.30 gm of ground sample at 490°C followed by digestion with 1.5 N HCl and concentrated HNO_3. The samples were then filtered and diluted to 25ml with double distilled water, and analyzed for ion content on the inductively coupled argon plasma spectrometer.

Data analyses.

All stands were classified and ordinated on the basis of their vegetation. TWINSPAN, a two-way indicator species analysis (Hill 1979, program CEP-41 in Cornell Ecology Programs Series), was used for the classification. The resulting matrix is analogous to that obtained by a Braun-Blanquet (1932) tabular classification, where stand groups and species groups are recognized. The stands are ordinated by reciprocal averaging, the ordination is then split up on basis of "indicator" species to produce dichotomous stand groups. These "indicator" species refer to the most highly differential species within a particular dichotomy, but are not necessarily restricted to that dichotomy. In this study, indicator species will refer to the differential species used by TWINSPAN to distinguish the stand groups.

Characteristic species will generally refer to species that typify a certain stand group, but are not necessarily restricted to it. The TWINSPAN program was run using the default options, with the exception of the pseudospecies cut levels, which were 0, 5, 10, 20, 40, 60 and 80.

DECORANA, a detrended correspondence analysis (Hill & Gauch 1980, CEP-40 in Cornell Ecology Programs Series) was used for the ordination. Based on reciprocal averaging, but without the associated arching and orthogonality problems, artificial scores are calculated for each stand. These can then be plotted along various axes, such that stands with similar vegetation appear close together, and those with dissimilar vegetation appear far apart. Spearman's rank order correlation was then used to correlate the DECORANA (DCA) ordination scores (based solely on the vegetation) to the chemistry variables. Wilcoxon matched-pair rank-sum test was used to test for significant differences between spring and fall water chemistry values, and between surface and subsurface peat chemistry values. Statistical tests were performed using a MIDAS package (Fox & Guire 1976).

D. RESULTS.

1. VEGETATION.

The TWINSPAN classification of the 60 Lesser Slave-Athabasca fen stands is shown in Fig. 2-3, along with the indicator species separating the stand groups. The first division separates the stands into two major groups: those characterized by *Drepanocladus vernicosus, Meesia triquetra, Menyanthes trifoliata, Carex chordorrhiza, Utricularia intermedia* and *Carex limosa*, and those with *Brachythecium mildeanum, Stellaria longifolia, Rubus arcticus, Drepanocladus aduncus, Carex aquatilis, Drepanocladus polycarpus* and *Rumex occidentalis*. Subsequent divisions separate out the drier shrub-moss stands (stand groups 6 & 9) from the wetter sedge-moss stands (stand groups 1-5, 7-8). Nine stand groups are recognized in this study.

In addition, twelve species groups are recognized, with their species occurrences across the nine stand groups shown in Fig. 2-4. A complete list of stands and species within each group is given in Appendix 2-1. Fig. 2-5 shows the frequency distribution of the species groups across the stand groups. Species group G is widely distributed throughout all the fens studied. It includes the hummock species *Betula pumila, Salix pedicellaris, Carex diandra, Bryum pseudotriquetrum, Aulacomnium palustre*, and hollow species such as *Triglochin maritima* and *Potentilla palustris*.

Species group A is characteristic of stand groups 1 to 6. In this species group, *Drepanocladus vernicosus, Meesia triquetra*,

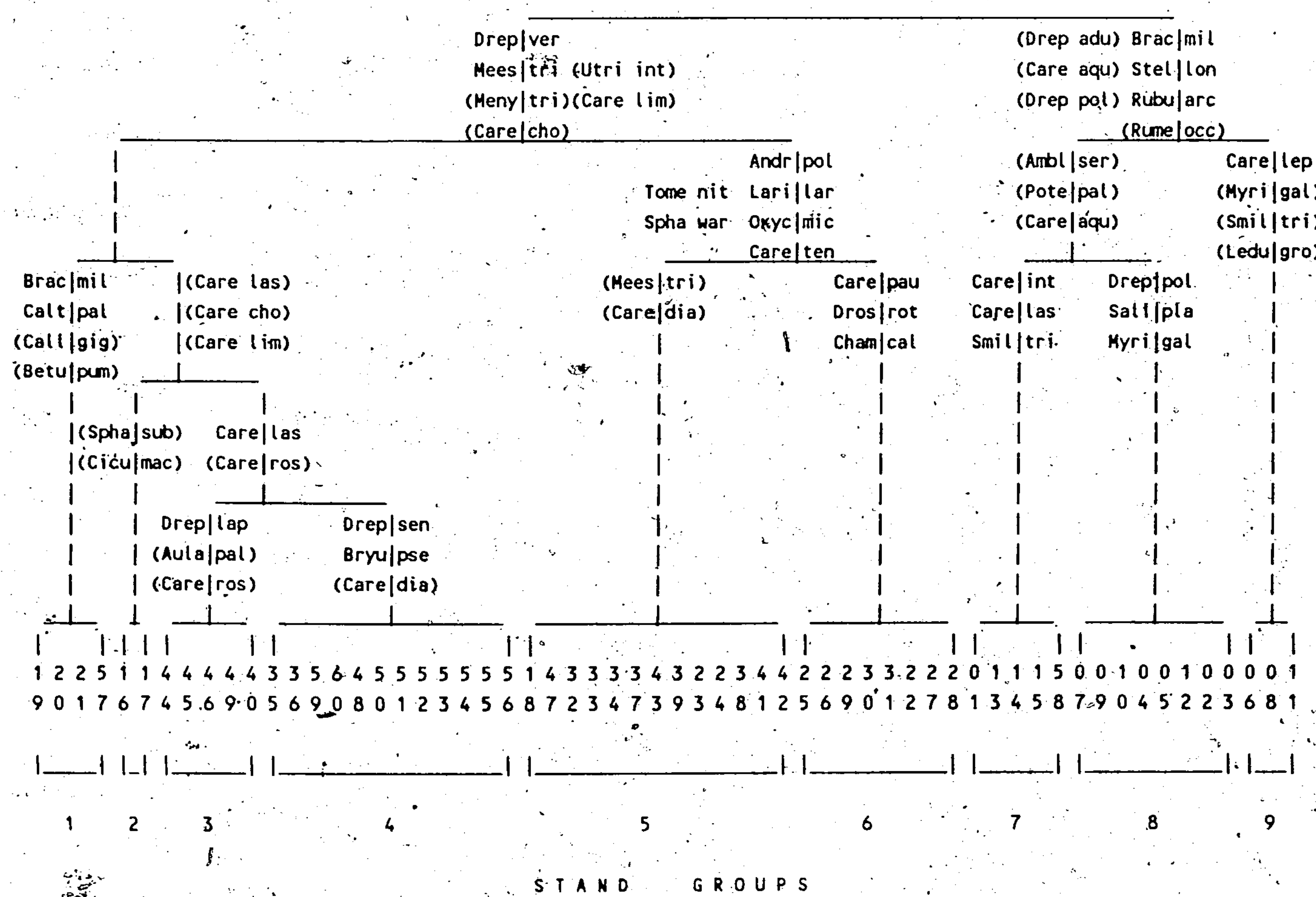


Figure 2·3. TWINSPAN dendrogram of 60 Lesser Slave-Athabasca fen stands. Indicator species names abbreviated to first four letters of the genus and first three letters of the species. Refer to Fig. 2·5 for full names. Species in parentheses are additional high fidelity species with a 75% minimum frequency within group, and a 25% maximum freqency in the dichotomously matched group.

Species groups		STAND GROUPS 1 (4)	2 (2)	3 (5)	4 (12)	5 (13)	6 (8)	7 (5)	8 (8)	9 (3)
A	8	8 (28) 88	8 (14) 88	8 (37) 92	8 (80) 83	8 (84) 81	8 (57) 89	7 (17) 42	5 (7) 18	1 (1) 4
B	4	1 (1) 6	4 (7) 88	2 (5) 25	0 (0) 0	4 (9) 17	0 (0) 0	0 (0) 0	0 (0) 0	0 (0) 0
C	5	2 (2) 10	1 (2) 20	5 (19) 76	5 (33) 55	4 (36) 55	3 (22) 55	4 (8) 32	2 (2) 5	0 (0) 0
D	9	4 (4) 11	0 (0) 0	4 (5) 11	9 (27) 25	5 (6) 5	1 (1) 1	1 (1) 2	1 (2) 3	0 (0) 0
E	9	0 (0) 0	1 (1) 6	4 (5) 11	2 (2) 2	7 (21) 18	9 (33) 46	1 (2) 4	0 (0) 0	0 (0) 0
F	11	5 (5) 11	1 (1) 5	5 (12) 22	4 (9) 7	10 (65) 45	11 (46) 52	9 (21) 38	8 (15) 17	8 (15) 45
G	9	8 (29) 80	6 (8) 44	9 (31) 69	9 (77) 71	9 (93) 79	8 (50) 69	9 (37) 82	8 (46) 64	8 (15) 55
H	12	4 (9) 19	6 (7) 29	4 (10) 17	5 (19) 13	9 (31) 20	7 (14) 15	7 (17) 28	7 (27) 28	11 (21) 58
I	11	10 (21) 48	3 (4) 18	2 (5) 9	8 (13) 10	11 (33) 23	6 (14) 16	11 (44) 80	11 (72) 82	11 (29) 88
J	7	3 (4) 14	0 (0) 0	1 (1) 3	3 (4) 5	5 (9) 10	2 (5) 9	7 (20) 57	5 (22) 39	2 (2) 10
K	6	1 (1) 4	0 (0) 0	1 (1) 3	1 (2) 3	1 (1) 1	1 (1) 2	2 (2) 7	6 (23) 48	2 (2) 11
L	8	2 (4) 12	0 (0) 0	1 (1) 2	2 (2) 2	4 (7) 7	3 (7) 11	4 (6) 15	6 (20) 16	8 (23) 96

Figure 2-4. TWINSPAN stand groups showing species occurrences.
The number of species in each species group, and the number of stands in each stand group are underscored. Upper number in table is the number of species occurring in the individual stand group. Number in parentheses is the number of species occurrences in the stand group. Lower number is the number of species occurrences adjusted to equal block size (after Lausi & Nimis 1985).

SPECIES GROUPS

A. Drepanocladus vernicosus, Carex limosa, Carex chordorrhiza, Menyanthes trifoliata, Meesia triquetra, Equisetum fluviatile, Utricularia intermedia, Eriophorum polystachion.

B. Sphagnum subsecundum, Cicuta maculata, Drepanocladus lapponicus, Calliergon stramineum.

C. Scheuchzeria palustris, Andromeda polifolia, Carex rostrata, Carex lasiocarpa, Agrostis mertensii.

D. Drepanocladus sendtneri, Brachythecium erythrorrhizon, Erigeron lonchophyllus, Stellaria crassifolia, Spiranthes romanzoffiana.

E. Chamaedaphne calyculata, Oxycoccus microcarpus, Drosera rotundifolia, Sarracenia purpurea, Ptilium crista-castrensis.

F. Larix laricina, Picea mariana, Tomenthypnum nitens, Pohlia nutans, Sphagnum warnstorfii, Carex tenuiflora, Sphagnum angustifolium, Sphagnum fuscum, Smilacina trifolia.

G. Betula pumila, Salix pedicellaris, Potentilla palustris, Aulacomnium palustris, Carex diandra, Bryum pseudotriquetrum, Triglochin maritima, Carex interior, Brachythecium turgidum.

I. Drepanocladus aduncus, Brachythecium mildeanum, Drepanocladus polycarpus, Carex aquatilis, Rumex occidentalis, Stellaria longifolia, Hypnum pratense, Rubus arcticus, Caltha palustris, Plagiomnium ellipticum, Calliergon giganteum.

K. Calamagrostis canadensis, Salix petiolaris, Salix planifolia, Salix pyrifolia, Calliergonella cuspidata, Drepanocladus exannulatus.

L. Ledum groenlandicum, Carex disperma, Myrica gale, Carex praegracilis, Betula occidentalis, Parnassia palustris, Vaccinium vitis-idaea, Carex leptalea, Drepanocladus uncinatus.

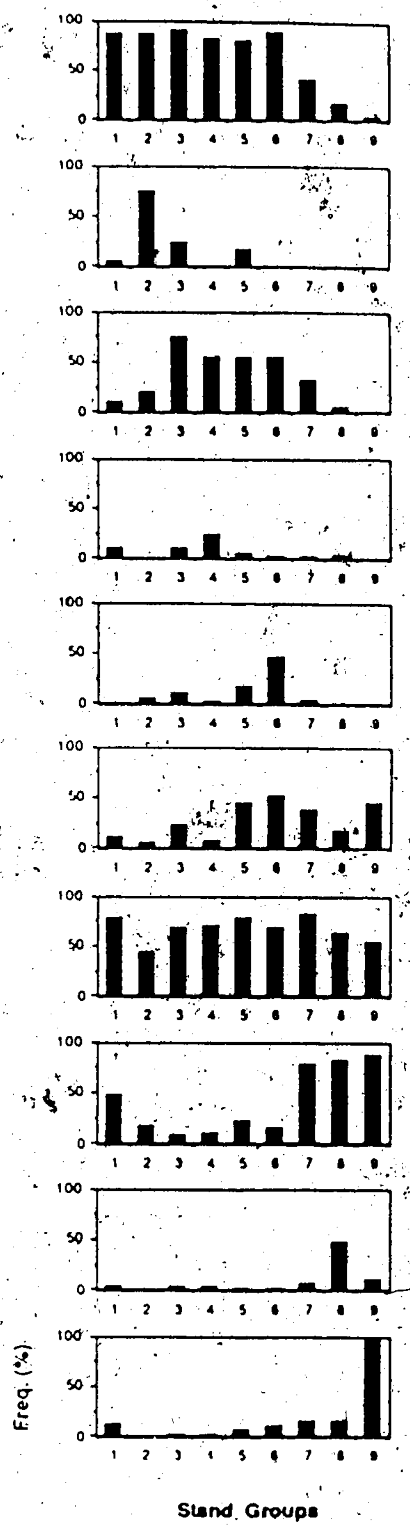


Figure 2-5. Frequency distribution of TWINSPAN species groups across the stand groups. Species groups H & J (low frequencies) omitted.

Menyanthes trifoliata, *Carex chordorrhiza* and *Carex limosa* are common to abundant. *Utricularia intermedia*, *Eriophorum polystachion* and *Equisetum fluviatile* are also common, but of lower abundance. Most of these are hollow species. *Drepanocladus vernicosus* may occur both as a hollow species as well as a mid-hummock species. Species group I characterizes stand groups 7 to 9. Here, *Brachythecium mildeanum*, *Carex aquatilis*, *Drepanocladus aduncus* and *Drepanocladus polycarpus* are common to abundant, while *Stellaria longifolia*, *Rubus arcticus*, *Rumex occidentalis*, *Hypnum pratense* and *Plagiomnium ellipticum* are common with low cover. Most of these are low to mid-hummock species, with *Drepanocladus aduncus* and *Carex aquatilis* also present in the hollows. Together, species groups A and I represent the first major dichotomy in splitting up the sixty stands.

The following is a description of the nine stand groups found in this study. Species that are underscored are indicator species chosen by TWINSPAN. Species in parentheses are high fidelity species (75% minimum frequency within group). Other species used are common species with relatively high abundances.

Stand Group 1 : *(Betula pumila)-Drepanocladus vernicosus-Menyanthes trifoliata* - *Brachythecium mildeanum* - *Caltha palustris* - *(Calliergon giganteum)*.

This stand group is characterized by some species of species group I in addition to species group A, which it shares with stand groups 2 to 6. In this shrub fen community, *Betula pumila* grows on top of low hummocks of *Drepanocladus vernicosus* and *Brachythecium mildeanum*, while *Menyanthes trifoliata*, *Caltha palustris* and *Calliergon giganteum* are found in the wet hollows. Graminoid cover is relatively low, and *Carex diandra* is the main sedge present. Other common species of lower abundance include *Carex limosa*, *Moesia triquetra*, *Equisetum fluviatile*, *Salix pedicellaris*, *Triglochim maritima*, *Potentilla palustris* and *Bryum pseudotriquetrum*.

Stand Group 2 : *(Sphagnum subsecundum - Cicuta maculata)*.

This stand group is characterized by species group B. The two dominant bryophytes are *Drepanocladus lapponicus*, which occurs as a robust submerged species, and *Drepanocladus vernicosus* which may be submerged, emergent or forms low scattered hummocks. *Sphagnum subsecundum*, *Cicuta maculata* and *Calliergon stramineum*, the preferential species, are not as abundant. *Carex limosa*, *Carex chordorrhiza*, *Menyanthes trifoliata*, *Carex rostrata* and *Potentilla palustris* are also common lawn species, while *Salix pedicellaris* is common on scattered low hummocks. Common species of low abundance include *Equisetum fluviatile* and *Utricularia intermedia*. Species richness is comparatively low (Fig. 2-8) in these stands.

Stand Group 3 : *Carex - Drepanocladus vernicosus* - *Drepanocladus lapponicus* - *(Aulacomnium palustre)*.

These stands are characterized by species of group C; especially *Carex rostrata* and *Scheuchzeria palustris*, as well as the the presence of *Drepanocladus lapponicus*. Graminoid cover of *Carex limosa*, *Carex chordorrhiza* and *Carex lasiocarpa* is high in the wet microsites, where *Meesia triquetra*, *Utricularia intermedia*, *Eriophorum polystachion* and *Equisetum fluviatile* are also common. *Drepanocladus vernicosus* is the dominant bryophyte. *Aulacomnium palustre* and *Andromeda polifolia* occur on low hummocks.

Stand Group 4 : *Carex lasiocarpa* - *Drepanocladus vernicosus*- *Drepanocladus sendtneri* - *Bryum pseudotriquetrum* - (*Carex diandra*) - *Meesia triquetra*.

Characterized by *Drepanocladus sendtneri* of species group D, and significant cover of *Bryum pseudotriquetrum*, this stand group also has high graminoid cover. *Carex lasiocarpa* is often the dominant sedge, with *Carex limosa*, *Carex chordorrhiza* and *Carex diandra* common. *Drepanocladus vernicosus* and *Meesia triquetra* are the dominant bryophytes. Widespread species such as *Utricularia intermedia*, *Menyanthes trifoliata*, *Eriophorum polystachion*, *Equisetum fluviatile* and *Triglochin maritima* are common in the wet microsites, while *Salix pedicellaris* and *Betula pumila* are present on scattered low to mid-hummocks.

Stand Group 5 : *Andromeda polifolia* - *Drepanocladus vernicosus*- *Tomenthypnum nitens* - *Aulacomnium palustre* - (*Carex diandra* - *Meesia triquetra*).

These are hummocky stands with *Andromeda polifolia*, *Drepanocladus vernicosus* and *Bryum pseudotriquetrum* occurring in both the wet hollows and the low hummocks. They are characterized by hummock species of species group F such as *Larix laricina, Tomenthypnum nitens, Carex tenuiflora, Sphagnum warnstorfii* and *Smilacina trifolia*. Other widespread hummock species such as *Betula pumila* and *Aulacomnium palustre* are also common. *Carex lasiocarpa, Carex limosa* and *Carex chordorrhiza* are common in the wet hollows and flarks.

Stand Group 6 : *Andromeda polifolia* - *Chamaedaphne calyculata* - *Drepanocladus vernicosus* - *Drosera rotundifolia* - *Sphagnum warnstorfii*- *Carex paupercula*.

These stands represent string stands in patterned fens. They are characterized by hummock species of species group E, such as *Chamaedaphne calyculata, Oxycoccus microcarpus* and *Ptilium crista-castrensis*. Other common hummock species include *Larix laricina, Tomenthypnum nitens, Sphagnum warnstorfii* and *Andromeda polifolia*. *Tomenthypnum falcifolium* may also be present. Two insectivorous species, *Drosera rotundifolia* and *Sarracenia purpureus*, are also present. The flarks are dominated by *Drepanocladus vernicosus, Carex lasiocarpa* and *Carex chordorrhiza*. These stand have the highest species diversity (Fig. 2-7) of this study.

Stand Group 7 : *Drepanocladus aduncus* - *Brachythecium mildeanum* - *Carex aquatilis* - *Carex interior* - *Carex lasiocarpa* - *Smilacina trifolia*.

This stand group is characterized by species group I. *Carex aquatilis, Drepanocladus aduncus, Calliergon giganteum* and *Caltha* *palustris* are found in the flarks and wetter microsites. *Brachythecium mildeanum, Drepanocladus polycarpus, Stellaria longifolia, Hypnum pratense, Rubus arcticus* and *Plagiomnium ellipticum* occur on low hummocks. (These group I species are also common in stand groups 8 and 9.) In addition to species of group I, *Drepanocladus vernicosus, Carex chordorrhiza, Tomenthypnum nitens* and *Aulacomnium palustre* are also common, but of lower abundance. *Carex interior, Carex lasiocarpa* and *Smilacina trifolia*, the three indicator species chosen by TWINSPAN, are also common in stand groups outside of this particular dichotomy.

Stand Group 8 : *Carex aquatilis - Drepanocladus aduncus - Drepanocladus polycarpus - Calliergon giganteum - Myrica gale - Salix planifolia*.

In addition to species of group I, this stand group of flarks is further characterized by species group K. *Calliergonella cuspidata* and *Drepanocladus exannulatus* occur together in the wettest flarks. Low *Salix* shrubs and *Calamagrostis canadensis* are found on low hummocks of *Brachythecium mildeanum, Drepanocladus polycarpus* and *Campylium stellatum*. *Carex aquatilis* and *Drepanocladus aduncus* are the dominant species in these flarks. Other common species of lower abundance include *Myrica gale, Calliergon giganteum, Potentilla palustris, Carex diandra* and *Bryum pseudotriquetrum*.

Stand Group 9 : *(Myrica gale) - Betula spp. - (Ledum groenlandicum) - Carex leptalea - Carex disperma - (Smilacina trifolia) - Aulacomnium palustre.*

This stand group is characterized by hummock species of species group L. They represent shrubby string stands dominated by *Myrica gale* with *Betula occidentalis*, *Betula glandulosa* or *Ledum groenlandicum*. *Carex disperma*, *Carex leptalea* and *Carex praegracilis* are the main sedges. Common hummock species of group L include *Parnassis palustris*, *Vaccinium vitis-idaea* and *Drepanocladus uncinatus*. Other hummock species such as *Rubus arcticus*, *Smilacina trifolia*, *Aulacomnium palustris* and *Sphagnum warnstorfii* are also common.

Detrended correspondence analysis (DCA).

Based on vegetation, the DCA ordination of the sixty Lesser Slave-Athabasca fen stands is shown in Fig. 2-6. The eigenvalue for axis 1 is 0.56, and 0.31 for axis 2. Axes 3 and 4, with eigenvalues of 0.19 and 0.12 respectively, are not plotted.

The separation of the sixty stands in the ordination space into the nine TWINSPAN stand groups is shown in Fig. 2-7. Axis 1 represents a vegetation gradient from *Drepanocladus vernicosus*, *Meesia triquetra*, *Menyanthes trifoliata* and *Carex chordorrhiza* dominated vegetation (stand groups 1-6) to *Brachythecium mildeanum* *Drepanocladus aduncus*, *Carex aquatilis* and *Drepanocladus polycarpus* dominated vegetation (stand groups 7-9). In contrast axis 2 represents a gradient from sedge-moss communities (stand groups

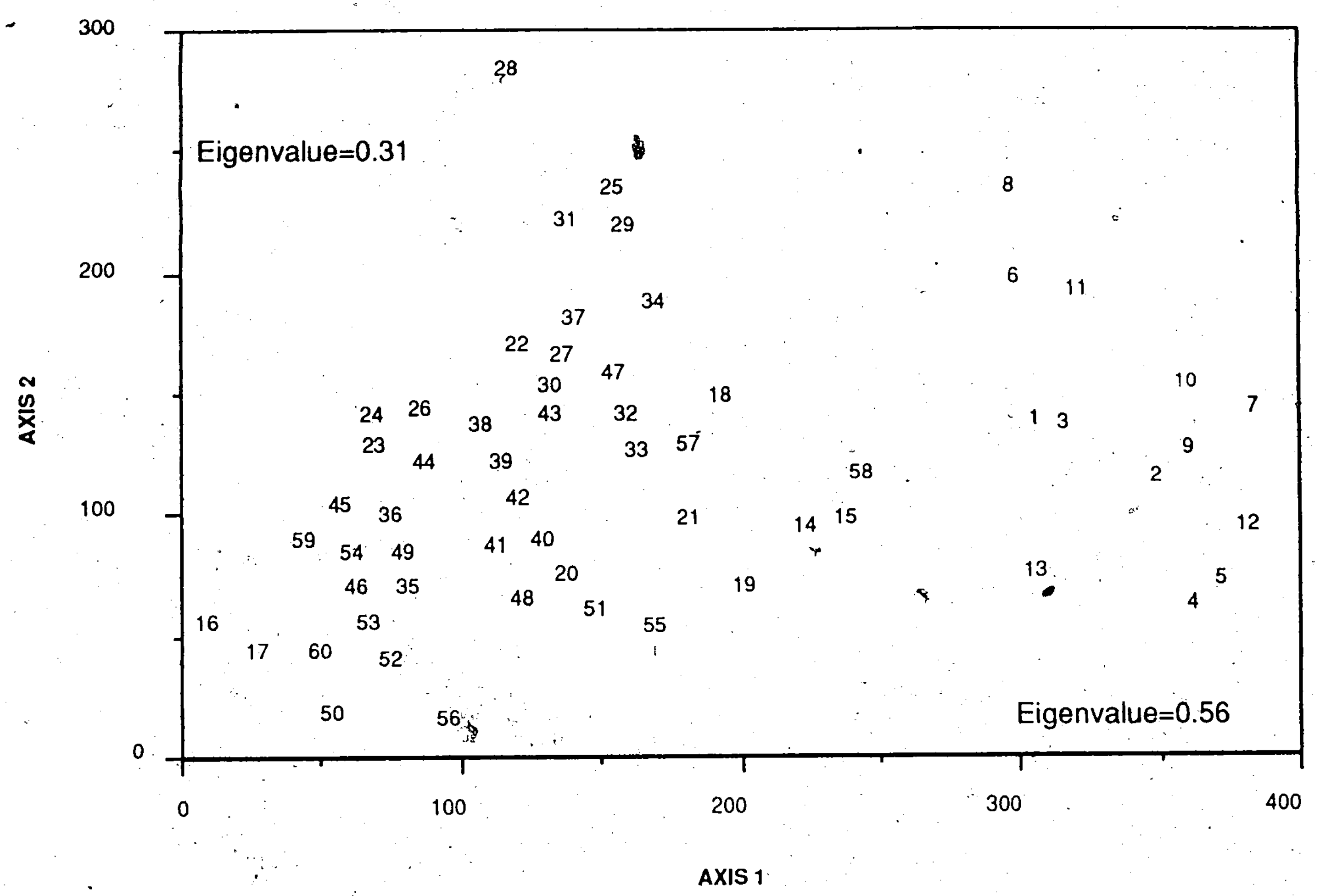


Fig. 2-6. DCA Ordination of 60 stands based on 166 species.

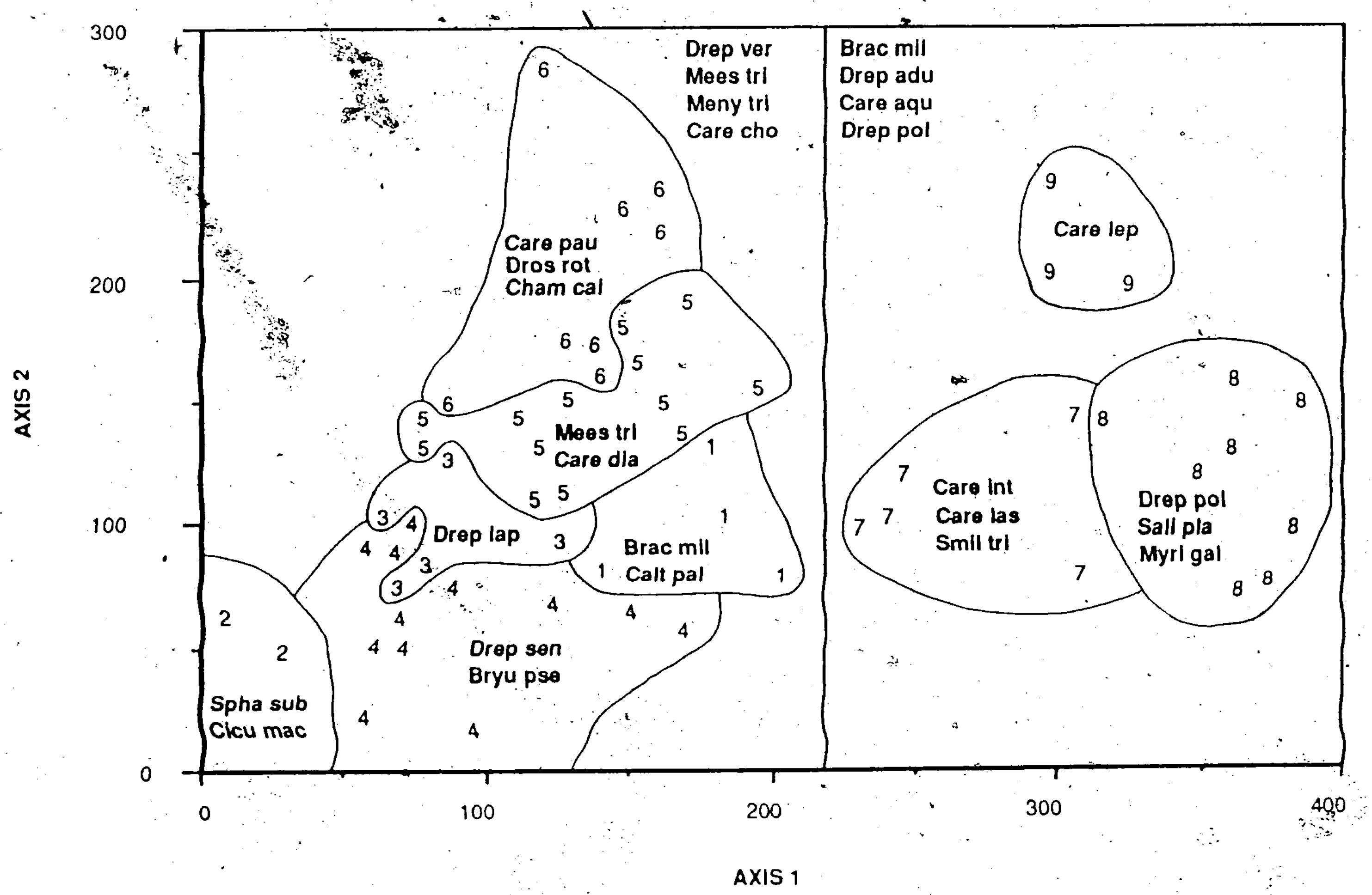


Fig. 2-7. TWINSPAN stand groups superimposed onto DCA ordination. Species names abbreviated to first four letters of genus, and first three letters of species. Refer to Fig. 2-5 for full names.

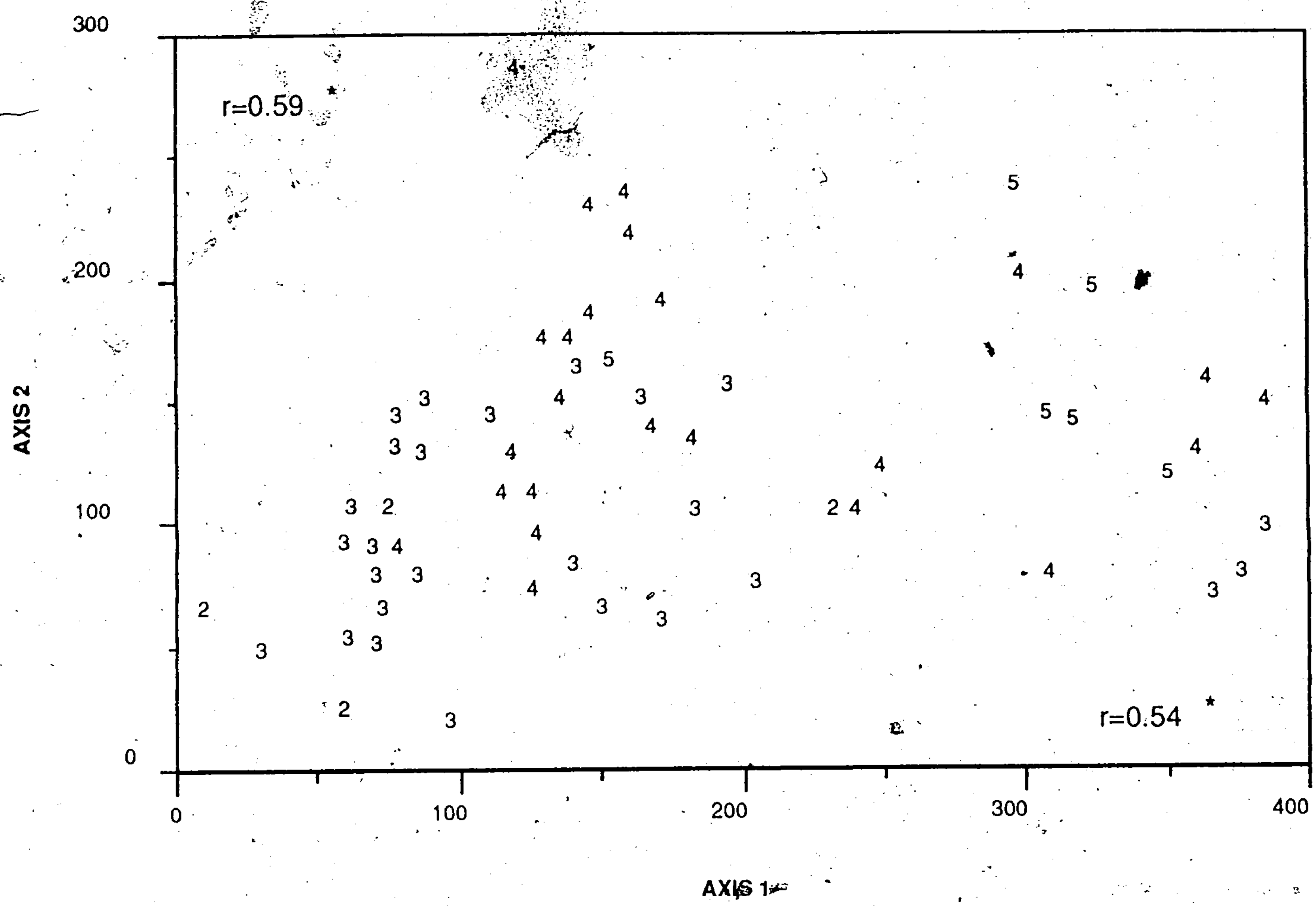


Fig. 2-8. Species richness superimposed onto DCA ordination. 1: 1-10, 2: 11-20, 3: 21-30, 4: 31-40, 5: 41-50. Species richness is significantly correlated to axis 1 and axis 2 scores as shown by the r-value.

1-4, 7-8) to shrub-moss communities (stand groups 5, 6, 9). Both axis 1 and axis 2 are significantly and positively correlated to species richness (Fig. 2-8).

2. CHEMISTRY.

The mean values and standard deviations of twelve water chemistry variables and the eight peat chemistry variables are shown in Tables 2-3a and 2-3b. The pH of the water in the sixty stands ranged from 5.8-7.1 in the spring and 5.3-6.9 in the fall, while the specific conductance ranged from 12-225 µS and 18-240 µS respectively. Magnesium, sodium, potassium, iron, organic nitrogen, nitrate and ammonium content of the fen waters were significantly higher in the fall than in the spring (Table 2-4). There were no significant differences between the spring and fall water values for calcium, sulphur and phosphorus. As for the peat chemistry, magnesium, sodium, potassium, sulphur and phosphorus were all significantly lower in the subsurface (30 cm) peats than in the surface (0 cm) peats (Table 2-4).

3. CORRELATIONS BETWEEN ENVIRONMENTAL FACTORS AND VEGETATION.

The relationships between environmental factors and vegetation can be indirectly determined by correlating the environmental data (mainly chemistry in this study) to the DCA axes scores that were derived from vegetation data. Correlations of chemical variables with the stand vegetation as represented by the DCA axes scores are shown in Tables 2-5a and 2-5b.

Table 2-6b. A comparison of macronutrient values found in fen peats.

	REFERENCE	STUDY AREA	Ca (g/kg)	Mg (g/kg)	Na (g/kg)	K (g/kg)	S (g/kg)	Fe (g/kg)	P (g/kg)	N (g/kg)
POOR FENS	Wilson & Fitter (1986)	England							680,400	
	Karlin & Bliss (1984)	Alberta	10421,15230	4862,1945						
	Wells (1981)	Newfoundland	10895					327		19950
	Waughman & Bellamy (1980)	Canada, Europe								7000-22000
	Pollett (1972)	Newfoundland	5070	1670		370		2090	640	13000
	Zoltai & Johnson (1987)	Alberta	3285	867	267	1587	872	2001	694	
TRANS	Karlin & Bliss (1984)	Alberta	12025,20842							
	Waughman & Bellamy (1980)	Canada, Europe								2000-24000
	Zoltai & Johnson (1987)	Alberta	15687	2874	194	898	2156	3942	774	
RICH FENS	Karlin & Bliss (1984)	Alberta	12825,81763	8752,5399						
	Waughman & Bellamy (1980)	Canada, Europe								8000-20000
	Pollett (1972)	Newfoundland	16130,30630	1310,3210		410,1001		10070,7240	920-1003	20000
	Zoltai & Johnson (1987)	Alberta	49942	4094	105	421	2955	3858	567	

Slave-Athabasca fens are intermediate between that of poor and rich fens, and compares favourably to Zoltai & Johnson's (1984) values for mesotrophic fens. Phosphorus content in peat in this present study is higher than that in both poor and rich fens.

"Transitional" fens cover a wide range in variation between poor and rich fens. The pH range of the fen waters in this study was 5.3-7.1. Transitional fens occupying this pH range have variously been called poor fens, intermediate fens, moderately rich fens, and rich fens (Table 2-2). These fen types are further distinguished by their vegetation (Tables 2-1a and 2-1b). A comparison of the vegetaton of the Lesser Slave-Athabasca fens to these four fen types follows.

The Lesser Slave-Athabasca fens are not poor fens as they do not have a *Sphagnum* dominated vegetation. Key characteristic species of poor fens such as *Sphagnum lindbergii, S. majus, S. riparium, S. jensenii, S. pulchrum* and *S. fallax* are absent. *Sphagnum subsecundum* and *Calliergon stramineum*, two species that are associated with vegetation that is transitional between *Sphagnum* dominated poor fens and brown moss dominated fens, were present in significant amounts in one of the communities described (stand group B). This community also had the lowest pH (5.3-5.5 in the fall) and specific conductance (21-23 µS in the fall). It is, however, not a poor fen as it is dominated by brown mosses such as *Drepanocladus lapponicus* and *Drepanocladus vernicosus*.

Characteristic species of intermediate fens such as *Sphagnum subfulvum, Odontoschisma elongatum, Calliergon sarmentosum, Scapania paludicola* and *Cinclidium subrotundum* (Table 2-1b) are absent from sites included in this study. With the exception of

Scapania paludicola, these species do not occur in Alberta. The Lesser Slave-Athabasca fens are not intermediate fens. Intermediate fens also been defined as having species that are more commonly found in poor fens, and those that are more commonly found in rich fens as well (Persson 1961). The fens of this study contain more species that are associated with rich fens (species group A & G) than with poor fens (species group B).

Rich fens in general, are brown moss dominated, with *Tomenthypnum nitens, Campylium stellatum, Bryum pseudotriquetrum, Meesia triquetra* and *Drepanocladus revolvens* being common. With the exception of *Drepanocladus revolvens*, these species are common in the Lesser Slave-Athabasca peatlands. Rich fens are further subdivided into extreme rich fens and moderately rich fens. Extreme rich fens have additional indicator species of highly calcareous conditions : *Meesia uliginosa, Catoscopium nigritum, Calliergon turgescens, Mühlenbergia glomerata, Habenaria hyperborea, Schoenus ferrugineus, Epipactis palustris* and *Liparis loeselii*. These species are absent from the fens in this study. The Lesser Slave-Athabasca fens are not extreme rich fens. Moderately rich fens are further characterized by *Drepanocladus exannulatus, Sphagnum warnstorfii, S. teres, S. contortum* and *S. subnitens* (Sjörs 1961, 1982; Malmer 1965, 1986). *D. exannulatus* and *S. warnstorfii* are present in some of the stands in this study, but none of the others are.

The Lesser Slave-Athabasca fens.

The Lesser Slave-Athabasca fens have ionic values that are intermediate between that of poor and rich fens (Tables 2-6a and 2-6b). Common and abundant species found in these fens include *Drepanocladus vernicosus, D. aduncus, D. polycarpus, D. lapponicus, Brachythecium mildeanum* and *Meesia triquetra*. With the exception of *Meesia triquetra*, these species are not characteristic of fen types that have previously been described.

Although peatland communities similar to the Lesser Slave-Athabasca fens have been described, they have not been classified as a particular fen type beyond the general "transitional" type that is neither poor fen nor rich fen. On the other hand, the Lesser Slave-Athabasca fens described in this study do not resemble any of the fen types that have previously been described. This may well be the result of comparing these fens in continental Alberta to others from widely disparate geographic areas. Much of the relevant peatland studies have been done in Scandinavia, the British Isles and Eastern Canada (Maritimes) where the climates are oceanic as opposed to continental. A few studies from continental Europe have described similar plant communities, but they have not been classified in the Scandinavian manner.

In determining the fen type, much stress is placed on the presence or absence of characteristic species. The indicator value of the characteristic species, however, is only as good as its range. Many peatland species have a circumboreal distribution. Sjors (1961) found 60% of all vascular plants and all but a few bryophytes to be common to both eastern Canada and northern Europe. Here, in Alberta, poor fens (Vitt *et al.* 1975) and extreme rich fens (Slack *et al.* 1980) with similar characteristic species to those in Scandinavia have been described. The Lesser Slave-Athabasca fens do not have these characteristic species because they are neither poor fens nor extreme rich fens in terms of their chemistries. They do not have the characteristic species of intermediate fens and moderately rich fens either, as the ranges of these species do not extend into this part of Alberta. Intermediate fen indicators such as *Calliergon sarmentosum, Odontoschisma elongatum, Cinclidium subrotundum* and moderately rich fen indicators such as *Sphagnum contortum* and *Sphagnum subnitens* have a more northerly and westerly distribution.

Another problem with using characteristic species is that the indicator value may change with regional variation (Pakarinen 1979). Certain species may have genetically differentiated ecotypes or varieties in different parts of their range, such that their ecological or physiological responses may not be equivalent (Longton 1974). *Drepanocladus vernicosus, D. aduncus, D. polycarpus, D. lapponicus, Brachythecium mildeanum* and other characteristic species of the Lesser Slave-Athabasca fens may not have been described as characteristic species in previous studies simply because they have little or no indicator value elsewhere.

Another hurdle in distinguishing this type of peatland lies in the identification of the various species of *Drepanocladus*. In the field, *Drepanocladus lapponicus, D. vernicosus, D. sendtneri, D. aduncus* and *D. polycarpus* can look very similar and may even be mistaken for *D. revolvens*, a species more commonly found in

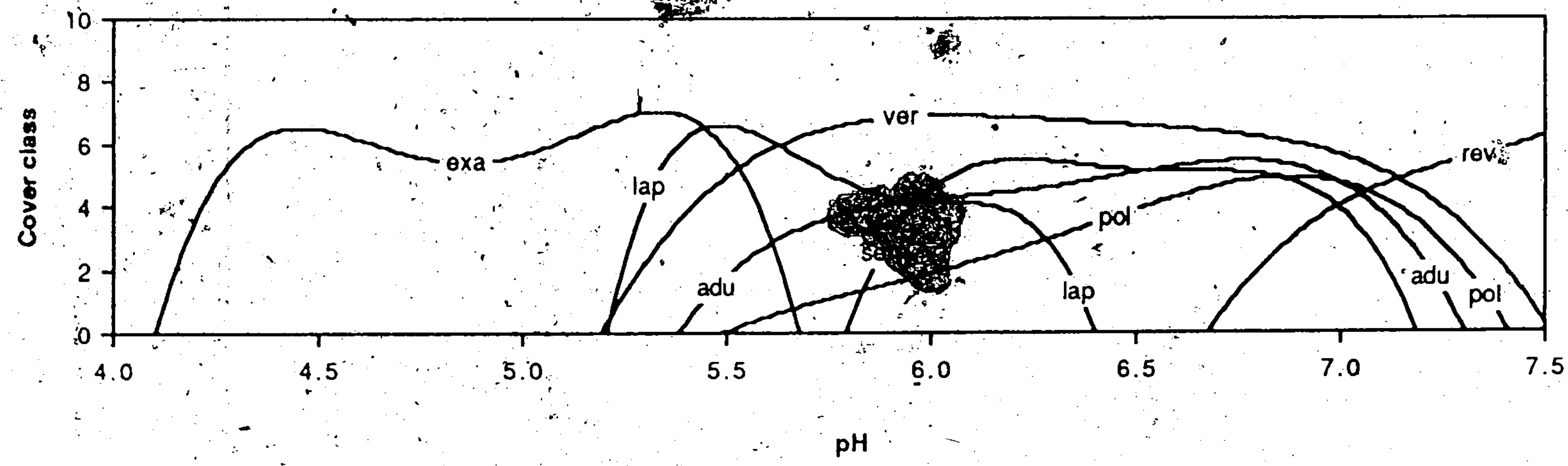


Fig. 2-12. Distribution of Drepanocladus species along a pH gradient.

D. exannulatus, D. lapponicus, D. vernicosus, D. aduncus, D. polycarpus, D. sendtneri, D. revolvens.

Cover class 1:0.1-2, 2:2.1-5, 3:5.1-10, 4:10.1-20, 5:20.1-40, 6:40.1-60, 7:60.1-80, 8:80.1-100.

Smoothed curves are third degree polynomials.

extreme rich fens. Despite their physical similarity, these species are ecologically different in terms of their response to water chemistry. An example of their responses to pH is shown in Fig. 2-12.

It is possible that the Lesser Slave-Athabasca fens are a type of fen with a local occurrence here in Alberta. Fens such as these have not been described in Canada. They may represent a variant of intermediate fens or of moderately rich fens. In addition to their own characteristic species, intermediate fens also have, by definition, a mixture of poor fen and rich fen species (Persson 1961). The Lesser Slave-Athabasca fens, on the other hand, have very few poor fen species present. These fens may be better classified as moderately rich fens instead, with common rich fen species such as *Tomenthypnum nitens, Bryum pseudotriquetrum, Campylium stellatum, Calliergon giganteum* and *Meesia triquetra*, as well as its own group of characteristic species that are different from those previously described.

It seems unlikely that this particular type of moderately rich fen should be restricted to central Alberta, given the circumboreal distribution of many of its characteristic species such as *Drepanocladus vernicosus, D. aduncus, D. polycarpus, D. lapponicus* and *Brachythecium mildeanum*. As mentioned before, similar communities have also been described in continental Europe, Finland and the British Isles, although they were not classified as moderately rich fens. Similar peatland communities have also been reported in interior British Columbia (Roberts 1984). It is more likely that, in areas of continental climate such as in central Alberta, *Drepanocladus vernicosus, D. aduncus, D. polycarpus, D.*

lapponicus and *Brachythecium mildeanum* replaces *Sphagnum warnstorfii*, *S. teres*, *S. contortum*, *S. subnitens* and *Drepanocladus exannulatus* as the characteristic species of moderately rich fens.

F. SUMMARY.

A summary of the vegetation and environmental gradients found in this study is presented in Fig. 2-13. The primary vegetation gradient is from stands dominated by *Drepanocladus vernicosus, Meesia triquetra, Menyanthes trifoliata* and *Carex chordorrhiza* to those dominated by *Brachythecium mildeanum, Drepanocladus aduncus, Carex aquatilis,* and *Drepanocladus polycarpus*. This vegetation gradient reflects an ionic and nutrient gradient of increasing pH, magnesium, sodium, sulphur, organic nitrogen, and phosphorus in the fen waters, as well as increasing magnesium, iron, and phosphorus in the fen peats. Potassium and sodium, however, show a decreasing trend along this vegetation gradient. A secondary gradient from shrub-moss vegetation to sedge-moss vegetation is significantly correlated with an increase in nitrate content in the spring waters and microtopography (an indirect measure of water level).

Species richness is highest in stands dominated by *Brachythecium mildeanum, Drepanocladus aduncus, Carex aquatilis, Drepanocladus polycarpus,* and such shrubs as *Salix* species and *Myrica gale*. Stands with the lowest species richness are very wet, with low pH's, and are characterized by *Sphagnum subsecundum, Drepanocladus lapponicus, D. vernicosus, Menyanthes trifoliata* and *Carex chordorrhiza*.

A total of nine stand groups are described. In addition to the species mentioned above, these stand groups are further distinguished on the basis of characteristic species such as *Drepanocladus lapponicus, Sphagnum subsecundum, Andromeda polifolia,*

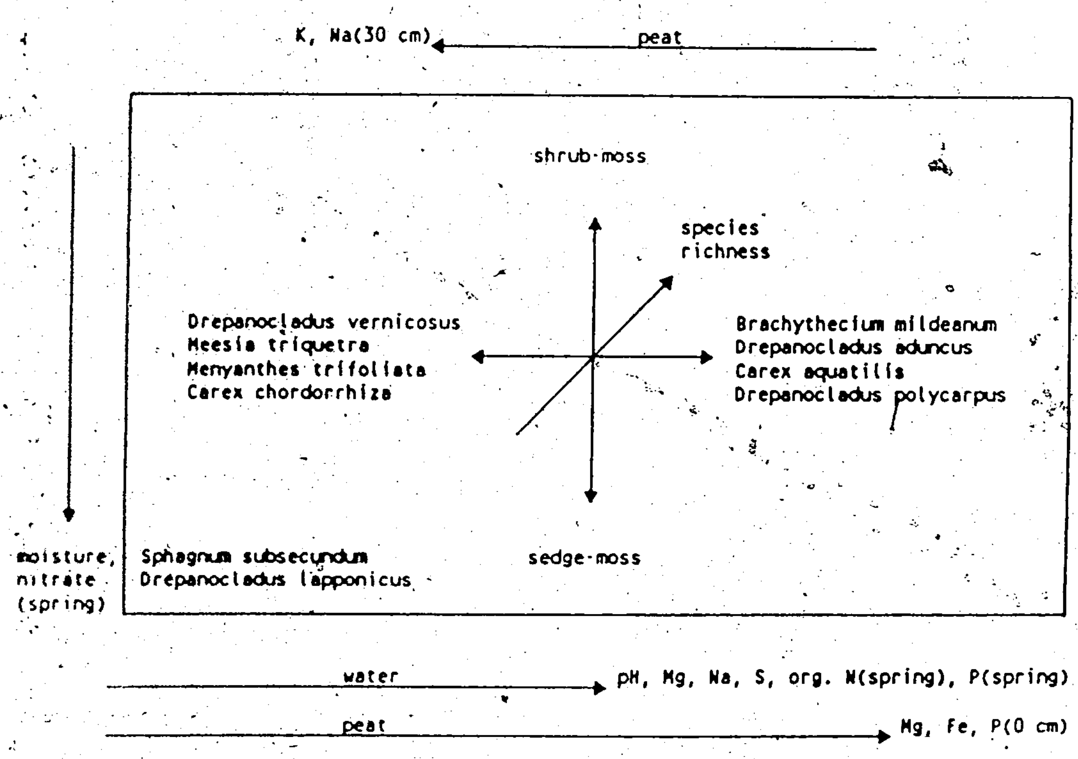


Figure 2.13. Summary of vegetation and environmental gradients.

Carex lasiocarpa, Drepanocladus sendtneri, Chamaedaphne calyculata, Sphagnum warnstorfii, Caltha palustris, Calliergon giganteum, Calliergonella cuspidata, Drepanocladus exannulatus and *Myrica gale.*

The fen waters in this study are in the 5.3-7.1 pH range, with specific conductance of 18-240 µS. The calcium content of the waters averaged 19.5-22.1 mg/l, while that of magnesium averaged 4.26-5.27 mg/l in spring and fall respectively. The subsurface fen peats were characterized by a calcium content of 17426 g/kg and magnesium content of 1791 g/kg. Organic nitrogen, nitrate and ammonium content in the spring and fall waters averaged 1967-2395 µg/l, 3.1-9.8 µg/l and 16.8-88.9 µg/l respectively.

The Lesser Slave-Athabasca fens are classified as moderately rich fens. The ionic content of the fen water and fen peat is intermediate between that of poor fens and rich fens that have previously been described. Common rich fen species such as *Tomenthypnum nitens, Bryum pseudotriquetrum, Campylium stellatum, Calliergon giganteum* and *Meesia triquetra* are present. In addition, characteristic species of these moderately rich fens include *Drepanocladus vernicosus, D. aduncus, D. polycarpus* and *Brachythecium mildeanum.* These species are believed to be characteristic of moderately rich fens in continental areas.

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CHAPTER III The relationships between vegetation, surface water chemistry and peat chemistry of fens in Alberta, Canada.

A. INTRODUCTION.

In general, peatlands are considered nutrient-poor in comparison to upland sites, where the plants are largely rooted in more nutrient-rich mineral soil. The supply of nutrients in a peatland depends on the quality and flow rate of the water entering the peatland (Sjors 1952). The quality of nutrients in the water depends on the chemical nature of its origin, and whether it is through atmospheric deposition or contact with the surficial and/or bedrock geology of the area. The fundamental division of peatlands into ombrotrophic (rain-fed) and minerotrophic (ground water origin) has often been studied with reference to pH, conductivity, calcium, magnesium, potassium and sodium content in the water. Calcium, magnesium and sodium are by far the most abundant cations present in the ground water. Nutrients such as nitrogen and phosphorus, are present in much smaller and often more limited amounts. These are actively taken up by plants, and are key elements in the fertility status of an ecosystem. In this study, the term limiting nutrient will refer to nitrogen and phosphorus, while mineral or ionic content will refer to major cations such as calcium, magnesium and sodium, as well as other ions such as potassium and iron.

The correlation between peatland vegetation and mineral content in its water has been well studied (Kivinen 1935; Witting 1949; DuRietz 1949; Sjors 1952, 1959, 1961a, 1961b, 1963; Gorham 1956;

Ritchie 1957; Henoch 1960; Jeglum 1971, 1972; Vitt *et al.* 1975; Horton *et al.* 1979; Slack *et al.* 1980; Sims *et al.* 1982; Karlin & Bliss 1983), but the terminology is not consistent. The poor-rich vegetation gradient (DuRietz 1949) in peatlands refers to the low number of indicator species present in *Sphagnum* dominated peatlands as opposed to the high number of indicator species found in brown moss dominated peatlands. This poor-rich vegetation gradient reflects an underlying hydrotopographical and chemical gradient often refered to as the ombrotrophic-minerotrophic gradient (Sjors 1952), from ombrogenous (rain-fed) mineral-poor conditions, to geogenous (ground water-fed) mineral-rich conditions. The bog-fen concept represents a composite vegetational, chemical and hydrotopographical gradient. Bogs are poorest in the number of indicator species and ombrotrophic, while fens are richer in the number of indicator species and minerotrophic.

Although the water chemistry *per se*, is a major factor in determining the type of vegetation, it is often difficult to separate it from hydrologic events. Sites with similar water chemistries may support very different plant communities as a result of different hydrotopographic developments that control the flow rate of water, and indirectly, the amount of nutrients and ions available. The use of water chemistry as a basis for classification can be hampered by periodic variation in water supply, and it is necessary to couple such studies with flow rates and annual water budgets to produce a complete picture (Moore 1984).

Peat chemistry, on the other hand, is less subject to seasonal variation. The chemical analysis of peat (Olenin 1951; Malmer & Sjors 1955) has been used in supplementary descriptions of peatlands. More recently, attempts have been made to use peat chemistry to characterize peatland types (Zoltai & Tarnocai 1971; Dirschl 1972; Rollett 1972; ; Stanek & Jeglum 1977). These studies have generally shown ombrotrophic peats to have a lower nutrient and ionic content than minerotrophic peats, a trend that is reflected in the water chemistry as well.

Comparatively few studies have been done on the nutrient status of peatlands (Heikurainen 1979; Wells 1980). Nitrogen and phosphorus contents in peatland waters are difficult to study because of their presence in extremely small quantities, and in different chemical forms. For example, nitrogen may be present as organic nitrogen, ammonium, ammonia, nitrate and/or nitrite. Few studies have described the nitrogen budget of peatlands (Waughman & Bellamy 1980; Hemond 1983; Urban & Eisenreich, manuscript), and there are no data on nutrient content over a broad range of peatland types. Nutrient gradients have also been found to exist in peats (Heikurainen 1979; Heikurainen & Pakarinen 1982). Although the nutrient content present in the peat is not necessarily available to plants, this measurement appeals to those who view it as a stored potential that may be released and exploited, should conditions change to favour increased decomposition.

Most of the peatland studies in Alberta have been done on forested peatlands or muskeg, as they are most abundant. Black spruce mires have been described in the Caribou Mountains of northern Alberta

Horton *et al.* 1979), and in central Alberta (Nicholson 1987; Zoltai & Johnson 1985). These are dominated by *Picea mariana, Sphagnum fuscum, S. magellanicum, S. angustifolium* and lichens of the *Cladina, Cetraria,* and *Cladonia* genera, and have a low water pH of 3.3-4.1. Some of these compared favourably to the ombrotrophic bogs described by Swedish researchers (see Tables 2-1 and 2-2). Open, non-forested peatlands have been less well studied. Non-forested poor fens have also been described in the Swan Hills (Vitt *et al.* 1975), and at Mariana Lakes (Nicholson 1987). These are dominated by *Sphagnum jensenii, S. majus, S. angustifolium* and *Drepanocladus exannulatus*, and have water pH of 4.2-5.8. In the Rocky Mountain Foothills, non-forested minerotrophic fens with an abundance of *Scorpidium scorpioides, Drepanocladus revolvens, Campylium stellatum, Tomenthypnum nitens, Calliergon trifarium, Catoscopium nigritum, Meesia triquetra* and *Triglochin maritima*, along with high pH of 6.8-7.4 were considered rich fens (Slack *et al.* 1980). Indeed, the abundance of *Scorpidium scorpioides* suggests that they were extreme rich fens. As can be seen, there is a gap between poor fens and rich fens in the pH range of approximately 5.8-6.8 that has not been described in Alberta.

In the Lesser Slave-Athabasca area, there are non-forested fens with water pH in the 5.3-7.1 range. Their vegetation is dominated by brown mosses of the genus *Drepanocladus*, but *Drepanocladus revolvens*, a rich fen indicator is rare. On the strength of the bryophyte layer, these peatlands appear superficially different from poor and rich fens. These peatlands have been identified as moderately rich fens (see previous chapter).

Objectives.

The primary aim of this paper is to examine the relationships of vegetation to chemistry over a broad range of non-forested fen types in Alberta. These peatlands include previously described poor fens and rich fens, as well as the moderately rich fens of the Lesser Slave - Athabasca area, and cover a pH range from 3.7-7.5. The following aspects of vegetation and chemistry are examined : 1) the distribution of key characteristic species across the different fen types; 2) the vegetation gradients with respect to the bryophyte and vascular component; 3) the distribution of the major ions across the fen types; 4) the distribution of nitrogen and phosphorus across the fen types; 5) the correlation between vegetation and chemical gradients; 6) the relationships between spring and fall water chemistry; and 7) the relationships between surface and subsurface peat chemistry.

B. STUDY AREA.

The twenty-three peatlands in this study are found in three general locations : the Lesser Slave-Athabasca area, the Swan Hills and Mariana Lakes area, and the Foothills area (Fig. 3-1).

Lesser Slave - Athabasca area.

These peatlands (sites 1-14) are located in central Alberta in the Lesser Slave Lowlands and the Eastern Alberta High Plains physiographic subzones (Anon. 1969) between the elevations of 580 and 640 metres. For a detailed description of this area, see previous chapter.

Swan Hills and Mariana Lakes area.

The two peatlands (sites 15-16) in the Swan Hills area are the same as Fens I and II of the Vitt *et al.* (1975) study on poor fens. Located in central Alberta, just south of Lesser Slave Lake, the Swan Hills Uplands cover an area of 520,000 hectares which is raised 500 to 600 metres above the surrounding plain to an elevation of 1300 to 1350 metres. They are underlain by a series of Tertiary and Late Cretaceous deposits (Jones 1962). An Upper Tertiary deposit of coarse, unconsolidated gravels consisting of quartzitic cobbles covers the bedrock in much of the higher elevations. The area was glaciated by Laurentide Ice in the Pleistocene and became ice-free about 12,200 years ago (Prest 1969).

The vegetation of the Swan Hills is transitional between the Boreal Forest and Rocky Mountain regions (Rowe 1972). The Boreal element is represented by *Pinus banksiana, Picea glauca* and *Abies balsamea*. Where there is frequent disturbance by fire,

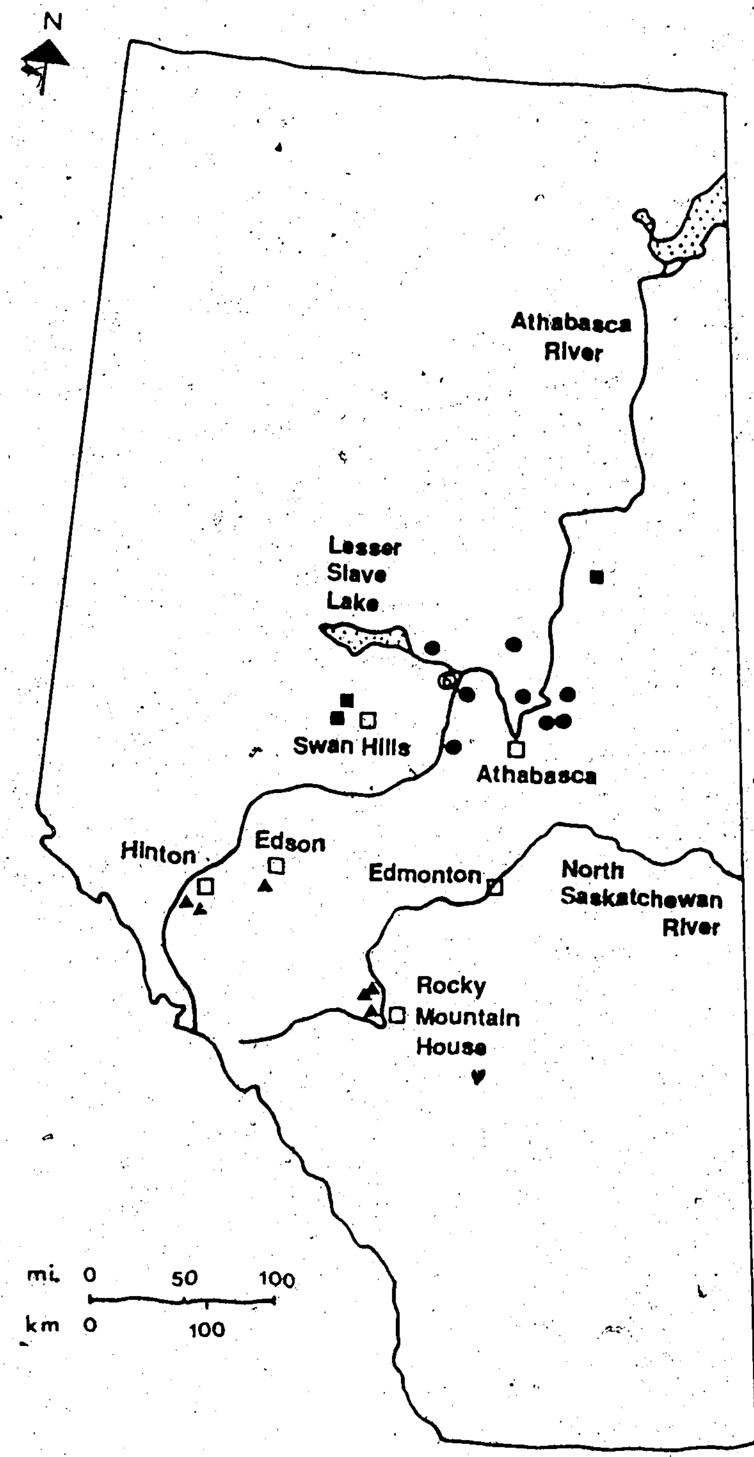

Fig. 3-1. Location of study area in central Alberta.

○ ● Moderately rich fens of the Lesser Slave-Athabasca area,

■ Poor fens of the Swan Hills and Mariana Lakes area, and

▲ Rich fens of the Foothills.

only. The vascular plant vegetation gradient from moderately rich fen to extreme rich fen to poor fen reflects a nutrient gradient. Phosphorus, organic nitrogen(fall), and ammonium(fall) are highest in moderately rich fens, while nitrate, ammonium and iron in the spring are highest in extreme rich fens (Fig. 3-28). The ordination based on bryophytes only, results in a vegetation gradient from extreme rich fen to moderately rich fen to poor fen. This bryophyte vegetation gradient reflects an ionic gradient (Fig. 3-27). Specific conductance, calcium, magnesium, and pH are highest in extreme rich fens, intermediate in moderately rich fens, and lowest in poor fens (Fig. 3-29). To a smaller extent, sodium and potassium also follow this trend.

Water chemistry values in the spring and in the fall are significantly different. Acidity, calcium, magnesium and iron are higher in the fall, while phosphorus in poor fens, organic nitrogen and ammonium in extreme rich fens are lower in the fall. Peat chemistry variables also show significant differences between surface and subsurface values. Magnesium, sodium, potassium, sulphur and phosphorus are higher in the surface peats. Correlations exist between water chemistry variables and peat chemistry variables. Calcium, magnesium and sodium are significantly correlated with that in the peat, as are potassium, phosphorus and sulphur in the fall water with that in the subsurface peat.

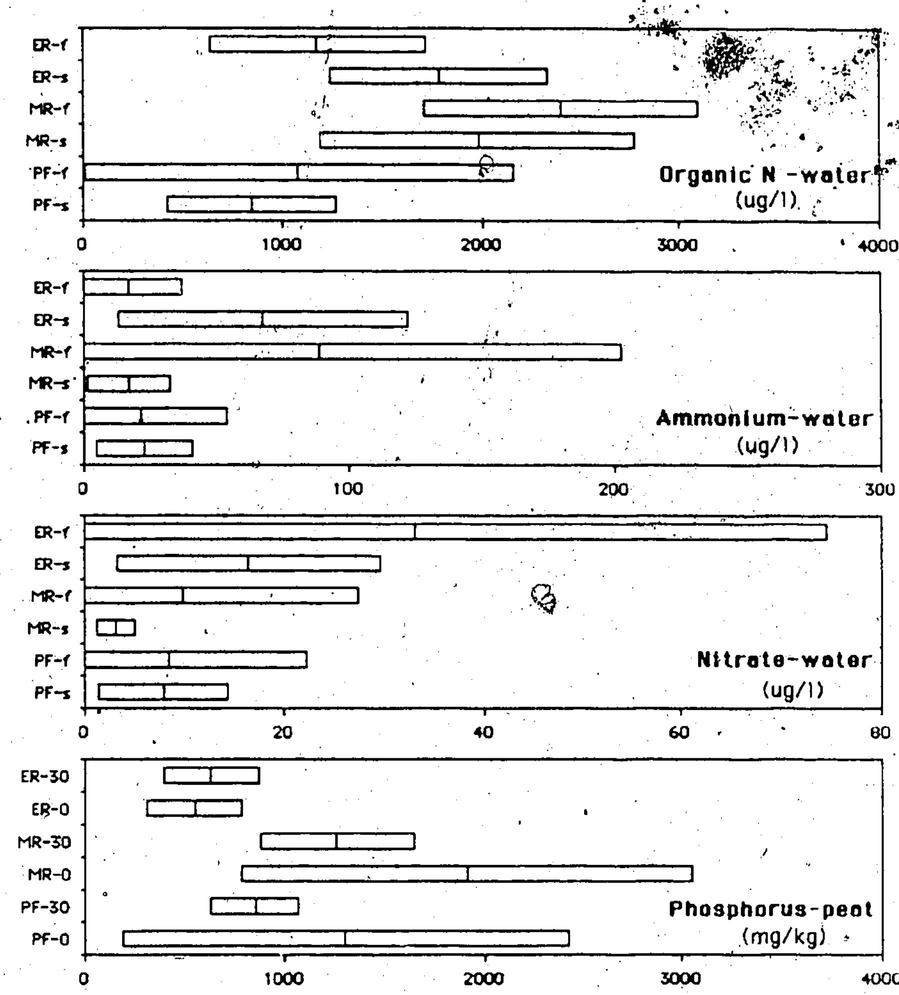

Fig. 3-28. Summary of nutrients underlying the poor to rich fen vegetation gradient. Values shown are means + one standard deviation. PF=poor fen, MR=moderately rich fen, ER=extreme rich fen. s=spring, f=fall, 0=surface, 30=subsurface.

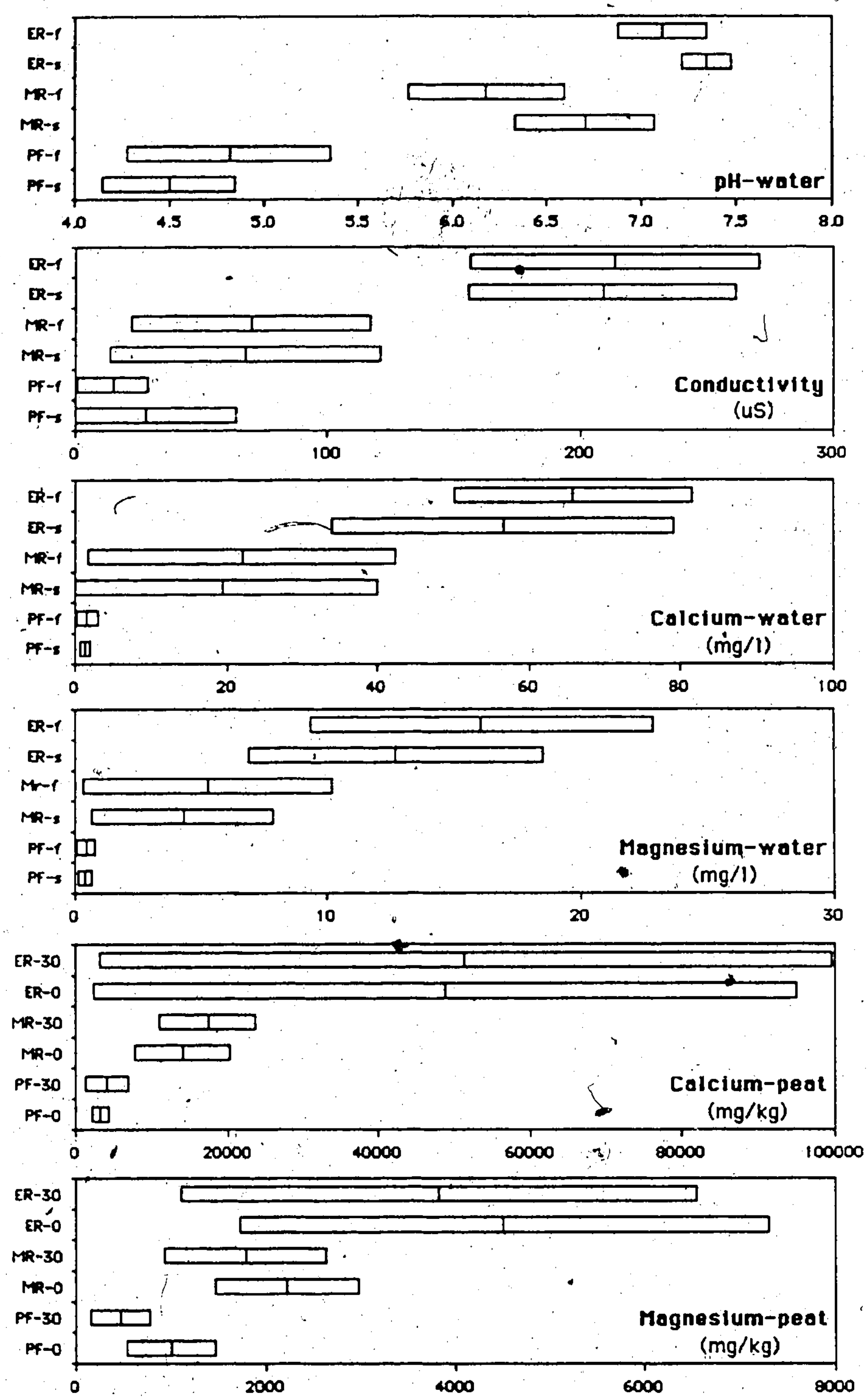

Fig. 3-29. Summary of some major cations underlying the poor to rich fen vegetation gradient. Values shown are means + one standard deviation. PF=poor fen, MR=moderately rich fen, ER=extreme rich fen. s=spring, f=fall, 0=surface, 30=subsurface.

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CHAPTER IV Summary of results.

The first part of this thesis characterizes the non-forested fens of the Lesser Slave-Athabasca area in terms of their vegetation, surface water chemistry and peat chemistry. Correlations between vegetational and environmental (mainly chemical) gradients are examined. The type of fen represented by these fens is then identified by a comparison with the relevant literature.

A summary of the vegetation and environmental gradients found in this study is presented in Fig. 4-1. The primary vegetation gradient is from stands dominated by *Drepanocladus vernicosus, Meesia triquetra, Menyanthes trifoliata* and *Carex chordorrhiza* to those dominated by *Brachythecium mildeanum, Drepanocladus aduncus, Carex aquatilis* and *Drepanocladus polycarpus*. This vegetation gradient reflects an ionic and nutrient gradient of increasing pH, magnesium, sodium, sulphur, organic nitrogen, and phosphorus in the fen waters, as well as increasing magnesium, iron, and phosphorus in the fen peats. Potassium and sodium, however, show a decreasing trend along this vegetation gradient. A secondary gradient from shrub-moss vegetation to sedge-moss vegetation is significantly correlated with an increase in nitrate content in the spring waters and microtopography (an indirect measure of water level).

A total of nine stand groups are described. In addition to the species mentioned above, these stand groups are further distinguished on the basis of characteristic species such as *Drepanocladus lapponicus, Sphagnum subsecundum, Andromeda polifolia, Carex lasiocarpa, Drepanocladus sendtneri, Chamaedaphne calyculata,*

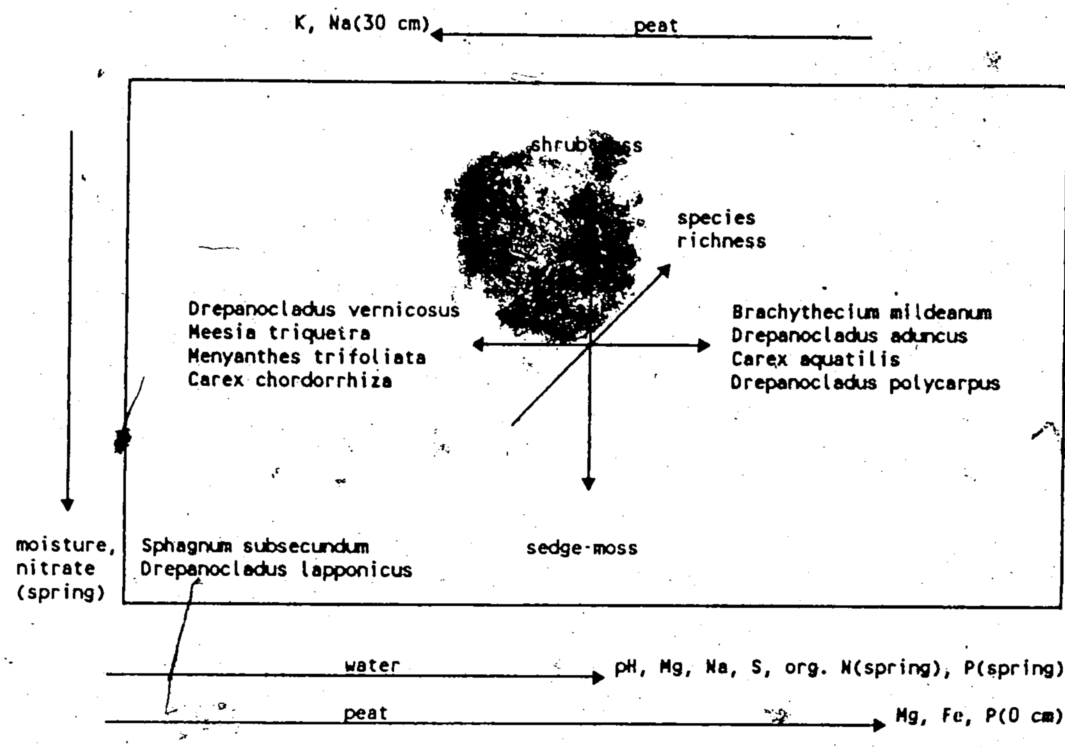


Figure 4-1. Summary of vegetation and environmental gradients.

Pinus contorta var. *latifolia* dominates. The Cordilleran element is represented by *Picea engelmannii, Abies lasiocarpa, Menziesia glabella* and *Rhododendron albiflorum*. The low-lying areas contain a complex mosaic of peatland types. *Picea mariana* is the main tree species found in these peatlands, with *Larix laricina* making an occassional appearance (Vitt *et al.* 1975). These peatlands are *Sphagnum* dominated.

The Mariana Lakes peatland (site 17) is located in the Stony Mountain Upland physiographic subzone (Anon. 1969), which is raised above the surrounding plain to an elevation of 762 m (Hackbarth and Nastasa 1979). The area is underlain by Cretaceous sandstones, siltstones and marine shales (Ozoray 1974). The topography is undulating, and glacial landforms are abundant. The Laurentide Ice retreated about 11,800 years ago (Prest 1969).

The vegetation of this area is also classified under the Mixedwood section of Rowe's (1972) Boreal Forest Zone, i.e. dominated by *Pinus banksiana, Populus tremuloides, Picea glauca* and *Abies balsamea*. The peatland complex in this study is dominated by *Sphagnum* mosses with *Picea mariana* on drier microsites. This is the same site as Nicholson's (1987) study.

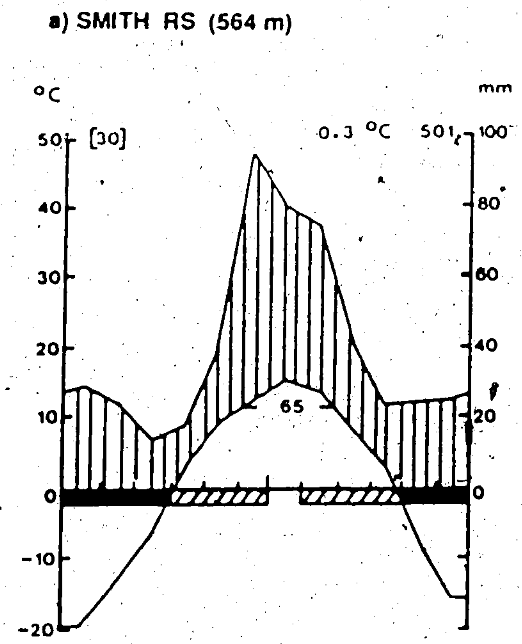
Foothills area.

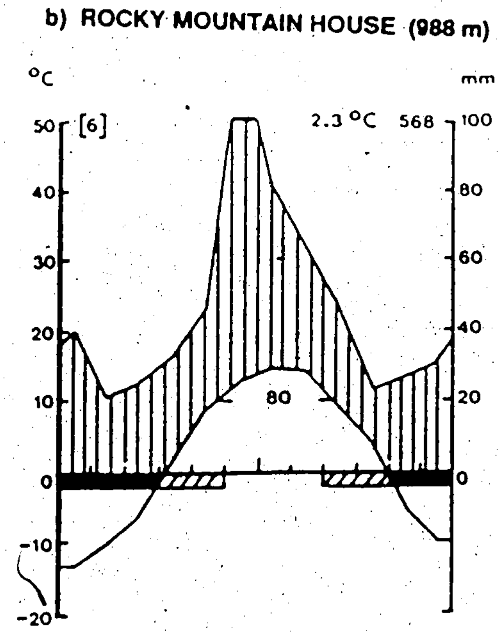
The six peatlands (sites 18-23) near Crimson Lake, Hinton and Edson are the same as Fens I, II, IV, VI, VII and VIII of the Slack *et al.* (1980) study of rich fens. Located in the Western Alberta High Plains physiographic subzone (Anon. 1969), the area is underlain by Upper Cretaceous to Paleocene bedrock, largely of the Paskapoo Formation consisting of sandstones interbedded with mudstone and shales (Boydell 1978). Tills, glaciolacustrine sediments and post-glacial aeolian sands make up the surficial geology. The Crimson Lake area was glaciated by Laurentide Ice and became ice-free about 12,200 years ago (Prest 1969). The Hinton sites were glaciated by Cordilleran Ice, while the Edson site was located between at the junction of the Laurentide and Cordilleran glaciers, and may have been in an ice-free corridor (Slack *et al.* 1980). Sand dune complexes associated with old pro-glacial lakes are also present near the Crimson Lake and Edson sites.

All six study sites are located within the Lower Foothills section of the Boreal Forest Region (Rowe 1972). The upland forests are dominated by *Pinus contorta var latifolia* and *Picea glauca*, with occasional stands of *Populus tremuloides*. Peatlands occupy depressional areas in the topography. Wet peatlands are dominated by sedges and brown mosses, and tend to be patterned or ribbed if there is sufficient surface water flow. *Larix laricina* is common on well-developed strings in these patterned fens. Drier, non-patterned and densely forested peatlands or muskegs dominated by *Picea mariana* and *Larix laricina* are also common in this area.

Climate.

The climate in all study sites is boreal cold temperate with cold winters and short, cool summers (climate type VIII, Walter and Lieth 1960, Fig. 3-2). This climate type is also typical of the aapamire or patterned peatland zone of Europe (Moore & Bellamy 1974). Mean monthly temperatures range from -20°C to 16°C, and annual precipitation ranges from 485-712 mm. Over 60% of the precipitation falls during the five-month growing season from May to September.





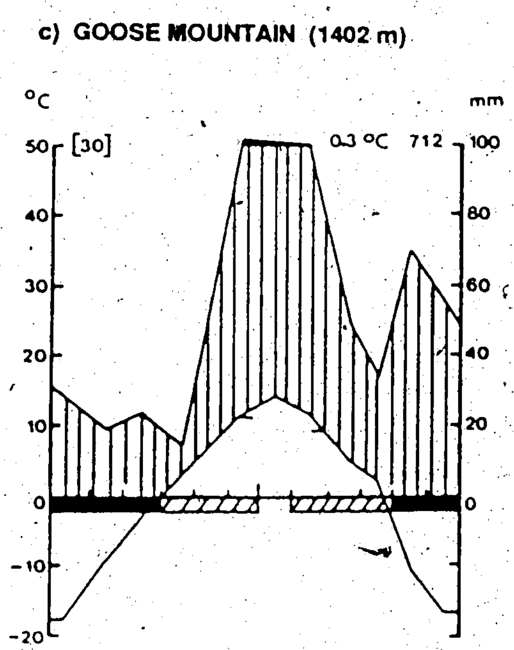


Fig. 3-2. Climate diagrams of a) the Lesser Slave-Athabasca area, b) the rich fen sites in Foothills, c) the poor fens in Swan Hills area, after Walter & Lieth (1960); upper line is monthly precipitation; lower line is mean monthly temperature; solid bar is months with mean temp. below 10°C; diagonally hatched bar months with absolute minimum temp. below 0°C; mean annual temp. and annual precipitation is in top right corner; number of frost free days is in middle. Data was obtained from meteorological records (Anon. 1984).

During the growing season, the poor fen sites near Goose Mountain in the Swan Hills Uplands receive the highest amount of precipitation (490 mm), and are the coolest with mean monthly temperature of 9°C. The poor fen sites near Mariana Lake in the Stony Mountain Upland also show a similar pattern of high summer precipitation, and lower summer temperatures compared to the surrounding plains (Anon. 1984). Discontinuous permafrost may also be present in this area (Ozoray & Lytviak 1980). By contrast, the rich fen sites in the Foothills are the warmest, with mean monthly temperature of 12.4°C, and moderate amounts of precipitation (370 mm) during the growing season. The peatlands in the Lesser Slave-Athabasca area are also relatively warm with mean monthly temperature of 12°C, but receive the least summer precipitation (340 mm).

Site Locations.

Sites 1-14 : stands 1-60, Lesser Slave-Athabasca area peatlands, see previous chapter for details.

Site 15 : stands 61-64 and 74-75; 54° 45′ N, 115° 52′ W, 1325 m; west of Swan Hills townsite, 23km east of Goose Mountain Lookout; a narrow, *Sphagnum* dominated, patterned fen with a drainage divide at a large central pool.

Site 16 : stands 65-73; 54° 45′ N, 115° 51′ W, 1300 m; west of Swan Hills townsite, 23 km east of Goose Mountain Lookout; a *Sphagnum* dominated patterned fen, with *Picea mariana* on well-developed strings.

Site 17 : stands 76-80; 55° 54′ N, 112° 04′ W, 750 m; 100 km SW of Fort McMurray; a patterned fen with *Sphagnum* dominated flarks and strings.

Site 18 : stands 81-82; 52° 56′ N, 115° 01′ W, 960 m; off Crimson Lake road, 5.2 km north of Hwy 11; a poorly-developed patterned fen in a depressional area within a sand dune complex.

Site 19 : stands 83-85; 52° 27′ N, 115° 01′ W, 960 m; off Crimson Lake Road, 5.6 km north of Hwy 11; a patterned fen in a depressional area within a sand dune complex, with *Larix laricina* on well-developed strings.

Site 20 : stands 86-89; 52° 24′ N, 115° 01′ W, 975 m; off Crimson Lake Road, 1.4 km south of Hwy 11.

Site 21 : stands 90-93; 53° 23′ N, 117° 34′ W, 1095 m; off Hwy 40, 1.6 km south of Hwy 16 near Hinton; a non-patterned fen in a small morainal depression.

Site 22 : stands 94-95; 53° 20′ N, 117° 30′ W, 1100 m; off Hwy 40, 12.2 km south of Hwy 16 near Hinton; a patterned fen marginal to a small lake in a morainal depression.

Site 23 : stands 96-100; 53° 30′ N, 116° 37′ W, 945 m; off Hwy 47, 9.3 km south of Hwy 16 near Edson; a patterned fen marginal to a small lake in a morainal depression.

C. METHODS.

Site selection.

Twenty-three peatlands containing one hundred stands were selected for this study. They were all open, non-forested (less than 10% tree cover), minerotrophic fens. Since the main thrust of this study is to compare the different fen types on the basis of vegetation, surface water chemistry and peat chemistry, a restriction to open non-forested sites was made to reduce any variation due to shade or other complex interactions in a canopied situation.

The fourteen sites in the Lesser Slave-Athabasca area were selected in May 1984, using the following criteria : pH of water 5.5-7.0; absence of *Scorpidium scorpioides* and *Drepanocladus revolvens;* not *Sphagnum* dominated; with rich fen and poor fen indicator species (Table 2-1) absent or negligible. These fens were identified as moderately rich fens (see previous chapter). The remaining sites were selected from previous studies listed below, and sampled for their water and peat chemistry, while their vegetation data was obtained from the authors. The six sites (20 stands) representing rich fens in the Foothills area were chosen from the Slack *et al.* (1980) study on the basis of accessibility, and represent much of the range of variation found in that study. Similarly, two sites (15 stands) representing poor fens in the Swan Hills area were chosen from the Vitt *et al.* (1975) study along with another poor fen site (5 stands) at Mariana Lakes from the Nicholson (1987) study. These poor fens were distinguished by *Sphagnum* dominated vegetation.

Vegetation sampling.

The vegetation of the fourteen Lesser Slave-Athabasca peatland sites was sampled in June-August 1984. A restricted random sampling technique (Daubenmire 1968) was used. Three to ten stands were sampled at each site, depending on the complexity and number of visually distinct communities in the peatland. In patterned peatlands, strings and flarks were sampled separately. In each stand, a base line was laid out (medially along the long axis of flarks in patterned peatlands). At random intervals along the baseline, a 25x25cm quadrat or subplot was again randomly placed within 5 metres perpendicular to the baseline, on an undisturbed patch of vegetation. A minimum of ten quadrats were sampled per stand. Additional quadrats were sampled until no new species were encountered. Each quadrat was assigned a microtopographic category (wet hollow, soft wet-moist carpet, firm moist lawn or high dry hummock), an indirect measure of water level. Additional quadrats were also added until a representative ratio of hollow to hummock subplots was obtained. A rough average of the subplot categories was assigned to the stand. Vegetation data was taken in the form of percent canopy cover (Daubenmire 1959). This sampling method was similar to that used in the poor fen studies (Vitt *et al.* 1975; Nicholson 1987) and the rich fen studies (Slack *et al.* 1981). Voucher specimens were collected and deposited in the University of Alberta Herbarium. Nomenclature follows Moss (1983) for vascular plants, Ireland (1982) and Nyholm (1954-1969) for mosses, Stotler and Crandall-Stotler (1977) for hepatics, and Hale and Culberson (1970) for lichens.

Chemical analyses.

Samples of fen water from natural pools, surface water table or water seeping into dugout holes were collected. All stands in the Lesser Slave-Athabasca area, the rich fens of the Rocky Mountain Foothills, and the poor fens of the Swan Hills and Mariana Lakes were sampled on May18-21, 1985 during a period of warm, dry weather. String stands were not sampled. Specific conductance (adjusted to 25°C and corrected for $[H^+]$ following Sjors (1952) and pH were also measured in the field at this time. The samples were stored at 4°C, filtered through a Whatman 42 filter, acidified with 1 part 4N HCl to 24 parts sample, and analyzed for cation content (Ca, Mg, Na, K, P, S, Fe) on an inductively coupled argon plasma spectrometer at the Northern Forest Centre, Edmonton, Alberta.

Three other water samples taken for determination of nitrogen content were analyzed within 48 hours at either the Limnology Lab or the Meanook Field Station of the Department of Zoology, University of Alberta. All lab analyses were done on triplicate subsamples, which were then averaged. Organic nitrogen plus ammonium was analyzed using the total Kjeldahl nitrogen method (D'Elia 1976). Nitrate content was obtained using the cadmium reduction method (Strickland & Parsons 1968) after filtration of the field sample through a 0.45 millipore filter. Ammonium content was obtained using the phenolhypochlorite method (Weatherburn 1967).

Peat samples were collected in fall (September 3-5) 1984. In each stand, samples were collected from the aerobic surface portion (0-5 cm), and from the anaerobic subsurface portion (30-35 cm). Total calcium, magnesium, sodium, potassium, sulphur, iron and phosphorus were analyzed by dry ashing 0.30 gm of ground sample at 490°C followed by digestion with 1.5 N HCl and concentrated HNO_3. The samples were then filtered and diluted to 25ml with double distilled water, and analyzed for ion content on the inductively coupled argon plasma spectrometer.

Data analyses.

All stands were classified and ordinated on the basis of their vegetation. TWINSPAN, a two-way indicator species analysis (Hill 1979, program CEP-41 in Cornell Ecology Programs Series), was used for the classification. This is a polythetic, sequential, divisive, hierarchical non-overlapping classification method based on reciprocal averaging. The resulting matrix is analogous to that obtained by a Braun-Blanquet (1932) tabular classification, where stand groups and species groups are recognized. The stands are ordinated by reciprocal averaging, the ordination is then split on basis of "indicator" species to produce dichotomous stand groups. These "indicator" species refer to the most highly preferential species within a particular dichotomy, but are not necessarily restricted to that dichotomy. In this study, indicator species will refer to the preferential species used by TWINSPAN to distinguish the stand groups. Characteristic species will generally refer to species that typify a certain vegetation type. The TWINSPAN program was run using the default options, with the exception of the pseudospecies cut levels, which were 0, 5, 10, 20, 40, 60 and 80.

DECORANA, a detrended correspondence analysis (Hill & Gauch 1980, CEP-40 in Cornell Ecology Programs Series) was used for the ordination. Based on reciprocal averaging, but without the associated arching and orthogonality problems, artificial scores are calculated for each stand. These can then be plotted along various axes, such that stands with similar vegetation appear close together, and those with dissimilar vegetation appear far apart. Spearman's rank order correlation was then used to correlate the DECORANA (DCA) stand scores (based solely on the vegetation) to the chemistry variables. Other statistical tests include the following : the Mann-Whitney two-sample test together with the Bonferroni inequality (Hays 1981) to test for significant differences in the chemistry values between the three possible pairings of fen types; the Wilcoxon matched pair rank sum test and the median (sign) test to test for significant differences between spring and fall water chemistry values, and between surface and subsurface peat chemistry values; and the least squares method of simple linear regression to describe the relationship between two highly correlated chemistry variables. All statistical tests were performed using a MIDAS package (Fox & Guire 1976).

D. RESULTS.

1. VEGETATION.

The poor fens of the Swan Hills (Vitt *et al.* 1975) and Mariana Lakes (Nicholson 1987) were both *Sphagnum* dominated. *Sphagnum jensenii, S. angustifolium, S. majus* and *Drepanocladus exannulatus* were some of the main species described. The extreme rich fens of the Rocky Mountain Foothills (Slack *et al.* 1980) were dominated by brown mosses, with *Scorpidium scorpioides* and *Drepanocladus revolvens*, as the main indicator species. The vegetation of the Lesser Slave-Athabasca fens is described in detail in chapter 2. These fens are dominated by brown mosses such as *Drepanacladus vernicosus, D. aduncus, D. polycarpus* and *Brachythecium mildeanum*, and carices such as *Carex lasiocarpa* and *Carex aquatilis*.

Two-way indicator species analysis (TWINSPAN).

The TWINSPAN classification of the 100 stands is shown in Fig. 3-3, along with the indicator species separating the stand groups. The separation of the moderately rich fen stands in stand groups 1 & 2 from extreme rich fen stands in stand groups 3 & 4 and poor fen stands in stand groups 5 & 6 is clear. A summary of species occurrences within the major stand groups and species groups as delimited by TWINSPAN is shown in Fig. 3-4. A complete list of species and stands within each group is given in Appendix 3-1. Six stand groups and eight species groups are recognized.

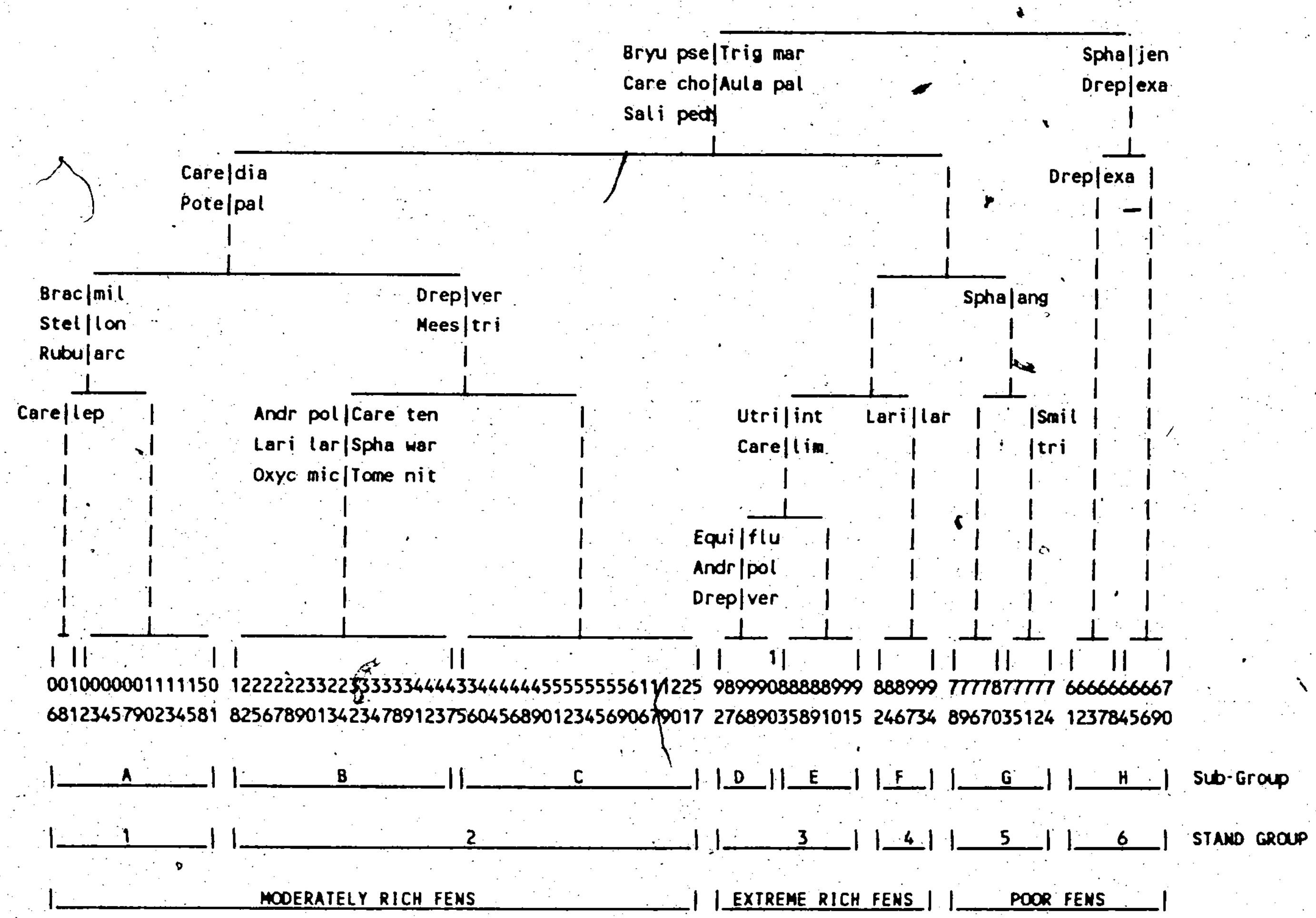
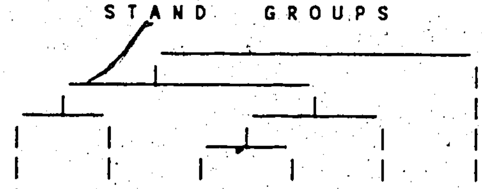
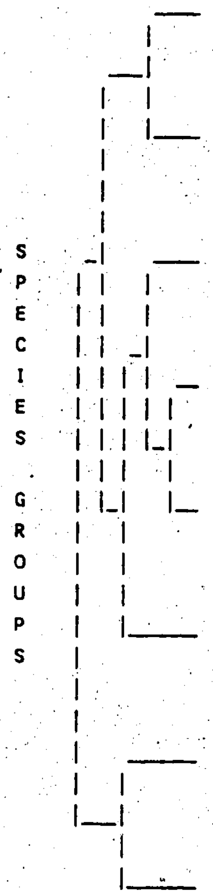


Figure 3-3. TWINSPAN dendrogram of 100 fen stands in central Alberta. Indicator species name abbreviated to first four letters of the genus and first three letters of the species. Refer to Fig. 3-5 for full names.

STAND GROUPS





Species groups		1	2	3	4	5	6
		<u>16</u>	<u>44</u>	<u>14</u>	<u>6</u>	<u>10</u>	<u>10</u>
A	<u>24</u>	24 (235) 61	20 (153) 14	3 (8) 2	4 (7) 5	1 (2) 1	0 (0) 0
B	<u>15</u>	12 (103) 43	15 (381) 58	6 (31) 15	6 (11) 11	6 (17) 11	0 (0) 0
C	<u>9</u>	8 (42) 29	10 (126) 32	4 (24) 19	4 (13) 24	9 (37) 41	4 (4) 4
D	<u>15</u>	9 (20) 8	10 (51) 8	2 (6) 3	6 (14) 16	15 (74) 49	0 (0) 0
E	<u>14</u>	3 (17) 8	8 (36) 5	14 (95) 45	11 (22) 24	0 (0) 0	0 (0) 0
F	<u>11</u>	7 (49) 28	11 (302) 62	10 (63) 41	8 (22) 33	7 (15) 14	1 (1) 1
G	<u>4</u>	3 (15) 23	4 (92) 52	2 (28) 50	3 (12) 50	4 (24) 60	4 (20) 50
H	<u>4</u>	2 (10) 16	2 (3) 2	1 (2) 4	1 (2) 8	3 (5) 13	4 (25) 63

Fig. 3-4. TWINSPAN stand groups showing species occurences. (Analysis based on all species.)

The number of species in each species group, and the number of stands in each stand group is underscored. Upper number in table is the number of species occuring in the individual stand groups. Number in parentheses is the number of species occurences in the stand group. Lower number is the number of species occurences adjusted to equal block size (after Lausi & Nimis 1985).

The distribution of the species groups across the six stand groups is shown in Fig. 3-5.

The moderately rich fens grouped in stand groups 1 & 2, are characterized by species of group B, especially *Potentilla palustris*, *Carex diandra*, *Aulacomnium palustre*, *Bryum pseudotriquetrum*, *Sphagnum warnstorfii* and *Salix pedicellaris*. *Eriophorum polystachion*, *Carex tenuiflora*, *Epilobium palustris* and *Galium labradoricum* are frequently common with low abundances. The dominant bryophyte is either *Drepanocladus vernicosus* or *Drepanocladus aduncus*.

Stand group 1 is further characterized by species group A. *Brachythecium mildeanum*, *Drepanocladus aduncus* and Drepanocladus polycarpus are the dominant bryophytes. *Calliergon giganteum*, *Amblystegium serpens*, *Plagiomnium ellipticum* and *Caltha palustris* are also common in lower amounts in wetter microsites. Hummock species include *Myrica gale*, *Rumex occidentalis*, *Stellaria longifolia*, *Carex disperma*, *Carex praegracilis*, *Hypnum pratense*, *Helodium blandowii*, *Rubus arcticus* and *Salix candida*. Widespread species such as *Carex aquatilis*, *Betula pumila*, *Tomenthypnum nitens* and *Smilacina trifolia* are also present here.

Stand group 2 differs from stand group 1 in the hollow species of species group B. *Drepanocladus vernicosus* and *Carex lasiocarpa* are the preferential species here, with *Drepanocladus sendtneri* and *Drepanocladus lapponicus* abundant in some of the stands. In addition, *Oxycoccus microcarpus* and *Andromeda polifolia* of species group C are also frequent. Widespread species

SPECIES GROUPS

A. MODERATELY RICH FEN SPECIES.
Myrica gale, Petasites sagittatus, Rumex occidentalis, Stellaria longifolia, Carex disperma, C. praegracilis, Amblystegium serpens, Brachythecium mildeanum, Calliergonella cuspidata, Drepanocladus aduncus, D. polycarpus, Hypnum pratense, Plagiomnium ellipticum, Caltha palustris, Helodium blandowii, Rubus arcticus, Salix candida, Epilobium palustris, Galium labradoricum, Calliergon giganteum.

B. MODERATELY RICH FEN SPECIES.
Potentilla palustris, Carex diandra, Eriophorum polystachion, Brachythecium turgidum, B. erythrorhizon, Drepanocladus lapponicus, Drepanocladus sendtneri, Carex tenuiflora, Sphagnum squarrosum, Aulacomnium palustre, Bryum pseudotriquetrum, Sphagnum warnstorfii, Salix pedicellaris, Carex lasiocarpa, Drepanocladus vernicosus.

C. WIDESPREAD HUMMOCK SPECIES.
Oxycoccus micrococcus, Andromeda polifolia, Carex aquatilis, Calamagrostis canadensis, Pleurozium schreberi, Pohlia nutans, Polytrichum strictum, Scheuchzeria palustris, Carex rostrata.

D. POOR FEN HUMMOCK SPECIES.
Kalmia polifolia, Rubus chamaemorus, Maianthemum canadensis, Carex pauciflora, Sphagnum angustifolium, S. fallax, S. magellanicum, S. fuscum, S. subsecundum, Tomenthypnum falcifolium, Picea mariana, Betula glandulosa, Ledum groenlandicum, Vaccinium vitis-idaea, Dicranum undulatum.

E. EXTREME RICH FEN SPECIES.
Drosera anglica, Equisetum variegatum, Parnassia palustris, Tofieldia glutinosa, Carex capillaris, Muhlenbergia glomearta, Scirpus caespitosus, S. hudsonianus, Calliergon trifarium, Campylium stellatum, Drepanocladus revolvens, Aneura pinguis, Scorpidium scorpioides, Carex interior.

F. RICH FEN SPECIES.
Spiranthes romanzoffiana, Triglochin maritima, Larix laricina, Betula pumila, Drosera rotundifolia, Tomenthypnum nitens, Utricularia intermedia, Carex chordorrhiza, Meesia triquetra, Chamaedaphne calyculata, Equisetum fluviatile.

G. WIDESPREAD MINEROTROPHIC SPECIES.
Menyanthes trifoliata, Carex limosa, Calliergon stramineum, Smilacina trifolia.

H. POOR FEN SPECIES.
Drepanocladus exannulatus, Sphagnum jensenii, Eriophorum chamissonis, Juncus stygius.

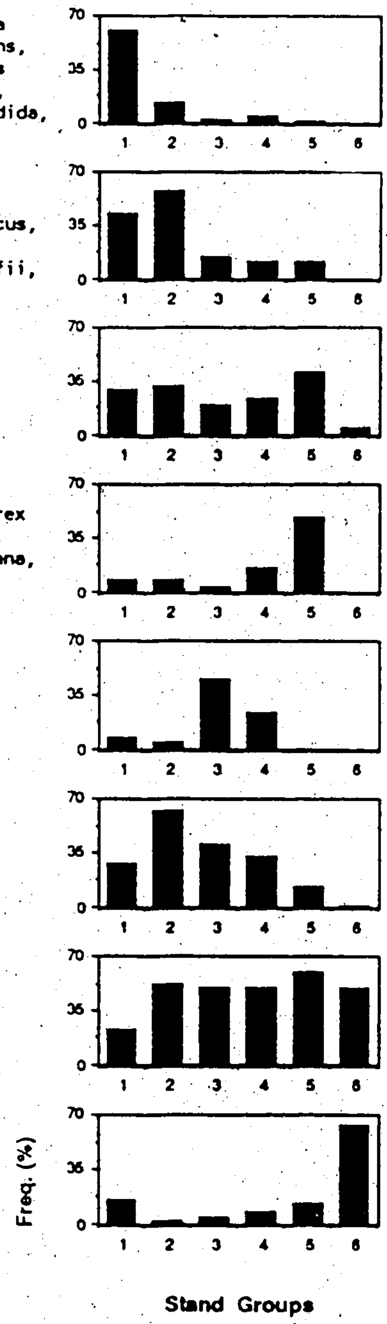


Fig. 3·5. Frequency distribution of TWINSPAN species groups across the stand groups. (8 species of very low frequency omitted).

such as *Larix laricina, Betula pumila* and *Tomenthypnum nitens* on hummocks, and *Triglochin maritima, Utricularia intermedia, Carex chordorrhiza, Meesia triquetra* and *Equisetum fluviatile, Carex limosa* and *Menyanthes trifoliata* in hollows are also common.

The <u>extreme rich fens</u> of the Foothills are grouped in stand groups 3 & 4. They are characterized by species of species group E, especially *Drepanocladus revolvens, Campylium stellatum* and *Tofieldia glutinosa.* Widespread species such as *Andromeda polifolia, Carex limosa* and *Menyanthes trifoliata* are also common.

Stand group 3 include the flark stands, and are further characterized by additional group E species such as *Scorpidium scorpioides, Aneura pinguis, Calliergon trifarium, Muhlenbergia glomerata, Scirpus caespitosus* and *Scirpus hudsonianus.* Other widespread species include *Carex lasiocarpa, Triglochin maritima, Utricularia intermedia, Carex chordorrhiza* and *Meesia triquetra.*

Stand group 4 includes the drier string stands, and are characterized by the widespread hummock species such as *Larix laricina, Betula pumila, Tomenthypnum nitens, Picea mariana* and *Ledum groenlandicum.*

The <u>poor fens</u> of the Swan Hills and Mariana Lakes are grouped in stand groups 5 & 6. These stands are *Sphagnum* dominated. *Carex limosa* and *Menyanthes trifoliata*, are common.

Stand group 5 includes the stands from Mariana Lakes, as well as string stands from the Swan Hills fens. They are characterized by hummock species of species group D. These include *Kalmia polifolia*, *Carex pauciflora*, *Sphagnum angustifolium*, *S. fallax*, *S. fuscum*, *S. magellanicum*, *Tomenthypnum falcifolium*, *Picea mariana*, *Betula glandulosa*, *Ledum groenlandicum* and *Vaccinium vitis-idaea*. The widespread hummock species, *Oxycoccus microcarpus* and *Andromeda polifolia*, are also common along with *Aulacomnium palustre*.

Stand group 6 includes the wet flark stands of the Swan Hills. *Sphagnum jensenii* and *Drepanocladus exannulatus* of species group H are the dominant species. *Carex limosa* and *Menyanthes trifoliata* are also abundant. These stands have low species richness (<10).

TWINSPAN based on bryophytes only.

The TWINSPAN classification of the 100 stands based on bryophytes only, is shown in Fig. 3-6, along with the indicator species separating the stand groups. As is the case with the analysis based on all species, the distinct separation of the moderatel, rich fens (stand groups 3 & 4) from extreme rich fens (stand groups 1 & 2) and poor fens (stand groups) 5 & 6 is clear. Extreme rich fen stands 82 and 86 are classified together with the moderately rich fen stands, suggesting affinities between these two fen types.

Detrended correspondence analysis (DCA).

The DCA ordination based on all species is shown in Fig. 3-7. Only the first two axes which account for the largest amounts of all the variation are plotted.

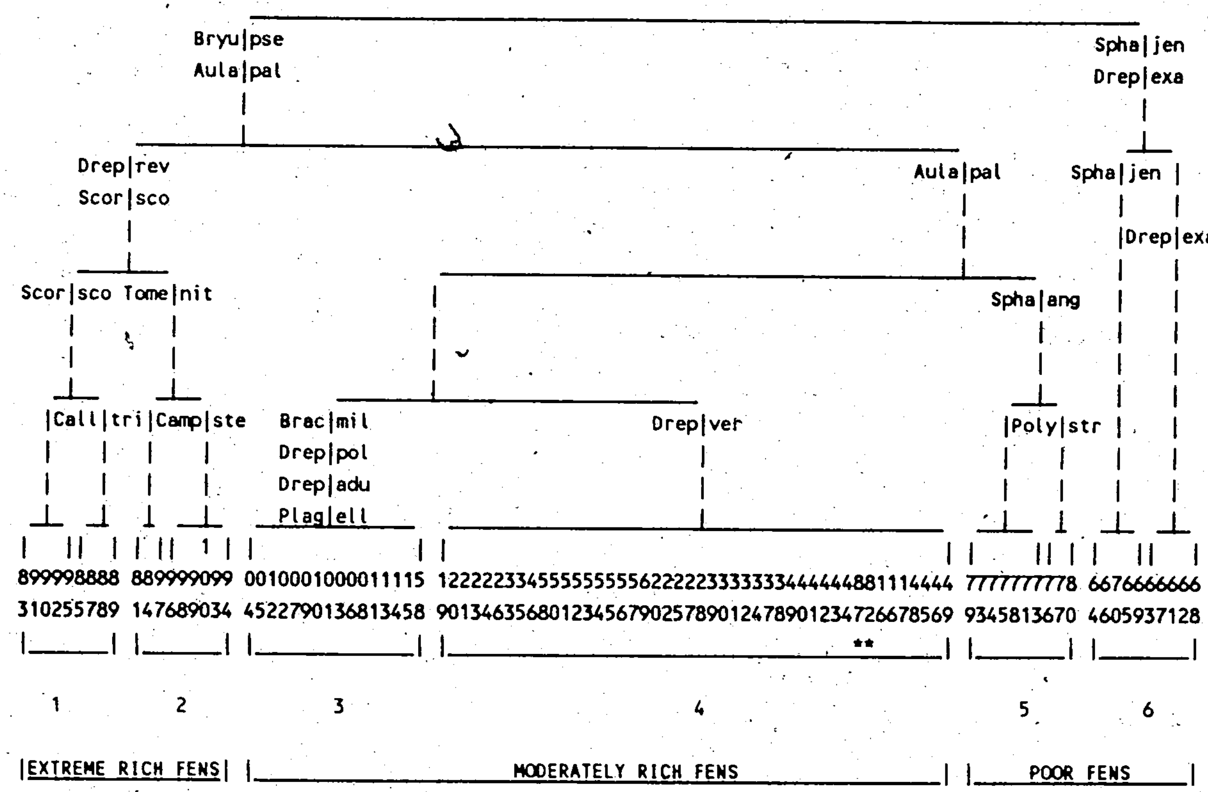


Figure 3-6. TWINSPAN dendrogram of 100 fen stands in central Alberta based on bryophytes only. Indicator species names abbreviated to first four letters of the genus and first three letters of the species. Refer to Fig. 3-5 for full names. * Extreme rich fen stands of the Foothills classified with moderately rich fen stands.

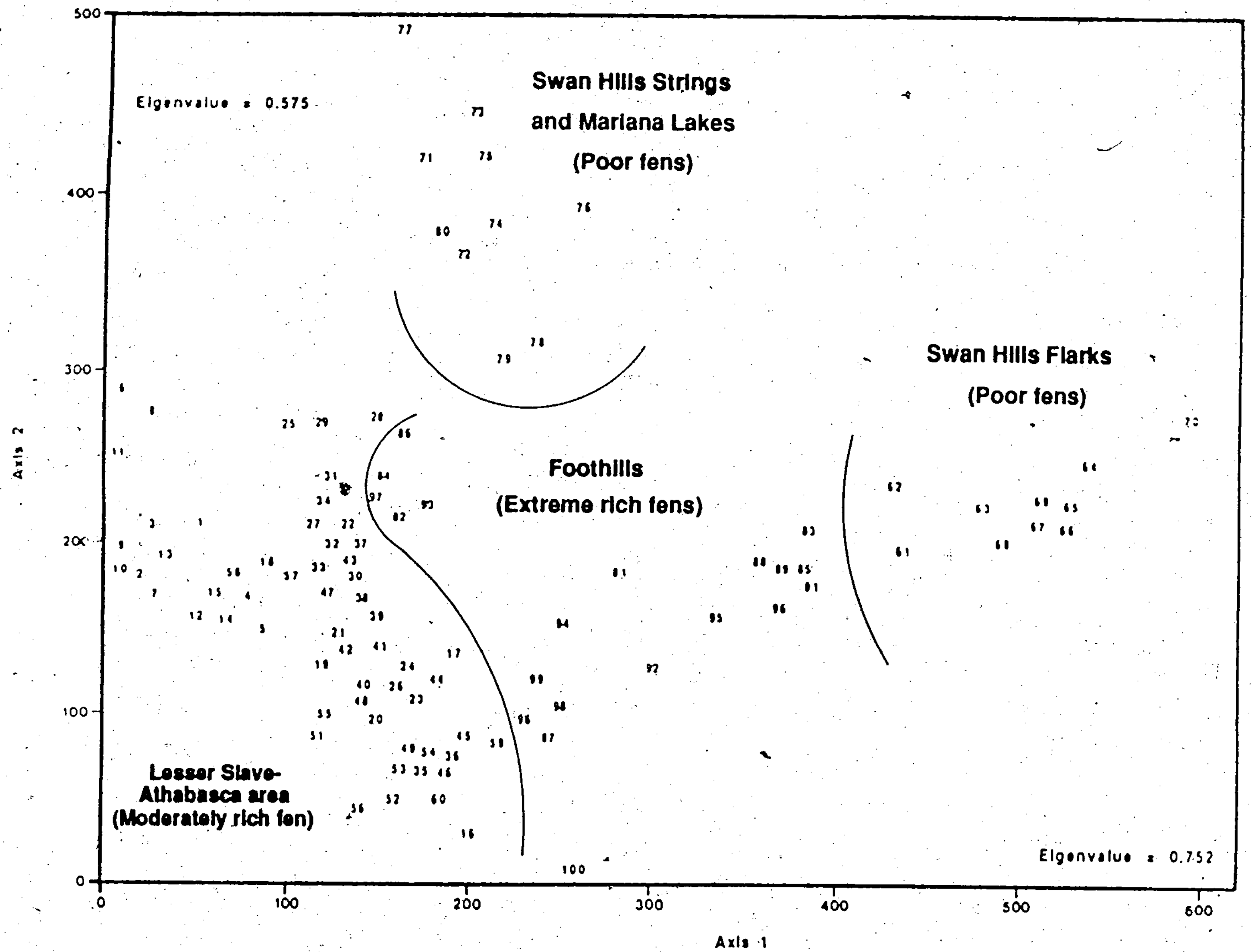


Fig. 3-7. DECORANA ordination of 100 stands based on 203 species.

String stands from the moderately rich fens (6, 8, 11, 22, 25, 27, 29, 37) and the extreme rich fens (82, 84, 86, 93, 97) appear to cluster together. The Mariana Lake stands are very similar in composition to the Swan Hill string stands, primarily due to the dominance of *Sphagnum angustifolium*. String stands are less variable and cannot be used to distinguish between fen types, since they are more removed from the influence of ground water. Omitting the string stands, the vegetation gradient along the main axis of variation is from moderately rich fen to extreme rich fen to poor fen. An ordination of the stands minus the 18 string stands results in a similar patterning of stands as that shown in Fig. 3-7.

The major stand groups obtained by the TWINSPAN classification can also be used to partition the DCA ordination space (Fig. 3-8). The ordination shows the relationship between moderately rich fens in stand groups 1&2, extreme rich fens in stand groups 3&4, and poor fens in stand groups 5&6. The TWINSPAN classification of the 100 stands into stand groups and fen types appears to be sound, with little overlap. Moderately rich fen stands appear to be more closely related to extreme rich fen stands than to poor fen stands.

A DCA ordination of the stands based only on the vascular species was also done. The results were similar to that obtained for the ordination based on all species. The vegetation gradient along the main axis (eigenvalue=0.644) was also from moderately rich fens to extreme rich fens to poor fens. Thus, the vegetation gradient based on the overall vegetation is primarily a vascular plant gradient.

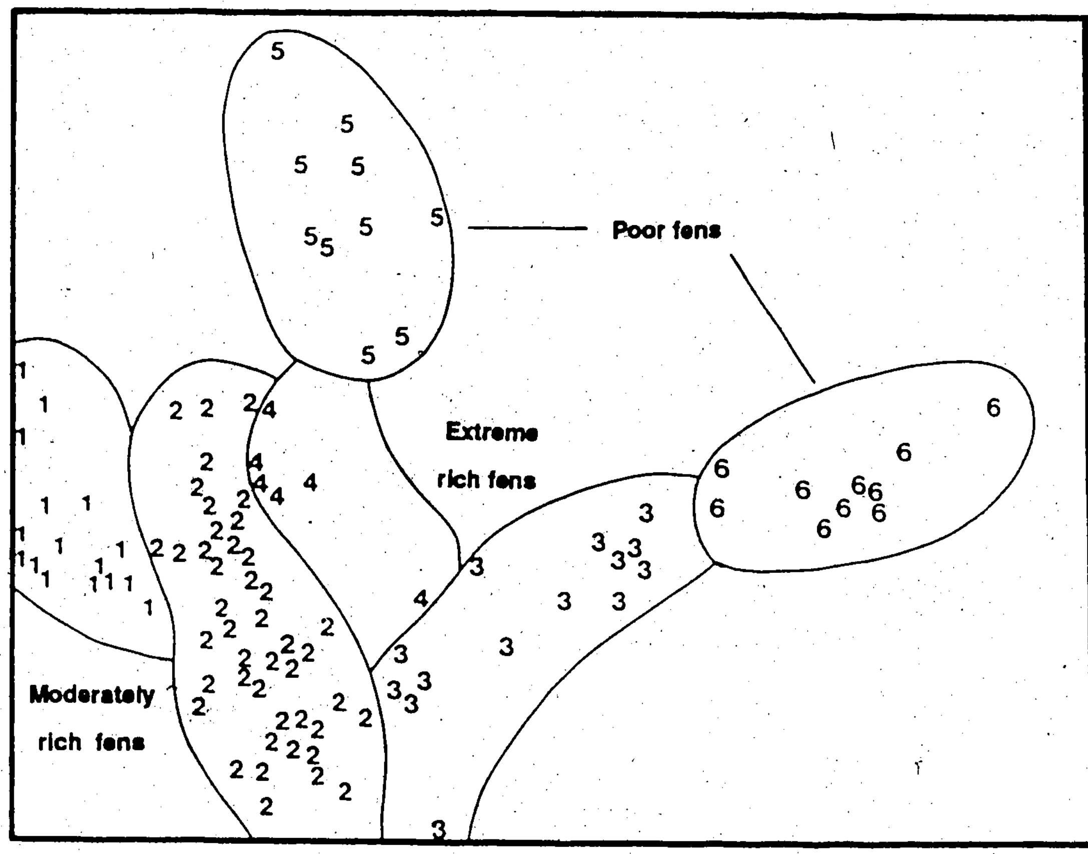


Fig. 3-8. DCA ordination based on all species, with TWINSPAN stand groups superimposed.

DCA based on bryophytes only.

The DCA ordination of the 100 stands based solely on the bryophytes is shown in Fig. 3-9. Unlike the DCA analysis based on all species, the vegetation gradient along the main axis of variation is from extreme rich fens to moderately rich fens to poor fens. This infers that different environmental factors underlie the bryophyte component as opposed to the vascular component of the vegetation.

The TWINSPAN stand groups based on bryophytes only are also used to partition the DCA ordination space (Fig. 3-10). Extreme rich fens in stand groups 1&2, moderately rich fens in stand groups 3&4, and poor fens in stand groups 5&6 can be separated with little overlap. (Extreme rich fen stands 82 & 87 are classified together with the moderately rich fens of stand group 4.)

The distribution of characteristic species.

The spatial distribution of the stands as shown by the ordination, also reflects the distribution of various characteristic species within these stands. The distributions of the more important characteristic species that separate the fen types are shown in Figs. 3-11 to 3-16.

Carex diandra, Potentilla palustris, Salix pedicellaris, Brachythecium mildeanum, B. turgidum, Drepanocladus vernicosus, D. aduncus and *D. polycarpus* are prevalent in the moderately rich fens. Extreme rich fens, on the other hand, are characterized by *Scirpus caespitosus, Scirpus. hudsonianus, Tofieldia glutinosa, Muhlenbergia glomerata, Scorpidium scorpioides, Drepanocladus revolvens, Calliergon trifarium* and *Aneura pinguis*. Poor fens

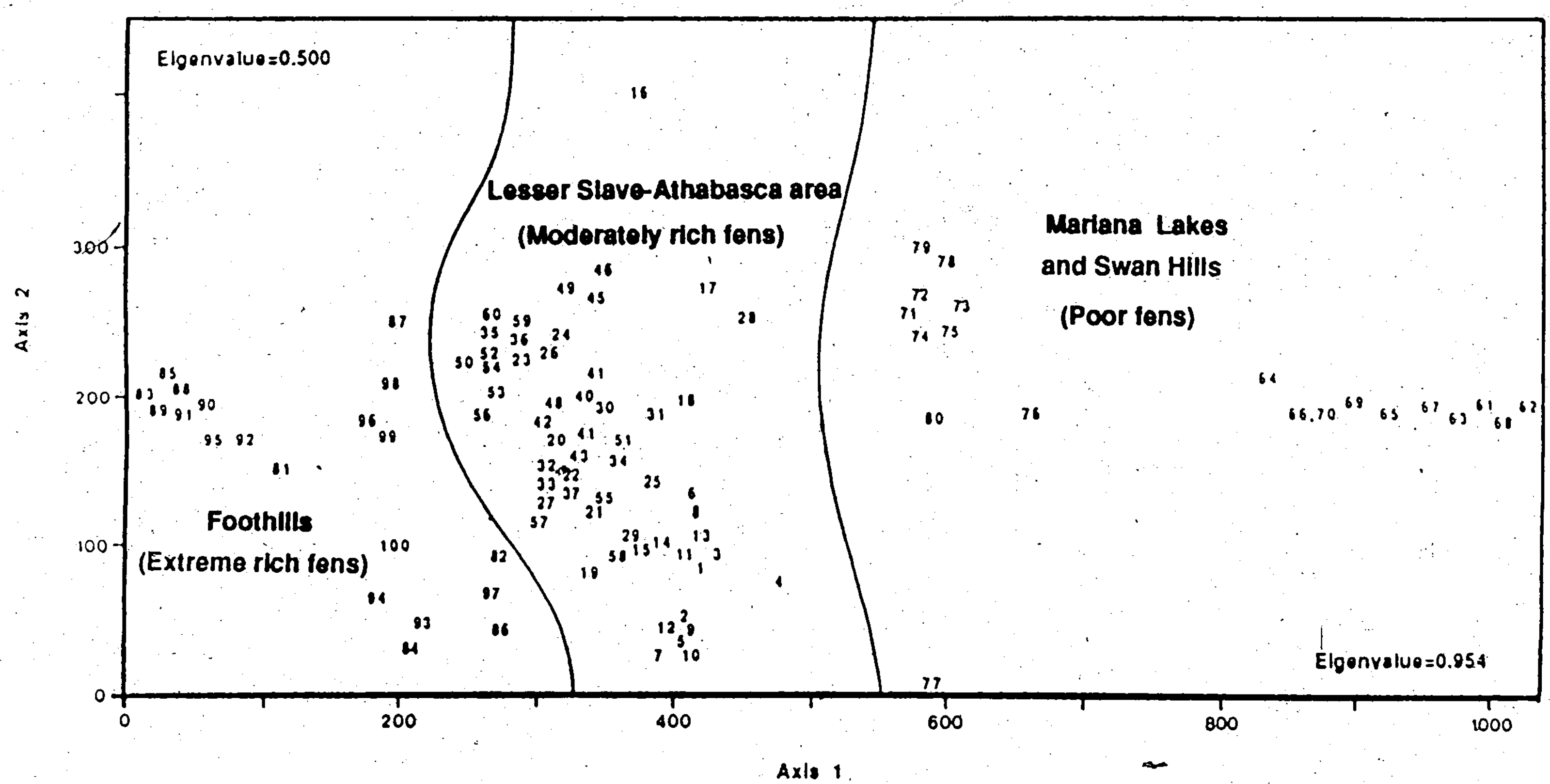


Fig. 3-9. DCA ordination of 100 stands based on 92 bryophytes.

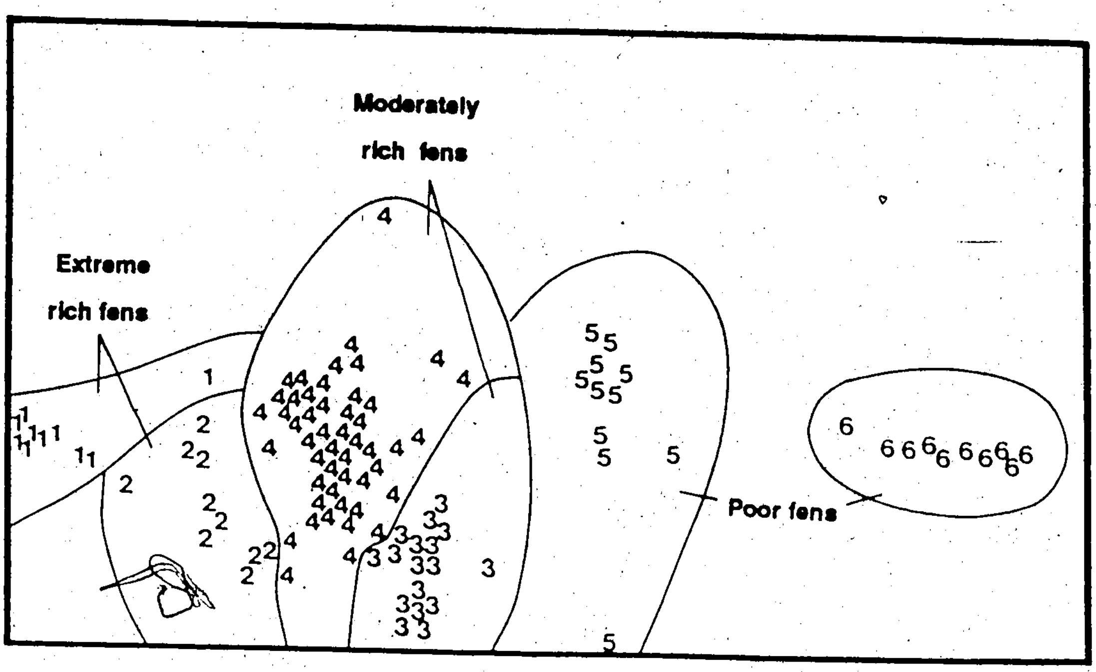
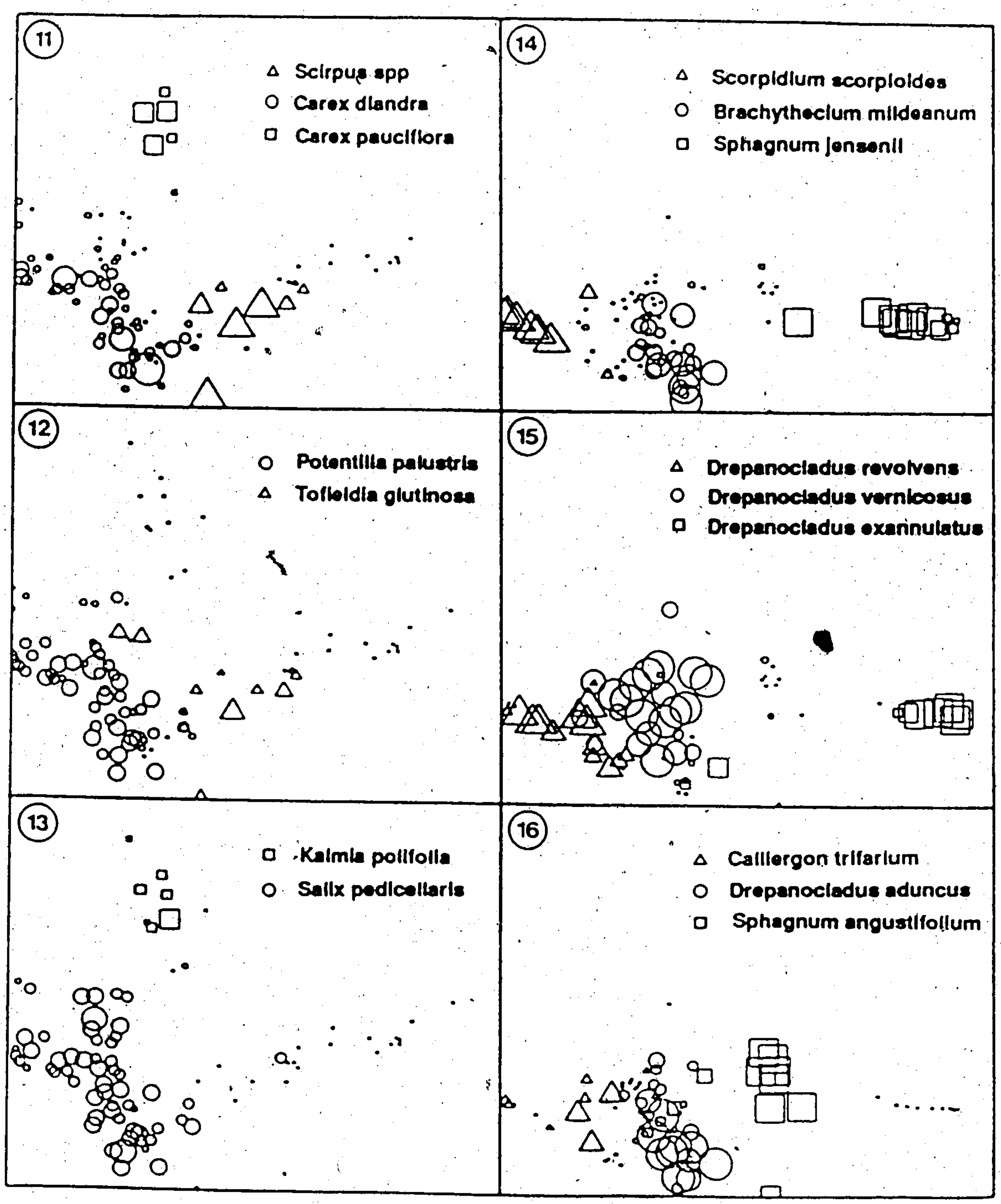


Fig. 3-10. DCA ordination based on bryophytes, with TWINSPAN stand groups superimposed.



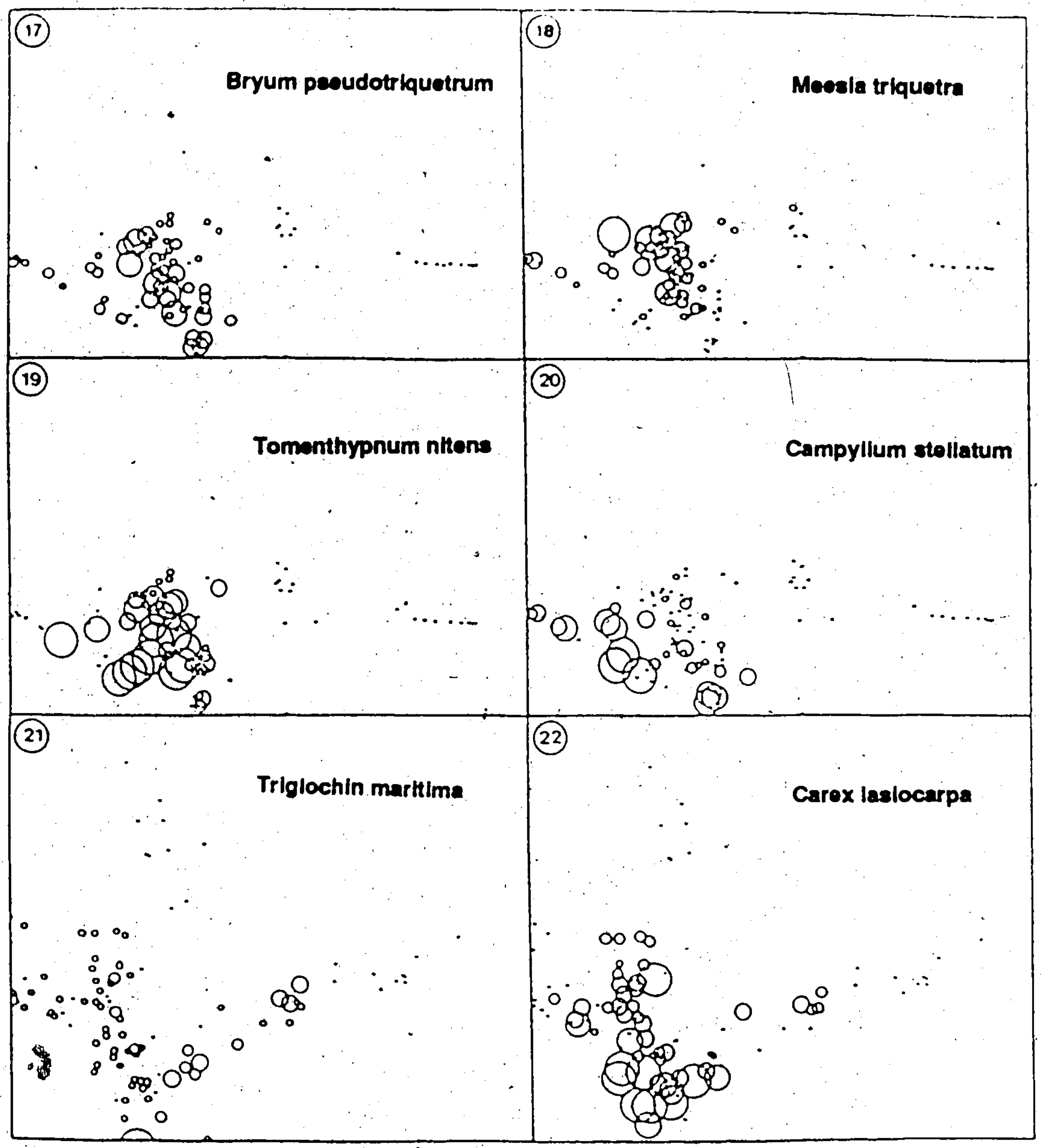
Figs. 3-11 to 3-16. Distribution of characteristic species relative to the DCA stand ordination based on all species (Figs. 3-11 to 3-13) and based on bryophytes only (Figs. 3-14 to 3-16). Cover classes: △○□ 0-2%, △○□ >2-5%, △○□ >5-10%, △○□ >10-20%, △○□ >20-40%, △○□ >40-60%, △○□ >60-80%. rich fen species, moderately rich fen species, poor fen species.

are distinguished by *Carex pauciflora, Kalmia polifolia, Sphagnum jensenii, Drepanocladus exannulatus* and *Sphagnum angustifolium*.

Common rich fen species that are also found in moderately rich fens include *Bryum pseudotriquetrum, Meesia triquetra, Tomenthypnum nitens, Campylium stellatum* and *Triglochin maritima* (Figs. 3-17 to 3-22). *Carex lasiocarpa* also shows a similar distribution, although other authors (Ruuhijarvi 1960, Eurola 1962) have also found them in poor fens.

The moderately rich fens have the highest species richness of the three fen types (Fig. 3-23). This may be due to the fact that, in addition to having their own characteristic species, they also have some of the rich fen species mentioned above, as well as poor fen species such as *Eriophorum chammisonis*.

A summary of the distribution of important characteristic and dominant species across the three fen types is shown in Table 3-1. The sequence of stand groups shown follow the traditional poor to rich fen vegetation gradient of Du Rietz (1949). As can be seen, each fen type has its own characteristic species that are rarely found in the other two types. In addition, the moderately rich fens also share more species in common with rich fens (eg. *Andromeda polifolia, Salix pedicellaris, Larix laricina, Carex lasiocarpa, Betula pumila, Triglochin maritima, Bryum pseudotriquetrum, Meesia triquetra, Campylium stellatum*) than with poor fens (*Eriophorum chamissonis, Scheuchzeria palustris*).



Figs. 3-17 to 3-22. Distribution of characteristic species common to both extreme rich fens and moderately rich fens, relative to DCA stand ordination based on bryophytes (Figs. 3-17 to 3-20) and based on all species (Figs. 3-21 & 3-22). Cover classes are • 0-2%, ○ >2-5%, ○ >5-10%, ○ >10-20%, ○ >20-40%, ○ >40-60%, ○ >60-80%.

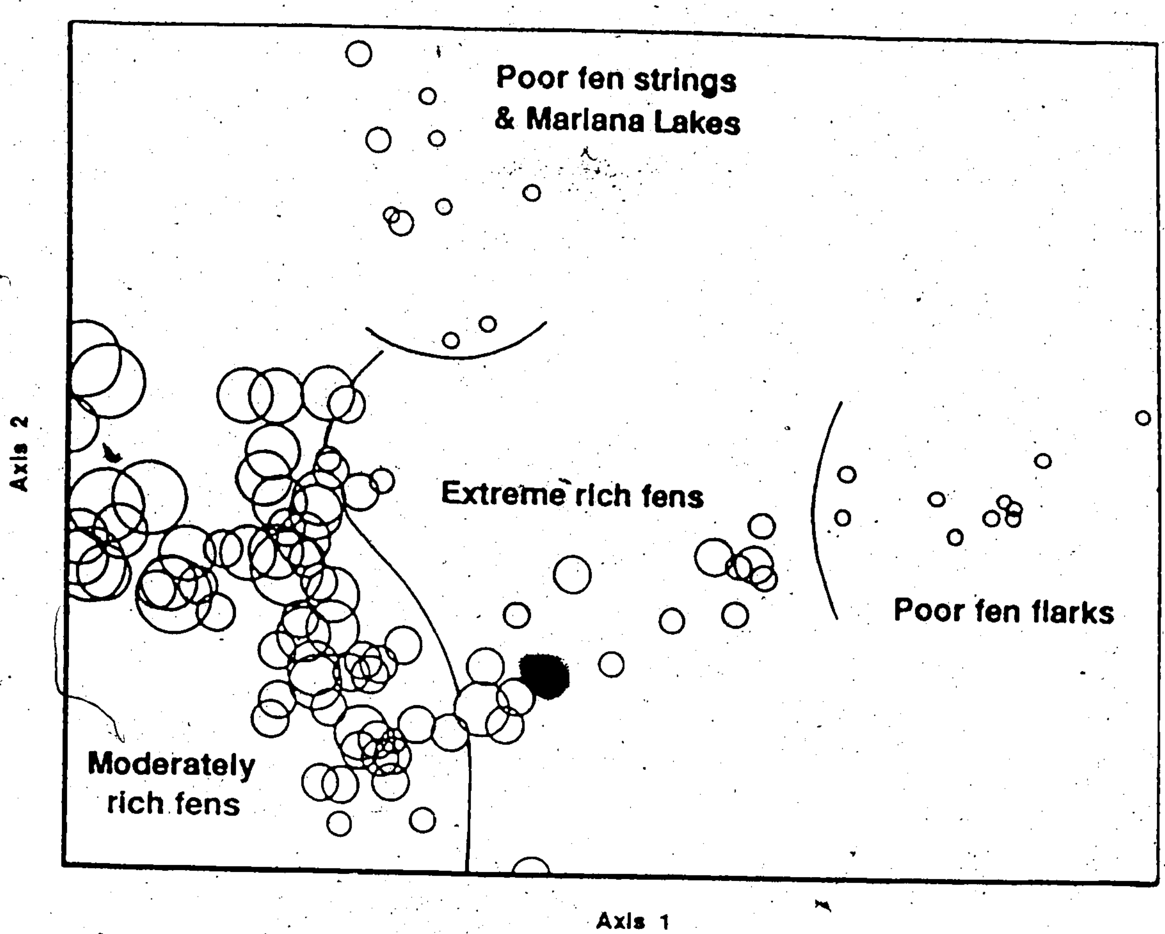


Fig. 3-23. Species richness superimposed onto the DCA stand ordination.

○ 1-10, ○ 11-20, ○ 21-30, ○ 31-40, ○ 41-50.

Table 3-1a. Distribution of common vascular species along the poor-rich vegetation gradient.

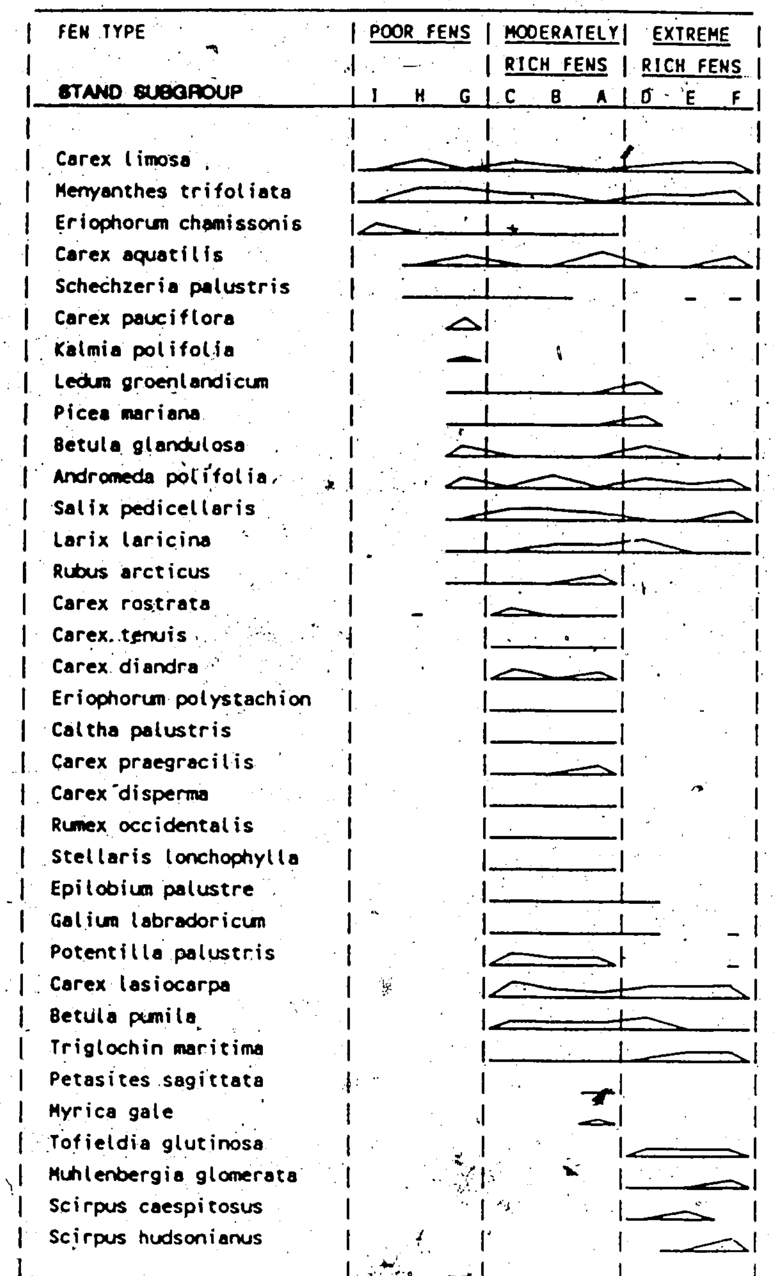
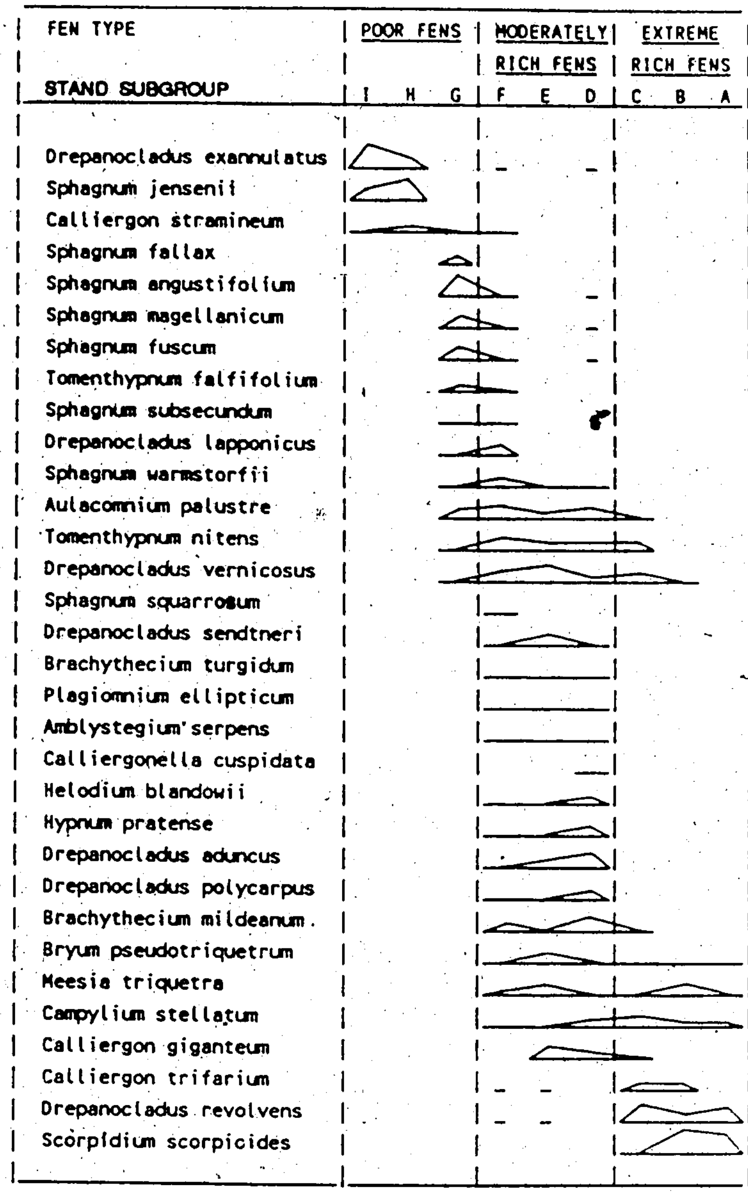


Table 3-1b. Distribution of common bryophyte species along the poor-rich vegetation gradient.



Vertical scale [represents cover classes 1-7 calculated from average class value within group. (0%<1≤2%<2≤5%<3≤10%<4≤20%<5≤40%<6≤60%<7≤80%).

2. CHEMISTRY.

Descriptive statistics for 21 chemical variables across the three fen types are given in Table 3-2. Mean pH values are given. Since the pH scale is logarithmic, arithmetic averaging is questionable. It is more correct to use H^+ concentrations instead. The problem with using H^+ concentration, however, lies in the large standard deviations resulting from the antilog conversion. Thus, mean pH values that are significantly different between the three fen types, may not necessarily have significantly different H^+ concentrations. Jeglum (1971) pointed out that biological data frequently show better normal distributional patterns when plotted in terms of logarithmic functions of measurements of fertility status, rather than directly in terms of absolute values. So, arithmetic treatments of pH may be justified in terms of the biological response.

Water chemistry results show pH, specific conductance, calcium and magnesium content in the fen waters to be significantly different among the three fen types (Table 3-2a). All are lowest in poor fens, intermediate in the moderately rich fens, and highest in extreme rich fens. In addition, the moderately rich fens have the highest organic nitrogen and ammonium content in the fall water. In the fen peats, calcium and magnesium contents are also lowest in poor fens, intermediate in moderately rich fens, and highest in extreme rich fens (Table 3-2b).

<u>Organic nitrogen</u>, the major component of the total Kjeldahl nitrogen (TKN) analyses, is the most abundant form of nitrogen found in the peatlands of this study. The organic nitrogen is higher in the

Water chemistry variables		Mean Values (standard deviations) POOR FENS		MODERATELY RICH FENS		EXTREME RICH FENS	
pH spring	s	4.50	(0.35)	6.70	(0.37)	7.34	(0.13)
fall	f	4.82	(0.54)	6.18	(0.41)	7.11	(0.23)
Con (µS/cm)	s	27.9	(35.3)	67.5	(53.7)	209.	(52.9)
	f	14.7	(13.8)	69.8	(47.5)	214.	(57.1)
Ca (mg/l)	s	1.40	(0.50)	19.5	(20.5)	56.5	(22.6)
	f	1.60	(1.40)	22.1	(20.3)	67.7	(15.7)
Mg (mg/l)	s	0.37	(0.24)	4.26	(3.58)	12.7	(5.83)
	f	0.43	(0.35)	5.27	(4.93)	16.1	(6.77)
Na (mg/l)	s	0.48	(0.27)	4.28	(5.12)	6.26	(4.73)
	f	0.34	(0.33)	6.87	(8.86)	7.12	(4.89)
K (mg/l)	s	0.63	(0.46)	1.60	(1.42)	1.87	(1.08)
	f	0.23	(0.61)	1.70	(3.21)	3.62	(5.55)
S (mg/l)	s	0.50	(0.21)	0.45	(0.65)	0.35	(0.29)
	f	0.36	(0.24)	0.44	(0.43)	0.17	(0,15)
Fe (mg/l)	s	0.32	(0.15)	0.20	(0.24)	0.55	(0.93)
	f	0.17	(0.07)	0.49	(0.58)	2.49	(2.89)
P (mg/l)	s	0.01	(0.03)	0.12	(0.30)	<.01	–
	f	0.02	(0.05)	0.05	(0.14)	<.01	–
Org.N (µg/l)	s	846.	(423.)	1983	(790.)	1788	(541.)
	f	1084	(1079)	2484	(690.)	1178	(538.)
NO_3 (µg/l)	s	7.90	(6.50)	3.10	(1.90)	16.5	(13.2)
	f	8.40	(13.9)	9.80	(17.6)	33.2	(41.2)
NH_4 (µg/l)	s	22.7	(18.3)	16.8	(15.3)	67.3	(54.2)
	f	21.3	(32.4)	88.9	(114.)	16.6	(20.6)

Table 3-2a. Mean values and standard deviations of water chemistry variables. The underscoring marks the fen types between which there is no significant difference in the distribution of data (Mann-Whitney test for $n>10$, median test for $n<10$, alpha=0.05/3 following the Bonferroni inequality).

Peat chemistry variables		Mean Values (standard deviations) POOR FENS		MODERATELY RICH FENS		EXTREME RICH FENS	
Ash(%)	0	3.0	(1.9)	12.1	(5.2)	10.6	(9.7)
	30	3.8	(2.4)	10.3	(7.1)	11.5	(9.9)
Ca (g/kg)	0	3241	(1063)	14018	(6341)	48780	(46306)
	30	4086	(2811)	17426	(6369)	51391	(48072)
Mg (g/kg)	0	1004	(465)	2222	(760)	4518	(2792)
	30	471	(308)	1791	(857)	3830	(2716)
Na (g/kg)	0	227	(110)	737	(447)	193	(68)
	30	124	(57)	214	(161)	158	(56)
K (g/kg)	0	640	(395)	1597	(873)	703	(273)
	30	278	(107)	403	(374)	599	(218)
S (g/kg)	0	2679	(381)	8267	(12618)	9364	(13495)
	30	1034	(274)	3348	(4939)	6788	(9307)
Fe (g/kg)	0	600	(253)	880	(458)	610	(417)
	30	368	(76)	1074	(729)	1263	(1170)
P (g/kg)	0	1307	(1117)	1916	(1132)	550	(236)
	30	851	(223)	1263	(384)	632	(237)

Table 3-2b. Mean values and standard deviations of peat chemistry variables. The underscoring marks the fen types between which there is no significant difference in the distribution of data (Mann-Whitney test for n>10, median test for n<10, alpha=0.05/3 following the Bonferroni inequality).

moderately rich fens than in poor and extreme rich fens, and especially in the fall sampling (Table 3-2a). Ammonium is the more abundant form of available nitrogen, while nitrate occurs in very small amounts in the peatlands studied. Nitrate values are highest in the extreme rich fens studied (Table 3-2a). Ammonium in the fen waters is significantly higher in extreme rich fens in the spring, but is significantly higher in moderately rich fens in the fall.

Phosphorus levels in the fen waters are extremely low in all the peatlands studied (Table 3-2a), and cannot be used to distinguish between the fen types. Total phosphorus in the peat is higher in the moderately rich fens than in extreme rich or poor fens .

Calcium is the most abundant ion, and is significantly different in each of the fen types, increasing from poor fens to moderately rich fens to extreme rich fens (Table 3-2a and 3-2b). Calcium content in peat follows a similar trend as that in water, that is, increasing from poor fens to moderately rich fens to rich fens. The concentrations obtained in this study fall well within the ranges found in other studies (Tables 3-3 and 3-4).

Magnesium content in water and peat follows a similar trend as calcium, increasing from poor fens to moderately rich fens to extreme rich fens (Table 3-2a and 3-2b). The magnesium content of fen waters in this study is low compared to some other studies (Table 3-3 and 3-4) done in maritime areas where magnesium is higher, probably due to salt spray (Gorham 1956).

Sodium content in the peatlands studied does not show a clear trend. There is no significant difference in the sodium content of water between moderately rich fens and extreme rich fens, although it

Table 3-3. A comparison of macronutrient values found in fen waters.

	REFERENCE	STUDY AREA	pH	Con (µS)	Ca (mg/l)	Mg (mg/l)	Na (mg/l)	K (mg/l)	S (mg/l)	Fe (mg/l)	P (mg/l)
POOR FENS	Present study - spring,fall	Alberta	4.5,4.8	28,15	1,2	.4,.4	.5,.3	.6,.2	.5,.4	.3,.2	.01,.02
	Comeau & Bellamy (1986)	Eastern Canada	4.3	-	7	2	4	0.4	77	-	-
	Wilson & Fitter (1986)	England	-	-	-	-	-	-	-	-	3-30
	Karlin & Bliss (1984)	Alberta	3.5-6.1	-	2-12	1-3	-	-	-	-	-
	Bellamy (1968)	Western Europe	4.5	-	20	5	7	2	86	-	-
	Sjors (1963)	Ontario	4.1-5.4	16-22	2	0.5	0.3	0.1	-	-	-
	Persson (1962)	Sweden	4.3-5.0	-	60-950	10-330	68-130	7-79	-	-	-
	Tolpa & Gorham (1960)	Poland	3.8	-	.4-.9	-	.4-.7	.1-.7	10-11	-	-
	Sjors (1948)	Sweden	4.2	-	6	2	2	0.4	12	-	-
	Zoltai & Johnson (1987)	Alberta	4.7	45	2	0.8	4	0.9	1	0.9	0.21
TRANSITIONAL	Present study - spring,fall	Alberta	6.7,6.2	68,70	20,22	4,5	4,7	2,2	.5,.4	.2,.5	.1,.1
	Comeau & Bellamy (1986)	Eastern Canada	5.5	-	15	6	7	1	12	-	-
	Karlin & Bliss (1984)	Alberta	4.6-7.1	-	4-51	2-12	-	-	-	-	-
	Schwintzer (1981)	Michigan	5.7-7.0	-	11-75	-	-	-	-	-	-
	Yefimov & Yefimova (1973)	U.S.S.R.	6.1	-	18	8	1	0.3	32	0.4	0.3
	Persson (1961)	Sweden	5.4-7.0	-	40-50	30	85-93	5-16	-	-	-
	Sjors (1948)	Sweden	6.0	-	68	12	2	0.4	25	-	-
	Zoltai & Johnson (1987)	Alberta	6.0	249	28	11	5	1	1.8	0.5	0.1
RICH FENS	Present study - spring,fall	Alberta	7.3,7.1	209,214	57,68	13,16	6,7	2,4	.4,.2	.6,.5	-
	Karlin & Bliss (1984)	Alberta	7.2-8.2	-	31-120	10-53	-	-	-	-	-
	Bellamy (1968)	Western Europe	6.6	-	183	19	11	2	216	-	-
	Sjors (1963)	Ontario	5.8-7.4	48	9	2	1	0.3	-	-	-
	Sjors (1961)	Ontario	7.9	207	32	7	5	0.6	-	-	-
	Persson (1961)	Sweden	5.7-7.9	-	100-1380	50-1690	47-144	4-36	-	-	-
	Zoltai & Johnson (1987)	Alberta	6.5	374	54	17	6	0.8	1.8	0.04	0.09

Table 3-4. A comparison of macronutrient values found in fen peats.

Fen type	REFERENCE	STUDY AREA	Ca (g/kg)	Mg (g/kg)	Na (g/kg)	K (g/kg)	S (g/kg)	Fe (g/kg)	P (g/kg)	N (g/kg)
POOR FENS	Present study	Alberta	3241,4086	1004,471	227,124	640,278	2679,1034	600,368	1307,851	-
	Wilson & Fitter (1986)	England	-	-	-	-	-	-	680,400	-
	Karlin & Bliss (1984)	Alberta	10421,15230	4862,1945	-	-	-	-	-	-
	Wells (1981)	Newfoundland	10895	-	-	-	-	327	-	19950
	Waughman & Bellamy (1980)	Canada, Europe	-	-	-	-	-	-	-	7000-22000
	Pollett (1972)	Newfoundland	5070	1670	-	370	-	2090	640	13000
	Zoltai & Johnson (1987)	Alberta	3285	867	267	1587	872	2001	694	
TRANSIT	Present study	Alberta	14018,17426	2222,1791	737,214	1597,403	8267,3348	880,1074	1916,1263	-
	Karlin & Bliss (1984)	Alberta	12025,20842	-	-	-	-	-	-	-
	Waughman & Bellamy (1980)	Canada, Europe	-	-	-	-	-	-	-	2000-24000
	Zoltai & Johnson (1987)	Alberta	15687	2874	19[illegible]	898	2156	3942	774	
RICH FENS	Present study	Alberta	48780,51391	458,3830	193,158	703,599	9364,6788	610,1263	550,632	
	Karlin & Bliss (1984)	Alberta	12825,81763	8752,5399	-	-	-	-	-	-
	Waughman & Bellamy (1980)	Canada, Europe	-	-	-	-	-	-	-	8000-20000
	Pollett (1972)	Newfoundland	16130,30630	1310,3210	-	410,1001	-	10070,7240	920-1003	20000
	Zoltai & Johnson (1987)	Alberta	49942	4094	105	421	2955	3858	567	-

is lower in the poor fens (Table 3-2a). Unlike the other fens, the poor fens of the Swan Hills area are not underlain by marine shales, the source of sodium in the ground waters. It should also be noted that the poor fens are more remotely located, while the Lesser Slave-Athabasca fens and rich fens are closer to roads and highways where salt may be applied. The sodium content of fen waters in this study are also low compared to other studies (Table 3-3).

Potassium occurs in relatively small amounts compared to calcium and magnesium. Potassium content in the fall water increases from poor fens to moderately rich fens ot extreme rich fens (Table 3-2a). The values found in this study are well within the range found in other studies (Table 3-3). In the surface peats, potassium is highest in the moderately rich fens. Waughman (1980) also found potassium to be highest in his "intermediate" fen peats as opposed to poor fens and rich fens.

Iron is not significantly different between the three fen types (Table 3-2). This suggests high standard deviations and overlap in iron content between the three fen types. Waughman (1980) found iron to be highest in "intermediate" fen peats compared to poor and rich fen peats.

Sulphur content is not significantly different between the three fen types (Table 3-2a and 3-2b).

3. CORRELATIONS BETWEEN VEGETATION AND CHEMISTRY.

The relationship between vegetation and chemistry can be inferred from an indirect gradient analysis which correlates chemical variables with the DCA stand scores representing plant communities along a vegetation gradient. The correlation of chemistry variables with DCA stand scores along the first two axes of variation is shown in Table 3-5a and 3-5b.

The DCA axes 1 scores based on all species represent a vascular plant vegetation gradient from moderately rich fens to extreme rich fens to poor fens. This axis is significantly correlated with the following chemical variables : organic nitrogen, ammonium, sodium, nitrate (spring), phosphorus (spring), iron (spring), sulphur (fall) in the fen water, and phosphorus, iron, potassium, sodium (surface), magnesium (subsurface), ash content (surface) in the fen peat. Most of these chemistry variables (with the exception of Na, Mg, S, which are more strongly correlated to the bryophyte component) represent those macronutrients that are usually present in limited amounts. Nitrogen, phosphorus and to a smaller degree, potassium and iron are elements usually associated with a fertility gradient.

These significant correlations infer that the vascular vegetation gradient of moderately rich fen to extreme rich fen to poor fen reflects an oligotrophic-eutrophic gradient. But this is not a simple gradient, as the correlations are both positive and negative, such that, a fen type may be oligotrophic with respect to some chemistry variables, and eutrophic with others. For example, while moderately rich fens have the highest organic N and ammonium values in

Water chem. variables		Correlation with DECORANA axes scores based on ALL SPECIES Ax 1	Ax 2	BRYOPHYTES Ax 1	Ax 2	VASCULARS Ax 1	Ax 2
pH spring	s	-.14	-.38*	-.74*	-.31*	-.14	.19
fall	f	-.14	-.37*	-.74*	-.32*	-.13	.23
Con.	s	-.12	-.27	-.65*	-.22	-.12	.16
	f	-.16	-.29*	-.68*	-.28	-.15	.21
Ca	s	-.19	-.36*	-.70*	-.30*	-.17	.05
	f	-.18	-.35*	-.71*	-.28	-.18	.14
Mg	s	-.23	-.30*	-.67*	-.38*	-.21	.13
	f	-.24	-.27	-.64*	-.38*	-.24	.18
Na	s	-.38*	-.31*	-.44*	-.39*	-.33*	.10
	f	-.40*	-.30*	-.44*	-.29*	-.33*	.02
K	s	-.20	-.22	-.23	-.15	-.23	.04
	f	-.11	-.25	-.47*	.04	-.13	.07
S	s	-.17	.26	.46*	.35*	-.26	.38*
	f	-.42*	.43*	.60*	.31*	-.42*	.08
Fe	s	.45*	.16	-.19	.25	.43*	.27
	f	-.04	.23	-.13	.27	-.06	.29
P	s	-.31*	.10	.28	-.22	-.34*	.08
	f	-.26	-.04	.21	-.05	-.30*	-.22
Org. N	s	-.45*	-.31	-.23	-.26	-.41*	-.08
	f	-.56*	-.27	-.04	.14	-.52*	-.62*
NO_3	s	.51*	-.08	-.20	.15	.41*	.45*
	f	-.03	-.07	-.26	.07	-.04	-.12
NH_4	s	.30*	-.02	-.20	-.02	.31*	.36*
	f	-.45*	-.21	-.03	.14	-.40*	-.58*

Table 3-5a. Spearman's rank order correlation of water chemistry variables with DCA stand scores.

Peat chem. variables		Correlation with DECORANA axes scores based on ALL SPECIES Ax 1	Ax 2	BRYOPHYTES Ax 1	Ax 2	VASCULARS Ax 1	Ax 2
Ash	0 cm	-.42*	.13	-.19	-.09	-.35*	-.22
	30 cm	-.18	-.13	-.35	.17	-.11	-.22
Ca	0	-.03	-.34*	-.70*	-.14	-.06	.15
	30	-.22	-.28	-.63*	-.25	-.22	-.08
Mg	0	-.15	-.22	-.46*	-.30*	-.17	.33*
	30	-.31*	-.13	-.42*	-.35*	-.30*	.28
Na	0	-.52*	-.31*	.16	-.01	-.46*	-.51*
	30	-.11	-.17	-.20	.11	-.08	-.13
K	0	-.35*	-.35*	-.07	-.16	-.25	-.56*
	30	-.46*	-.21	-.40*	.34*	.47*	.12
S	0	.06	.02	-.06	.07	.14	.02
	30	.12	.14	-.33*	.01	.15	.10
Fe	0	-.55*	.13	.35*	.37*	-.54*	-.07
	30	-.52*	.04	.02	-.63*	-.53*	.18
P	0	-.52*	-.04	.41*	-.19	-.49*	-.38*
	30	-.53*	-.19	.15	-.11	-.47*	-.49*

Table 3-5b. Spearman's rank order correlation of peat chemistry variables with DCA stand scores.

the fall, they also have the lowest nitrate and ammonium values in the spring. A summary of all the chemical variables that are significantly corelated with the DCA axis 1 scores is graphically shown in Fig. 3-24.

The variation along the second DCA axis is correlated with pH, conductivity, calcium, magnesium, sodium and sulphur (Table 3-5a), that is, elements associated with an ionic gradient, as opposed to an oligotrophic-eutrophic nutrient gradient. These chemical variables are better correlated with another component of the vegetation and will be discussed later.

Correlations based on the bryophyte component.

The DCA results based on bryophytes only, shows the axis 1 scores to represent a vegetation gradient from extreme rich fens to moderately rich fens to poor fens. This axis is significantly correlated with pH and specific conductance. The conductivity is correlated to major ions such as calcium, magnesium, sodium and potassium (Table 3-6). Calcium, magnesium, sodium, potassium (fall) and sulphur in the fen water, and calcium, magnesium, potassium (subsurface), sulphur (subsurface), iron (surface), phosphorus (surface) in the fen peat (Tables 3-5a and 3-5b) are all significantly correlated to the ordination scores based on bryophytes. With the exception of Fe and P, these macronutrients represent an ionic gradient. Thus, the bryophyte component of the vegetation reflects what is basically an ionic gradient. A summary of all the chemistry variables that are significantly correlated to the DCA axes scores is graphically shown in Fig. 3-25.

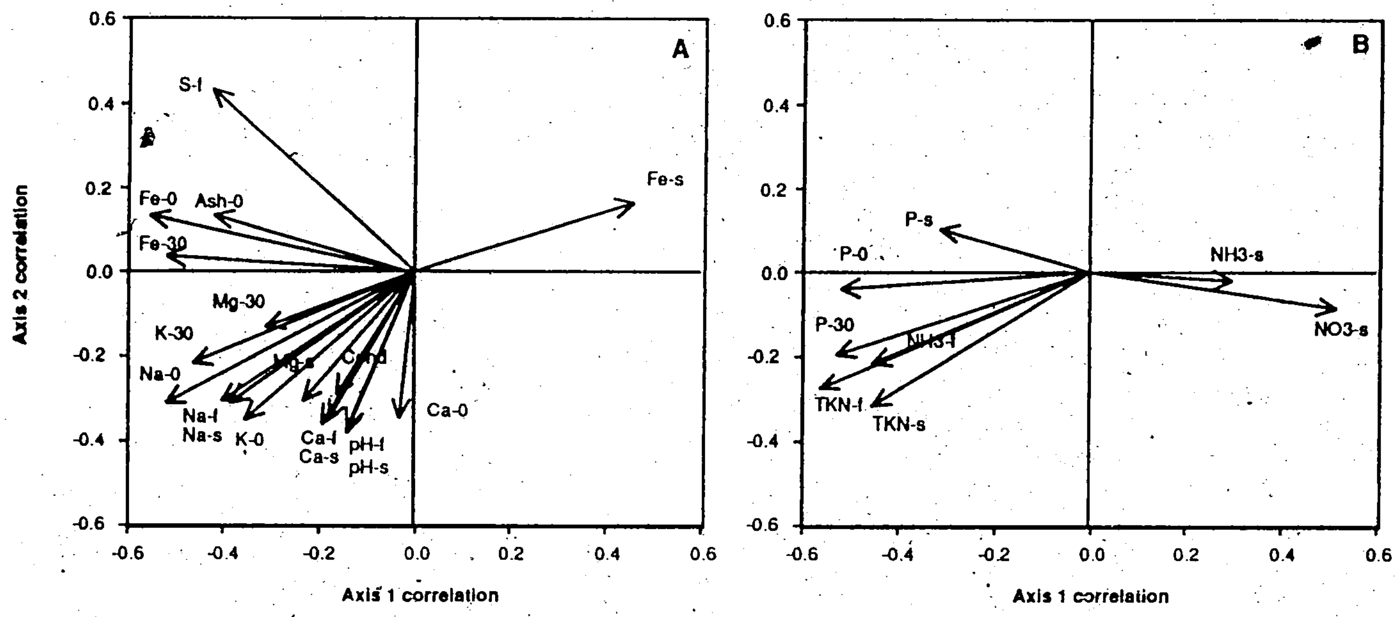


Fig. 3-24. Correlation vectors of chemistry variables that are significantly correlated to DCA axes scores based on all species.

A. Ions. B. Nutrients. s=spring, f=fall, 0=surface, 30=subsurface.

Variables		Correlation with conductivity in spring water	Correlation with conductivity in fall water
pH	s	.77*	.78*
	f	.78*	.87*
Calcium	s	.89*	.82*
	f	.85*	.93*
	0	.75*	.76*
	30	.73*	.76*
Magnesium	s	.90*	.86*
	f	.84*	.93*
	0	.69*	.73*
	30	.64*	.74*
Sodium	s	.64*	.74*
	f	.60*	.76*
	0	.22	-.14
	30	.07	.16
Potassium	s	.36*	.35*
	f	.43*	.42*
	0	-.09	-.13
	30	.06	.07
Sulphur	s	-.15	-.09
	f	-.21	-.14
	0	-.06	-.10
	30	.29*	.26*

Table 3-6. Spearman's rank order correlation of major ions with conductivity of fen water. s=spring water, f=fall water. 0=surface peat, 30=subsurface peat.

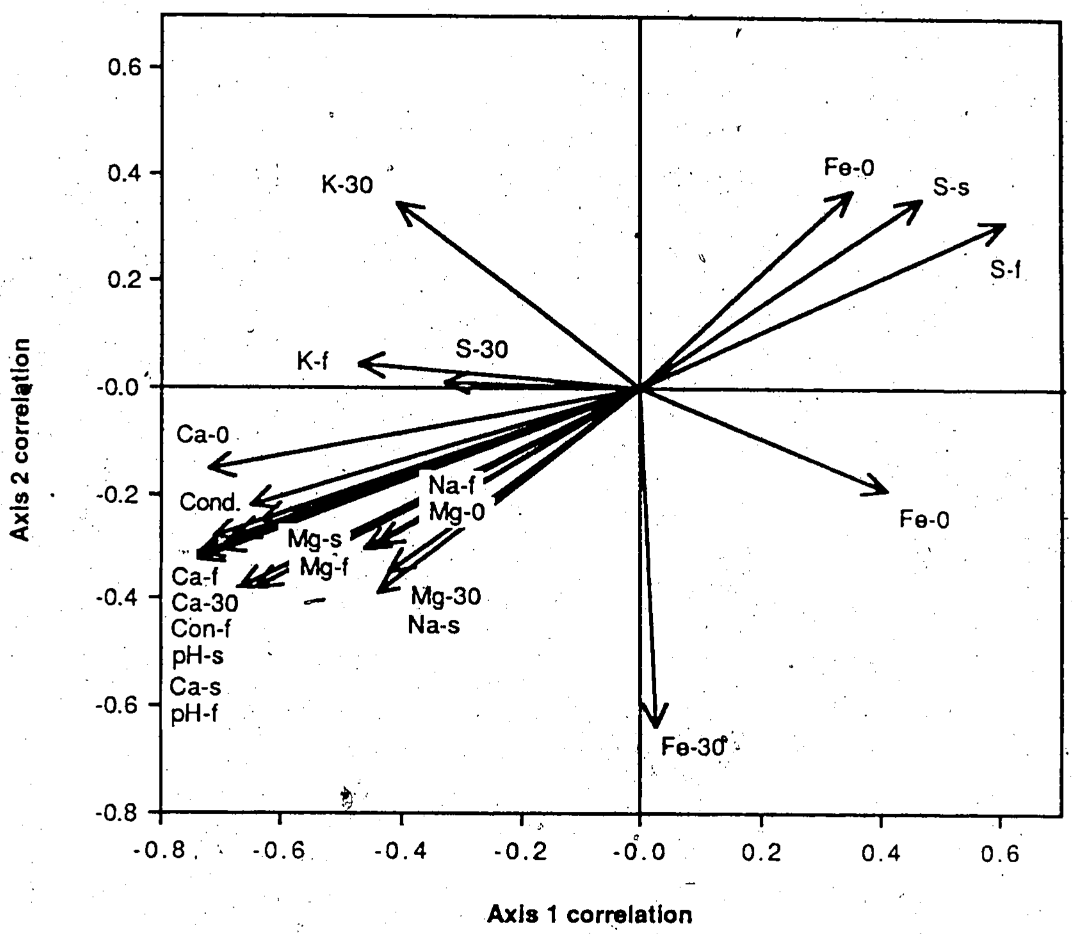


Fig. 3-25. Correlation vectors of chemistry variables that are significantly correlated to DCA axes scores based on bryophytes only. s=spring, f=fall, 0=surface, 30=subsurface.

E. DISCUSSION.

The role of nitrogen and phosphorus.

Nitrogen has a complex role in peatlands. Inputs via atmospheric deposition, nitrogen fixation and run-off from the surrounding uplands are almost equal to losses via stream flow, denitrification and incorporation into the anaerobic peat, such that the pool of actively cycling nitrogen in the fen water is very small (Urban and Eisenreich, manuscript). Much of the literature dealing with nitrogen in peatlands have dealt with its presence in the peat (Malmer and Sjors 1955, Malmer 1962, Damman 1978, Pollett 1972, Waughman 1980), but this is not necessarily available to plants. Nitrogen in fen waters is generally low and difficult to detect. Uptake of nitrogen and phosphorus during the growing season results in low levels of extractable nutrients (Malmer 1962). Despite this, nitrogen was found to be correlated to peatland vegetation in this study.

Organic nitrogen, the major component of the total Kjeldahl nitrogen (TKN) analyses, is the most abundant form of nitrogen found in the peatland waters of this study. Much of this organic nitrogen is the result of organic decomposition in the narrow aerobic zone of the peat profile. The organic nitrogen is higher in the moderately rich fens than in poor and extreme rich fens, and especially in the fall sampling (Table 3-2a). This may be due to higher decomposition rates in the moderately rich fens, which may be the result of greater lowering of the water table throughout the growing season, allowing for higher microbial activity in the aerobic zone. Extreme rich fens, while they may have a higher influx of water and nutrients, also tend to have a higher drainage loss (Waughman and Bellamy, 1980) due to greater flow of water through the peatland. In addition, there may be more active uptake by a greater number of nutrient-demanding plants in these fens (Waughman 1980). Poor fens are more acidic, and this can inhibit microbial activity, and hence, decomposition is lower. This organic nitrogen is only available to plants through further mineralization resulting in ammonium, nitrite or nitrate.

Ammonium is the more abundant form of available nitrogen, while nitrate occurs in very small amounts in the peatlands studied. This is consistent with other studies (Hemond 1983; Urban and Eisenreich manuscript; Persson 1962). Higher nitrate values are found in the extreme rich fens (Table 3-2a). Nitrate values tend to be higher in peatlands with high pH's (above 7), where the higher redox potentials favour the presence of the NO_3 form over the NH_3 form (Campbell 1970, Waughman 1980). Nitrate values are also low in poor fens due to nitrifying bacteria being inhibited below pH 5 (Harmsen and Kohlenbrander 1965). Ammonium in the fen waters is higher in extreme rich fens in the spring, probably due to greater influx from the surrounding uplands. However it is higher in the moderately rich fens in the fall. Once again, this may be due to a combination of high decomposition and lower drainage loss, or it may be related to N-fixation. Waughman and Bellamy (1980) found nitrogenase activity to be highest in intermediate and rich fens, as opposed to extreme rich fens, poor fens and bogs.

Phosphorus levels in the fen waters are extremely low in all the peatlands studied, and cannot be used to distinguish between the fen types. Other studies (Wilson & Fitter 1984) have found low phosphorus values to be associated with high pH's. The low phosphorus values in this study may be the result of many factors :- low concentration in precipitation (Allen *et al.* 1968), rapid uptake by plants, or phosphate binding to Fe and Al in the peat (Damman 1978). Indeed, phosphorus may be the limiting nutrient in peatlands, and not nitrogen (Tamm 1954). This is certainly the case with freshwater lake ecosystems (Munn & Prepas 1986). Experimental fertilization of peatlands has also shown phosphorus to increase tree growth in some peatlands, while nitrogen had little effect (Ferda 1972; Pessi 1973). This, nevertheless, does not underplay the importance of nitrogen in peatlands.

Total phosphorus in the peat is higher in the moderately rich fens than in extreme rich or poor fens (Table 3-2b). Waughman (1980) also found phosphorus to be highest in "intermediate" fen peats when compared to poor and rich fen peats, with values in the 400-1000 ppm range. In this study, the values were higher yet, in the 1263-1916 ppm range. The phosphorus stored in the peat is not necessarily available to plants. Although total amount of phosphorus may be high, dissolved or extractable amounts in various forms are very low (Giller and Wheeler 1986). In the aerobic zone, organic phosphorus is released very slowly during decomposition (Tukey 1970), and the mineralized phosphorus is usually bound to the peat as iron and alumunium phosphates, especially in the pH 5.4-6.5 range (Waughman 1980). This is the range in which most of the moderately rich fens lie. Wilson and Fitter (1984) also suggest that the mineralized phosphorus may be immobilized by microbial activity into an organic form that is unavailable to plants. In the anaerobic zone, iron is reduced to the ferrous (Fe^{2+}) form which is mobile, and easily leached away along with the phosphate.

Spring versus Fall water chemistry.

The chemistry variables with significantly different spring and fall values are shown in Table 3-7. Acidity, calcium, magnesium and iron are higher in the fall. This is probably due to the slow drying out of the peatlands over the growing season, which has the overall effect of concentrating the ions left in the remaining water. Phosphorus in poor fens, and organic nitrogen and ammonia in rich fens decrease over the growing season. This is probably due to uptake by the plants, and hence a depletion of what is already a limited resource (Damman, 1978). Organic nitrogen, nitrate and ammonia in moderately rich fens, however, increase over the growing season. This may be interpreted by a combination of high decomposition rates with lower drainage loss and lower uptake than in rich fens.

In addition to seasonal drying, uptake by plants, and release through decomposition, other factors may also account for the significant changes in spring versus fall chemistry values. For example, the trends may reflect the weather conditions at or near the time of sampling. This problem was minimized in that all fens were all sampled within a 2-3 day period. In addition, water levels and flow rates differ between peatlands. Soligenous peatlands with continuous water flow are expected to show less seasonal variation due to the continuous replenishment of inflowing nutrients.

Variables		Significant differences within All fens	Poor fens	Moderately Rich fens	Extreme Rich fens
SPRING vs FALL water chemistry	pH	S>F	-	S>F	S>F
	Con	-	-	-	-
	Ca	S<F	-	-	S<F
	Mg	S<F	-	S<F	S<F
	Na	-	-	S<F	-
	K	-	S<F	-	-
	Fe	S<F	-	S<F	-
	P	-	S>F	-	-
	Org.N	-	-	S<F	S>F
	NO_3	-	-	S<F	-
	NH_3	-	-	S<F	S>F
SURFACE vs SUBSURFACE peat chemistry	Ash	-	0<30	0>30	-
	Ca	0<30	-	0<30	-
	Mg	0>30	-	0>30	-
	Na	0>30	-	0>30	-
	K	0>30	0>30	0>30	-
	S	0>30	0>30	0>30	0>30
	Fe	-	-	0<30	-
	P	0>30	-	0>30	-

Table 3-7. Significant differences between spring and fall water chemistry, and between surface and subsurface peat chemistry, based on Wilcoxon's matched pair rank sum test (significant at the 0.05 level).

The seasonal variation in the water chemistry makes it a difficult parameter to use in distinguishing between peatland types. If we are to assume that plant growth best reflects the chemistry of the peatland, then spring water chemistry is the more appropriate measure, since mosses and vascular plants do most of their growing in spring and early summer, as opposed to late summer and fall. Giller & Wheeler (1986), however, argue that sampling is best done in late summer at low water levels when there is less nutrient uptake by plants, as this is a better measure of availability. With the exception of nitrate and ammonia, the spring and fall water chemistry values are correlated to one another (Spearman's rank order correlation, significant at the 0.01 level). Knowing one of them, the other can usually be predicted from a regression analysis, for example, pH (Fig. 3-26).

Surface versus Subsurface peat chemistry.

Peat chemistry was sampled at the surface (0-5 cm) and just below the dense rooting mat (30-35 cm). The surface sample mainly represents the living portion of the bryophyte layer, and the aerobic part of the peat. The subsurface sample represents the dead portion and the anaerobic part of the peat. The chemical variables, along with the significantly different surface and subsurface values, are shown in Table 3-7.

Magnesium, sodium, potassium, sulphur and phosphorus decrease with depth. These can easily be accounted for following Damman's (1978) explanations. Sodium and potassium are very mobile elements that are easily leached away. In addition, potassium is also taken up

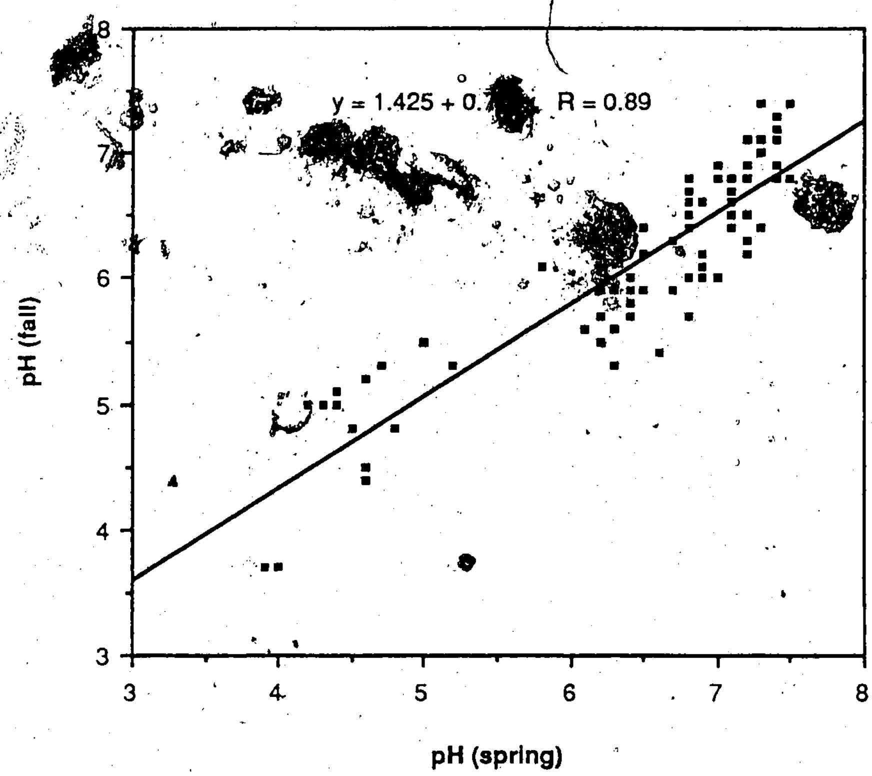


Fig. 3-26. Regression of spring water pH on fall water pH. (Significant at the 0.05 level).

by plants causing it to accumulate in the living portion. Similarly, magnesium is leached away, and taken up by vascular plants. Phosphorus and sulphur are both taken up by plants and concentrated in the living portion (Bidwell 1974) in addition to being leached away. Calcium, surprisingly shows an increase in the subsurface layer. According to Damman, calcium accumulates in the aerobic zone as a result of absorption to surface of mosses via cation exchange, but is found in low concentrations in the anaerobic zone. No clear explanation is given for this trend. Considering that passive cation exchange takes place in dead portions of mosses as well, one would expect calcium levels to remain high or be concentrated with increasing bulk density at greater depth.

In using peat chemistry to distinguish between peatland types, the surface peat chemistry may be more accurate in reflecting those nutrients that are taken up and required for growth, as well as those elements that the vegetation is tolerant to. Nevertheless, one must be careful not to confuse this with anomalously high values due to proximity to roads and disturbances. For example, ash content may be excessively high in those fens located near highways. The subsurface peat chemistry, on the other hand, is not as prone to surficial disturbance. Thus, it is a more accurate measure of the stored nutrient reserves in the peat. Of course, this nutrient reserve in the peat is not necessarily available to the living vegetation due to the anaerobic conditions.

Although the subsurface peat does not necessarily reflect the present day vegetation, it is, nevertheless, correlated with the surface peat with respect to ash content, Ca, Mg, S, Fe, and P

(Spearman's rank order correlation, significant at the 0.05 level), and regression equations can be used to predict one from the other.

Water chemistry versus Peat chemistry.

In distinguishing between fen types, the vegetation is one of he main criteria used. The vegetation best reflects the water chemistry in the sense that the plants present and growing there should reflect the nutrients directly available to them through the water. That is why the highest correlations to the vegetation (as represented by the DCA axis scores) are with water chemistry variables (Table 3-5a) as opposed to peat chemistry variables (Table 3-5b). The water chemistry, however is subject to seasonal variation. There is a flush of nutrients at snow melt in spring, followed by generally low levels throughout most of the growing season. The slow drying of peatlands over the growing season has an additional effect of concentrating the remaining nutrients resulting in higher fall values. Higher fall values may also be the result of ground water recharge. In addition, precipitation events may act to dilute the fen waters as well.

The macronutrients incorporated in the peat, on the other hand, is less subject to seasonal variation. Apart from major disturbances in the hydrology or aerial deposition, it is not as sensitive to seasonal variation. It represents a long term sink of macronutrients that have been taken up or adsorbed onto the vegetation, and as such their values are much larger than the water chemistry values by several orders of magnitude. The seasonal variation of macronutrients incorporated into the peat is much smaller than that which has already accumulated, and so, the peat chemistry values do not reflect seasonal variation. Thus, peat chemistry can be a good parameter for characterizing peatlands. The vegetation, however, does not directly reflect the peat chemistry, since the macronutrients stored in the peat is not necessarily available to the plants.

Correlations exist between water chemistry parameters and peat chemistry parameters. The major cations calcium, magnesium and sodium in water are significantly correlated with that in peat, as are potassium, phosphorus and sulphur in the fall water with that in the subsurface peat (Spearman's rank order correlation, significant at the 0.05 level). This is not surprising, since one would expect the macronutrients composition of plants to reflect the macronutrients in the water that are available for plant growth. As both water chemistry parameters and peat chemistry parameters can be correlated to one another, either set may be used for characterizing peatland types. In terms of practical consideration, such water chemistry parameters as pH and conductivity are easy to measure in the field, while peat chemistry parameters are easier to detect and measure in the lab because of their higher orders of magnitude.

F. SUMMARY.

TWINSPAN classifies the 100 stands of this study into separate stand groups that represent the moderately rich fens of the Lesser Slave-Athabasca area, the extreme rich fens of the Foothills, and the poor fens of Swan Hills and Mariana Lakes without much overlap. These three fen types each have their own characteristic species. The extreme rich fens of the Rocky Mountain Foothills are characterized by *Scirpus caespitosus, S. hudsonianus, Tofieldia glutinosa, Muhlenbergia glomerata, Drepanocladus revolvens, Scorpidium scorpioides* and *Calliergon trifarium*. The moderately rich fens of the Lesser Slave-Athabasca area are characterized by *Brachythecium mildeanum, Drepanocladus vernicosus, D. aduncus, D. polycarpus, Carex diandra* and *Equisetum fluviatile*. The poor fens of the Swan Hills and Mariana Lakes area are characterized by *Kalmia polifolia, Carex pauciflora, Sphagnum fuscum, S. magellanicum, S. angustifolium. S. jensenii, S. majus* and *Drepanocladus exannulatus*. Species common to both moderately rich fens and extreme rich fens that are not common in poor fens include *Larix laricina, Salix pedicellaris, Tomenthypnum nitens, Campylium stellatum, Bryum pseudotriquetrum, Carex lasiocarpa, Triglochin maritima, Meesia triquetra* and *Potentilla palustris*. Moderately rich fens have fewer species in common with poor fens :- *Picea mariana, Eriophorum chamissonis* and Scheuchzeria palustris. Species richness is highest in the moderately rich fens.

A summary of vegetation and environmental gradients found in this study is shown in Fig. 3-27. DCA ordination of the 100 stands based on all species is similar to that based on vascular species

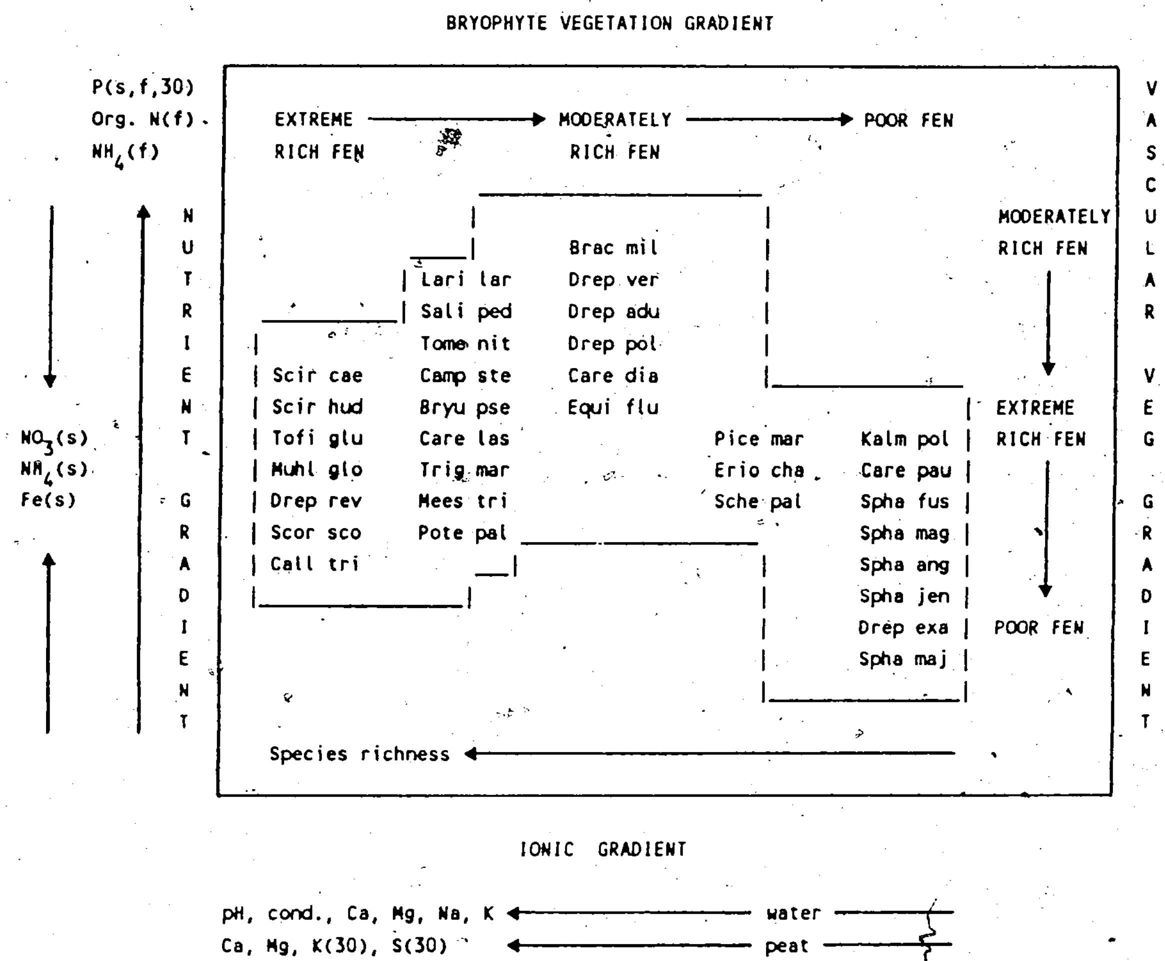


Figure 3-27. Summary of vegetation and chemical gradients of fens in central Alberta. Species are abbreviated to the first four letters of the genus and first three letters of the species. For complete names, see Fig. 3-5. Columns of species are from left to right : extreme rich fen species; species common to extreme and moderately rich fens; moderately rich fen species; species common to moderately rich fens and poor fens; poor fen species. s=spring value, f=fall value, 30=subsurface value.

Sphagnum warnstorfii, Caltha palustris, Calliergon giganteum, Calliergonella cuspidata, Drepanocladus exannulatus and *Myrica gale*.

The fen waters in this study are in the 5.3-7.1 pH range, with specific conductance of 18-240 µS. The calcium content of the waters averaged 19.5-22.1 mg/l, while that of magnesium averaged 4.26-5.27 mg/l in spring and fall respectively. The subsurface fen peats were characterized by a calcium content of 17426 g/kg and magnesium content of 1791 g/kg. Organic nitrogen, nitrate and ammonium content in the spring and fall waters averaged 1967-2395 µg/l, 3.1-9.8 µg/l and 16.8-88.9 µg/l respectively.

The Lesser Slave-Athabasca fens are classified as moderately rich fens. The ionic content of the fen water and fen peat is intermediate between that of poor fens and rich fens that have previously been described. Common rich fen species such as *Tomenthypnum nitens, Bryum pseudotriquetrum, Campylium stellatum, Calliergon giganteum* and *Meesia triquetra* are present. In addition, characteristic species of these moderately rich fens include *Drepanocladus vernicosus, D. aduncus, D. polycarpus* and *Brachythecium mildeanum*. These species are believed to be characteristic of moderately rich fens in continental areas.

The second part of this thesis examines the relationships between vegetation and chemistry in non-forested fens in central Alberta. The Lesser Slave-Athabasca fens that have been identified as moderately rich fens in the first part, along with poor fens (Vitt *et al.* 1975) and extreme rich fens (Slack *et al.* 1980) from previous studies are included in this study.

TWINSPAN classifies the 100 stands of this study into separate stand groups that represent the moderately rich fens of the Lesser Slave-Athabasca area, the extreme rich fens of the Foothills, and the poor fens of Swan Hills and Mariana Lakes without much overlap. These three fen types each have their own characteristic species. The extreme rich fens of the Rocky Mountain Foothills are characterized by *Scirpus caespitosus, S. hudsonianus, Tofieldia glutinosa, Muhlenbergia glomerata, Drepanocladus revolvens, Scorpidium scorpioides* and *Calliergon trifarium*. The moderately rich fens of the Lesser Slave-Athabasca area are characterized by *Brachythecium mildeanum, Drepanocladus vernicosus, D. aduncus, D. polycarpus, Carex diandra* and *Equisetum fluviatile*. The poor fens of the Swan Hills and Mariana Lakes area are characterized by *Kalmia polifolia, Carex pauciflora, Sphagnum fuscum, S. magellanicum, S. angustifolium. S. jensenii, S. majus* and *Drepanocladus exannulatus*. Species common to both moderately rich fens and extreme rich fens that are not common in poor fens include *Larix laricina, Salix pedicellaris, Tomenthypnum nitens, Campylium stellatum, Bryum pseudotriquetrum, Carex lasiocarpa, Triglochin maritima, Meesia triquetra* and *Potentilla palustris*. Moderately rich fens have fewer species in common with poor fens :- *Picea mariana, Eriophorum chamissonis* and *Scheuchzeria palustris*. Species richness is highest in the moderately rich fens.

A summary of vegetation and environmental gradients found in this study is shown in Fig. 4-2. DCA ordination of the 100 stands

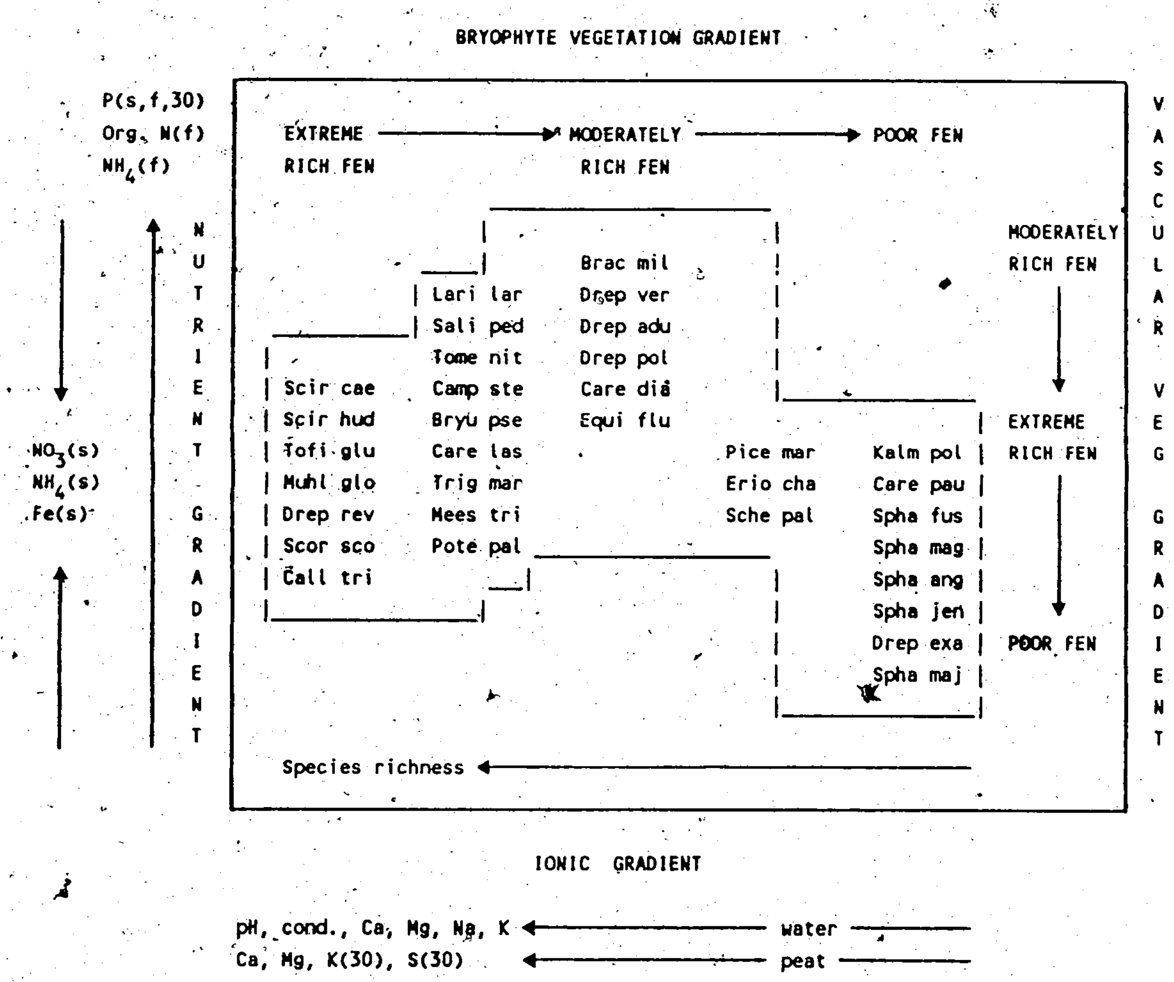


Figure 4-2. Summary of vegetation and chemical gradients of fens in central Alberta. Species are abbreviated to the first four letters of the genus and first three letters of the species. For complete names, see Fig. 3-5. Column of species are, from left to right : extreme rich fen species; species common to extreme and moderately rich fens; moderately rich fen species; species common to moderately rich fens and poor fens; poor fen species. s=spring value, f=fall value, 30=subsurface value.

based on all species is similar to that based on vascular species only. The vascular plant vegetation gradient from moderately rich fen to extreme rich fen to poor fen reflects a nutrient gradient. Phosphorus, organic nitrogen(fall), and ammonium(fall) are highest in moderately rich fens, while nitrate, ammonium and iron in the spring are highest in extreme rich fens. The ordination based on bryophytes only, results in a vegetation gradient from extreme rich fen to moderately rich fen to poor fen. This bryophyte vegetation gradient reflects an ionic gradient (Fig. 4-2). Specific conductance, calcium, magnesium, and pH are highest in extreme rich fens, intermediate in moderately rich fens, and lowest in poor fens. To a smaller extent, sodium and potassium also follow this trend.

Water chemistry values in the spring and in the fall are significantly different. Acidity, calcium, magnesium and iron are higher in the fall, while phosphorus in poor fens, organic nitrogen and ammonium in extreme rich fens are lower in the fall. Peat chemistry variables also show significant differences between surface and subsurface values. Magnesium, sodium, potassium, sulphur and phosphorus are higher in the surface peats. Correlations exist between water chemistry variables and peat chemistry variables. Calcium, magnesium and sodium are significantly correlated with that in the peat, as are potassium, phosphorus and sulphur in the fall water with that in the subsurface peat.

Appendix 2-1. TWINSPAN analysis of 60 Lesser Slave-Athabasca fens. Cover classes are 1:0.1-2.0%, 2:2.1-5.0%, 3:5.1-10.0%, 4:10.1-20.0%, 5:20.1-40.0%, 6:40.1-60.0%, 7:60.1-80.0%, 8:>80%.

Species / Stands	1225 9017	11 67	44444 45690	335645555555 569080123456	1433334322344 8723473834812	22233222 56901278	01115 13458	00100100 79045223	001 681
Utricularia intermedia	212-	11	-2221	1-41112-122-	1-11---211111	-112111-	-----	--------	---
Carex limosa	1211	32	44433	235531134312	-21-112131231	-221-221	--111	--------	-1-
Meesia triquetra	1121	-1	-3241	5434421--423	-324222-33221	11221-11	--1--	--------	---
Menyanthes trifoliata	5454	41	23122	34412-2-14-1	-212172434313	23143333	---11	1-------	---
Drepanocladus vernicosus	5654	35	75557	678655665513	5544545477555	28365445	1344-	------1-	---
Carex chordorrhiza	-213	42	44433	334433244444	2233323234233	33223323	2-213	------12	---
Eriophorum polystachion	11--	1-	111-1	111-1-1---1-	------1-111--	-1[illegible]1111	--1--	------1-	---
Equisetum fluviatile	1111	11	11111	--1211212121	11111-1211111	1[illegible]12112	-11--	-----111	---
Sphagnum subsecundum	----	32	-----	------------	3-----------3	--------	-----	--------	---
Cicuta maculata	--1-	11	---1-	------------	-----1-------	--------	-----	--------	---
Drepanocladus lapponicus	----	83	-4543	------------	------25--43-	--------	-----	--------	---
Calliergon stramineum	----	-4	-----	------------	---11--------	--------	-----	--------	---
Scheuchzeria palustris	----	--	22221	22-11----1--	------11--121	11-11-11	-----	--------	---
Andromeda polifolia	----	--	312-2	111-1---22--	1344434434443	42434432	1---1	--------	---
Carex rostrata	1---	13	3342-	11--1111--21	3----11----11	--------	-1---	------2-	---
Carex lasiocarpa	---2	--	34543	125536654555	-333233322234	21221332	-2433	----1---	---
Agrostis borealis	----	--	---1-	----1--1----	------------1	--------	----1	--------	---
Equisetum variegatum	----	--	----3	----1-------	-------------	--------	-----	--------	---
Eriophorum sp.	---1	--	---1-	---1-------1	-------------	--------	-----	--------	---
Brachythecium sp.	----	--	24---	------1134--	-----------1-	--------	-----	--------	---
Calliergon trifarium	----	--	---1-	-----3------	-------------	--------	-----	--------	---
Drepanocladus sendtneri	---4	--	-----	--3546-65446	------------5	--------	-----	---1--1-	---
Hypnum lindbergii	---1	--	-----	-----------3	-----1-------	--------	-----	--------	---
Erigeron lonchophyllus	---1	--	-----	1---1---1--1	-------------	--------	----1	--------	---
Spiranthes romanzoffiana	--[illegible]	--	-----	1-1-1-------	-1-----------	------1-	-----	--------	---
Stellaria crassifolia	----	--	----1	1-4---------	---1---1-----	--------	-----	--------	---
Oyxcoccus microcarpus	----	--	11---	------------	-111111-11-11	33223--3	1-1--	--------	---
Chamaedaphne calyculata	----	-3	-----	------------	3--------1---	2-21-213	-----	--------	---
Drosera rotundifolia	----	--	---1-	-1----------	---------11--	1111-211	-----	--------	---
Oxycoccus quadripetalus	----	--	-----	--1---------	-------------	-----34-	-----	--------	---
Sarracenia purpureus	----	--	-----	------------	---------1---	1--112--	-----	--------	---
Ptilium crista-castrensis	----	--	-----	------------	-------------	1-1--2-1	-----	--------	---
Sphagnum palustre	----	--	---1-	------------	1------------	3-------	-----	--------	---
Sphagnum nemoreum	----	--	-----	------------	-1---1-------	-------5	-----	--------	---
Sphagnum squarrosum	----	--	1----	------------	-1---------2-1	--3--2--	-----	--------	---
Tomenthypnum nitens	---6	--	-1114	----4---4333	-455565441434	44533563	-3345	-32---11	122
Picea mariana	---1	--	-----	------------	-1--111------	-------1	-----	--------	-1-
Carex tenuiflora	--1-	1-	111--	------------	12111-111-111	22113211	1-1--	---1---1	2--
Dicranum undulatum	----	--	-----	-------1----	-2--1-1------	-----2--	-----	-------1	---
Sphagnum angustifolium	----	--	11---	------------	-1--22-------	----31-3	1----	-------1	---
Smilacina trifolia	----	--	-----	------------	-2233-1------	--2-1-12	1111-	-1------	322
Pohlia nutans	---1	--	-----	------------	-111111------	1--12-1-	----1	--1-----	112
Larix laricina	---1	--	----2	----1------1	-3123332112-2	21322223	-1111	111----1	-5-
Sphagnum warnstorfii	----	--	1--2-	-------1----	-2--23--22333	6-54514-	2-31-	-------1	-33
Sphagnum fuscum	----	--	-----	------------	------22-----	1-4-----	1----	--------	--1
Sphagnum magellanicum	----	--	-----	------------	-------------	-------4	1----	--------	---

Appendix 2-1. TWINSPAN analysis of 60 Lesser Slave-Athabasca fen stands. (Continued).

Species / Stands	1225 9017	11 67	44444 45690	335645555555 569080123456	1433334322344 8723473934812	22233222 56901278	01115 13458	00100100 79045223	001 681
Betula pumila	4156	--	---1-	11--212-2311	-3-434342132-	323-3332	-1345	12---1--	--6
Salix pedicellaris	3233	33	22232	21-133343333	3322322213233	32334222	23223	11222-23	12-
Triglochin maritima	1111	2-	1--11	113111111111	-11111-112211	11111211	11111	12------	-1-
Carex interior	2-12	--	----1	--------11--	--111121---11	-----11-	-1111	--------	---
Potentilla palustris	2321	33	22134	11--23333322	322311331-223	12122122	22223	22313322	-11
Aulacomnium palustre	--34	-2	54343	----4-2-1-33	6354545423444	53454433	45434	13311-25	555
Carex diandra	3433	1-	-1112	323521232213	-211112211211	1----1--	11324	33321121	1-1
Bryum pseudotriquetrum	1233	-1	11111	443323331244	1243122211111	1111-111	31--4	33323322	221
Brachythecium turgidum	----	--	--43-	--124-------	-2-----------	--------	---2-	1--2---1	2--
Betula glandulosa	----	11	112-2	--11---1----	1-3---------3	---3----	3----	--2---22	5--
Epilobium palustris	-111	--	--111	2-111-------	------111-111	--1-1---	-11-1	111111--	--1
Galium labradoricum	2111	-1	----1	1---1-111111	1111-111-----	-1------	12111	11111111	111
Salix candida	----	--	----2	--------1-11	-------------	--------	-----	1-11--11	---
Carex curta	----	-2	-----	------------	-------------	--------	-----	-------1	11-
Helodium blandowii	---4	--	-----	3-3---------	-1-1-1-1--3-2	--------	-1334	--1----1	123
Polytrichum strictum	---1	-4	1----	------------	---11--1----1	--1-1---	1--2-	--------	112
Cephalozia catenulata	----	-1	-----	------------	1------------	------1-	-----	--------	-11
Dicranum polysetum	----	--	-----	------------	-----------1-	--------	-----	--------	12-
Habenaria hyperborea	----	1-	-----	------------	---11--------	--------	-1---	--------	-1-
Carex paupercula	----	--	-----	------------	-------------	1-1-1-11	1----	------11	-2-
Pleurozium schreberi	----	--	-----	------------	-2-----------	1----1--	-----	--------	-31
Caltha palustris	3221	[illegible]	[illegible]	[illegible]-----1-11--	-----1-1-----	--------	-3---	1-1-1-11	111
Calliergon giganteum	655-	[illegible]	[illegible]	[illegible]----------1	--3----------	--------	--33-	--314321	1--
Brachythecium mildeanum	3133	[illegible]	[illegible]	[illegible]	432221---1-43	--1-----	43344	55542354	244
Drepanocladus aduncus	---1	[illegible]	[illegible]	----2-5-2-5-	-2--11-2-----	---2-2--	46555	24264544	341
Carex aquatilis	----	1[illegible]	[illegible]	--1---------	--211---1----	-1--11-1	34214	54544543	111
Drepanocladus polycarpus	1---	-1[illegible]	[illegible]	----------1-	12--1--------	1-23--11	4111-	54532443	213
Rumex occidentalis	111-	--	-----	------1-----	---1---------	--------	1-1-2	11111111	1-1
Stellaria longifolia	--1-	--	-----	--1---------	-----1-------	--------	11111	1111-111	111
Hypnum pratense	--1-	--	-----	----2-------	1-13--------1	1-------	1223-	1--1--13	312
Rubus arcticus	---2	--	-----	------------	-----1-------	--------	13121	111---11	232
Plagiomnium ellipticum	1-1-	--	---1-	------------	1--1-1-------	-----1--	11111	223--11-	-22
Campylium stellatum	--11	--	---1-	----------33	--------1--21	--1-1---	2-1-2	4--344--	1--
Petasites sagittatus	----	--	-----	------------	-------------	--------	121-1	-1-1--21	---
Eriophorum chamissonis	----	--	-----	-----------1	-1-----------	--------	-111-	---1-1-1	---
Amblystegium serpens	----	--	-----	------------	-1--1--------	--1---11	11111	11211111	---
Calamagrostis stricta	-1--	--	-----	------------	4----1-------	--------	--2-	2-31----	---
Climacium dendroides	--1-	--	-----	------------	1------------	--------	--32-	--------	1--
Calamagrostis inexpansa	----	--	-----	--1---------	-------------	--------	--2-1	--------	---
Calamagrostis canadensis	---3	--	-----	----1--1----	-------1-----	--------	-3---	-2--1211	-1-
Salix petiolaris	----	--	-----	------------	-------------	--------	--1--	11----1-	---
Salix planifolia	----	--	-----	------------	-------------	-------1	-----	111-11-3	---
Salix pyrifolia	----	--	-----	------------	-------------	--------	-----	11------	-1-
Calliergonella cuspidata	----	--	-----	------------	-------------	--------	-----	---243--	---
Drepanocladus exannulatus	----	--	-1---	------------	-------------	--------	-----	-1-421--	---

Appendix 2-1. TWINSPAN analysis of 60 Lesser Slave-Athabasca fen stands. (Continued).

Species / Stands	1225 9017	11 67	44444 45690	335645555555 569080123456	1433334322344 8723473934812	22233222 56901278	01115 13458	00100100 79045223	001 681
Carex praegracilis	----	--	----1	------------	---11--------	-1----1-	-4---	132--2--	122
Ledum groenlandicum	----	--	-----	--------1---	-21-1--------	1---2-11	1----	-------1	143
Carex disperma	---1	--	-----	------------	-1-----------	-------1	1---1	--1---11	412
Myrica gale	----	--	-----	------------	-------------	--------	-----	122222--	435
Betula occidentalis	111-	--	-----	------------	-------------	--------	-----	2-1---1-	33-
Parnassia palustris	----	--	-----	1-----------	-------------	--------	-11--	111-----	-31
Vaccinium vitis-idaea	----	--	-----	------------	-1-----------	--------	-----	--------	32-
Carex leptalea	----	--	-----	------------	-------------	--------	-----	--------	212
Drepanocladus uncinatus	----	--	-----	------------	-------------	--------	-----	--------	32-

Appendix 3-1. TWINSPAN analysis of 100 fens in Central Alberta. Cover classes are 1:0.1-2.0%, 2:2.1-5.0%, 3:5.1-10.0%, 4:10.1-20.0%, 5:20.1-40.0%, 6:40.1-60.0%, 7:60.1-80.0%, 8:>80%.

Species / Stand						
			1			
Stand	0010000001111150	1222222332233333344443344444455555555611225	98999088888999	888999	7777877777	6666666667
Species	6812345790234581	8256789013423478912375604568901234569067901 7	27689035891015	246734	8967035124	1237845690
Betula occidentalis	33-1---2-1------	---	--------------	------	----------	----------
Myrica gale	435--221222-----	---	--------------	------	----------	----------
Salix planifolia	----3-11111-----	-----1-------------------------------------	--------------	------	----------	----------
Petasites sagittatus	---211--1--21-11	---	--------------	------	----------	----------
Rumex occidentalis	1-111111111-1-21	----------1-----------------1---------111-	--------------	------	----------	----------
Stellaria longifolia	111111-1111111-1	-------------1---------------------1-----1-	--------------	------	----------	----------
Calamagrostis stricta	-----1-2-3---2--	4-----------------1----------------------1--	--------------	------	----------	----------
Carex disperma	41211----1----11	-----1--------------1-----------------------1	--------------	------	----------	----------
Carex praegracilis	122----13224----	---11-------11--------1--------------------	--------------	------	----------	----------
Amblystegium serpens	---1111112111111	----111------1------1----------------------	--------------	------	----------	----------
Brachythecium mildeanum	2445442555333444	4-----1---12221--43-3--1---------------13133	----1---------	--1---	----------	----------
Calliergonella cuspidata	-----24---3-----	---	--------------	------	----------	----------
Climacium dendroides	1----------32---	1-----------------1----------------------1-	--------------	------	----------	----------
Drepanocladus aduncus	3414464242565554	-1-----2-----11-2---2--42232--5-2-5--------1	--------------	------	----------	----------
Drepanocladus polycarpus	21343325454111-4	1-1-1123-----1------2--------------1----22---	--------------	------	----------	----------
Hypnum pratense	312131-1---223-1	1-1--------13-----1-------2--------------1-	--------------	------	----------	----------
Plagiomnium ellipticum	-221---223111111	11-----------1-1-----------1------------1-1-	--------------	------	----------	----------
Caltha palustris	11111-11-1-3----	-------------1-1-----------1-11-----3211	--------------	------	----------	----------
Helodium blandowii	123-1----1-1334-	-----------1-131-2-1------3--3------------4	--------------	------	----------	----------
Rubus arcticus	23231--111-31211	-------------1-----------------------------2	--------------	------	-------11-	----------
Salix candida	---111-1-1------	----------------------2--------1-11--------	--------------	-2----	----------	----------
Epilobium palustris	--1--11111111-1-	------1-11-----11111-2-1--111--------11---111	--------------	1---2-	----------	----------
Galium labradoricum	1111111111121111	1--1-------11-1-1--111-1---1--111111---12111	-11-1---------	112---	----------	----------
Calliergon giganteum	1--2114--33-33--	------------3------------------------1----655-	--222-----1---	------	----------	----------

Appendix 3-1. TWINSPAN analysis of 100 fens in Central Alberta.
(Continued).

Species / Stand			1			
Stand	0010000001111150	1222222332233333344443344444455555556111225	98999088888999	888999	7777877777	6666666667
Species	6812345790234581	82567890134234789123756045689012345690679017	27689035891015	246734	8967035124	1237845690
Potentilla palustris	-112213223322232	3112221221-2311232332114221233333322--332321	-12-1---------	------	----------	----------
Carex diandra	1-12121333113241	-11------111111221122322-11211232213351-3433	--------------	------	----------	----------
Eriophorum polystachion	---1--------1---	-1-111--111----1---1-1111111--1---1-1-1-11--	--------------	------	---------1	----------
Brachythecium turgidum	2---12-1-----2--	------------------2-----443-------12------	--------------	------	----------	----------
B. erythrorhizon	----------------	-----------------1------24----1134----------	--------------	------	----------	----------
Drepanocladus lapponicus	----------------	1---------------453-2---3-45-4---------83-[illegible]	[illegible]--------	------	-1--------	----------
Drepanocladus sendtneri	---1-1----------	------------------5---------4-6-6544635[illegible]	--------------	------	----------	----------
Carex tenuiflora	2---1-1-----1--1	1222111131-111-111112---111------------1---1-	--------------	------	----------	----------
Sphagnum squarrosum	----------------	-2----3---------2--1-1---1------------------	--------------	------	----------	----------
Aulacomnium palustre	5552511133-54344	64533345423[illegible]453--[illegible]44-2-1-33---2--34	-----------1---	3-2---	3111112444	----------
Bryum pseudotriquetrum	221222333331--43	11111111-1[illegible]333124433-11233	2-2121-1-1112-	----22	----------	----------
Sphagnum warnstorfii	-33-1-------31-2	-16-4-54522[illegible]1---2--1------------	--------------	4-----	-1--1-----	----------
Salix pedicellaris	12-2322112-32232	3232223341322[illegible]3323212222333343333-1333233	-32-2---2-----	--23--	1---1-----	----------
Carex lasiocarpa	------1---2433-	-3213222122332323343312334534665455555-----2	-431--22323---	522---	----------	----------
Drepanocladus vernicosus	---1-------344-1	54284536577445454555567775555566551386355654	-45553--------	---3--	-1--------	----------
Oxycoccus microcarpus	--1---------1--1	--33-3223111111--1111---11------------------	----1--1--2---	122--2	2-53322222	-----2----
Carex aquatilis	1114344545542143	-1-1-1--11-211---------------1-------12----	--3441-1-----1	---341	15324-----	2---------
Andromeda polifolia	--------------11	1442324343444434443431123121----22--1-------	33334211222--2	2434-4	65545441-1	----------
Calamagrostis canadensis	-1-11-1-2-23----	----------------1----------1---1-------3----	--------------	------	-------142	----------
Pleurozium schreberi	-31-------------	-11-----------------2-----------------------	--------------	--1---	-----12---	----------
Pohlia nutans	112------1----1-	--1-1--12--1111----11---------------------1	--------------	------	--1--1-1--	----------
Polytrichum strictum	112-----------2-1	------1-1---11--1-1------------------------1	--------------	------	--331-----	----------
Schechzeria palustris	----------------	--1111-11------11211-22122212----1---1------	----1---1----1	------	213-------	-2-------1
Carex rostrata	---2-------1----	3-------------1--111-11-33412111--21--131---	--------------	------	----------	--2-------

Species / Stand			1			
Stand	0010000001111150	12222223322333334444334444445555555556111225	98999088888999	888999	7777877777	6666666667
Species	6812345790234581	82567890134234789123756045689012345690679017	27689035891015	246734	8967035124	1237845690
Kalmia polifolia	----------------	--	--------------	------	---1-22224	----------
Rubus chamaemorus	-1--------------	--	--------------	--3---	---1-52---	----------
Maianthemum canadensis	----------------	--	--------------	------	1--42-----	----------
Carex pauciflora	----------------	--	--------------	------	1---424412	----------
Sphagnum angustifolium	----1----------1	-1---3--3---22-----1---11-------------------	--------------	------	5664575775	----------
Sphagnum fallax	----------------	--	--------------	------	-1421-----	----------
Sphagnum fuscum	--1------------1	--1---4---------2--2------------------------	--------------	------	--4742----	----------
Sphagnum magellanicum	---------------1	---4--	--------------	------	4-44525--5	----------
Sphagnum subsecundum	----------------	3---------------3-------------------32------	--------------	------	35------2-	----------
Tomenthypnum falcifolium	----------------	--3---	--------------	------	-----12424	----------
Picea mariana	-1--------------	-----1-------11----11----------------------1	2------1--111-	2-4-22	--11121---	----------
Betula glandulosa	5--22----2-----3	1------3---3------3----2112----1----1111----	4-------------	---25-	3-1-322343	----------
Ledum groenlandicum	143-1----------1	--1-11--2--1-1-------2---------1------------	--------------	2-4-33	--11112---	----------
Vaccinium vitis-idaea	32--------------	---------------------1----------------------	--------------	--2---	-----111--	----------
Dicranum undulatum	----1-----------	-2-----------1-----12--------1--------------	--------------	-44---	-1--------	----------
Drosera anglica	----------------	--------------------------------11----------	---2-122--1---	------	----------	----------
Equisetum variegatum	----------------	--------------------------3---1-------------	4-1--------32-	---23-	----------	----------
Parnassia palustris	-------111-11---	------------------------------1-------------	-11----1--1---	1-----	----------	----------
Tofieldia glutinosa	----------------	--	4-2-12-1--1322	-1-332	----------	----------
Carex capillaris	----------------	--	2-------4-----	----5-	----------	----------
Muhlenbergia glomerata	----------------	--	-12221--1-22--	----2-	----------	----------
Scirpus caespitosus	----------------	--	--------1--2325	-----4	----------	----------
Scirpus hudsonianus	----------------	--	5----6------2-	------	----------	----------
Calliergon trifarium	----------------	------------------1---------13--------------	-23213-2221---	------	----------	----------
Campylium stellatum	1----344--4-1-22	------1-11-------21---------1-----33------11	4-4246--32---3	2---55	----------	----------
Drepanocladus revolvens	----------------	----------------------------------1---------	6165642---4525	34-323	----------	----------
Aneura pinguis	----------------	------------------1-------------------------	-2121-23112--1	1-----	----------	----------
Scorpidium scorpioides	----------------	--	53----88885665	-2----	----------	----------
Carex interior	-----------1111-	-1--1------1111-1112---1---------11------2-12	34-------111-3-	1--1--	----------	----------

Appendix 3·1. TWINSPAN analysis of 100 fens in Central Alberta.
(Continued).

Species / Stand			1			
Stand	0010000001111150	1222222332233333344443344444455555555611225	98999088888999	888999	7777877777	6666666667
Species	6812345790234581	825678901342347891237560456890123456906790 17	27689035891015	246734	8967035124	1237845690
Spiranthes romanzoffiana	----------------	----1--------------11-----1--------1-------	------111-----	------	----------	----------
Triglochin maritima	-1-----112-11111	-21111111211112111-11111--111111111312-1111	22232131331111	--11--	----------	----------
Larix laricina	-5--1--111-1111-	-2212332211123322-233--2---1---g---1-------1	-1----2-1-2---	34544-	--31------	----------
Betula pumila	--6----12-11345-	-332323-321-434342-3311----2112-2311----4156	-13-11----2--1	2544-2	----------	----------
Drosera rotundifolia	----------------	-2111111-11-----------1-----1---------------	------1-------	1-----	1---------	----------
Tomenthypnum nitens	12211---32-3345-	-5446353341555644345 4--4-1141---4333-------6	----4-----5---	67785-	----1-----	----------
Utricularia intermedia	----------------	11-11-1211111--1211--1-1-2212122122241112 12-	-1122223133--1	------	-3--------	----------
Carex chordorrhiza	---12-------2132	233323223343332223332333444333244444442-213	214332---2121-	--22--	53--4-2-21	----------
Meesia triquetra	------------1---	--11112213324222-2123541-324421--42334-11121	26212--23-1---	---1--	-1--------	----------
Chamaedaphne calyculata	----------------	322-1321--1-------------------------3----	--------------	------	1-2-2-----	----------
Equisetum fluviatile	---11-----111---	11111211211111-121111--111111121212112111111	-23211--------	---2--	----------	2---------
Menyanthes trifoliata	-------1-----11-	-32333143341217341322342231 22-2-14-141415454	-4323332234234	1444--	65----1245	554--1---2
Carex limosa	-1----------111-	-2-22121-311-112131222334443311343125532 1211	44454144444554	-341-2	433-121-22	5247757872
Calliergon stramineum	----------------	------11--------------------------4----	--------------	------	11-----112	1----4----
Smilacina trifolia	322-----1--111-1	---122-1--233-----12------------------------	-------------1	1--222	-----24242	11------2-
Juncus stygius	----------------	--	------21------	3--1--	----------	111-------
Eriophorum chamissonis	----11----1111--	1-----------------------------1---------	--------------	------	-----12---	-----2--25
Drepanocladus exannulatus	-----42-1-1-----	------------------------1------------------	--------------	------	----1-----	77778-5242
Spahgnum jensenii	----------------	--	--------------	------	-15-------	2145287878