Plant Composition, Standing Crop and Environmental Parameters in the Estuary of the Churchill River, Manitoba.

by

MARIA W. ZBIGNIEWICZ

A thesis
presented to the University of Manitoba
in partial fulfillment of the
requirements for the degree of
Master of Science
in
The Faculty of Graduate Studies

Winnipeg, Manitoba

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ABSTRACT

Patterns of plant composition, standing crop and environmental parameters of four transects positioned along the lower 17km of the Churchill River estuary are described. Three major plant communities, distributed according to salinity are identified. Two saline transects are dominated by *Puccinellia phryganodes* in the lower geolittoral zone, *Carex subspathacea* in the mid and upper geolittoral zones and *Calamagrostis deschampsioides* in the epilittoral zone. The brackish transect is dominated by *Eleocharis uniglumis* in the lower geolittoral zone and *Carex aquatilis* in the mid geolittoral zone. The freshwater transect is dominated by *Eleocharis acicularis*.

This study indicates that salinity (quantified by the exchangable sodium percentage value and the potassium concentration) determines the composition of the plant communites up river, while relative elevation determines the vertical distribution of species within each community.

Mean above-ground standing crop values along the four transects ranged from 102 to 214g m^{-2} comparing favorably with other sub-arctic sites. Above ground standing crop values were 16 to 48g m^{-2} lower in 1984, probably as a result of the many reprecusions of decreased precipitation.

Mean below-ground standing crop values along the four transects ranged from 798 to 2015g m^{-2}. Above-ground:below-ground standing crop ratios ranged from 1:1 to 1:23.

Mean salinities of tidal water for the 1983 and 1984 growing seasons decreased up river from 16ppt at Sandspit to 7.0ppt at Esker and were 0.5ppt at Pumphouse which is non-tidal. Mean transect soil salinity values for the 1983 growing season showed a similar trend with 4.0ppt at Sandspit and 0.7ppt at Pumphouse.

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Chapter I

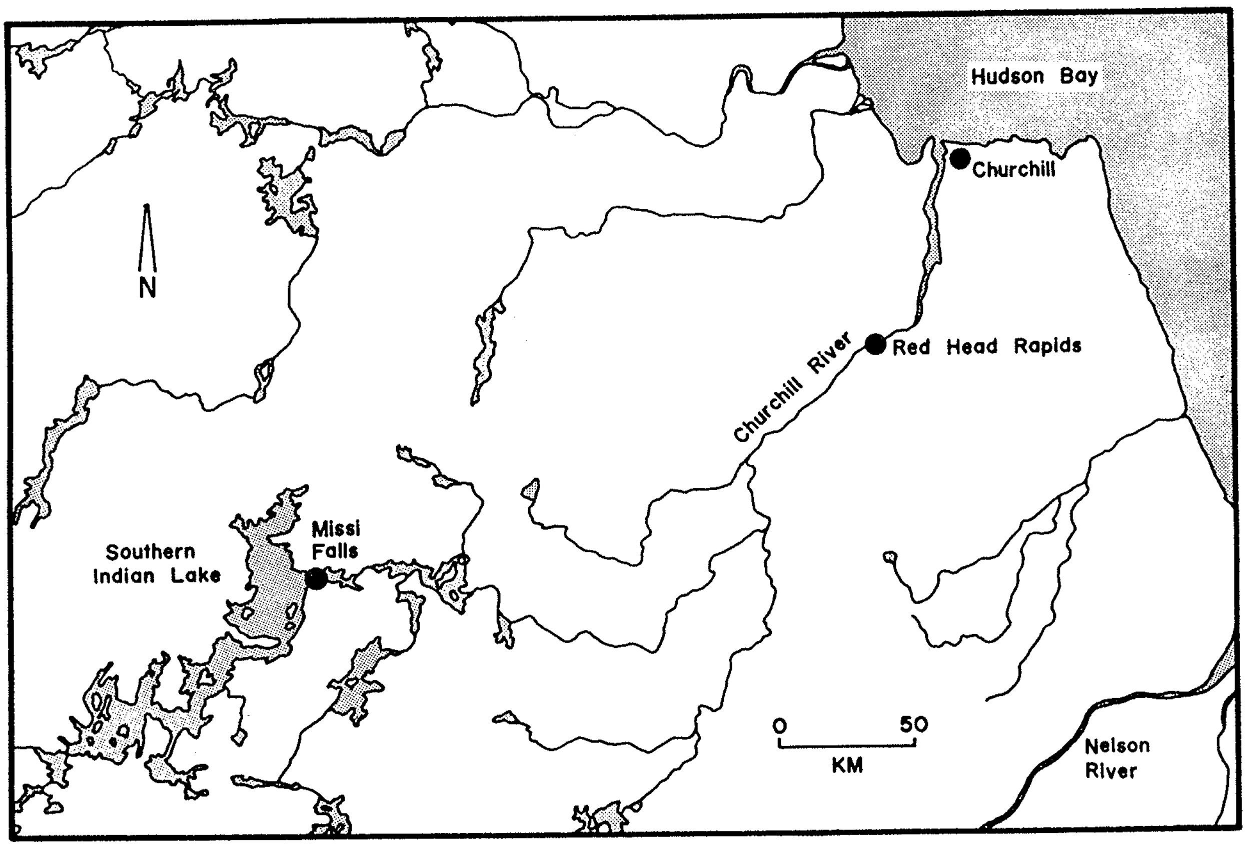
INTRODUCTION

1.1 HISTORY OF CHURCHILL RIVER DIVERSION

The Nelson and Churchill Rivers drain a basin of approximately 1,378,000km^2. The basin lies between the Mackenzie basin to the north, the Rocky Mountain divide to the west, the Mississippi basin to the south, and the Great Lakes basin and Hudson Bay to the east (McDougall 1971). The southern part of the basin (1,079,000km^2) empties into the Hudson Bay via Lake Winnipeg and the Nelson River, while the northern segment (299,000km^2) empties into the Hudson Bay through the Churchill River system (McDougall 1971).

In 1974, a proposal was made to construct a dam on the Churchill River at Missi Falls 288km upstream from the river mouth (Figure 1). The objective was to store part of the Churchill River flow in Southern Indian Lake, which in turn would be diverted south to the Nelson River via the Rat-Burntwood River complexes (Cumming 1969). This would eventually transfer waters from a watershed of 234,000km^2 to the Nelson River system, thereby increasing its hydro-electric potential (Cumming 1969; McDougall 1971; Guilbault et al. 1979).

Figure 1: Map showing Churchill River system and estuary, guaging station at Red Head Rapids, Southern Indian Lake (post impoundment) and control structure at Missi Falls.


Hudson Bay
Churchill
N
Red Head Rapids
Churchill River
Southern
Indian Lake
Missi
Falls
0
50
KM
Nelson
River

The Lake Winnipeg, Churchill and Nelson Rivers Study Board (LWCNRSB 1974) noted that control of the Churchill River at Missi Falls would reduce the discharge of the lower Churchill River by approximately 40% of the average historic flow. Cumming (1969) proposed that the resulting decrease in volume of freshwater entering Hudson Bay at the mouth of the Churchill River would substantially increase the length of the shipping season at Port Churchill. The build up of slush ice in the harbour (a critical factor in terminating grain shipments in the fall - Guilbault et al. 1979), would be delayed by several weeks due to the more brackish nature of the water in the harbour area (Cumming 1969). With controlled outflow and reduced water levels, navigation on the lower Churchill River would be more difficult and sport fishing would be detrimentally affected (LWCNRSB 1974).

It was also proposed by the LWCNRSB (1974) that variation in the date of freeze up and break up, combined with the change in the zone of tidal influence, could alter the type and abundance of plants in the estuary. A change in vegetation could in turn affect the abundance of muskrats caught by trappers on a limited basis, and waterfowl which inhabit the estuary on their fall migration (LWCNRSB 1974). A small population of waterfowl which usually spends the late summer feeding on <u>Puccinellia</u> <u>phryganodes</u> and <u>Carex</u> <u>subspathacea</u> in the estuary could move elsewhere if these plants were less abundant (LWCNRSB 1974).

At the time of the Churchill River diversion proposal (1974), the town of Churchill obtained its domestic water supply from the Churchill River. In 1963, the water intake pipe was located on the Churchill River just upstream of its confluence with Goose Creek (Figure 2). With the proposed reduction of river flows and in turn water levels, the water intake pipe would not be deep enough to avoid being damaged by ice formation and movement. In addition, reduced water flows and levels would shift the zone of tidal influence 15km upstream to the intake pipe for short periods of time throughout the year. Therefore in 1977 a new pumping facility, pressure supply main and water intake line were constructed 5.5km upstream of the old pump house at Goose Creek (Figure 2).

In June of 1976, Manitoba Hydro commenced operation of the Churchill River Diversion, which was part of the Churchill-Nelson Hydro-electric Scheme (Guilbault et al. 1979). Mean daily discharge in the Churchill River, at Red Head Rapids (40km upstream from Churchill, Figure 1), averaged $1343 m^3 s^{-1}$ during the 1972-1975 period (Table 1). Since the completion of the hydro-project in 1976, the mean daily discharge has been considerably reduced ($409 m^3 s^{-1}$ in 1983 and $136 m^3 s^{-1}$ in 1984, at Red Head Rapids, Table 1). As a result, the river is now confined to a narrow channel in the middle of its broad valley and extensive boulder strewn mudflats are exposed for much of the summer season (Figure 2).

Figure 2: Location map of the four study transects in the Churchill River estuary. The extent of foreshore flats exposed at low tides are indicated by dotted lines within the estuary.

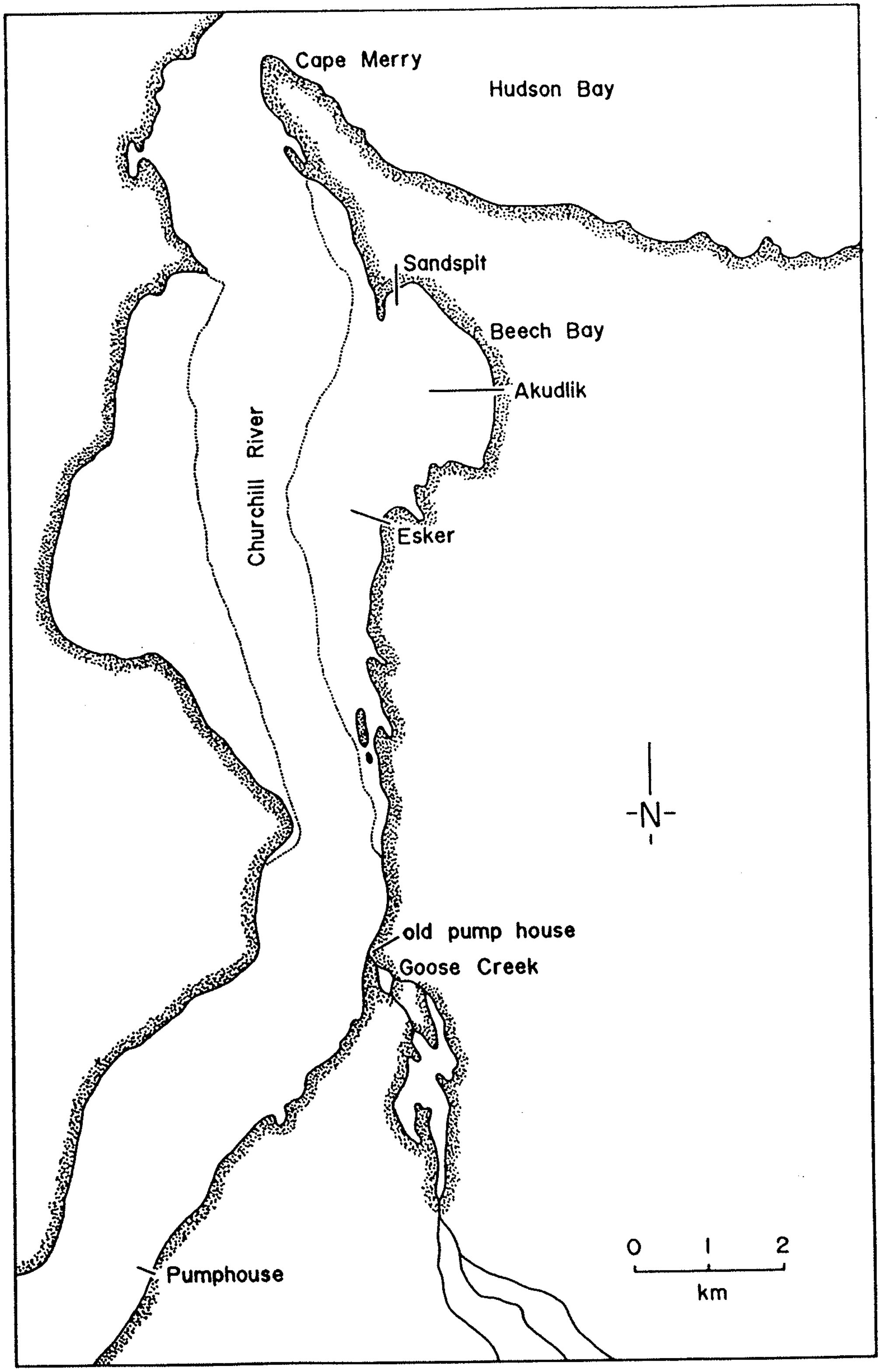

Cape Merry
Hudson Bay
Sandspit
Beech Bay
Akudlik
Churchill River
Esker
N
old pump house
Goose Creek
0 1 2
km
Pumphouse

TABLE 1

Churchill River flows at Red Head Rapids

Mean Daily Discharge (m^3 s^{-1})

Data from Environment Canada, Inland Waters Directorate 1983, 1984. pers. comm. D.R. Kimmett.

Pre-diversion Year	Flow	Postdiversion Year	Flow
1972	1530	1976	970
1973	1083	1977	999
1974	1361	1978	650
1975	1399	1979	453
		1980	572
		1981	234
		1982	299
		1983	409
		1984	136
Mean=1343 ± 188		Mean=525 ± 305	

Since the construction of the diversion there has been an increase in water turbidity (370%), total inorganic carbon (28%), hardness (31%), calcium (43%), total phosphorus (100%) and aluminum (1250%) in the lower Churchill River (Guilbault et al. 1979). There has been no change in the levels of magnesium and total dissolved solids. Many of these changes were predicted by the LWCNRSB (1974). However, order of magnitude increases in the levels of total phosphorus and aluminum were not anticipated.

Water flowing down the Churchill River dilutes saline tidal water in its estuary. Over time, the new water flow regime could substantially alter the composition, distribution and productivity of the estuarine vegetation. Shay et al. (1976) recommended that monitoring studies be carried out at the mouth of the Churchill River to provide data essential for determining the impact of the Churchill River diversion on the estuarine vegetation. The need for vegetation description and monitoring of changes due to river diversions was emphasized by Sims et al. (1979). Until the pilot study of Staniforth & Shay (1982), however, none had been undertaken.

1.2 OBJECTIVES

The objectives of this thesis were:

1. To describe and quantify the vegetation composition and standing crop along four transects positioned in the lower 17km of the Churchill River, and
2. To relate species distribution and standing crop to environmental parameters such as elevation, tidal and interstital water salinity, conductivity and pH, soil chemistry, soil texture, organic matter and redox potential.

Chapter II

LITERATURE REVIEW

2.1 SALT MARSHES

A salt marsh is an area of land bordering on the sea, more or less covered with vegetation and within the range of periodic tidal innundation (Chapman 1974). It can originate as bare mud or sand flats colonized by algae and flowering plants. Plants can occupy this habitat due to their tolerance of the conditions occurring in the salt marsh. Plant growth on the bare tidal mudflats causes accumulation of sediment and organic material and therefore changes the environment and promotes the invasion of new species (Chapman 1960). The salt marsh is classified as a halosere, and its upper boundary coincides with the limit of periodic tides (annual high tide level) (Provost 1976).

There is an elevation gradient between the seaward and the landward part of the salt marsh, with a change in the type of vegetation occurring across the gradient. The lower portions are inundated more frequently and to a greater depth than the upper portions. Many salt marshes are intersected by creeks that are empty or almost empty at low tide and full at high tide (Chapman 1960). Shallow pools (salt pans) containing tidal water which may or may not evaporate between consecutive inundations also occur in the salt marsh.

Salt marshes are usually found in sheltered areas supplied with sediments of riverine or marine origin (Chapman 1960). They may border saline or brackish environments such as bays and estuaries (Frey & Basan 1978). Salt marshes develop on stable, submerging or emerging shorelines and are constantly changing under the controlling influence of the sea.

Chapman (1960) delineated arctic salt marshes as those in Alaska, northern Canada, Greenland, Iceland, Spitsbergen, northern-most Fennoscandia, Russia and Siberia. In Canada, the largest areal extent of salt marsh vegetation occurs in arctic and sub-arctic regions including Labrador, the northern arctic coast and islands, and the lowlands surrounding Hudson Bay (Glooschenko 1980). The total area of the marshes is not known, but there are some 80,000ha in Ontario alone (Glooschenko & Martini 1978).

There have been several studies of the vegetation of subarctic/arctic Canada. Polunin (1948) and Jefferies (1977) described the vegetation of coastlines in the eastern Canadian arctic, but the majority of the research has been carried out in salt marshes along the Hudson and James Bays (Glooschenko 1980). Polunin (1948) described the Hudson Bay marshes in northern Quebec, several Hudson Bay islands and western Hudson Bay at Chesterfield Inlet. Most of the previous studies carried out in the Hudson and James Bay areas have stressed analyses of species composition. These have included Ritchie (1957), Schofield (1959) and Scoggan (1959) working at Churchill, and Riley & Moore (1973), McKay & Arthur (1975), Routledge (1975), Kershaw (1976), Pielou & Routledge (1976), Jefferies et al. (1979) and Ringius (1980) working along the Hudson and James Bays. Much of the early information is wholly descriptive with a general shift to quantitative data in the past few years.

Studies of above-ground vegetation biomass in James Bay have been conducted by Glooschenko (1978) and Glooschenko & Harper (1982), and nutrient limitation and grazing effect on salt marsh productivity in Hudson Bay by Cargill and Jefferies (1984a & b), while Jefferies (1977) collected limited data for various locations in the high arctic.

The following section summarizes most of the ecological descriptions and qualitative information available on arctic salt marshes (Table 2). On a global scale, earlier studies tended to be descriptive while more recent reserch has tended towards quantification of plant community structure.

TABLE 2

Summary of arctic salt marsh studies

Location	Reference
Alaska Glacier Bay	Cooper 1931
Alaska central western	Hanson 1951
Alaska Cape Thompson	Johnson et al. 1966
Alaska Chichagof Island	Stephans & Billings 1967
Alaska Pacific coast	Crow 1977
Alaska Sergief Island	Sparks et al. 1977
Alaska south east	del Moral & Watson 1978
Alaska south east	Mason 1981a & b
Alaska north west	Taylor 1981
Alaska south central	Snow & Vince 1984
Alaska south central	Vince & Snow 1984
Norway Finmark	Nordhagen 1954, 1955
Norway	Kristiansen 1977
Spitsbergen	Walton 1922
Spitsbergen Cape Napier	Dobbs 1939
Spitsbergen Sassenquarter	Hadac 1946
Iceland	Steindorsson 1954
Greenland north east	Hartz & Kruuse 1911
Greenland west	Hultrun 1922
Greenland west	Porsild 1926
Greenland north east	Eastwood 1948
Greenland north east	Oosting 1948
Greenland north east	Raup 1971
Greenland south east	De Molenaar 1974

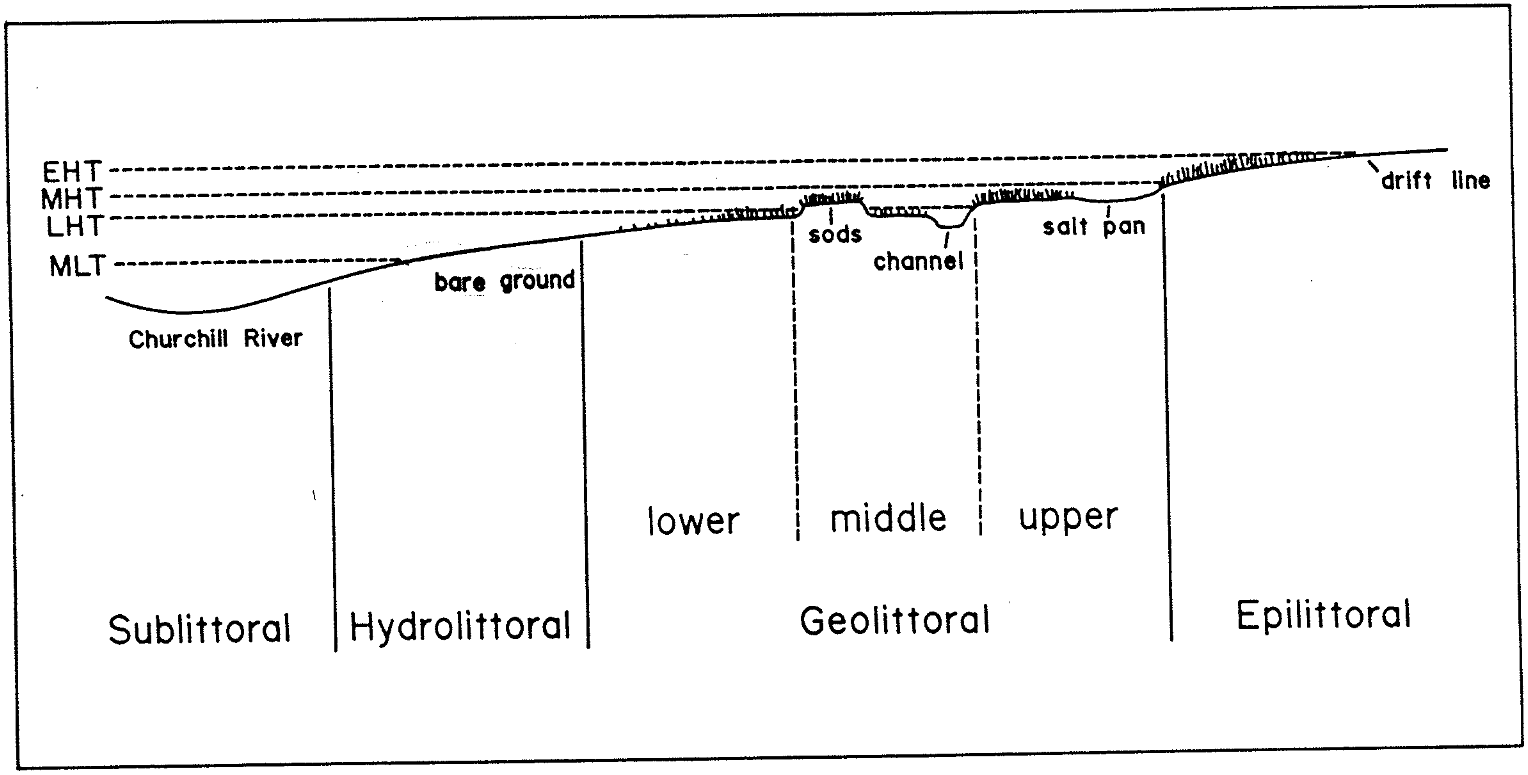
2.2 COMMUNITY STRUCTURE

In general, the Hudson and James Bay marshes are similar to those in Alaska, Greenland, Iceland, northern Europe and northern Siberia in terms of vegetation composition (Chapman 1974; Glooschenko 1980). The main spatial successional sequence in arctic marshes consists of an initial *Puccinellia phryganodes* (nomenclature follows Porsild & Cody 1980, full names and authorities cited in Appendix A) association on bare mud followed by a Festuceto rubrae-Caricetum glareosae association (Chapman 1960).

Generally, the lowest intertidal zone colonized by vegetation (the lower geolittoral zone, Kristiansen 1977, Figure 3) is dominated by Puccinellia phryganodes (Hanson 1951; Kershaw 1976; Jefferies 1977; Glooschenko 1978; Jefferies et al. 1979; Taylor 1981; Snow & Vince 1984). Kershaw (1976) reported the occurrence of Carex subspathacea in the lower geolittoral zone on East Pen Island in Hudson Bay, while Jefferies (1977) also reported Stellaria humifusa and Cochlearia officinalis. Jefferies et al. (1979) found Hippuris tetraphylla colonizing unconsolidated sediments while Puccinellia phryganodes established itself in areas not subjected to ice-scouring. Both Kershaw (1976) and Jefferies et al. (1979) found that Carex subspathacea increased in abundance in the upper levels of the lower geolittoral zone. In Alaska, Salicornia herbacea and Suaeda maritima (Hanson 1951), Carex ramenskii (Taylor 1981), Salicornia europaea, Spergularia canadensis, and Suaeda depressa (Vince & Snow 1984) occurred in the lower geolittoral zone.

Farther upshore from the lower geolittoral zone is the middle geolittoral zone, characterized by Carex subspathacea, Stellaria humifusa, Plantago maritima var. juncoides, Ranunculus cymbalaria, Puccinellia lucida, Atriplex glabriuscula, Glaux maritima, Salicornia europaea, Triglochin maritima and Potentilla egedii (Hanson 1951; Kershaw 1976;

Figure 3: Generalized physiography within the tidal reaches of the Churchill River estuary. (Sandspit, Akudlik and Esker transects). Extreme high tide (EHT), mean high tide (MHT), low high tide (LHT), mean low tide (MLT) are indicated.


EHT
MHT
LHT
MLT
drift line
sods
channel
salt pan
bare ground
Churchill River
lower
middle
upper
Sublittoral
Hydrolittoral
Geolittoral
Epilittoral

Glooschenko 1978; Jefferies et al. 1979; Mason 1981a & b; Vince & Snow 1984). Hanson (1951) noted *Hippuris vulgaris* and *Carex rameskii* growing from sods which had been washed down from higher zones. Taylor (1981) described a *Carex subspathacea/Puccinellia phryganodes* community dominating this second zone, with *Stellaria humifusa*, *Carex ramenskii* and *C. ursina* as co-dominants.

The upper geolittoral zone generally supports *Calamagrostis deschampsioides*, *Puccinellia lucida*, *Salix brachycarpa* and *Chrysanthemum arcticum*, *Puccinellia triflora*, *Carex glareosa*, and *Potentilla pacifica* (Hanson 1951; Kershaw 1976; Glooschenko 1978; Jefferies et al. 1979; Snow & Vince 1984; Vince & Snow 1984). Other species that occur in this zone are *Dupontia fisheri*, *Stellaria humifusa*, *Poa eminens*, *Puccinellia borealis*, *Elymus mollis*, *Glaux maritima*, and *Spergularia canadensis*. A few taxa are more typical of higher zones, including *Triglochin maritima*, *Plantago juncoides* and *Elymus mollis*. This zone also contains *Calamagrostis neglecta*, *Ranunculus gmelinii*, *Cicuta virosa* and *Senecio congestus*, while in more sheltered areas, *Arctophila fulva*, *Dupontia fisheri*, *Hippuris tetraphylla* and *Carex ramenskii* are present (Jefferies 1977). *Hippuris vulgaris*, *Senecio congestus* and *Ranunculus hyperboreus* were recorded in saltpans within the upper geolittoral zone by Kershaw (1976).

The epilittoral zone, is usually dominated by *Dupontia fisheri* var. *psilosantha* (Taylor 1981). Kershaw (1976) suggested that presence of freshwater flushes from upland may permit populations of *Calamagrostis neglecta* to develop in this zone.

In the lower geolittoral zone of brackish marshes small scattered colonies of *Eleocharis palustris*, *E. smallii*, and *E. uniglumis* thrive, while *Potamogeton filiformis* and *Hippuris tetraphylla* grow in intertidal pools (Ringius 1980). *Triglochin palustris* is also present in intertidal areas. At the location of mean daily high tide *Puccinellia phryganodes* dominates with some overlap with *Hippuris tetraphylla*. The upper geolittoral supports *Scirpus lacustris*, *S. maritimus* var. *paludosus*, *Eleocharis* spp. *Senecio congestus*, *Ranunculus cymbalaria*, *Triglochin palustre* and *T. maritimum*. In the epilittoral zone, *Puccinellia lucida*, *Carex paleacea*, *C. mackenziei*, *C. salina*, and *Deschampsia caespitosa* are present.

2.3 PRODUCTIVITY

Net aerial primary production (NAPP) is defined as the net above-ground biomass produced per unit area per year (Odum 1971). Factors that govern primary production in a salt marsh are tidal inundation, marsh physiography, climate, salinity and soil nutrient concentration (Mendelssohn & Marcellus 1976).

In a James Bay salt marsh, the average NAPP for the geolittoral and epilittoral zones was between 120 and 384g m^{-2} y^{-1} (Glooschenko & Harper 1982). Jefferies (1977) examined populations of Puccinellia phryganodes in the lower geolittoral zone in a high arctic salt marsh, and found a maximum NAPP of 10g m^{-2} y^{-1}. These values may represent the extremes of productivity in arctic coastal marshes, since they include the whole extent of the latitudinal range. Cargill & Jefferies (1984a), who worked near Churchill, reported a NAPP value of 50-100g m^{-2} y^{-1} for the geolittoral zone.

In most cases, NAPP values are difficult to obtain because they require repeated sampling during the growing season. In many studies, therefore, only the presumed peak standing crop is collected. Several studies have indicated that above-ground peak standing crop in salt marshes occurs from late July to mid-August (Tyler 1971; Keefe & Boynton 1973; Wallentinus 1973; Hatcher & Mann 1975; Glooschenko 1978). Values for peak standing crop are therefore usually under-estimates of NAPP (Linthurst & Reimold 1978; Shew et al. 1981), since no allowance is made for death and decomposition of plant parts during the growing season. Furthermore, peak standing crop omits the contribution to annual productivity made by plants maturing before or after peak standing crop is reached (Eilers 1975). This underestimation may be quite small in the arctic, because rates of leaf turnover (Muc 1977) and decomposition of dead material are slow (Bliss et al. 1973; Widden 1977; Webber 1978).

When the entire salt marsh was considered values of above-ground peak standing crop were 228-564g m^{-2} at North Point in James Bay (Glooschenko 1978), 18-610g m^{-2} in James and Hudson Bay (Jones & Hanson 1983), 218-466g m^{-2} in Alaska (Vince & Snow 1984), and 324g m^{-2} in Sweden (Wallentinus 1973). Above-ground peak standing crop values for Puccinellia phryganodes were 145g m^{-2}, for Carex subspathacea were 94g m^{-2}, for Dupontia fisheri were 61gm^{-2} and for Stellaria humifusa were 73g m^{-2} (Jefferies 1977).

Arctic graminoids vary considerably in the quantity of below-ground biomass produced annually. Average below-ground standing crop at various locations in Alaska ranged from 1,520 to 2,185g m^{-2} (Dennis & Johnson 1970) and in a salt marsh near Churchill from 500 to 1000g m^{-2} (Cargill & Jefferies 1984b). Below-ground values for Puccinellia phryganodes were 64-139g m^{-2}, for Carex subspathacea were 179g m^{-2}, for Dupontia fisheri were 271g m^{-2}, and for Stellaria humifusa were 45g m^{-2}(Jefferies 1977).

Shaver & Billings (1975) found that Eriophorum angustifolium produced an entirely new crop of roots in each growing season, while annual turnover of roots of Dupontia fisheri and Carex aquatilis was much lower.

The high ratio of above-ground to below-ground biomass has been interpreted as an adaptation to generally low availability of nutrients in wet arctic systems (Haag 1973;

Chapin 1978). Reported average shoot:root biomass ratios range from approximately 1:1 in a wet tundra meadow (Johnson & Kelley 1970), to 1:10 to 1:20 in dry tundra (Bliss et al. 1973; Dennis et al. 1978) and 1:30 to 1:45 in various environments around Barrow, Alaska (Dennis & Johnson 1970). The data of Wielogolaski (1975) for Norwegian alpine communities indicate above-ground and below-ground production values were about 250 and 400g m^{-2} respectively (1:1.6). Wielgolaski (1972) found that the above-ground to below-ground biomass ratio in arctic areas may be as low as 1:23 but usually was between 1:3 and 1:10, while Jefferies (1977), who worked in the high arctic, found this ratio to be around 1:0.03 to 1:3.4. A value of 1:10 was reported by Cargill & Jefferies (1984a).

Net primary production is generally low in the arctic, due to the short growing season, low soil and air temperature, poor nutrient supply and sometimes inadequate water and illumination (Savile 1972; Muc 1977). Low temperatures during the growing season may strongly affect the rates at which essential nutrients are cycled through the ecosystem by depressing the activities of soil micro-organisms and decreasing the rate at which plant roots absorb nutrients (Haag 1973; Chapin 1978).

According to Savile (1972) temperature is the most limiting factor for plant growth while Ulrich & Gersper (1978) believe that nutrient deficiencies are more important.

Available nitrogen is limited in salt marshes, although freshwater areas have higher values (Pigott 1969; Valiela & Teal 1974). Similarly available nitrogen is a critical limiting factor for growth in estuaries (Ryther & Dunstan 1971). Cargill & Jefferies (1984a) found that net primary production by Carex subspathacea and Puccinellia phryganodes is limited by an inadequate supply of mineral nitrogen in the salt marsh sediments. Pomeroy (1970) noted that phosphorus is generally not limiting in salt marshes. Phosphate is readily exchanged between the clay matrix and the bulk of the water in the sediment, the latter partly recycled as a result of exchange at the sediment-water interface. No phosporus limitation was found in a salt marsh near Churchill (Cargill & Jefferies 1984a), although Alaskan salt marshes were deficient in nitrogen and phosphorus (Mason 1981a).

2.4 SOIL

2.4.1 Physical and chemical properties

The physico-chemical properties of estuarine salt marsh sediments are strongly influenced by the discharge volume, and suspended sediment load of the river (Hutchinson 1982) as well as the topography, tides, drainage pattern and vegetation (Clarke et al. 1982). For example, positive correlations between clay content and elevation reflect a reduction in grain size towards the epilittoral zone (Clark et al. 1982).

Freshwater nutrient-rich sediments from upstream may be trapped by marsh plants. They increase the nutrient status of the marsh (Ranwell 1964a & b), and maintain high productivity (DeLaune et al. 1979). Ranwell (1964b) recorded high levels of potassium, phosphorus, nitrogen and organic carbon in newly accreted silt in Bridgewater Bay, England. Concentrations of these materials decreased with distance seaward while calcium levels increased. Pigott (1969) found that concentrations of nitrogen and phosphorus decreased similarly in Scott Head Island, England.

In addition to the supply of nutrients from upstream, tides move nutrients from marine sources into salt marshes (Hoffnagle 1980). Wolf & Fucik (1981) noted that nitrate levels in an Alaskan salt marsh showed a positive correlation with tidal fluctuations. Ammonia, phosphate, and dissolved and total organic carbon trends were less definite (Wolf & Fucik 1981). There was evidence that phosphate levels were positively correlated with the tidal cycle while dissolved and total organic carbon was negatively correlated.

In James Bay, there were strong seasonal changes in the chemical properties of marsh sediments such as increases in percent organic carbon, pH and redox potential and decreases in conductivity (Clarke et al. 1982). Elevation was positively correlated with soil pH and conductivity. They also observed strong lateral differences in mean redox potential associated with drainage patterns. Reducing conditions were consistently recorded in marsh zones that retained standing water, had high electrical conductivity and were subject to frequent tidal inundation. An important process in wet marsh environments is the increase of organic matter which forms organic colloids that adsorb exchangeable ions necessary for plant growth (Keefe 1972; Hoffnagle 1980).

2.4.2 Salinity

2.4.2.1 Tidal and interstitial water exchange

The dominant factors controlling soil salinity of the salt marsh are the frequency, duration, salinity, and inland extent of tidal inundation as well as the surface slope, duration of sunshine, evaporation and incidence and amount of rainfall (Mahall & Park 1976; Ringius 1980).

Interstitial water salinity is controlled by the salinity of the overlying water, but exchange rates are low and only persistent changes in overlying water salinity are reflected in the interstitial water (McLusky 1968). The interstitial water salinities of sediments change seasonally and parallel seasonal changes in river flow (Sanders et al. 1965; Matisoff et al. 1975; Chapman 1979; Chapman 1981). These changes are due to rates of diffusion between the sediment water and the overlying water (Bricker & Troup 1975).

In Denmark, Mikkelsen (1949) found that long periods of inundation had a direct influence on the interstitial salinities of sediments in surface layers 0-4cm deep, some influence on layers 4-12cm deep, and generally insignificant effects on layers 12-20cm deep. These results showed that exchange between interstitial water and tidal water proceed very slowly. Mikkelsen (1949) in Denmark, and Scholl (1965) and Lindeberg & Harriss (1973) in Florida reported that the mean interstitial salinities in sediments from a salt marsh decreased with depth from a maximum near the sediment surface. This maximum is a reflection of the salinity of tidal water in contact with the surface. Density-gradient induced exchange controls interstitial water salinities near the sediment surface. The response of the fresh groundwater table beneath the marsh controls interstitial salinities at the lower depths.

Friedman & Gavish (1970) measured water chlorinity above and below the sediment surface in a single core from a salt marsh tidal channel in New York state, and found little variation between interstitial and overlying water values. Emery & Stevenson (1957) in California stated that interstitial water salinities may represent median values of interface salinities, while Dobbins et al. (1970) found that interstitial water chlorinity was lower than that of overlying water in a North Carolina estuarine system. They suggested that the decrease of salinity with depth reflected fresh groundwater discharge.

The time period for exchange between tidal waters and soil solution decreases landward. Ion exchange is the dominating influence on soil salinity up to just below the mean high tide (MHT), causing the soil salinity to be similar to that of tidal water. Water of high tides in estuaries contains a greater proportion of ocean water and is more saline than that of low tides (Lindberg & Harriss 1973). Tidal waters reaching areas above MHT would therefore be more saline than those of low tides. The presence of salt in soil above MHT is primarily dependent upon innudation by spring tides, wind tides and spray. Soil salinity declines, in the epilittoral towards the extreme high tide limit. Duration of evaporation from soil increases towards the epilittoral particularly above MHT, and may produce a concentrated soil solution near the soil surface (Mahall & Park 1976).

Chapman (1960) found very distinct and definite seasonal changes in vertical salinity gradients in the soil in temperate sites. He noted that from October to April, the salinity increases with depth, while from May to September the reverse held true.

Field analyses in Isefjord by Mikkelsen (1949) showed that the salt concentration in soil water increased in the summer due to rapid evaporation. Salinity peaked towards the end of July or the beginning of August, and fell thereafter. Heavy thundershowers combined with such topographical features as depressions caused the lowering of maximum salt concentation. The influence of rainfall is more imporant than tides farther landward in salt marshes, since salinity tends to decrease more in this direction during rainy periods (Ranwell et al. 1964). Heavy precipitation and runoff can decrease the salinities of tidal waters and therefore decrease or even reverse the movement of salts from tidal water to sediments (Lindberg & Harriss 1973; Kershaw 1976; Ringius 1980). Rarely inundated areas, which have low salt concentrations, attain maximum salt concentrations immediately after inundations in any month of the summer. Mikkelsen (1949) concluded that analyses of salt content of soil collected at the end of July or beginning of August could be regarded as relatively good reflections of maximum salt concentration in soil water at various locations.

2.4.3 Water table

Chapman (1964) reported that the influence of tides upon the soil water table were counteracted or complemented by the occurrence of rainfall. He observed that movement of the water table may be significant if it causes waterlogging of roots for any great period of time. He also noted that water movement varied with distance from a major source (eg. creek), resulting in vegetation zonation.

2.4.4 Redox potential

When a soil is submerged, gas exchange with the air ceases. As a result, oxygen and other gases can enter only by interstitial water diffusion, which is generally 10,000 times slower than through gas-filled pores (Greenwood 1961). A submerged or saturated soil is not uniformly devoid of oxygen; the concentration may be high in surface layers a few millimeters thick in contact with oxygenated water, while the oxygen concentration may drop to nearly zero below the surface layer (Mortimer 1941; 1942).

Redox potential and oxygen concentrations in soil are not linearly correlated, although at low redox potentials there is a decrease in oxygen concentration (Armstrong 1967; Ponnamperuma 1972). Anaerobic soil chemistry changes also occur which alter the state in which a number of plant nutrients exist. There is no direct relationship between nutrient concentration in soil and nutrient availability for plants. Actual availability of nutrients depends on varying levels of oxygenation. Redox potentials are higher around roots because plants transport air to their roots from which oxygen diffuses into the soil (Ponnamperuma 1972). Ewing (1983) found that a decrease in redox potential in unconsolidated sediments and saltpans could be attributed to limited sod development or the disappearance of sod. Poor drainage and prolonged inundation with tidal waters were highly correlated with the presence of unconsolidated sediments and decreasing redox potential.

Although redox potentials are not uniform throughout the soil (Strumm & Morgan 1970), they are reproducible and therefore useful (Bagander & Niemisto 1978) for comparisons between and within sites. Platinum electrodes give steady readings in reduced sediments (Ponnamperuma 1972) although the potentials may vary between locations (Zobell 1946).

2.5 PLANT ZONATION

Vegetation zonation is strongly expressed in a salt marsh. As a result, it is an ideal habitat to study the relationships between plant species distribution and environmental gradients (Disraeli & Fonda 1979). Salt marshes provide a continuous gradient of conditions from extremely wet, inundated and saline to relatively dry and fresh. Zones can vary considerably in width, depending upon the elevation gradient, which causes differences in frequency and depth of inundation, salinity, drainage, and rate and depth of silt and organic matter deposition. Where the gradient is steep, the minor zones merge into major zones while in areas where the gradient is small, many minor zones can be recognized (Hanson 1951).

There are two conventional theories for the basis of arrangement of species along an environmental gradient. In one, species may occur in groups making up relatively distinct zones (communities)(Scott 1974). In the second, species may be distributed independently (Whittaker 1967). It is likely that for each species, the location of its upper and lower zone boundaries depends on its tolerance limits for the abiotic factors that vary along the gradient, and to some extent by interspecific competition (Pielou & Routledge 1976). Floristic composition changes gradually along the gradient and the distinction of zones depends on the degree of dominance and the physiognomy of the constituent species.

Salt marshes, although productive, are low in species diversity and richness. Both of these features are indicative of a stressed community. Stress factors affecting distribution of plants are usually edaphic rather than biotic (Parrando et al. 1978).

There have been many studies of the causes of stress-induced zonation of coastal tidal marsh species; Johnson & York (1915), Gray & Bunce (1972), Redfield (1972) and Provost (1976) concluded that periodicity of tidal inundation was the predominant factor while Adams (1963), Mendelssohn & Marcellus (1976) and Hackney & de la Cruz (1978) considered that salinity was more important. Burg et al. (1980) and De Jong & Drake (1981) named both inundation and salinity factors and Reed (1947), Miller & Egler (1950), Shiflet (1963), Vogl (1966), Jefferson (1975), Eilers (1975), del Moral & Watson (1978), Disraeli & Fonda (1979) discussed a complex of many factors, including salinity, inundation, substrate composition, depth of water table, precipitation, temperature and competition. In these studies, the two most commonly emphasized factors were flooding conditions of the substrate (inundation) and salinity.

2.5.1 Inundation

Periodic tidal inundation of the sediment creates an anaerobic environment which few species can tolerate around their roots. Marsh plants, which are adapted to flooded sediment, must have a mechanism to provide their root system with oxygen (Parrando et al. 1978).

Few species can tolerate the alternating periods of submergence and exposure, and species are distributed in relation to the amount of tidal inundation or exposure they can withstand. Vertical zonation of vegetation develops as a response to the varying duration of tidal submergence across the marsh platform and is influenced by interactions between tidal shear, sediment accretion, substrate water content and potential rates of photosynthesis by marsh phanerogams in turbid estuarine waters (Hutchinson 1982).

Literature relating salt marsh vegetation to tide levels is voluminous, ranging from the early classical works of Ganong (1903) and Johnson & York (1915), through the work of Hinde (1954) and Chapman (1960), to much of the recent work carried out using elaborate multivariate techniques (eg. Eilers 1975).

Specific salt marsh macrophytes have been shown to occupy relatively narrow elevational limits and the vertical boundaries of salt marshes tend to be somewhat uniform from one coastal location to the next. Jackson (1952) found that a very slight change in elevation was related to a marked change in the appearance and composition of a community. Redfield (1972) reported that flooding by only 1% of the tides for two or more hours could negatively affect the vegetation.

2.5.2 Salinity

It is generally believed that salinity plays a role in the distribution of tidal marsh species in salt marsh ecosystems (Harshberger 1911; Adams 1963; Mall 1969; Cooper 1974; Mahall & Park 1976; Medelssohn & Marcellus 1976; Nestler 1977; Smart & Barko 1978). High salinity inhibits growth by way of direct toxicity, osmotic dehydration and by creating nutrient imbalances within the plant (Parrando et al. 1978). Soil salinity has received more attention than any other enviromental parameter considered to influence plant zonation in tidal salt marshes (Mahall & Park 1976).

Previous ecological studies regarding the water salinity relations of tidal marshes have relied primarily upon measurement of marsh water salinities and correlations between species distribution or growth tolerances and the ranges of salinities measured (Purer 1942; Adams 1963; Hackney & de la

Cruz 1978). Hypersaline soil water resulting from prolonged periods of exposure is the major factor influencing plant distribution and monotypic zonation (Shiflet 1963). Although clear correlations between species distribution and soil and water salinity have often been difficult to demonstrate (Adams 1963; Hackney & de la Cruz 1978) it has been shown that certain species have greater tolerance to salinity than others (Penfound & Hathaway 1938; Barbour & Davis 1970; Parrando et al. 1978).

An exhaustive study on the relationships between salinity and vegetation zonation was carried out in New England salt marshes (Steiner 1934). Steiner claimed that the NaCl content of the soil varied over short distances horizontally and could be correlated with vegetation zones, while Chapman (1960) concluded that if salinity exerted any controls in determining zonation it appeared to do so at the higher levels of the gradient.

Glooschenko & Clarke (1982) noted that substrate salinity was an important parameter affecting the distribution of plant species in a sub-arctic salt marsh along James Bay. They found that conductivity and soluble cations decrease in concentration from June to August with the least amount of decrease occurring in the lower zone which is subject to frequent tidal inundation.

2.5.3 Inundation and salinity

The most important parameters that influence the distribution of the phanerogams in estuarine marshes are salinity and duration and depth of flooding (Adams 1963; Stalter 1968). Burg et al. (1980) and DeJong & Drake (1981) found that water salinity and elevation-inundation appeared to be the significant environmental gradients influencing zonation of vegetation on the Nisqually, Washington salt marsh. In the Pacific northwest, salinity and elevation or inundation were recognized as having an important role in controlling community composition (Eilers 1975; Jefferson 1975; Burg et al. 1976; Disraeli & Fonda 1978).

Jackson (1952) proposed that the vertical range and frequency of tides are important factors in a tidal marsh. The vertical extent of tides is important in estimating whether any given tide will be high enough to inundate the whole marsh. Tides that do not inundate the whole marsh are also significant because evaporation proceeds unhampered during exposure, with a consequent increase in salinity.

Burg et al. (1980) found that the patterns of vegetation distribution in a salt marsh indicated the degree of freshwater influence on the presence or absence of a certain plant species, and that the elevation-inundation relationship determined the vertical distribution of species within the boundaries set by salinity.

2.5.4 Other mechanisms

Tidal phenomena *per se* cannot be shown to account for salt marsh zonation and the clear distinction between zones. Each plant species relationship with tide levels is complex and obviously entails other environmental factors, especially edaphic conditions and possibly biotic interactions (Eleuterius & Eleuterius 1979). Factors affecting zonation in intertidal marshes include nutrient and oxygen availability, the amount of organic material in the soil, undecomposed macro-organic fragments and sod in the root zone, soil texture, micro-relief, soil temperature, and ice scour (Hinde 1954; Ewing 1983).

Chapter III

STUDY AREA

3.1 GEOMORPHOLOGY

The study area lies between latitude 58° 30'N and 58° 48'N and longitude 94° 05'W in the Churchill River estuary (Figures 1 & 2). Underlying horizontal Palaeozoic limestone beds are covered by glacial till overlain by marine clays resulting from a postglacial submergence period (Ritchie 1956; Lee 1959). The presence of the sedimentary Palaeozoic limestone and the marine component create highly calcareous conditions in the area. In the vicinity of Churchill, a narrow strip of the Hudson Bay Lowland (the Marine Clay Zone - Coombs 1954) is characterized by extensive clay flats, with surface deposits of alluvial, glacio-fluvial and marine materials and relatively thin layers of peat (Coombs 1954; Cheney & Brown-Beckel 1955).

The Hudson Bay area has been undergoing isostatic uplift at an estimated rate of 0.80 to 2.19m $100y^{-1}$ since the retreat of the Wisconsin ice sheet (Barnett 1966; Hansell et al. 1983). The National Harbours Board and the Canadian Geodetic Survey has computed the rate of uplift at Churchill to be approximately 0.82m $100y^{-1}$, but the influence of isostatic uplift is negligible interms of recent changes to the water regimes within the study area.

Soils of the area are cryosolic. Permafrost is widespread and extends under the tidal zone in Beech Bay (Figure 2)(Hansell et al. 1983), with depth varying according to local topography.

Churchill has two complete tidal oscillations daily, both high tides having similar amplitude. The normal tidal fluctuations for mean tide for the mouth of the Churchill River is 3.4m with lesser fluctuation inland. Winds may produce significant variations in this mean range from 0.2 to 0.4m plus or minus the average value. Spring tides have a range of 4.6m (Table 3).

TABLE 3

Summary of tide levels for Churchill, Manitoba.

Data from Canadian Hydrographic Service, 1984.
Mean water level = 2.3m above sea level
Heights in meters above sea level

	Yearly Range	Heights	
		Highest high tide	Lowest low tide
Mean Tide	3.4	4.0	0.6
High Tide	4.6	4.5	-0.1
Recorded Extremes		5.4	-0.6

Water salinity in Hudson Bay is generally lower (10-32ppt) than that of sea water (36ppt). There are north-west and south-east gradients across the bay with the highest values in the north-west (32ppt), and lowest values in the south-east area (10ppt) due to extensive inflow of freshwater from rivers and the melting of ice and snow. At the mouth of the Churchill River, water salinity increases with depth, from 28ppt at the water surface to 32ppt at 50m below the water surface (Barber 1968).

3.2 CLIMATE

Churchill lies between the arctic and sub-arctic climatic zones which are separated by the 10°C warmest month isotherm. In the humid cool microthermal zone (annual evapotranspiration is 32cm), the frost-free period extends from the end of June to the end of August (70 days). The mean annual air temperature is -7.3°C, with summer and winter maxima 8°C and -25°C respectively (Rouse 1982). The area receives a mean annual precipitation of 402mm with approximately 65% falling as rain and the remainder as snow (November to May). Average precipitation during the growing season is 260mm, producing relatively high humidity in contrast with many locations in the high arctic.

From April to July, 200 or more hours of bright sunshine per month are recorded. In late June as many as 17 hours of bright sunshine may occur in a single day. The monthly mean temperature, total precipitation and total hours of sunshine, for 1983 and 1984 are given in Table 4. The study occurred during two years in which the growing seasons at

Churchill were quite different from normal. In 1983, the precipitation for June through September was 73% above normal. In 1984, precipitation during the same period was 78% of the normal precipitation. Mean temperature for 1983 was lower in June and July while August and September temperatures were above normal. In 1984, mean temperature was above normal during June, July and August but below normal in September. Hours of sunshine in June through September 1983 totalled 731.8, 85% of the normal while hours of sunshine for the same period in 1984 totalled 934.7, 8% above normal.

3.3 VEGETATION

The Churchill area lies within the transition zone between the arctic tundra and the sub-arctic forest (Weir 1960), and is referred to as the Hudson Bay lowlands (Rowe 1972). Ritchie (1956) described the various plant communities on the three physiographic formations at Churchill; sand deposits, outcrop and gravel ridges.

Along the east shore of the Churchill River estuary are extensive river flats originating from young sediments being exposed and subsequently colonized by vegetation (Ritchie 1957). This process is regulated by the deposition of alluvium and recession of the level of the Hudson Bay (Ritchie 1957). Vegetation on these flats forms distinct bands (zones) parallel with the river (Ritchie 1957). Ritchie la-

TABLE 4

Summary of average climatic monthly means

for Temperature, Precipitation and Hours of Sunshine
at Churchill, Manitoba
for the growing seasons of (1) 1951-1980
(2) 1983
(3) 1984

Data from Environment Canada, Atmospheric
Environment Service, pers. com. H.M.Fraser

			June	July	August	September	Annual
TEMPERATURE	mean (°C)	(1)	6.2	11.8	11.3	5.4	
		(2)	5.5	11.3	12.9	5.9	
		(3)	7.4	12.2	14.5	4.1	
	maximum (°C)	(1)	10.8	16.6	15.3	8.5	
		(2)	9.5	16.8	17.6	8.4	
		(3)	12.5	17.2	20.5	6.7	
	minimum (°C)	(1)	1.5	6.8	7.2	2.2	
		(2)	1.5	5.8	8.2	3.4	
		(3)	2.3	7.1	8.5	1.4	
Precipitation (mm)		(1)	43.5	45.6	58.3	50.9	402
		(2)	58.1	64.3	100.5	119.1	616
		(3)	34.5	32.2	67.9	19.0	413
Hours of Sunshine		(1)	233.7	285.1	232.1	111.8	1,828
		(2)	205.1	244.7	186.9	95.1	1,557
		(3)	221.6	302.8	307.9	103.4	1,801

belled these zones; meadow, shrub, invading forest, white spruce forest and mixed forest. The meadow zone may be considered a salt marsh, as the constituent plants are predominantly salt marsh species (Schofield 1959). The Churchill salt marsh is most extensively developed on the flats along the Churchill River estuary and forms a band 0.5-1.0km wide (Schofield 1959).

Glooschenko (1980) reported that this type of estuarine salt marsh is typically dominated by Carex subspathacea. In general, the plant community structure is similar to sub-arctic salt marshes described by Polunin (1948), Kershaw (1976), Glooschenko (1978), Jefferies et al. (1979), Ringius (1980), Taylor (1981), and Glooschenko & Harper (1982).

Schofield (1959) described the vegetation sequence of the Churchill salt marsh. He noted that Puccinellia phryganodes colonized the lowest reaches of the tidal zone (geolittoral, Figure 3). Above this, a Carex subspathacea zone was inter-mixed with small islands of dense Calamagrostis deschamp-sioides. Scattered individuals of Dupontia fisheri spp. psilosantha were found, especially in the drier areas. Above the Carex subspathacea zone was a grassy zone contain-ing Calamagrostis deschampsioides and patches of Montia lam-prosperma, Stellaria humifusa, Triglochin maritima, Chry-santhemum arcticum ssp. polaris, Hippuris tetraphylla, Potentilla egedii var. groenlandica, Stellaria crassifolia, and rarely Cochlearia officinalis ssp. groenlandica, Ranun-culus cymbalaria, Carex glareosa var. amphigena, Puccinellia phryganodes and P. vaginata. Occasionally, this grassy zone persisted farther inland and penetrated the more elevated patches of the shrub zone (Schofield 1959). Populations of Hippuris tetraphylla and Potamogeton filiformis var. boreal-is were found in creeks and pools that cut through the marsh.

A generalized diagram of a tidal transect bisecting the estuary (Figure 3) consists of a series of zones, determined by the periodicity and magnitude of tides (Kristiansen 1977). The sublittoral zone is never exposed, while the hydrolittoral zone is the area deliniated by the range of the low tide. The geolittoral zone extends from the top of the hydrolittoral to the level of mean high tide. The epilittoral zone is under tidal influence only during extremes in the spring and fall or during very strong winds.

Each marsh zone has a particular inundation regime with characteristic species able to tolerate these regimes. Only non-vascular plants grow below the geolittoral zone. From the lower geolittoral to the epilittoral, there is a gradient of increasing species size and diversity and of vegetation cover. This sequwence my be interrupted by the random appearance of sods.

Sods are dislodged chunks of soil bound by roots and rhizomes, moved within the epilittoral and geolittoral zones by ice scour and water. The plant taxa that colonize sods may differ from those of adjacent areas where they have been deposited. Most sods are dislodged from the upper geolittoral zone. Hanson (1951) found that the presence of upland species in the lower and mid geolittoral zones was due to the sods that had been washed in. These sods could become centers of aggregation which favored the development of more advanced stages of succession. Many of the species on the sods make adjustments to the deposition of alluvium by the formation of new roots and rhizomes at successively higher levels on the stems and by the upward growth of old rhizomes. Moody (1978) considered that these patches of compacted sediment and root mats were virtually immune to erosion, but tidal erosion occurred around the edge of the colony.

The salt marsh area is dissected by a complex dendritic system of small drainage channels a few centimeters deep, which empty into main channels (several decimeters deep). Vegetation often changes markedly along the margins of drainage channels (Chapman 1960; Sparks et al. 1977).

Saltpans are isolated barren circular or semi-circular depressions characterized by light colored and highly crystalline crusts (Chapman 1974; Kershaw 1976; Ringius 1980). Saltpans are usually located in depressions at high elevations (above MHT) which fill with salt water during extremely high tides. Subsequent evaporation leads to salt deposition. Saltpans rarely contain macrophytes, and then only extremely salt tolerant species. L.G. Goldsborough (pers.comm.) found that marine diatoms (primarily <u>Navicula</u> spp.) form a dark upper layer on the sediments in many saltpans.

These bare areas can be produced by the prolonged deposition of flotsam (Niering & Warren 1980). Accumulated tidal trash may be deposited over large areas (up to 10m dia.) by storm tides, and is frequently thick enough to kill the plants beneath. Miller & Egler (1950) found that these bare areas fill with salt water and ultimately formed saltpans. Chapman (1960) suggests that the coalesion of patches of vegetation can isolate an area that retains water and subsequently becomes a salt pan.

Chapter IV

METHODS

4.1 FIELD METHODS

4.1.1 Site selection

Four sites (previously studied by Staniforth & Shay 1982) were selected at increasing distances from Cape Merry on Hudson Bay. The selection was partly governed by accessibility and partly because the transects covered a range of water salinities. 'Sandspit' lies 3km upstream from Cape Merry, 'Akudlik' 5km, 'Esker' 8km and 'Pumphouse' 17km (Figure 2). At each site, a main transect was established perpendicular to the edge of the Churchill River, surveyed with a transit and Philadelphia rod and permanently marked. The three tidal transects (Sandspit, Akudlik, and Esker) extended from the lower limit of emergent vegetation (lower geolittoral) on the intertidal flats up to the extreme high tide level (drift line, Figure 3). The non-tidal transect (Pumphouse) extended from the river's edge to the border of a willow thicket which was assumed to be the limit of high spring river water levels due the extent of bank erosion and deposition of debris. The transects were 400m, 675m, 525m, and 100m long at the four sites respectively. In 1984, the Pumphouse transect was extended an additional 200m towards the river's edge due to a decrease in the water level of the Churchill River for a total of 300m. The orientation of each transect was related to prominent land marks (eg. grain elevator, water tower, etc.), to aid in future location.

4.1.1.1 Main and lateral transect positioning

Profiles of the four main transects were prepared using elevation readings taken every 5m along each transect. Owing to the absence of bench marks in the area, all elevations were relative. The elevations were measured from a temporary bench mark designated on a large boulder near each main transect. Subsequently, 10m lateral transects were laid out perpendicular to the main transect. The number of lateral transects per main transect was governed by the length and slope of the main transect. Laterals were positioned along each transect at approximately 5cm elevation increments (Figure 4).

Soil and water sampling stations were established along each main transect at 10-15cm elevation increments (Figure 4). The number of sampling stations (8 to 11) was determined by the length and slope of the main transect. In the vicinity of each station, tidal and soil water and soil samples were collected, and soil redox potential and plant standing crop measured.

4.1.2 Vegetation

4.1.2.1 Transect sampling

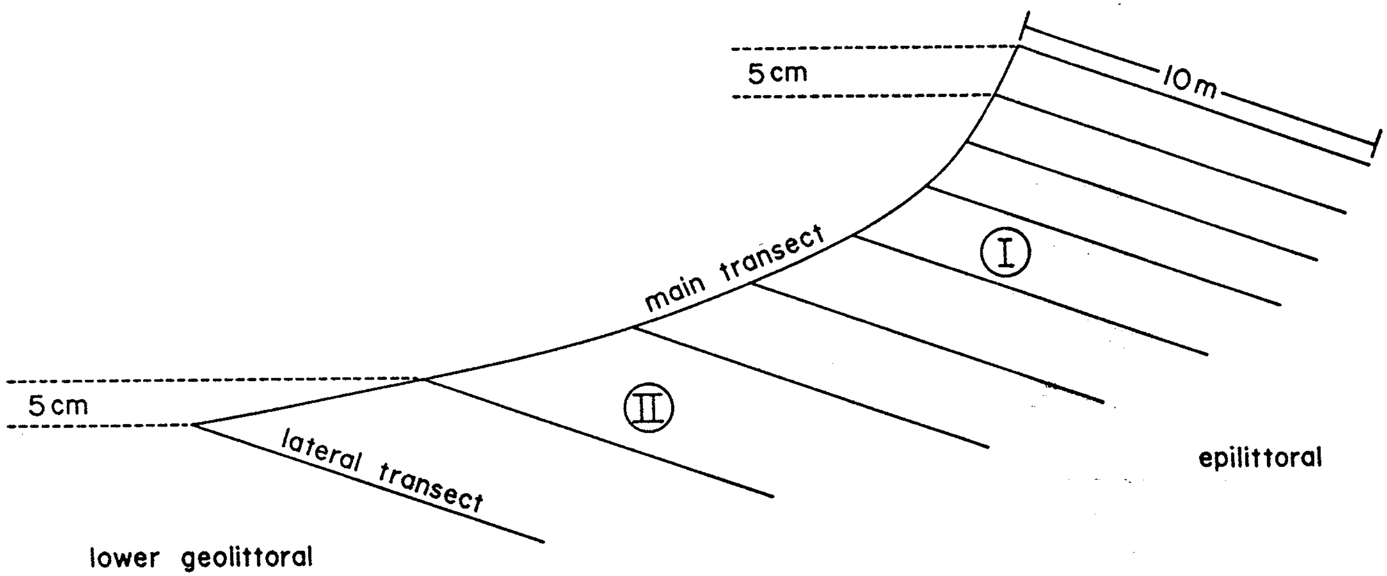
Examples of all species encountered along and beside each of the four main transects were collected, identified and pressed (nomenclature follows Porsild & Cody 1980). Reference specimens were placed in the University of Manitoba herbarium. A complete species list was prepared for each site (Appendix A).

In the last week of July (1983 and 1984), vegetation was sampled along the 10m long lateral transects using 0.5m point frames positioned every alternate 0.5m. Each point frame contained ten pins spaced 5cm apart. Species cover was determined by recording species touching each pin. Each point frame was treated as one sample in the data analysis.

4.1.2.2 Standing crop sampling

In early August (1983 and 1984), species density and standing crop were determined along each of the four transects. Above-ground standing crop was collected at each of the sampling stations along the four main transects. In 1983, plant density was measured in four randomly placed $0.0625m^2$ square quadrats near each sampling station. In 1984, 10 $0.0625m^2$ square quadrats were placed at every 1m interval along the closest lateral transect to each of the sampling stations. All vegetation was clipped to ground level, sealed in plastic bags and frozen. Samples were later

Figure 4: Main and lateral transect and sampling station layout. Lateral transects were positioned at each 5cm increment of elevation. Sampling stations (I & II) were established at 10-15cm elevation increments along the main transects. At each station, tidal and soil water and soil samples were collected, and soil redox potential and plant standing crop measured.


5 cm
10 m
main transect
I
II
5 cm
lateral transect
epilittoral
lower geolittoral

thawed and rinsed to remove any silt, separated into species, oven dried to constant weight at 55°C and weighed. Weights were converted to grams dry-weight per square meter (g m^{-2}).

In 1983, total root standing crop was assessed using random selections of one of four quadrats used in above-ground standing crop collections. After the quadrat was clipped, it was excavated to maximum rooting depth (ranging in depth from 2-15cm from the lower to higher elevations of the transect), washed free from soil, and the root material dried and weighed. Since it was not possible to distinguish between living and dead roots or to separate the roots by species, total root standing crop was calculated.

4.1.3 Environmental parameters

Environmental parameters (elevation, tidal and interstitial water chemistry, soil chemistry, soil texture, organic matter and redox potential) were measured during the summer, with the assumption that the physical and chemical regimes critical to marsh plant survival and growth occur during the growing season.

4.1.3.1 Tidal inundation

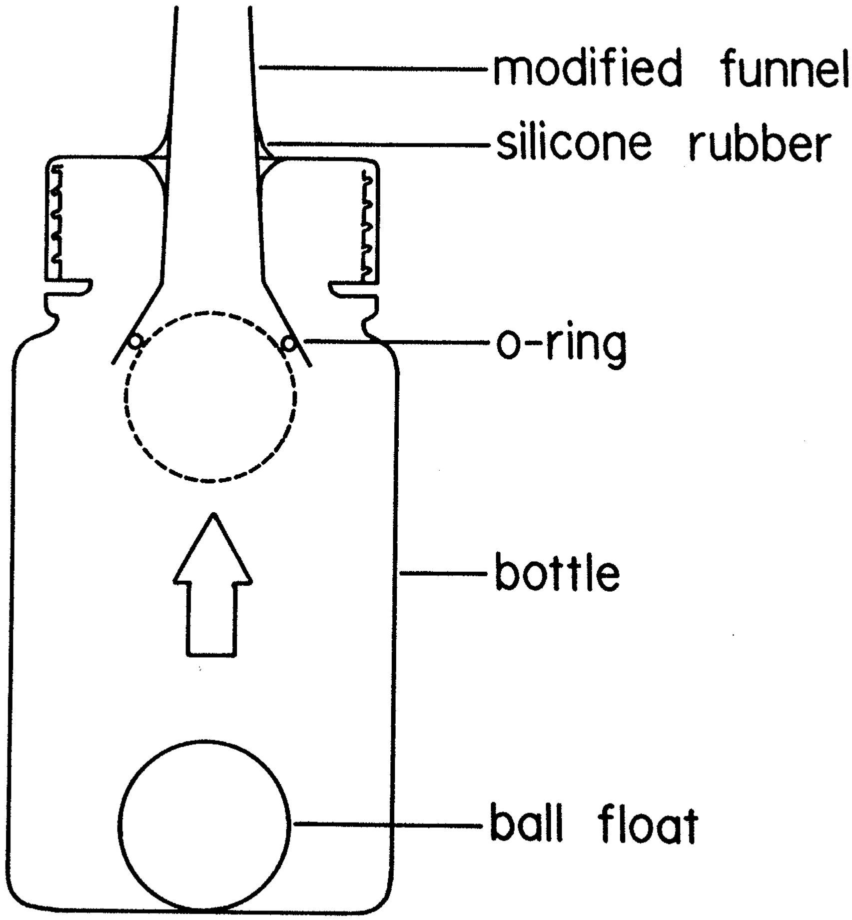
Tide height was measured from a calibrated stake surveyed in to the temporary bench marks located along each of the transects during summer extreme and low high tides in 1984. The stake was used to determine the tidal height that flooded the three tidal transects (Sandspit, Akudlik and Esker). The average frequency of flooding was then estimated using predicted tide heights for Churchill (Canadian Hydrographic Service 1983,1984).

4.1.3.2 Water quality (tidal and interstitial)

In 1983, water samples were collected in river channels, distributary channels and tidal pools, at both high and low tide periods during the course of the field season at each of the four study transects. These were analysed for salinity and conductivity using a YSI 33 meter, and for pH using a Fisher Scientific digital pH meter. In 1984, passive tidal water samplers (Figure 5) were positioned at each sampling station, at the three transects under tidal influence. Water was collected from samplers twice weekly during the incursion of tides.

Tidal water samplers were constructed using modified 125mL Nalgene bottles. A 15mm hole was drilled in the bottle cap and fitted with a Bel-Art polyethylene funnel (54mm diameter, 38mm stem length). The funnel cone was shortened to fit through the mouth of the bottle and glued to the cap using contact cement and then sealed with silicone rubber. Rubber o-rings were glued within the funnel cone and the joint sealed with silicone rubber. A ball float placed inside the bottle floated up with influent water and sealed

Figure 5: Passive tidal water sampler. (Figure drawn full size).


modified funnel
silicone rubber
o-ring
bottle
ball float

the bottle when filled. A bottle was attached to a permanent stake at each sampling station with wide rubber bands to facilitate removal of samples. In most cases, rubber bands were replaced every two weeks because of saltwater corrosion. During sampling, the cap was removed and the ball float removed from filled bottles with forceps, and placed in a new clean bottle. The cap was secured and the new bottle was attached to the stake.

In 1984, water table depth was measured and interstitial water samples collected using capped PVC piezometers (modification of Disraeli & Fonda 1979) at each of the sampling stations. Water samples were collected from piezometers with a suction tube during routine visits twice weekly. The water samples were returned to the laboratory and centrifuged (International Clinical Centrifuge Model CL) to remove suspended sediment, and pH and conductivity measured using an Accumet Portable pH meter model 156 and YSI 33 salinity/conductivity meter respectively.

4.1.3.3 Soils

In the first week of August 1983, three soil samples were collected randomly around each of the sampling stations along the main transects. Depth of sample collection was based on maximum rooting depth. It ranged from 2 to 15cm from the lower to higher regions of the transect. Samples were taken to the laboratory and stored in air-tight plastic bags at $4^{0}C$ until analysed. In 1984, <u>in situ</u> soil redox potential was determined at each of the sampling stations at approximately four week intervals (first week in July, first and last weeks in August and last week in September) using an Accumet 156 meter and a 1cm platinum electrode. This was inserted into the soil to measure redox at a depth between 0 and 1cm depth. Three soil cores (ca. 6cm dia.) were then extracted at each station and redox potential measured at 1,2,3,4,5,10 and 15cm, from the top of the surface (where depth permitted this) by inserting the electrode horizontally. Redox potential was calculated using the following formula:

$$Eh_7(mV) = 247 + E\ obs + (7-pH)(-60)$$

where (Eh_7) is the redox potential adjusted to pH 7, (247(mV)) is the reference potential and (E obs) is the measured potential (Vince & Snow 1984). The pH term represented the mean pH value for the transect. When the observed pH range is less than 0.3 units the mean transect pH can be used in the above equation because it will result in a redox potential shift of less than 50mV (Bohn 1971).

4.2 <u>LABORATORY METHODS</u>

4.2.1 <u>Soils</u>

Soil pH was determined using a soil and water saturation paste extract (McKeague 1978). The paste was left for 24 hours to equilibriate and then the extract suctioned off and the pH measured using a Radiometer 29 pH meter. Conductivity and salinity of the samples were determined with a YSI 33 meter using the same saturation paste extract.

Texture of the samples was determined using particle size analysis and Stokes's law of sedimentation (McKeague 1978) on oven-dried samples of known weight (ca. 10g).

Organic carbon content of oven dried 0.4g soil samples was determined using the Walkley-Black Method (McKeague 1978), and converted to organic matter using a 1.724 organic carbon:organic matter factor (McKeague 1978).

Soil samples were analysed by the Manitoba Provincial Soil Testing Laboratory for calcium carbonate content, and concentration of nitrate-nitrogen (N), available phosphorus (P), and available potassium (K).

Saturation paste extracts prepared above were analysed for sodium (Na), magnesium (Mg), and calcium (Ca) concentration using a Perkin Elmer Model 290 Atomic Absorption Spectrophotometer. Sample dilution was necessary prior to analysis (1:50 dilution for Ca, 1:2500 for Mg and 1:50 and 1:2500 for Na, depending on the location of the sample in the estuary). The Na, Ca and Mg concentrations were then used in the calculation of sodium adsorption ratio (SAR) and exchangable sodium percentage (ESP) using the following formulae (Richards 1954):

$$SAR = Na / \sqrt{((Ca + Mg) / 2)}$$

$$ESP = (100 (-0.0126 - 0.01475 SAR)/(1 + (-0.0126 + 0.01475 SAR)$$

Where Na,Ca and Mg are the concentrations of designated cations expressed in milliequivalents per liter. Mean soil data for each of the sampling stations along the four transects; Sandspit, Akudlik, Esker and Pumphouse, are tabulated in Appendix B.

4.3 DATA ANALYSIS

All statistical analyses (unless otherwise mentioned) of vegetation and environmental parameters were performed with the use of the Statistical Analysis System (SAS 1982). A predetermined minimum significance level of 0.05 ($p<0.05$) was chosen to indicate statistical significance. Simple statistics for the data were calculated using the SAS MEAN procedure. Correlations between environmental parameters were determined using SAS procedure CORR.

4.3.1 Vegetation

4.3.1.1 Transect data

Topographic gradients of all the transects were irregular so there was no direct relationship between distance along the transect and elevation. Therefore it was decided to consider each point frame individually and sum all the point frames with the same elevation within a transect instead of grouping them by laterals. The point frames were grouped by 0.05m increments of elevation for each transect using a SAS sorting procedure. Species occurring within a point frame were sorted by elevation. The relative percent cover was then calculated for each species at each of the elevation intervals using the following formula:

$$(R\%C)i = (\%C)i / \Sigma(\%C)i \times 100$$

where (R%C)i is the relative percent cover for species (i), (%C)i is the percent cover for species (i) and Σ(%C)i is the total percent cover for all the species present at an elevation interval. Each of these elevation intervals with species cover are referred to as an 'elevation class'.

A species-percent cover matrix for each transect was tabulated using elevation classes to show species occurrences at a specific elevation. The species percent cover was reduced to the five Braun-Blanquet (1932) categories, (1) 1-5%, (2) 6-25%, (3) 26-50%, (4) 51-75% and (5) 76-100%.

Species diversity (species richness and evenness), number of species and ground cover for each elevation along each transect were also included in the above matrix. Species diversity for each transect elevation class was calculated using the Shannon-Weiner formula (Shannon & Weaver 1949):

$$H' = -\Sigma(pi)(\ln pi)$$

where (H') is the index value and (pi) is the proportion of all individuals in the sample belonging to species (i) and (ln) is the natural log.

4.3.1.2 Standing crop

Simple statistics for 1983 and 1984 above-ground standing crop as well as 1983 below-ground standing crop data were calculated using SAS MEAN procedure. A SAS sorting procedure was used to group 1984 above-ground standing crop samples by 0.33m increments of elevation for each transect because the sample size was small. The percent of total above-ground standing crop for species X at a specific elevation was calculated by determining its percentage of the total dry weight (g m^{-2}). Species with over 10% of the total dry weight were examined further. Above-ground:below-ground standing crop ratios were calculated for only 1983 data as there were no 1984 root data.

4.3.2 Environmental parameters

4.3.2.1 Water quality (tidal and interstitial)

Analysis of tidal and interstitial water salinity used Jonckheere's distribution-free test for ordered alternatives (Hollander & Wolfe 1973).

4.3.3 Vegetation and environmental parameter interactions

4.3.3.1 Environmental parameter ordination

Principal components analysis (PCA) is considered an objective ordination technique, as its ordination scores are derived from a data matrix alone (Whittaker 1960). Instead of using only selected indicator variables the PCA enables the whole data matrix to be used. It reduces the samples (for example, soil samples) from a multidimensional space into fewer dimensions with the least possible distortion. The original data axes represent individual soil parameters, whereas the derived PCA axes are complex linear combinations of soil parameters. The location of individual data points on a PCA axis is specified by a linear equation of the form:

$$PCA\ (axis) = \alpha \times SV_1 + \beta \times SV_2 + \ldots$$

Where PCA (axis) is a derived axis, (SV_1) and (SV_2) are soil variables 1 & 2 and (α) and (β) are variable loadings. The factor (variable) loadings give an indication of factors controlling a specific PCA axis. PCA assumes linear responses and therefore maybe unreliable in the presence of non-linear trends in the data.

Principal components analyis of the total soil data was based on the correlation matrix using SAS PRINCOMP. Subsequent PCA's were run on data divided into the three groups indicated by the first run, Sandspit & Akudlik (saline), Esker (brackish) and Pumphouse (fresh).

4.3.3.2 Vegetation ordination

The species data matrix, had many zeros (species were not present) and DECORANA (Hill 1979), a FORTRAN program for detrended correspondence analysis (DCA), was used. Data matrices containing percent cover scores of a species for each elevation class were analysed. Both species and site ordinations were performed simultaneously.

Ordinations reduce the dimensionality of community data into two or three dimensions with similar stands located closer to one another (Gittins,1969).

Hill (1979) suggests that in DCA the the derived unit of distance along the axis can be referred to as 'standard deviations' (sd). Samples with a separation of more than 4sd usually have no species in common. In this work the DCA axis have been labelled using 'sd'.

A preliminary run was performed using the complete data set to determine the spatial arrangement of the four transects. Interpretation of the first axis of the ordination was determined by linear regression of environmental parameters and principal component scores against sample DCA axis scores. The data were then divided into three groups indicated by the first run (see results). The first group consisted of Sandspit and Akudlik data, the second of Esker data and the third of Pumphouse data. Each group of data was then ordinated individually.

Chapter V

RESULTS

5.1 VEGETATION

5.1.1 General description

In the four sites 81 species of vascular plants were identified (Appendix A), of which 54 occurred along the transects and 25 had a cover of 20% or greater within an elevation sample. The species richness encountered in the sites and along the transects during both years increased from Sandspit to Pumphouse. Differences in species diversity for the four sites exhibited similar trends (Table 5).

5.1.1.1 Sandspit

Sandspit point frame data showed a zonation of species from high to low elevations (epilittoral to lower geolittoral zones)(Table 6). Emergent vegetation existed beyond an elevation of 2.9m above sea level (asl). The upper 0.5m or 34% of the 1.45m elevational gradient (coinciding with the epilittoral and upper geolittoral zones) was dominated by *Puccinellia nuttalliana*, *Chrysanthemum arcticum*, *Calamagrostis deschampsioides*, *Carex subspathacea*, *Stellaria humifusa*, *Potentilla egedii* var. *groenlandica*, and *Ranunculus cymbalaria*. In the next 28% (0.4m) of the gradient (middle geolit-

TABLE 5

Species richness and Shannon-Weiner diversity indices

encountered along the four sampled transects.

Collected during the field seasons of: (1) 1983
(2) 1984

		Sandspit	Akudlik	Esker	Pumphouse
Species richness along transect	(1)	9	21	17	28
	(2)	10	17	18	33
Species richness at site		16	25	23	59
Mean species diversity	(1)	0.51	0.96	1.10	1.14
	(2)	0.54	0.86	1.10	1.24

toral), only Stellaria humifusa and Carex subspathacea remained. Below 0.55m, S. humifusa disappeared, and there was an influx of Hippuris tetraphylla on unconsolidated sediments, and Puccinellia phryganodes on consolidated mud in the lower geolittoral zone.

Species diversity decreased from the epilittoral to the lower geolittoral zones (Table 6) and was related to elevation ($r=0.61$, $p<0.0003$). The species richness at each elevation also decreased with elevation (Table 6).

In the epilittoral zone the ground was completely covered (100%) by litter (Table 6), but the proportion of bare

TABLE 6

Species percent cover matrix (Sandspit)

Sandspit species cover, Shannon-Weiner diversity, species richness, litter, bare gound and rock cover in relation to elevation (n = 270).
(1) 1-5% (2) 6-25% (3) 26-50% (4) 51-75% (5) 76-100%

Elevation (m)

Species	1.45	1.40	1.35	1.30	1.25	1.20	1.15	1.10	1.05	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.00
<u>Puccinellia nuttalliana</u>	2	2	1	1		1				1																				
<u>Chrysanthemum arcticum</u>	3	2	2	2	2	1		1																						
<u>Calamagrostis deschampsioides</u>	2	2	2	2	2	2	1	1	1																					
<u>Carex subspathacea</u>	3	3	4	3	3	4	5	4	5	5	5	5	4	5	5	5	5	5	5	5	5	5	5	5	5		5	5	2	4
<u>Stellaria humifusa</u>		2	2	2	2	2	2	2	2	2	2	2	3	2	2				1											
<u>Potentilla egedii</u> var. <u>groenlandica</u>			1	1																		1								
<u>Ranunculus cymbalaria</u>			1	2	1	2		1																						
<u>Triglochin palustris</u>							1		1																					
<u>Puccinellia phryganodes</u>								1		1																		2	5	3
<u>Hippuris tetraphylla</u>																			1	2	2				2				2	2
Species Diversity	1.3	1.4	1.4	1.5	1.3	1.2	0.6	1.0	0.6	0.6	0.3	0.3	0.6	0.2	0.4	0.0	0.0	0.0	0.2	0.3	0.5	0.1	0.0	0.0	0.5	0.0	0.0	0.2	0.7	1.0
No. of Species	4	5	7	7	5	6	4	6	4	4	2	2	2	2	2	1	1	1	3	2	2	2	1	1	2	0	1	2	3	3
Litter	5	5	5	5	5	5	5	5	5	5	5	4	5	3	4	5	5	2	3	3	2	2	1		1					
Bare ground				1			1	1		2	2	3		4	3			5	4	4	5	5	5	5	5	5	5	5	5	4
Rock		1						2						2					1				1	1	2		2	2	2	3

ground gradually increased from the upper and mid geolittoral zones until there was almost 100% bare ground in the lower geolittoral zone. There was a concomittant increase in numbers of rocks and boulders.

5.1.1.2 Akudlik

Emergent vegetation started at an elevation of 2.6m asl. The Akudlik data showed that Chrysanthemum arcticum, Festuca rubra spp. rubra, Calamagrostis deschampsioides, Stellaria longipes, and Carex subspathacea occupied the upper 40% of the 1.70m gradient (epilittoral and upper geolittoral)(Table 7). In the mid geolittoral zone, there were nearly pure swards of Carex subspathacea with areas of unconsolidated sediments colonized by patches of Hippuris tetraphylla. Below mid-elevation (0.75m), populations of Potentilla egedii var. groenlandica, Stellaria humifusa and Ranunculus cymbalaria appeared with the Carex subspathacea. In the lower geolittoral zone, Puccinellia phryganodes became the only vascular species to survive.

Akudlik showed an erratic species diversity (Table 7). The species diversity was highest at the higher elevations, decreased at the mid elevations due to a mono-culture of Carex subspathacea and began to increase again at the low elevations, with the influx of other species. The species diversity did not become as high as at the higher elevations. Beyond the lowest elevation on the transect (hydrolittoral

TABLE 7

Species percent cover matrix (Akudlik)

Akudlik species cover, Shannon-Weiner diversity, species richness, litter, bare ground and rock cover in relation to elevation (n = 480).
(1) 1-5% (2) 6-25% (3) 26-50% (4) 51-75% (5) 76-100%

Elevation (m)

Species	1.70	1.65	1.60	1.55	1.50	1.45	1.40	1.35	1.30	1.25	1.20	1.15	1.10	1.05	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.00
Chrysanthemum arcticum	2		1	2	1	1								1																					
Festuca rubra ssp. *rubra*	4		4	3	2	2	2	2	1	1		1																							
Calamagrostis deschampsioides		3	2	2	2	2	3	2	2	1	2	2	2																						
Stellaria longipes		2		1	1		1	1			2	2	2	1	1																				
Carex subspathacea		3	2	3	3	3	3	4	4	5	4	4	4	5	5	5	4	5	5	5	4	4	4	4	4	4	4	3	3	3	3	2			
Potentilla egedii var. *groenlandica*			1	2	2	2							1							1	1	2	1	1	1	1	1	1	2		1				
Stellaria humifusa				1				1	1	1	1	1	2	2					2	2	2	2	1	1	1	1	1	2	1			1			
Salix brachycarpa				2	1																														
Triglochin palustris					1																1						1								
Ranunculus cymbalaria					1		2	2	1	1	2		1								1	1	1	1	1	1	1			2					
Dupontia fisherii var. *psilosantha*						1			1																										
Plantago juncoides var. *glauca*						1		1																											
Carex glareosa var. *amphigena*												1																							
Puccinellia phryganodes												1	1										1	1	2	1	1	2	2	3	3	5	5	5	5
Hippuris tetraphylla																1	3		1	2	2	2	2	2	2	2	2	3	2	2	2	1			
Eleocharis uniglumis																							1	1	1	1	1								
Potamogeton filiformis																							1			1		2	1						
Species Diversity	0.6	1.0	1.2	1.7	1.6	1.7	1.3	1.3	1.1	0.6	0.9	1.2	1.1	0.6	0.2	0.2	0.6	0.0	0.4	0.6	0.9	0.9	1.1	0.9	1.2	1.1	1.2	1.4	1.4	1.2	1.1	0.7	0.0	0.0	0.0
No. of Species	2	3	5	8	9	7	5	7	6	5	5	7	7	4	2	2	2	1	3	4	6	5	8	7	7	8	8	6	6	4	4	4	1	1	1
Litter	4	5	5	5	5	5	5	5	4	3	4	3	4	3	5	3	3	3	5	4	4	4	4	3	3	2	2	2	2	2	1				
Bare ground		2					2	2	3	4	3	4	3	4	2	4	4	4	2	3	3	3	3	3	4	4	5	4	4	4	4	5	4	4	4
Rock	3																				1	2	2	2	2	2	2	2	2	2	2	3	2	3	3

zone), there were no plants present. The species richness at each elevation followed a similar trend. Litter, bare ground and rock distribution at Akudlik were similar to those of Sandspit (Table 7).

5.1.1.3 Esker

Emergent vegetation existed from an elevation of 2.0m asl. The upper 30% (0.4m) of the 1.45m gradient (middle geolittoral) was occupied by Calamagrostis neglecta, Potentilla egedii var. groenlandica, Carex aquatilis, Deschampsia caespitosa var. littoralis, Ranunculus cymbalaria and many species of lesser importance (Table 8). In the next 25% (0.35m) of the gradient, many of the less important species in the upper part disappeared leaving a mixed community of Carex aquatilis, Deschampsia ceaspitosa var. littoralis, Ranunculus cymbalaria, Dupontia fisheri var. psilosantha, and Eleocharis uniglumis. Little vegetation was established in the lower geolittoral zone, with the exception of patches of Eleocharis uniglumis which occurred together with Ranunculus cymbalaria, Triglochin palustris and Puccinellia langeana. Both, species diversity ($r=0.81$, $p<0.0001$) and species richness decreased from the mid to the lower geolittoral zone (Table 8).

Esker was characterized by a high percentage of bare ground and rock in the lower geolittoral zone and more large boulders than the previous two sites.

TABLE 8

Species percent cover matrix (Esker)

Esker species cover, Shannon-Weiner diversity, species richness, litter, bare ground and rock cover in relation to elevation (n = 380).
(1) 1-5% (2) 6-25% (3) 26-50% (4) 51-75% (5) 76-100%

Elevation (m)

Species	1.45	1.40	1.35	1.30	1.25	1.20	1.15	1.10	1.05	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.00
Eriophorum angustifolium	1																													
Aster junciformis	1		1	1			1																							
Calamagrostis neglecta	2	3	3	3	3	3	3	3	2	2		1																		
Potentilla egedii var. *groenlandica*	3		2	2	1	2	1	1	1	1	1	1	2	1			1													
Carex aquatalis	3	4	2	3	3	2	2	3	2	2	2	2	1	1	1	2		2												
Deschampsia caespitosa var. *littoralis*	1		3	2	2	1	1	1	2	2	3	4	3	3	3	2	2	1		1	1					1				
Ranunculus cymbalaria	2		1	2	2	2	2	2	2	1	2	2	2	2	1	1	2	2		2	2		2	1	1		1			
Dupontia fisheri var. *psilosantha*			1		1	1		2	1	2		1	1	2	2	2	1	2		1										
Cicuta mackenzieana				1																										
Rumex occidentalis				1																										
Ranunculus gmelini var. *hookeri*				1			2	2	2	2		1	1	1																
Eleocharis uniglumis				2		2	2	1	2	2	3	2	3	3	4	4	4	4	5	5	5	5	5	5	5	5	5	5	5	
Triglochin palustris						1	1		1	1	1	1	1		1		1	1	1	1			1		1					
Puccinellia phryganodes									2																					
Myriophyllum exalbescens													1																	
Potamogeton filiformis														1											1			2		
Limosella aquatica																	1													
Puccinellia langeana																					1		2	2						
Species Diversity	1.7	0.7	1.5	1.9	1.6	1.9	1.9	1.9	2.3	2.1	1.5	1.7	1.8	1.6	1.4	1.2	1.4	1.1	0.1	0.8	0.6	0.0	0.6	0.3	0.2	0.2	0.2	0.4	0.0	0.0
No. of Species	7	2	7	10	6	8	9	8	10	9	6	9	9	8	6	5	7	6	2	5	4	1	4	3	4	2	2	2	1	0
Litter	5	5	4	4	5	4	4	4	4	3	4	4	2	2	2	1	3	3	3		2									
Bare ground			3	2	2		3	3	3	2	3	2	4	3	4	3	4	3	3	4	3	3	4	4	4	4	4	4	3	4
Rock				2		3		1		3	1	1	2	3	3	3	2	2	2	3	4	4	3	3	3	3	3	3	4	3

5.1.1.4 Pumphouse

Calamagrostis lapponica dominated the upper 0.50m of the 2.00m gradient at Pumphouse (Table 9). In the next 20% (0.4m) of the elevation gradient, *Carex aquatilis*, *Salix planifolia*, *Equisetum arvense* produced 50% cover with 20 other species also present. *Eleocharis acicularis* and *Juncus bufonius* provided more than 75% cover in the middle elevations (0.95-0.40m), while pools (1-30cm deep) permitted the growth of *Sagittaria cuneata* and *Potamogeton* spp. in the fine sands of the lower reaches of the transect.

Species diversity along the Pumphouse transect decreased with a decrease in elevation (r=0.54, p,0.0006)(Table 9). The species richness at each elevation followed a similar trend. Litter covered the top 50% of the gradient with bare ground dominant in the lower 50%.

TABLE 9

Species percent cover matrix (Pumphouse)

Pumphouse species cover, Shannon-Weiner diversity, species richness, litter, bare ground and rock cover in relation to elevation (n = 300).
(1) 1-5% (2) 6-25% (3) 26-50% (4) 51-75% (5) 76-100%

Elevation (m)

Species	2.00	1.90	1.85	1.80	1.60	1.50	1.45	1.40	1.35	1.30	1.25	1.20	1.15	1.10	1.05	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.00
Potentilla palustris var. *parvifolia*	2	1	2		1					1																										
Potentilla anserina	3	1	2	2								1		1																						
Equisetum arvense	2		2	2	2	1	3	3	2	2	2	1	2	1		1	1																			
Calamagrostis lapponica	3	4	3	4	2	3	1	2	2	2	1	1		1																						
Carex aquatalis	2	2	1		4	2	3	2	2	2	3	2	2	2	2	2	1	1																		
Salix planifolia	1	1	2			2	2	2	2	2	2	2		2		1	1		1																	
Polygonum amphibium var. *stipulaceum*		2		2				1																												
Parnassia palustris var. *neogaea*		1	1	2	1		2	2	1	1																										
Euphrasia arctica		2	2		2		2	2		1	2	2		1																						
Salix spp.		1	1				1			2	2	2	2	2	3	1																				
Lomatogonium rotatum ssp. *rotatum*					2		1																													
Epilobium palustre					1			1					1	2																						
Eleocharis palustris								1			2	2				1																				

capillaceus												1		1																						
Deschampsia caespitosa var. *littoralis*												1		2		2	1		1																	
Primula egalisksensis												1																								
Triglochin palustris													1				1			1																
Poa alpigena													2		2	2	2	2	2	2		2														
Stellaria crassifolia														1		1	2	2																		
Rumex occidentalis															2																					
Juncus bufonius															3	3	2	2	3	3	3	3	5	5	2	1	1		1							
Eleocharis acicularis																2	3	3	3	4	4	3			5	5	5	5	5	4	3	4		2		
Ranunculus gmelini var. *hockeri*																	1																			
Limosella aquatica																	1																			
Polygonum lapathifolium																	1																			
Sagittaria cuneata																										2				2	2	1	3	4	1	1
Potamogeton filiformis																													2	2	2	2	4	3		2
Potamogeton vaginatus																														2		2		2		4
Potamogeton richardsoni																														1		1		3	3	2
Potamogeton pusillus																																			3	2
Species Diversity	1.5	1.6	1.9	1.1	1.4	1.3	1.6	1.9	1.7	1.9	1.9	2.1	1.8	2.3	1.6	2.2	1.9	1.7	1.4	1.1	1.0	1.0	0.0	0.0	0.2	0.5	0.1	0.0	0.5	1.0	1.3	1.1	0.6	1.4	0.9	1.3
No. of Species	6	9	9	5	8	4	8	10	6	9	8	12	6	13	5	13	5	8	6	6	4	3	1	1	2	3	2	1	3	5	3	5	2	5	3	5
Litter	5	5	3	5	4	4	5	3		4		3	4	5	3	3																				
Bare ground			4		2		2		2	2	4	3		2	4	4	5	5	5	5	5	3	4	5	5	5	4	5	5	5	5	5	4	4	5	5
Rock					2	3	1	4	5	3	3	3	3	2	2	2	2	2	2	2	2	4	3	2		2	3	2	1	2	1	2	3	3		

5.1.2 Standing crop

The mean above-ground standing crop values along the four transects ranged from 103 to 215g m^{-2} in 1983, and from 105 to 199g m^{-2} in 1984. The above-ground standing crop values along the transects were 16 to 48g m^{-2} lower in 1984 with the exception of Pumphouse which was 2g m^{-2} higher (Table 10). Mean transect above-ground standing crop decreased from Sandspit to Pumphouse when considered by elevation within each transect. On an average, lower transect elevations supported less above-ground standing crop than the upper elevations in both years (Figure 6). Since they are based on a larger sample size, only the 1984 data are presented.

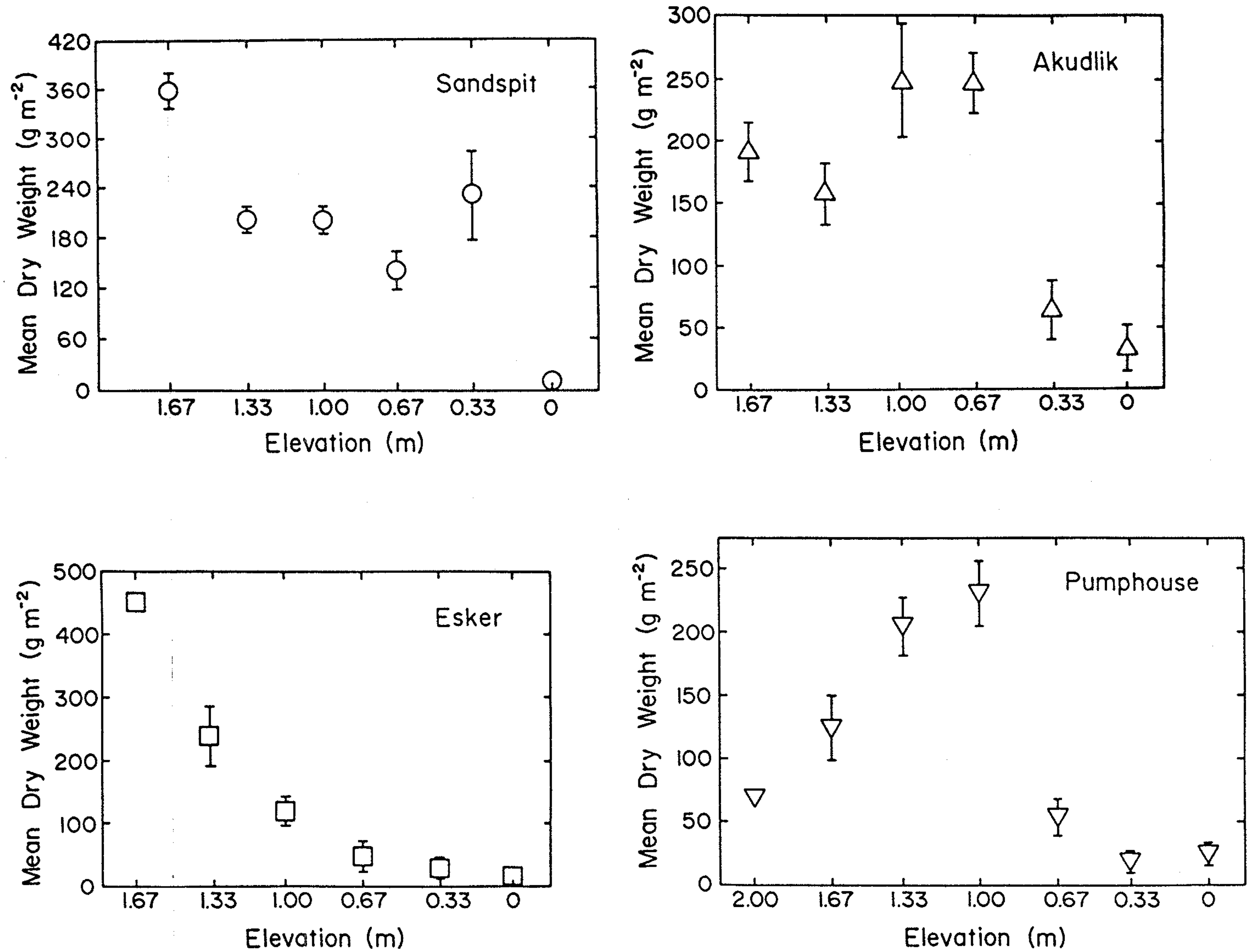
TABLE 10

Total above-ground standing crop (g m^{-2})

Collected during the field seasons of: (1) 1983
(2) 1984

Site		No. of samples	Mean	Standard error	Minimum	Maximum
Sandspit	(1)	44	214.86	14.26	15.36	547.20
	(2)	69	198.98	14.35	0.26	620.03
Akudlik	(1)	48	205.80	14.96	42.24	455.04
	(2)	91	178.69	13.92	0.26	499.84
Esker	(1)	36	171.80	22.20	19.20	577.28
	(2)	87	123.89	15.92	0.19	615.74
Pumphouse	(1)	24	102.53	22.86	1.28	418.56
	(2)	72	104.80	15.32	0.83	549.12

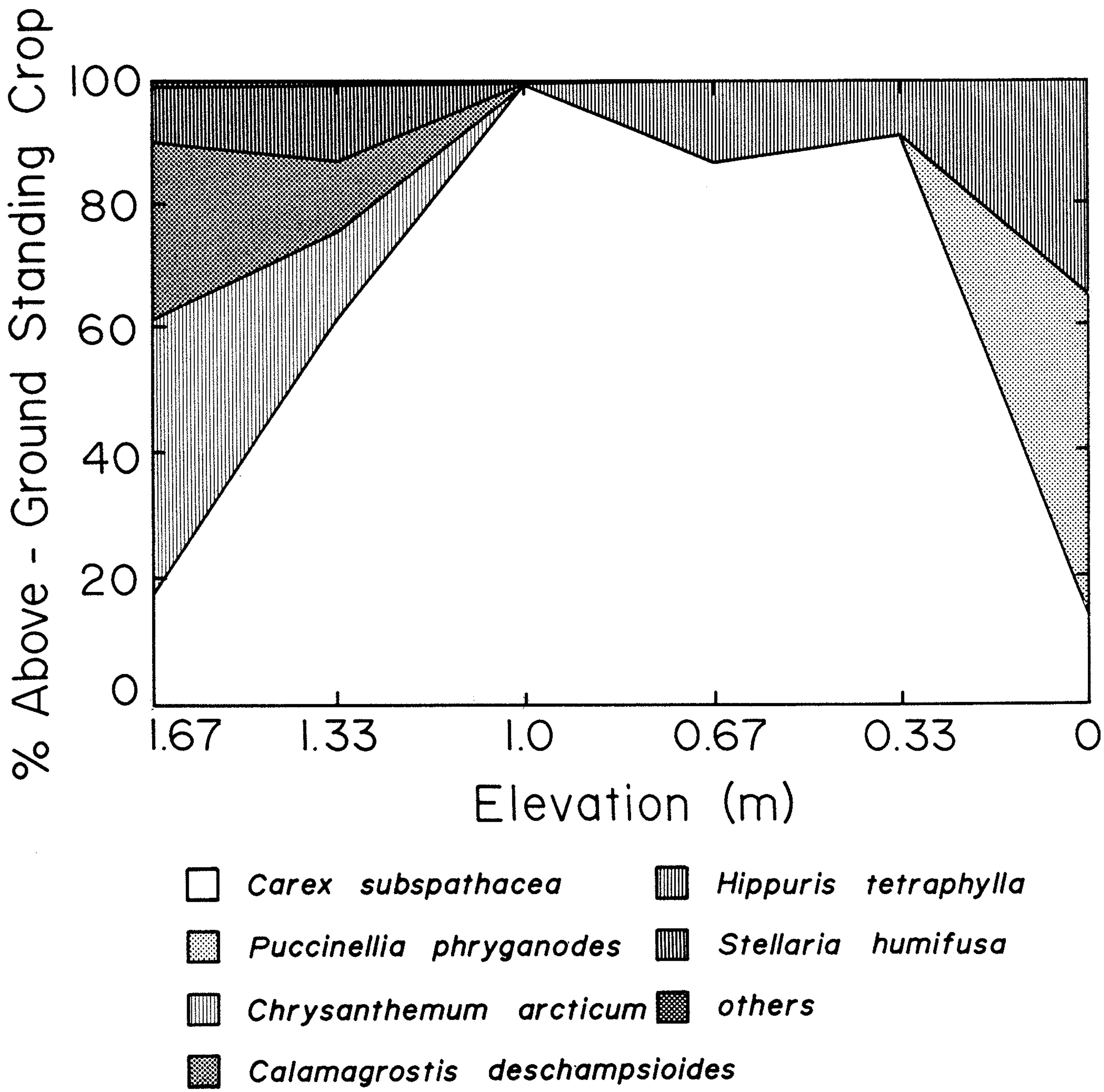
Figure 6: Above-ground standing crop along the Sandspit, Akudlik, Esker and Pumphouse transects. Vertical line indicates ± se.
Note - elevations are relative to the individual transect.


Sandspit
Mean Dry Weight (g m-2)
Elevation (m)
420
360
300
240
180
120
60
0
1.67
1.33
1.00
0.67
0.33
0
Akudlik
Mean Dry Weight (g m-2)
Elevation (m)
300
250
200
150
100
50
0
1.67
1.33
1.00
0.67
0.33
0
Esker
Mean Dry Weight (g m-2)
Elevation (m)
500
400
300
200
100
0
1.67
1.33
1.00
0.67
0.33
0
Pumphouse
Mean Dry Weight (g m-2)
Elevation (m)
250
200
150
100
50
0
2.00
1.67
1.33
1.00
0.67
0.33
0

Above-ground standing crop at Sandspit at 1.67m (epilittoral zone) totalled 356g m^{-2} and decreased through the upper and mid geolittoral zones to a minimum of 3g m^{-2} at 0.0m (Figure 6). At Akudlik's top elevation (1.67m), above-ground standing crop was 191g m^{-2} (Figure 6). Above-ground standing crop increased at elevations of 1.00m and 0.67m to a maximum of 247g m^{-2} and decreased to a minimum of 33g m^{-2} at 0.0m. Esker's top elevation (1.67m) had a maximum standing crop of 452g m^{-2} (Figure 6). Above-ground standing crop gradually decreased with decreasing elevation to a minimum of 11g m^{-2} at 0.0m. Pumphouse above-ground standing crop was quite low at the highest elevation (2.0m) with only 71g m^{-2} (Figure 6). The above-ground standing crop increased to a maximum of 231g m^{-2} at 1.00m and then dropped dramatically to a minimum of 25g m^{-2} at 0.0m.

By plotting the percent total above-ground standing crop contributed by individual taxa, spatial trends in zones along each main transect could be observed. At Sandspit, Carex subspathacea supplied the highest overall standing crop (Figure 7) but Chrysanthemum arcticum, Stellaria humifusa, and Calamagrostis deschampsioides made a significant contribution in the epilittoral zone. Hippuris tetraphylla increased from the upper to the lower geolittoral zone where Puccinellia phryganodes comprised over 50% to the total standing crop.

Figure 7: Percent above-ground standing crop (Sandspit) contributed by major taxa.

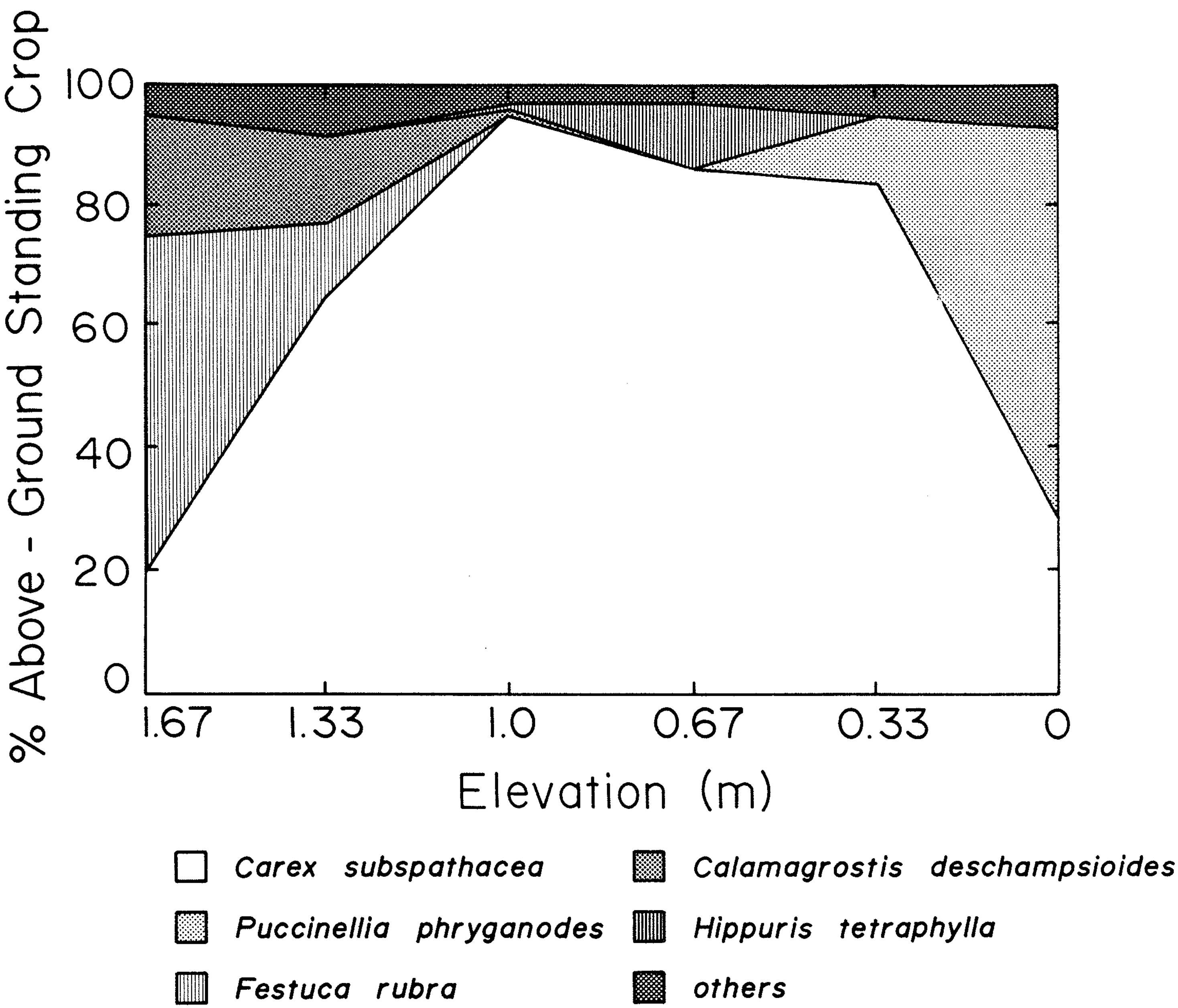

% Above - Ground Standing Crop
100
80
60
40
20
0
1.67
1.33
1.0
0.67
0.33
0
Elevation (m)
Carex subspathacea
Puccinellia phryganodes
Chrysanthemum arcticum
Calamagrostis deschampsioides
Hippuris tetraphylla
Stellaria humifusa
others

Akudlik productivity data revealed a similar species dominance to that of Sandspit (Figure 8). Carex subspathacea comprised the bulk of the standing crop along the transect. In the epilittoral zone, C. subspathacea dominated with Festuca rubra ssp. rubra, and Calamagrostis deschampsioides contributing 30%. Below 1.0m (upper and mid geolittoral zones), Hippuris tetraphylla and Carex subspathacea contributed over 90% of the standing crop. Below 0.67m of elevation, Puccinellia phryganodes standing crop became increasingly important making up over 60% at 0.0m.

At Esker, Carex aquatilis, Calamagrostis neglecta and Deschampsia ceaspitosa var. littoralis contributed the major part of the standing crop in the mid geolittoral zone (Figure 9). Eleocharis uniglumis increased in importance from high to low elevations and was the main component (88-93%) in the lower geolittoral zone.

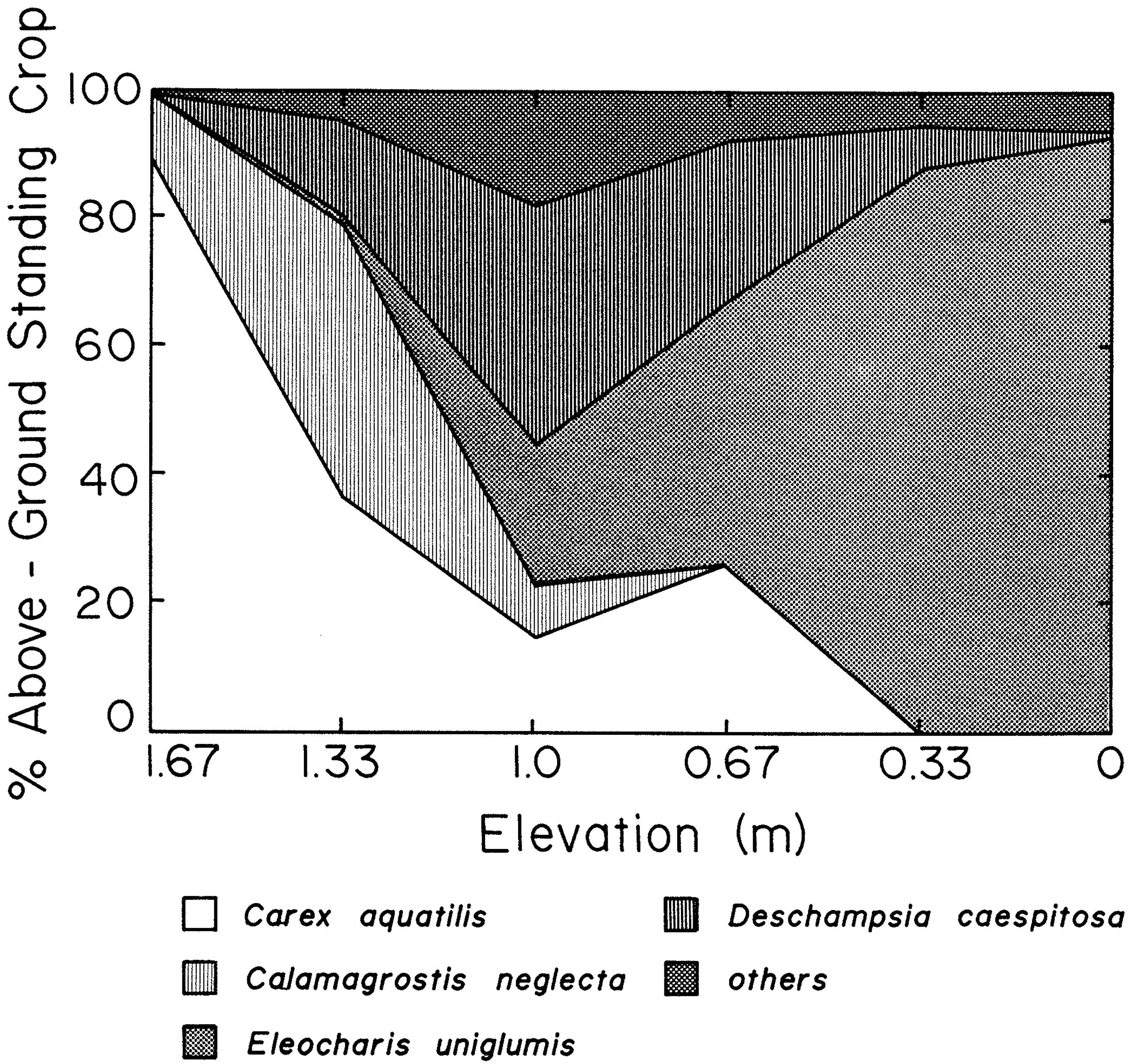
At the top of the Pumphouse transect, Potentilla anserina produced 50% of the standing crop, the other half being provided by Calamagrostis lapponica and Carex aquatilis (Figure 10). Salix planifoila saplings appeared at an elevation of 1.67m and their standing crop increased to a maximum of 47% at 1.00m. Eleocharis acicularis first made its appearance at an elevation of 1.33m (1.8%) and gradually increased to 89% of the standing crop at 0.33m. Juncus bufonius supplied an additional 28% at 0.66m. At 0.00m, Potamogeton vaginatus and Eleocharis acicularis contributed 95%, while other Potamogeton spp. contributed the rest of the standing crop.

Figure 8: Percent above-ground standing crop (Akudlik) contributed by major taxa.



% Above - Ground Standing Crop
100
80
60
40
20
0
1.67
1.33
1.0
0.67
0.33
0
Elevation (m)
Carex subspathacea
Puccinellia phryganodes
Festuca rubra
Calamagrostis deschampsioides
Hippuris tetraphylla
others

Figure 9: Percent above-ground standing crop (Esker) contributed by major taxa.



% Above - Ground Standing Crop
100
80
60
40
20
0
1.67
1.33
1.0
0.67
0.33
0
Elevation (m)
Carex aquatilis
Calamagrostis neglecta
Eleocharis uniglumis
Deschampsia caespitosa
others

Figure 10: Percent above-ground standing crop (Pumphouse) contributed by major taxa.

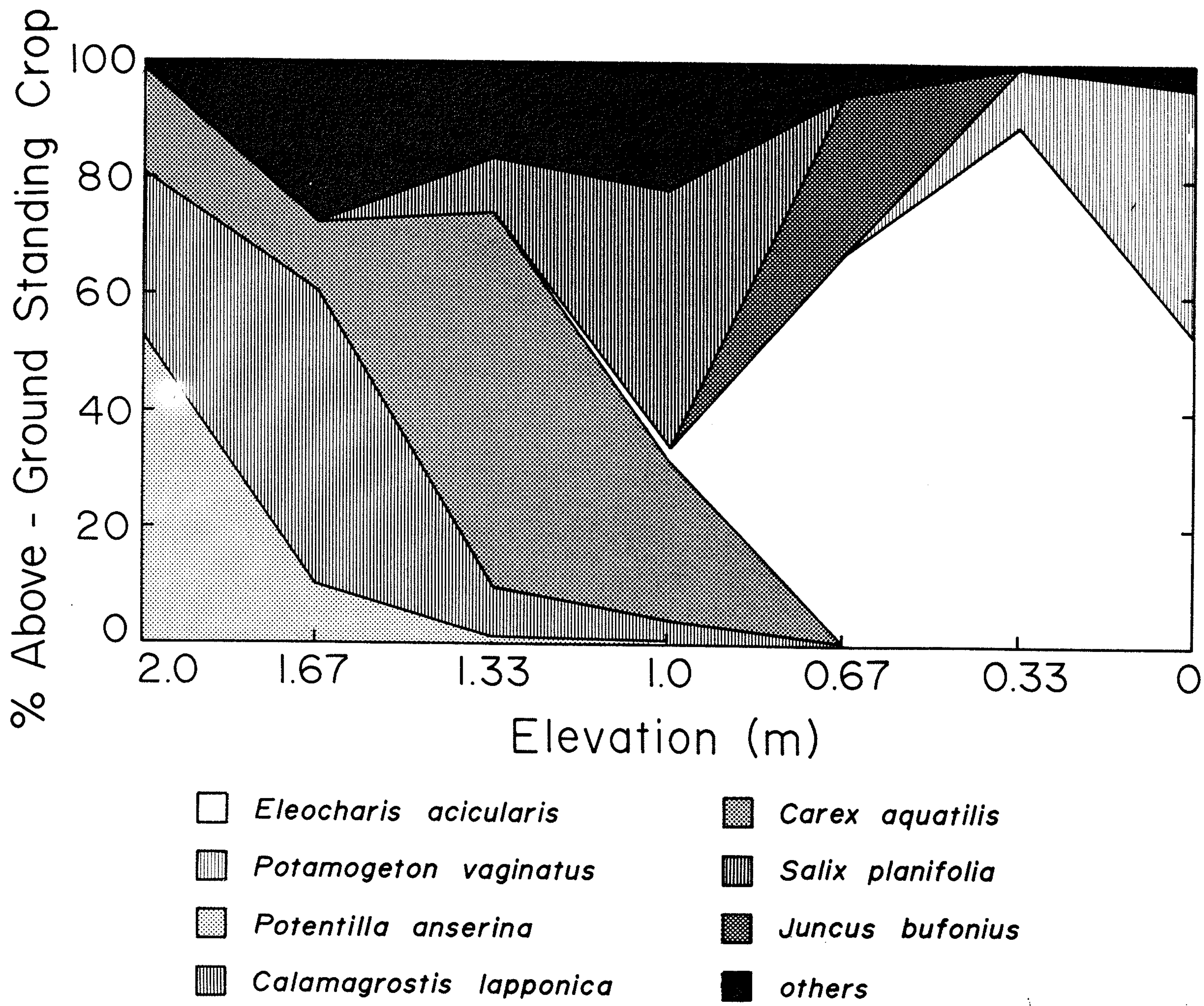

% Above - Ground Standing Crop
100
80
60
40
20
0
2.0
1.67
1.33
1.0
0.67
0.33
0
Elevation (m)
Eleocharis acicularis
Potamogeton vaginatus
Potentilla anserina
Calamagrostis lapponica
Carex aquatilis
Salix planifolia
Juncus bufonius
others

TABLE 11

Total below-ground standing crop (g m^{-2})

collected during the 1983 field season

Site	No. of samples	Mean	Standard error	Minimum	Maximum
Sandspit	11	1,261	268	123	2,560
Akudlik	12	2,015	337	109	4,172
Esker	8	1,330	221	312	2,499
Pumphouse	6	798	352	128	2,360

Mean below-ground standing crop values for the four sites ranged from 798 - 2,015g m^{-2} (Table 11). Maximum mean below-ground standing crop was recorded at Akudlik and minimum below-ground standing crop at Pumphouse.

For the four sites, the weight of below-ground standing crop was substantially higher than above-ground standing crop (Table 12). The above-ground:below-ground standing crop ranged from 1:1 to 1:23.4.

TABLE 12

Above-ground:below-ground standing crop ratio

for samples collected during the 1983 field season

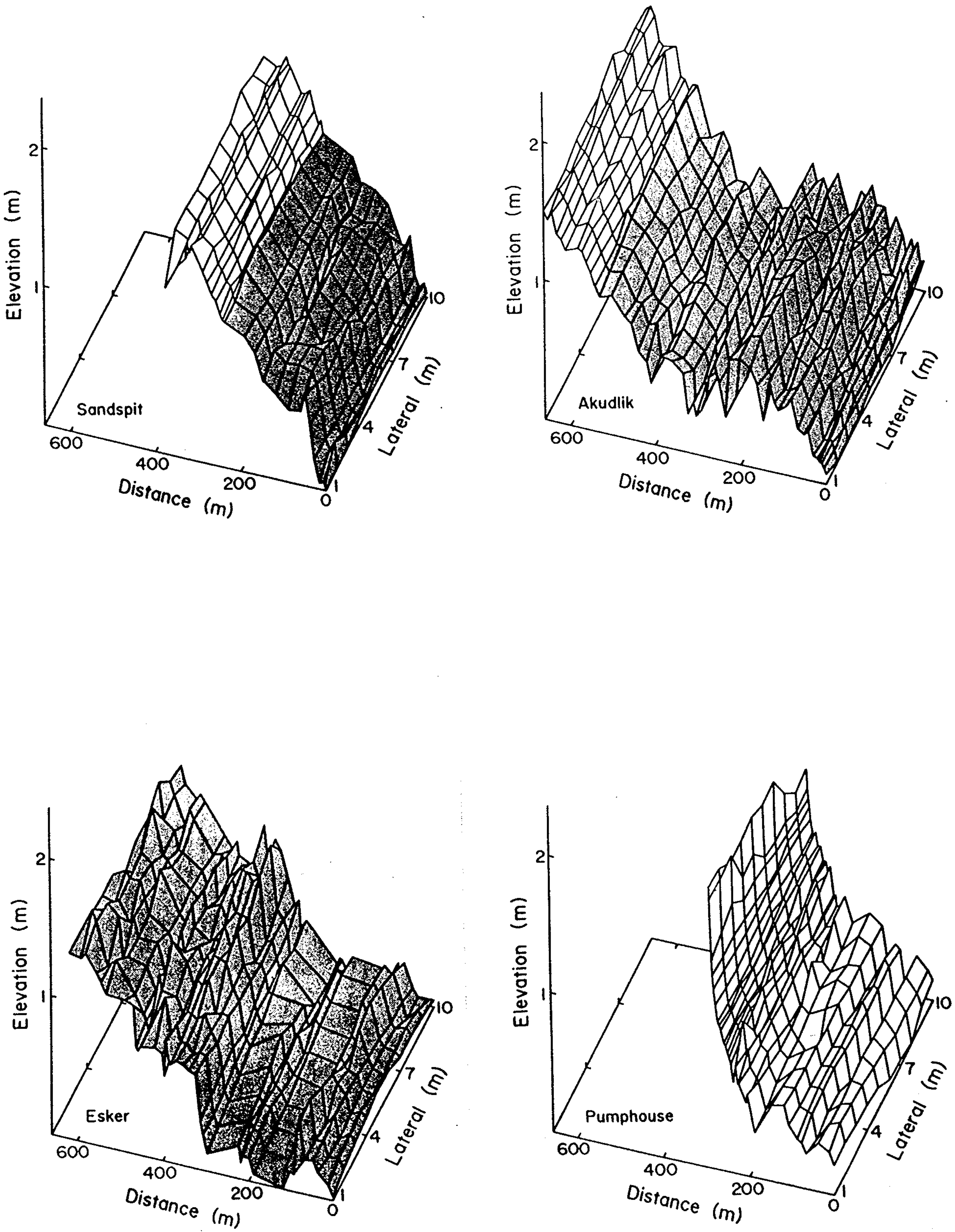
Site	No. of samples	Mean	Standard error	Minimum	Maximum
Sandspit	11	1:7.3	1.6	1:1	1:16.1
Akudlik	12	1:10.5	2.0	1:2.1	1:23.4
Esker	9	1:9.9	2.2	1:3	1:20.1
Pumphouse	6	1:6.3	2.6	1:2.4	1:10.3

5.2 ENVIRONMENTAL PARAMETERS

5.2.1 Topography

The elevation gradients of the four main transects along the Churchill River were variable (Figure 11). Sandspit had an overall slope of 0.37m $100m^{-1}$ (1 in 268), Akudlik 0.24m $100m^{-1}$ (1 in 412), Esker 0.25m $100m^{-1}$ (1 in 400) and Pumphouse 0.75m $100m^{-1}$ (1 in 136). Due to low slopes, small vertical variations in tides affected wide horizontal zones of vegetation. Sandspit, Akudlik and Esker had gradual slopes along the whole transect, while Pumphouse dropped 1.3m within the first 50m and then gently decreased. Although elevation and distance along sampling transects were highly correlated ($r=0.86$, $p<0.0001$), elevation could be variable at each distance.

Figure 11: Three dimensional topographic profiles of the four transects (Sandspit, Akudlik, Esker and Pumphouse). At the three tidal sites shaded area is geolittoral zone, unshaded area is epilittoral zone. Distance axis is highly compressed.


Sandspit
Elevation (m)
2
1
600
400
200
0
Distance (m)
1
4
7
10
Lateral (m)
Akudlik
Elevation (m)
2
1
600
400
200
0
Distance (m)
1
4
7
10
Lateral (m)
Esker
Elevation (m)
2
1
600
400
200
0
Distance (m)
1
4
7
10
Lateral (m)
Pumphouse
Elevation (m)
2
1
600
400
200
0
Distance (m)
1
4
7
10
Lateral (m)

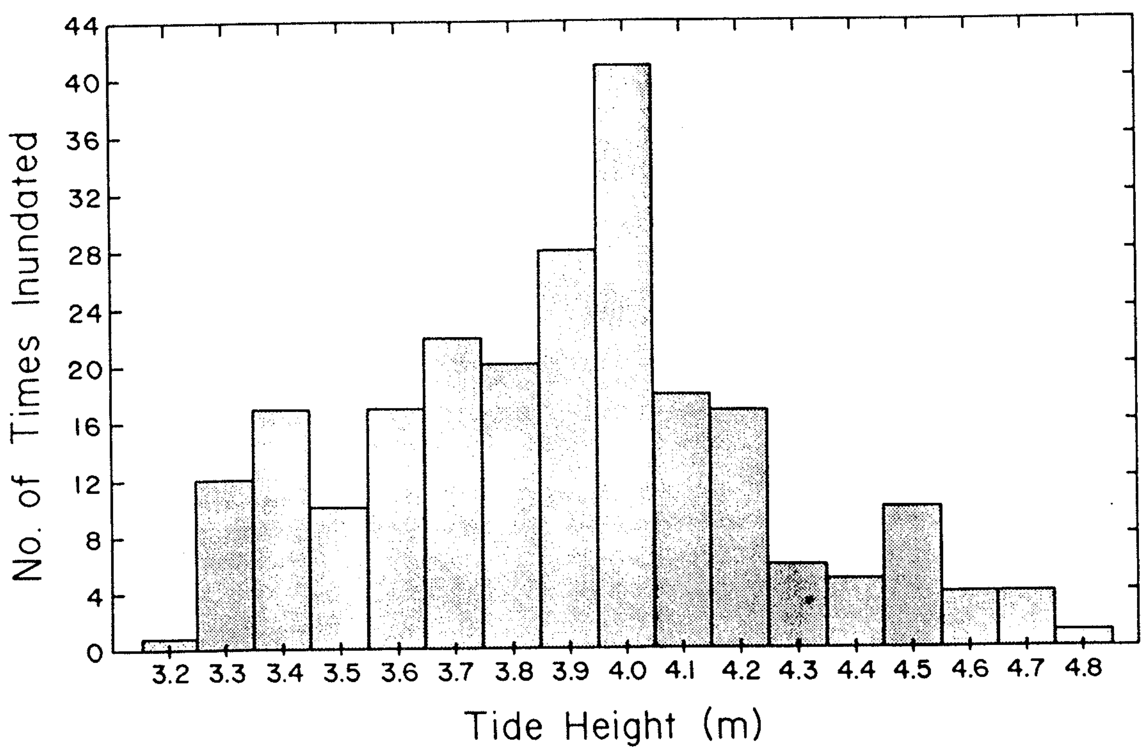
5.2.1.1 Tidal inundation

Examination of the distribution of high tides during the growing season showed that median and mean high tide height were identical (4.0m) in 1983 and 1984. The lowest high tide (LHT) reached 3.2m(asl) and the extreme high tide (EHT) 4.8m(asl)(Figure 12).

The tides at Churchill are semi-diurnal. For each month there was a 14.5 day cycle of spring (high) and neap (low) tides (Figure 13). The spring tides rise higher and fall lower, than neap tides. Tides were in the neap phase at the commencement of the growing seasons in both 1983 and 1984. In 1984 there was a 20 day delay in the upswing of the tidal cycle (Figure 13).

Figure 14 illustrates the percent of times a specific elevation was inundated at high tide during June through September 1984 at each of the three tidal sites. The mean high tide (MHT) occurred at a different relative elevation at each site, partly due to a lag up the estuary and partly due to selection of arbitrary datum points. At Sandspit, MHT occurred at 1.0m, Akudlik at 1.15m and Esker at 1.5m, the highest elevation of the transect. This height variation led to a difference in the extent and duration of inundation at each of the three transects. At the three tidal sites (Sandspit, Akudlik and Esker), the epilittoral zone was subjected to flooding during spring tides. Tidal inundation occurred from 1% to 11% of the time (1-24 times) during the

Figure 12: Number of times an elevation was inundated at the Port of Churchill during the 1984 growing season.



No. of Times Inundated
0
4
8
12
16
20
24
28
32
36
40
44
3.2
3.3
3.4
3.5
3.6
3.7
3.8
3.9
4.0
4.1
4.2
4.3
4.4
4.5
4.6
4.7
4.8
Tide Height (m)

Figure 13: Variation in maximum daily tide heights at the Port of Churchill, during the 1983 and 1984 growing seasons.

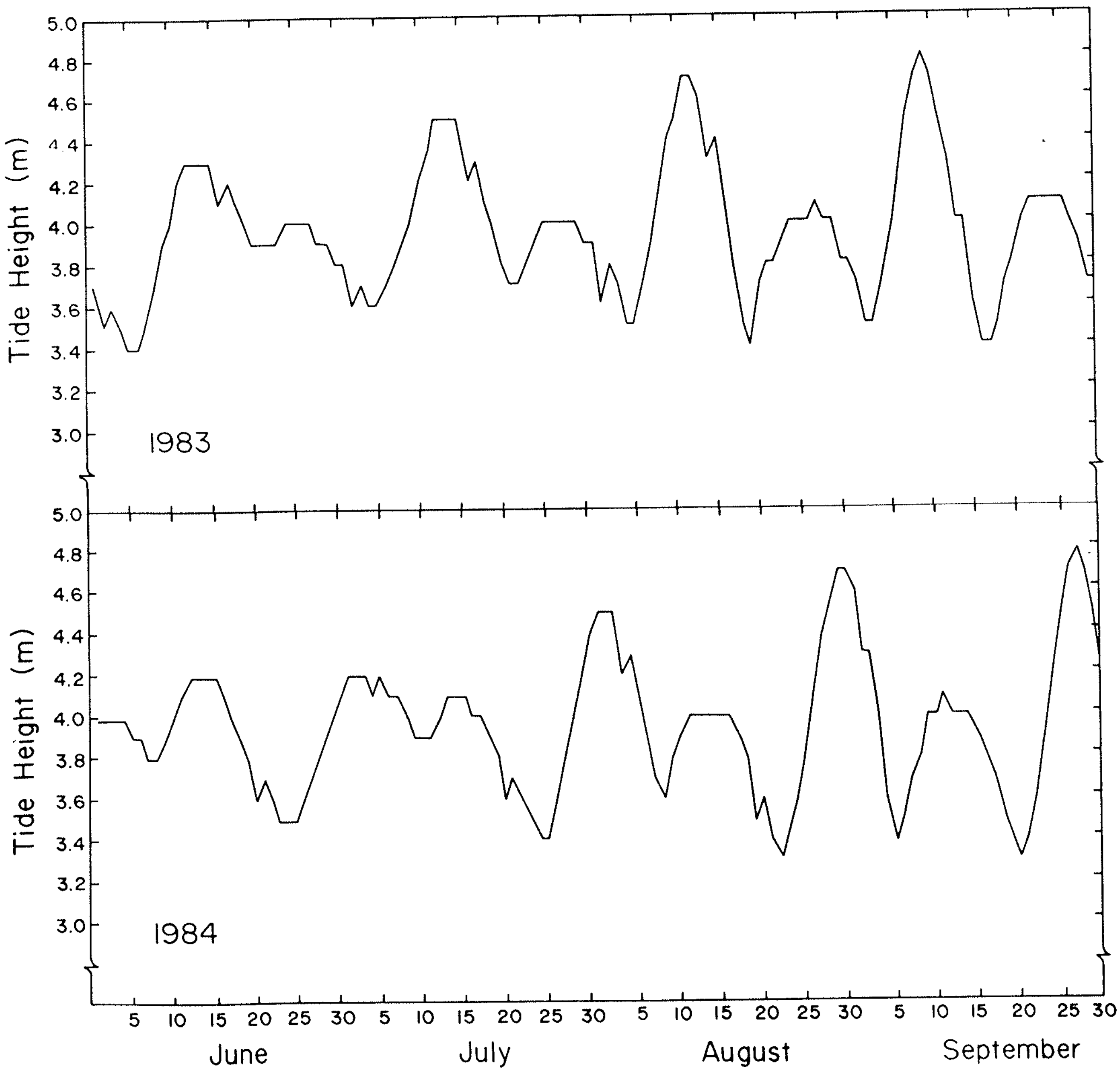
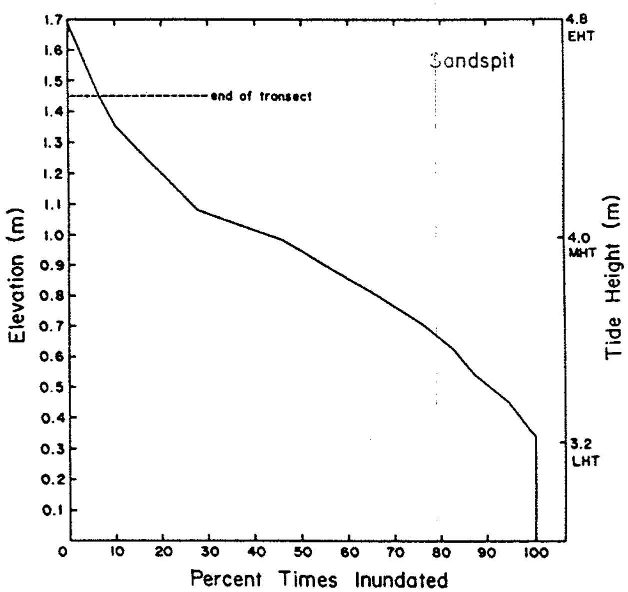
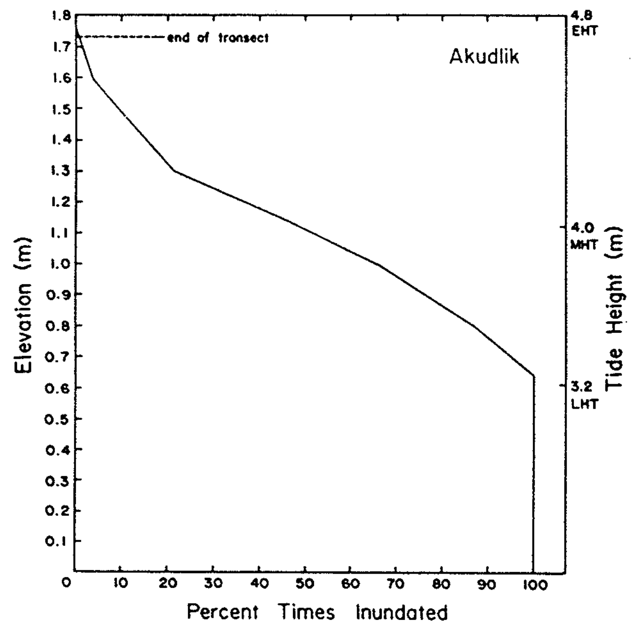

Tide Height (m)
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
1983
1984
5 10 15 20 25 30 5 10 15 20 25 30 5 10 15 20 25 30 5 10 15 20 25 30
June
July
August
September

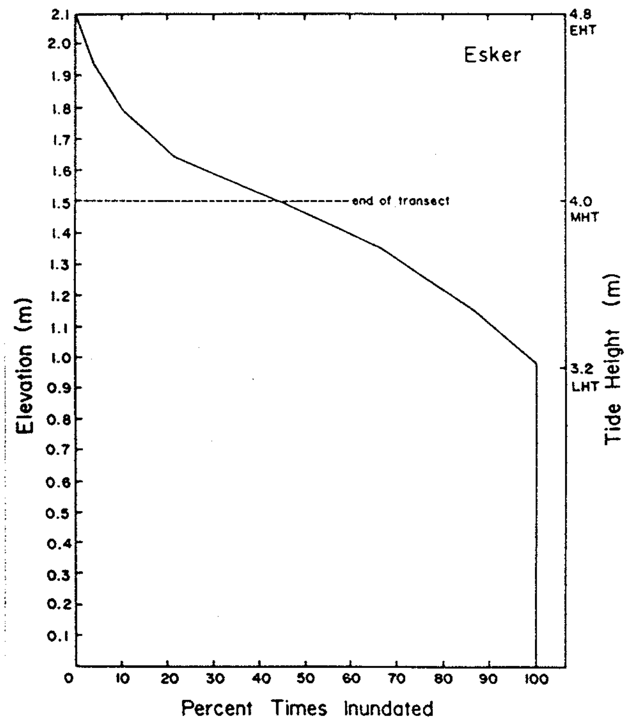
Figure 14: Inundation profiles of tidal sites. Percent times a specific elevation along a transect was inundated at high tide during the 1984 growing season (100% = 236 times inundated).



Sandspit
end of transect
Elevation (m)
Tide Height (m)
4.8 EHT
4.0 MHT
3.2 LHT
Percent Times Inundated



Akudlik
end of transect
Elevation (m)
Tide Height (m)
4.8 EHT
4.0 MHT
3.2 LHT
Percent Times Inundated



Esker
end of transect
Elevation (m)
Tide Height (m)
4.8 EHT
4.0 MHT
3.2 LHT
Percent Times Inundated

1984 growing season. The upper geolittoral zone was flooded 12% to 44% of the time (25-94 times). The mid geolittoral zone had more and longer periods of flooding than those of the upper geolittoral zone 45% to 99% of the time (95-237 times). The lower geolittoral zone was flooded twice a day (236 times) by tides and submergence was as long as 15 hours a day at the lowest fringe of this zone.

5.2.2 Water quality

5.2.2.1 Tidal water

In both years, the highest mean water salinities (15.9 and 16.6 ppt in 1983 and 1984 respectively) were measured at Sandspit and decreased up the river, with Pumphouse having the lowest mean salinities (0.69 and 0.41ppt in 1983 and 1984 respectively, Table 13). The salinity ordering of sites was Sandspit > Akudlik > Esker > Pumphouse. There was a relationship between distance upriver and water salinity (Jonckheere's test, $p<0.0001$) with Sandspit highest and Pumphouse lowest. Mean values for the three tidal sites were higher in 1984 than in 1983. In addition, the minimum and maximum observed salinities were higher in 1984 in all cases but one. The summer of 1984 was dry (Table 4), with 135.5mm of precipitation recorded from June to September compared with 229.5mm in 1983 for the same period (a decrease of 41%). The reduced river flow in 1984 resulted in an increase of 67% in mean salinity at Akudlik and 196% at Esker (Table 13).

TABLE 13

Tidal water salinities for the four transects (ppt)

collected during the field seasons of: (1) 1983
(2) 1984

Site		No. of samples	Mean	Standard error	Minimum	Maximum
Sandspit	(1)	31	15.86	1.4	4.20	28.10
	(2)	80	16.60	0.4	11.30	23.00
Akudlik	(1)	40	8.98	0.8	0.00	19.50
	(2)	115	14.93	0.3	6.90	25.20
Esker	(1)	40	3.62	0.6	0.00	12.50
	(2)	102	10.73	0.3	3.00	18.20
Pumphouse	(1)	30	0.69	0.1	0.00	2.40
*	(2)	57	0.41	0.1	0.00	2.20

* non-tidal

Mean salinities at Akudlik and Esker at a specific date were correlated with tide heights ($r=0.71$, $p<0.02$; $r=0.66$, $p<0.05$ respectively).

As expected, water conductivity trends were similar to those for salinity, with corresponding values being highly correlated ($r=0.98$, $p<0.0001$). The highest conductivities were measured at Sandspit and the lowest at Pumphouse (Table 14).

In both years, the lowest mean water pH was measured at Akudlik (Table 15), and the highest at Pumphouse. At all the sites pH values were higher in 1984 than in 1983. Mini-

TABLE 14

Tidal water conductivities for the four transects (dS m^{-1})

collected during the field seasons of: (1) 1983
(2) 1984

Site		No. of samples	Mean	Standard error	Minimum	Maximum
Sandspit	(1)	31	20.8	1.6	6.4	34.7
	(2)	80	23.8	0.5	16.0	34.7
Akudlik	(1)	40	13.4	1.1	3.6	26.2
	(2)	115	21.4	0.3	11.0	32.9
Esker	(1)	40	5.5	0.8	0.8	16.2
	(2)	102	16.6	0.5	4.8	27.1
Pumphouse	(1)	30	1.8	0.2	1.0	4.2
*	(2)	57	1.1	0.2	0.1	5.6

* non-tidal

mum values were lower in 1984 for Sandspit and Akudlik but were higher for Esker and Pumphouse. Maximum values were higher in 1984 for all the sites. The pH values were negatively correlated with salinity ($r=-0.68$, $p<0.0001$).

5.2.2.2 Interstitial water

Interstitial water salinity and conductivity trends were similar to those of tidal water (Tables 13 & 14) with the highest mean values at Sandspit and the lowest mean values at Pumphouse (Table 16). Minima and maxima reflected the same trends. The conductivity ordering of sites was Sandspit > Akudlik > Esker > Pumphouse. There was a relation-

TABLE 15

Tidal water pH for the four transects

collected during the field seasons of: (1) 1983
(2) 1984

Site		No. of samples	Mean	Standard error	Minimum	Maximum
Sandspit	(1)	31	7.71	0.03	7.36	8.25
	(2)	79	7.72	0.05	6.70	9.20
Akudlik	(1)	40	7.58	0.05	6.99	8.23
	(2)	115	7.70	0.03	6.79	8.60
Esker	(1)	40	7.84	0.06	7.12	8.50
	(2)	101	8.21	0.04	7.20	9.20
Pumphouse	(1)	30	8.13	0.05	7.10	8.32
*	(2)	56	9.07	0.09	7.35	10.08

* non-tidal

ship between distance upriver and interstitial water salinity (Jonckheere's test, $p<0.0001$). The greatest interstitial water salinity (24ppt) was recorded at Sandspit in saltpan areas devoid of vegetation. At Akudlik, salinity increased from the epilittoral to the lower geolittoral zone ($r=-0.69$, $p<0.0001$).

Mean and minimum interstitial water pH values for the four sites were almost the same (Table 16) but the maximum values showed a decreasing trend from Sandspit to Pumphouse.

TABLE 16

Interstitial water chemistry for the four transects

Site	No. of samples	Mean	Standard error	Minimum	Maximum
Salinity (ppt)					
Sandspit	135	15.8	0.2	9.9	23.9
Akudlik	112	12.4	0.3	7.0	21.1
Esker	108	7.6	0.3	2.0	14.7
Pumphouse	14	5.5	1.1	0.2	9.9
Conductivity (dS m^{-1})					
Sandspit	135	22.7	0.3	14.5	31.9
Akudlik	112	18.6	0.4	10.1	34.1
Esker	108	12.2	0.5	3.2	23.4
Pumphouse	14	8.8	1.7	0.6	18.9
pH					
Sandspit	137	7.2	0.03	6.7	8.6
Akudlik	113	7.1	0.03	6.6	8.0
Esker	109	7.1	0.03	6.4	8.1
Pumphouse	14	7.1	0.08	6.5	7.5

5.2.3 Soil

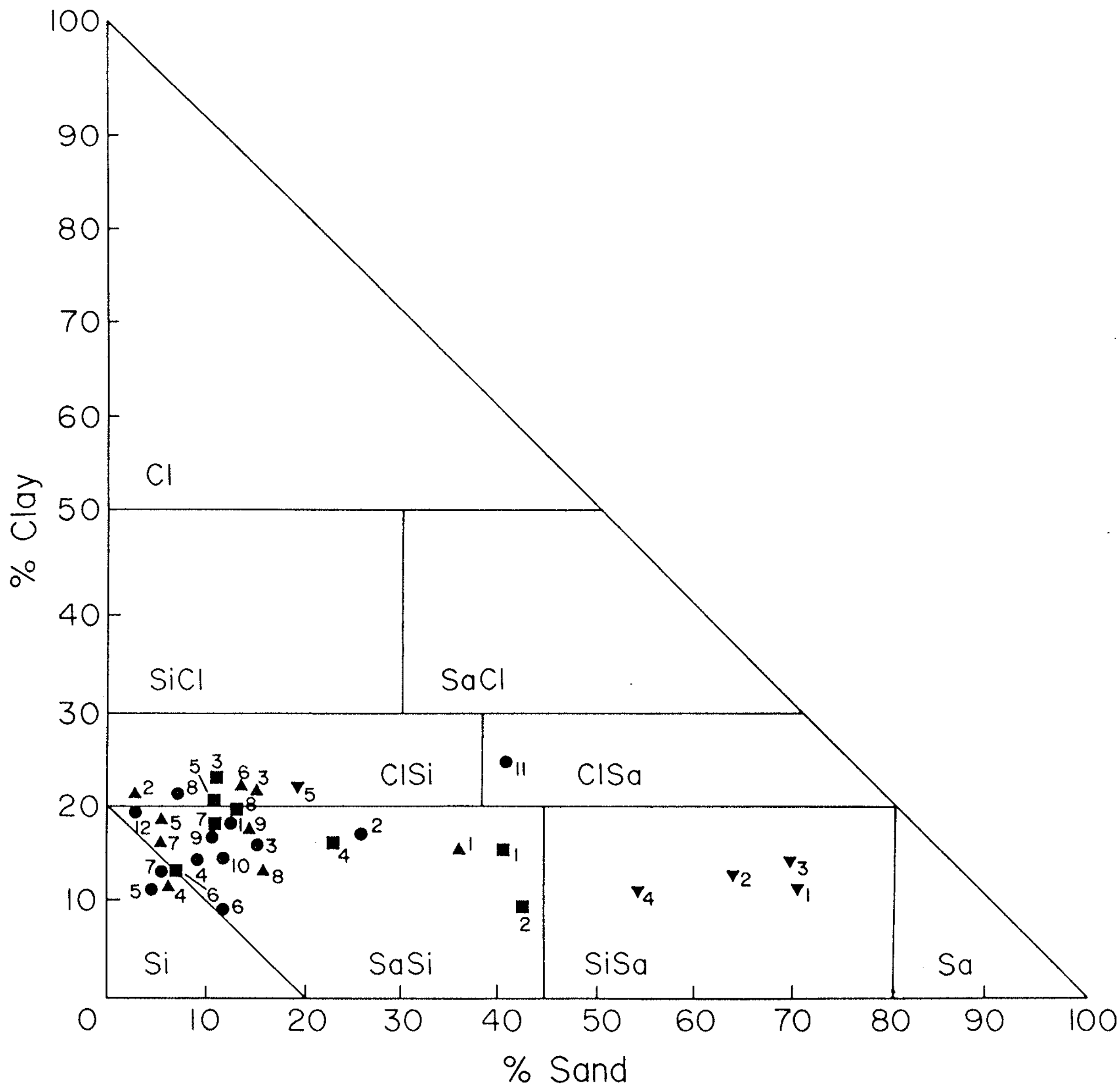
5.2.3.1 Physical parameters

The proportions of sand, silt and clay in sampled soils ranged from 3-71%, 16-83%, and 10-26% respectively. Soil textures varied with distance upstream and up the shore from the river. Sandspit, Akudlik and Esker had similar mean percentages for sand, silt and clay, while Pumphouse had a mean value for sand greater than 50% (Table 17) and a concomitant lower value for silt. The soil texture of the upper portions of all the four transects and the lower portion of Sandspit was within the silt, sandy silt and clay silt (silty loam) texture classes (Figure 15). The lower portions of Esker and Akudlik transects fell close to the silty sand (sandy loam) division, while the lower portion of Pumphouse fell within the silty sand category. There was a negative correlation between sand and silt ($r=-0.88$, $p<0.0001$ pooled site data, Table 18).

Elevation could not be included in texture comparisons between transects as it was not a standard variable with a known datum point. It could therefore only be used for within-transect comparisons. Negative correlations were found between sand and elevation along three transects (Akudlik $r=-0.69$, Esker $r=-0.59$, Pumphouse $r=-0.77$; all $p<0.0001$). In the epilittoral zone, sedimentation would be limited to the spring and fall seasons. In the spring, high river levels from spring discharge and in the fall storm surges drive tidal waters into the higher areas and suspended materials are trapped by the vegetation. Sands are often deposited in channel beds, while finer sediments in the geolittoral zone may be resuspended by wave action.

There was a decrease in percent organic matter (OM%) up river; Sandspit had a mean value of 9.0% and Pumphouse had a mean value of 3.2% (Table 17). A landward increase in average OM% was noted which was significantly correlated with

Figure 15: Soil texture of total soil data matrix. Numbers in sequence progress from the hydrolittoral to the epilittoral zones.
(●)-Sandspit (▲)-Akudlik (■)-Esker
(▼)-Pumphouse. (Sa)-Sand (Si)-Silt (Cl)-Clay.
Soil texture categories according to Eilers (1975).



% Clay
% Sand
Cl
SiCl
SaCl
ClSi
ClSa
Si
SaSi
SiSa
Sa
0
10
20
30
40
50
60
70
80
90
100

TABLE 17

Soil parameter means, standard errors and ranges

(in parentheses) for the four transects.
Data collected during the 1983 growing season.

Number of species	Sandspit (37)	Akudlik (27)	Esker (24)	Pumphouse (15)
Sand (%)	12.2±1.2 (3 - 26)	13.4±1.8 (2 - 39)	19.0±1.8 (7 - 40)	57.7±3.7 (21 - 71)
Silt (%)	70.8±1.2 (49 - 83)	67.9±2.3 (46 - 81)	62.7±2.3 (44 - 79)	27.9±3.4 (16 - 56)
Clay (%)	16.9±1.3 (10 - 26)	18.7±1.7 (13 - 24)	18.3±1.5 (13 - 24)	14.4±1.4 (10 - 22)
Organic matter (%)	9.0±0.7 (4 - 16)	8.4±0.7 (3 - 14)	5.5±0.3 (3 - 7)	3.2±1.0 (1 - 9)
pH	7.3±0.03 (7.2 - 7.6)	7.3±0.03 (7.2 - 7.4)	7.4±0.03 (7.3 - 7.5)	7.5±0.0 (7.3 - 7.7)
Salinity (ppt)	3.9±0.3 (0.7 - 6)	3.9±0.1 (3.0 - 5)	0.9±0.1 (0.5 - 1.5)	0.7±0.3 (0 - 3.5)
Conductivity (dS m^{-1})	16.4±1.0 (9 - 22)	12.0±0.5 (9 - 15)	4.1±0.3 (4 - 5)	3.1±1.3 (1 - 12)
Sodium (ppm)	2893±164 (1395-4000)	2169±79 (1608-2493)	658±44 (429-839)	590±258 (15-2085)
Calcium (ppm)	359±53 (59 - 717)	129±8 (79 - 188)	98±8 (67 - 132)	188±50 (63 - 483)
Magnesium (ppm)	418±33 (149 - 606)	286±16 (171 - 383)	116±7 (94 - 147)	117±37 (28 - 353)
Exchangeable Sodium (%)	69±1.1 (64 - 74)	69±0.8 (63 - 72)	47±1.2 (41 - 55)	21±6.3 (1 - 59)
Sodium Absorbtion Ratio	158±5.3 (132 - 200)	154±5.0 (120 - 177)	64±3.2 (49 - 85)	31±11 (2 - 100)
Potassium (ppm)	504±17 (313 - 657)	398±18 (243 - 500)	190±9 (121 - 261)	64±9 (40 - 144)
Nitrogen (ppm)	2.6±0.5 (1 - 7)	4.0±0.6 (2 - 8)	4.2±0.4 (2 - 5)	5.8±2.1 (1 - 17)

Table 17 cont.

	Sandspit	Akudlik	Esker	Pumphouse
Phosphorus (ppm)	189.9±1.1 (6 - 46)	21.1±1.3 (7 - 59)	17.3±0.9 (5 - 32)	9.4±1 (4 - 26)

elevation (Sandspit r=0.77, Akudlik r=0.58, Esker r=0.72, p<0.0001 and Pumphouse r=0.70, p<0.0025). Sand content was negatively correlated with OM% (r=-0.69, p<0.0001).

5.2.3.2 Chemistry

Soil pH values ranged from 7.2 to 7.7 with mean pH values for each transect ranging from 7.3 to 7.5 (Table 17).

Soil salinity and conductivity were highly variable between and along transects. Soil salinity was highest at Sandspit with 3.9ppt and lowest at Pumphouse with 0.7ppt. Mean soil salinity trends were the same as the tidal and interstitial water salinity trends, in which values decreased with location up river (Table 17).

Concentrations of sodium, calcium, magnesium, exchangeable sodium percentage (ESP) and potassium, all decreased with position upstream (Table 17). Nitrogen levels increased upstream, while phosphorus levels showed no trend (Table 17). Sodium, calcium, and magnesium were highly intercorrelated (Table 18). ESP was highly correlated with

TABLE 18

Correlation matrix of environmental parameters

Correlation matrix of environmental parameters

	%SAND	%SILT	%CLAY	O.M.	pH	SALT	COND	Na	Ca	Mg	ESP	K	N	P
% SAND	-	-0.88	-0.17	-0.69	0.33	-0.36	-0.36	-0.42	-0.07	-0.34	-0.59	-0.67	-0.14	-0.46
% SILT	-	-	-0.32	0.59	-0.28	0.33	0.35	0.39	0.08	0.34	0.53	0.62	0.03	0.40
% CLAY	-	-	-	0.12	-0.06	0.02	-0.02	-0.02	-0.03	-0.03	0.01	0.04	0.22	0.09
% O.M.	-	-	-	-	-0.18	0.33	0.30	0.33	0.01	0.30	0.40	0.76	0.22	0.56
pH	-	-	-	-	-	-0.37	-0.35	-0.55	-0.34	-0.59	-0.58	-0.30	0.14	-0.06
SALT	-	-	-	-	-	-	0.98	0.96	0.52	0.73	0.63	0.59	-0.30	0.17
COND	-	-	-	-	-	-	-	0.95	0.52	0.73	0.65	0.56	-0.26	0.14
Na	-	-	-	-	-	-	-	-	0.66	0.91	0.78	0.66	-0.27	0.15
Ca	-	-	-	-	-	-	-	-	-	0.83	0.24	0.23	-0.25	-0.18
Mg	-	-	-	-	-	-	-	-	-	-	0.58	0.59	-0.30	0.02
ESP	-	-	-	-	-	-	-	-	-	-	-	0.67	-0.25	0.34
K	-	-	-	-	-	-	-	-	-	-	-	-	-0.10	0.60
N	-	-	-	-	-	-	-	-	-	-	-	-	-	0.13
P	-	-	-	-	-	-	-	-	-	-	-	-	-	-

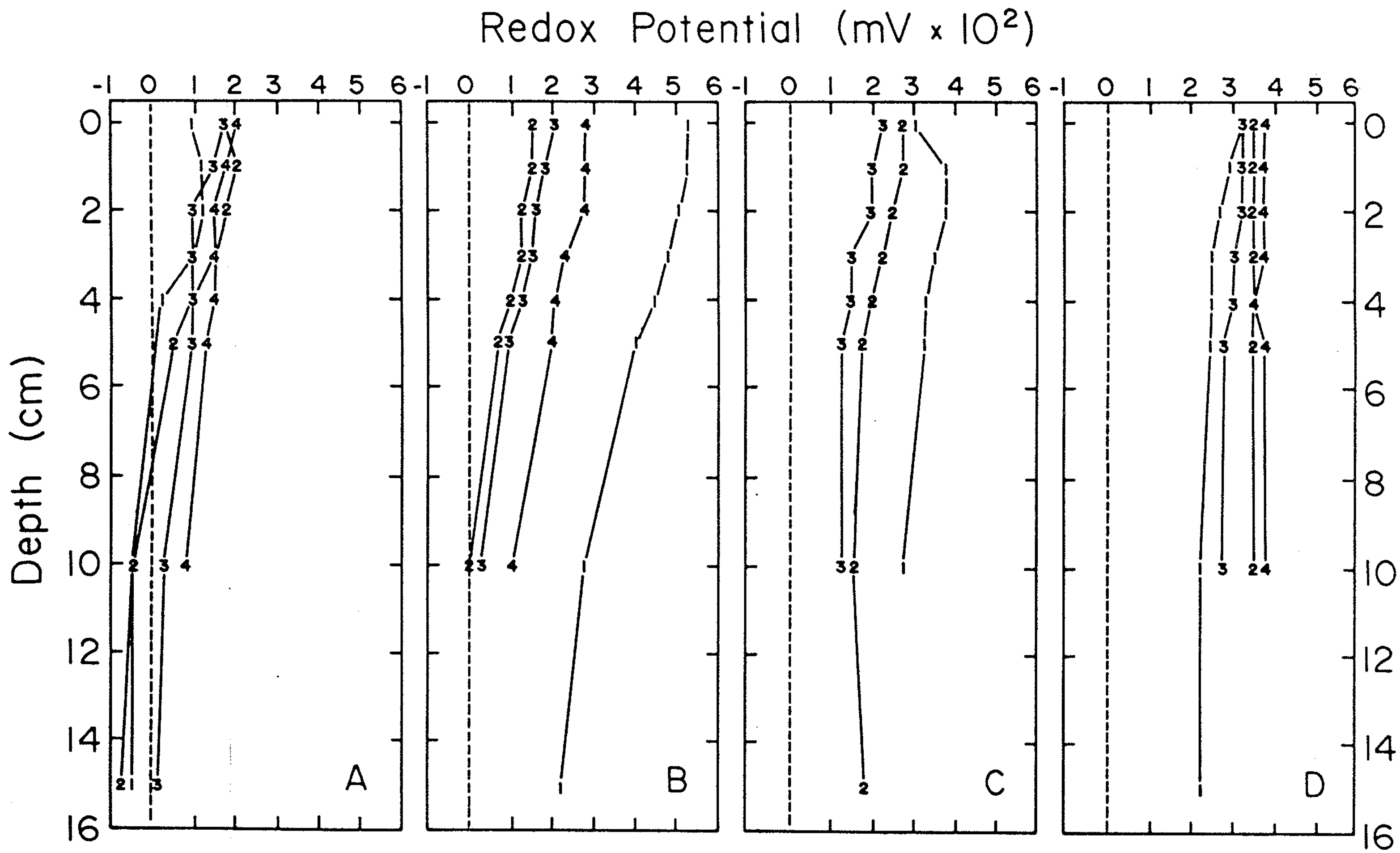
Mg, Na and K, and K was correlated with Na. Overall ESP values ranged from 1 to 74. Mean transect ESP values decreased from Sandspit (69) to Pumphouse (21)(Table 17).

5.2.3.3 Redox potential

Areas of anoxic sediments (low soil redox potential) had a disjunct distribution and appeared in the mid geolittoral to epilittoral zones throughout the three tidal sites. They bore no vegetation, were black, 2 to 5mm below the soil surface, and released hydrogen sulfide with soil disturbance. These areas were usually found in unconsolidated sediments.

Redox potential values were variable in the study and the author suggests that subsequent determination of redox potential may be omitted. Redox potential, although variable showed some site and seasonal differences (Figure 16). At Sandpit (A) the first sampling date (first week of July) had the lowest redox potential with a slight increase throughout the season. Values were highest on the first sampling date at Akudlik (B) and Esker (C) with the second (first week of August) and third (last week of August) sampling dates being similar. At Akudlik, the fourth sampling date (last week of September), mean redox potential values were between those of the first and third sampling dates. Pumphouse (D) had the lowest redox potential on the first sampling date, with the second, third and fourth sampling dates being fairly similar.

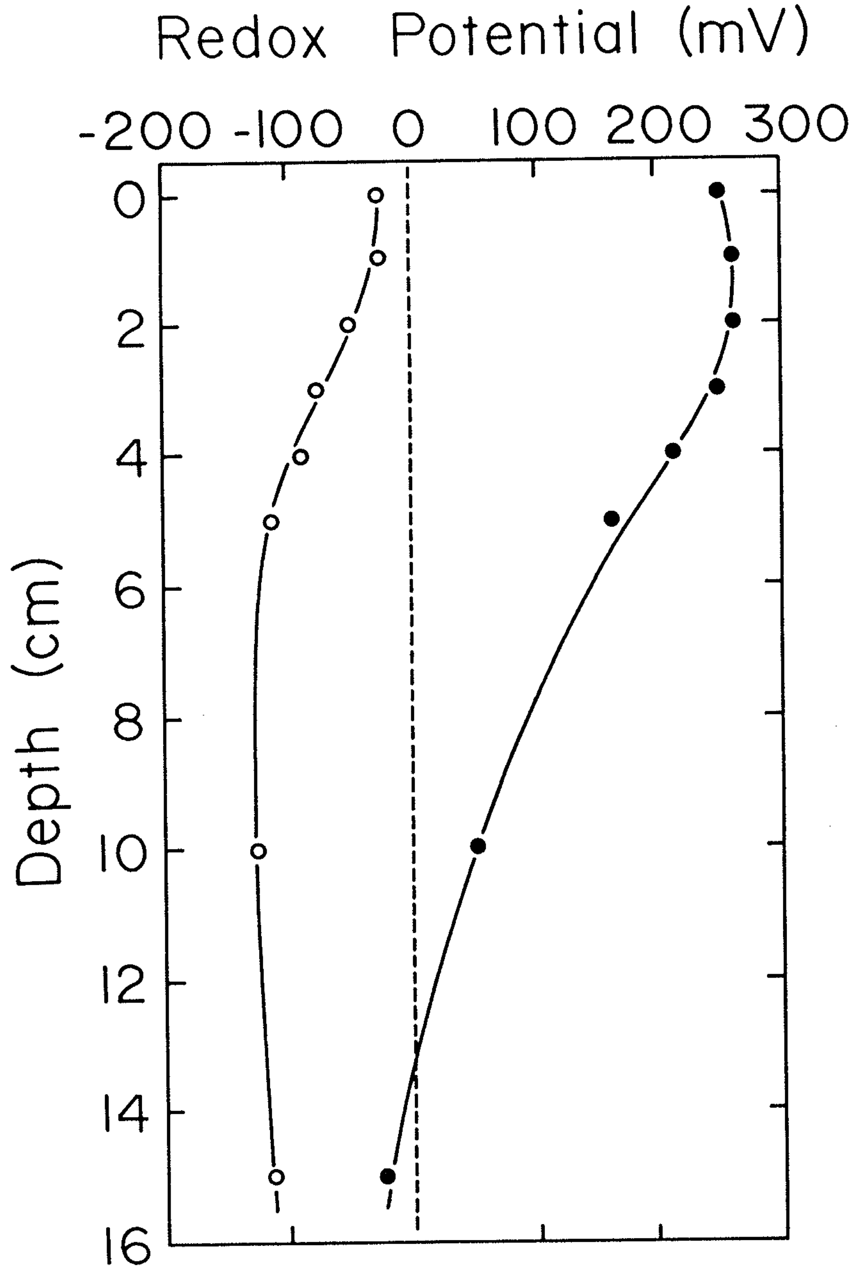
Figure 16: Mean soil redox potential at specific depths and sampling dates. (A)-Sandspit (B)-Akudlik (C)-Esker (D)-Pumphouse. (1)-First week of July (2)-First week of August (3)-Last week of August (4)-Last week of September.



Redox Potential (mV x 10²)
-1 0 1 2 3 4 5 6
Depth (cm)
0
2
4
6
8
10
12
14
16
A
B
C
D

Of the four transects, soils at Sandspit had the lowest mean redox potentials, while those at Pumphouse were the highest. Akudlik and Esker soils had similar redox potentials (Figure 16). At the three tidal sites (A, B & C) redox potentials were higher in the root zone (0-5cm) than below it (10+cm)(Figure 16). At Pumphouse (D) the redox potential remained almost constant throughout the 15cm soil depth profile. At Sandspit, the redox potential was higher in vegetated than unvegetated sediments (Figure 17). The difference between the vegetated and unvegetated sediments decreased from 300mV at 0-5cm to 90mV at 15cm below the surface.

Figure 17: Mean soil redox potentials at Sandspit in vegetated and unvegetated areas.
(●)-vegetated (o)-unvegetated


Redox Potential (mV)
-200 -100 0 100 200 300
Depth (cm)
0
2
4
6
8
10
12
14
16

5.3 VEGETATION AND ENVIRONMENTAL PARAMETER INTERACTIONS

5.3.1 Principal components analysis of soil data

The principal component analysis (PCA) of the soil data correlation matrix for all four transects results in the loading of 12 environmental variables on 12 components, of which the two with the highest eigenvalues are examined (Table 19).

TABLE 19

Principal components analysis of soil data

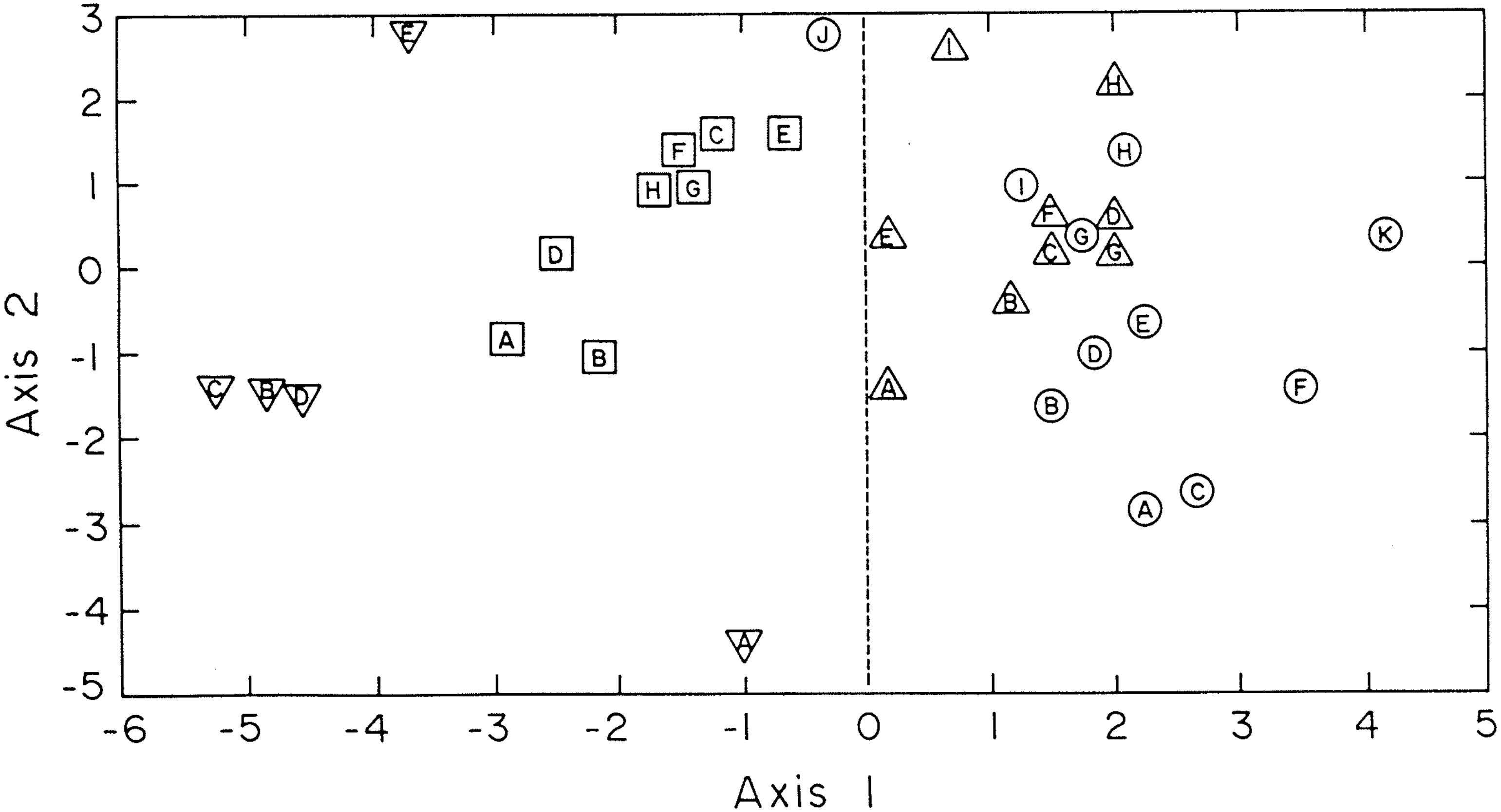
Environmental variables	Eigenvectors Component 1	Component 2	
SAND%	-0.29	-0.33	
CLAY%	0.07	0.39	
OM%	0.25	0.38	
pH	-0.32	0.09	
SALT	0.35	-0.15	
Na	0.37	-0.17	
Ca	0.21	-0.38	
Mg	0.36	-0.24	
ESP	0.36	0.01	
P	0.20	0.40	
N	-0.12	0.39	
K	0.36	0.16	
Eigenvalue	6.08	2.82	Total
% variance explained	51	23	74

These two components explain 74% of the total variance, while the subsequent ten components contribute 26%, with a substantial decrease with each consecutive component (max=8%). Loadings of each variable on each eigenvector reflect a measure of the degree to which the derived component represents that variable (Gittins 1969).

The first component accounts for 51% of the total variance. Salinity, Na, Mg, ESP, and K showed the highest positive loadings, while pH showed a high negative loading on the first axis. The first axis is therefore considered a measure of salinity. A PCA scatter plot (Figure 18) is divided into positive and negative quadrants for each axis and shows that Sandspit and Akudlik soils are weighted positively on axis 1. Their interspersion is expected on the basis of similar soil salinity values (Table 17). The orientation of Esker and Pumphouse data, which is increasingly negative on the plot, is related to their lower salinity.

Component 2 accounts for a further 23% of the total variance. CLAY%, OM%, N and P show high positive loadings, while SAND% and Ca show high negative loadings on the second axis. This component measures the nutrient and physical properties (texture and organic matter) of the soil. The physical properties have previously been shown to be highly correlated with elevation. This is also indicated by the ordination scattergram, with low elevations (A through D) of all the transects being below zero on axis 2. Samples from the upper geolittoral and epilittoral zones (E through J) are located above zero.

Figure 18: Principal components analysis of soil data. Letters in sequence progress from the hydrolittoral to the epilittoral zones. (o)-Sandspit (Δ)-Akudlik (□)-Esker (▽)-Pumphouse.


Axis 1
Axis 2
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
A
B
C
D
E
F
G
H
I
J
K

The next step is to examine individual groups of the large heterogeneous data matrix. The soils are divided into three groups according to their PCA values along the first axis. Sandspit and Akudlik comprised one data group, Esker a second group and Pumphouse the third group.

TABLE 20

Principal components analysis of Sandspit and Akudlik soil data

Environmental variables	Eigenvectors Component 1	Component 2	
SAND%	-0.01	-0.41	
CLAY%	-0.26	-0.16	
OM%	0.21	0.49	
pH	-0.32	0.07	
SALT	0.30	0.01	
Na	0.42	0.16	
Ca	0.41	0.04	
Mg	0.45	0.17	
ESP	-0.07	0.19	
P	-0.30	0.35	
N	-0.24	0.04	
K	0.00	0.59	
Eigenvalue	4.08	2.58	Total
% variance explained	34	21	55

A second PCA was performed using only Sandspit and Akudlik data. The first two components of this analysis explain 55% of the variance with axis 1 accounting for 34% and axis 2 for 21% (Table 20). Salinity, Na, Ca, and Mg showed the highest positive loadings while pH and P showed high negative loadings on the first axis. Organic matter percentage, P and K showed high positive loadings while SAND% showed a high negative loading on axis 2. These two axes separate Sandspit and Akudlik soil properties effectively (Figure 19). Sandspit soils located in the lower and mid geolittoral zones are on the extreme right of the scatter plot. Adjacent to them are the Akudlik soils from the lower and mid geolittoral zones. The soils of the upper geolittoral and epilitorral zones of both transects are on the left of the scatter plot. Salinity is highest in the soils at lower elevations, increasingly inundated by saline tidal water.

The first two axes of the Esker data PCA explain 78% of the total variation (Table 21). The first axis explains 51% with OM%, P, N and K showing the highest positive loadings while SAND% and Ca show the highest negative loadings. The second axis explains 27% of the variation with salinity, Na, Mg, and ESP showing the highest positive loadings. Texture and nutrients (axis 1) are the main separating factors (Figure 20), and are apparently linked with the soils' proximity to the river. Soils of the lower geolittoral zone of the transect are on the left of axis 1 and soils of the mid geolittoral zone are on the right with the exception of (C).

The first axis of the Pumphouse PCA explains 67% of the total variance and the second explains 29% (Table 22). Sa-

Figure 19: Principal components analysis of Sandspit and Akudlik soil data. Letters in sequence progress from the hydrolittoral to the epilittoral zones. (o)-Sandspit (Δ)-Akudlik.

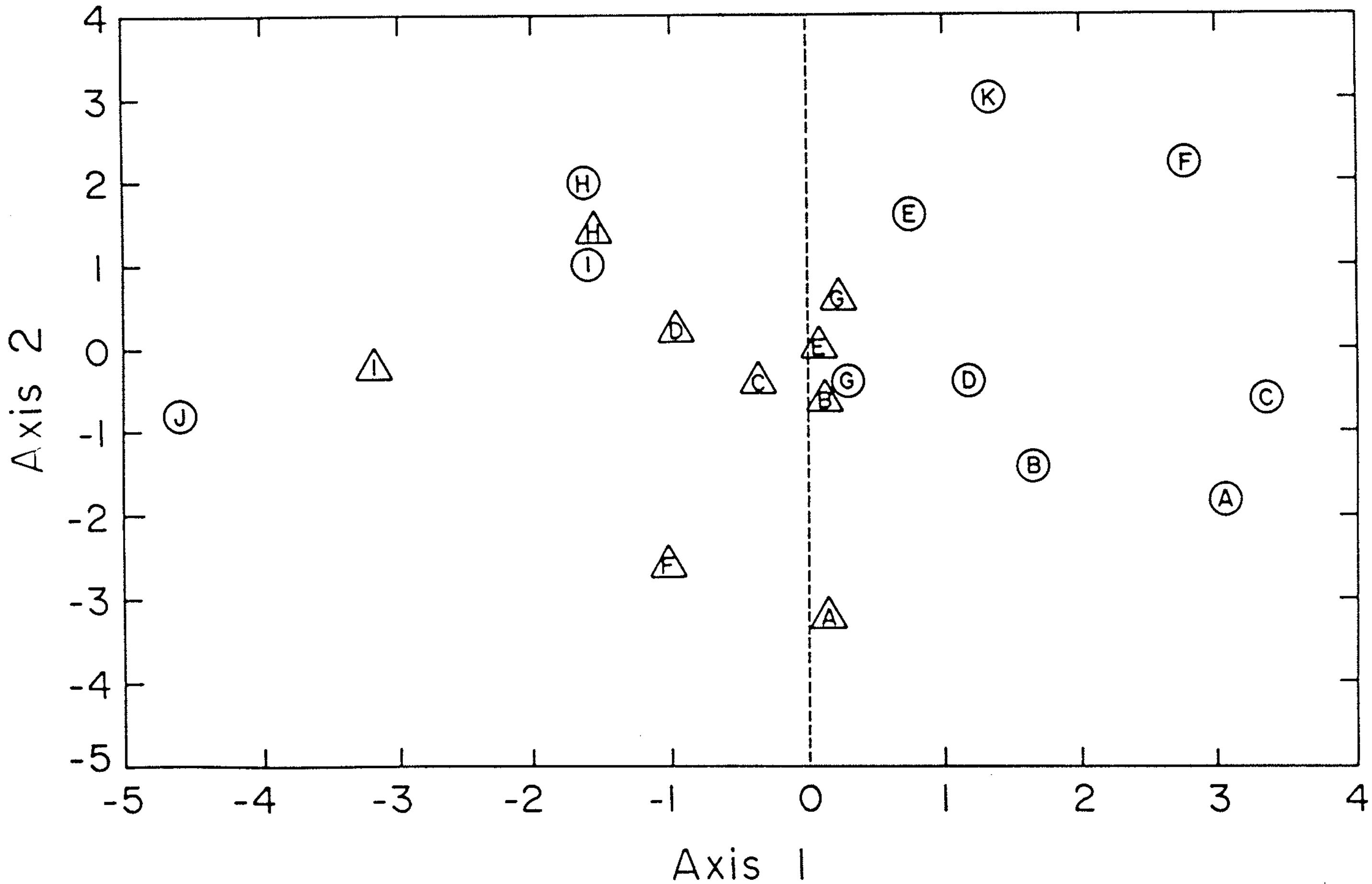

4
3
2
1
0
-1
-2
-3
-4
-5
Axis 2
-5
-4
-3
-2
-1
0
1
2
3
4
Axis 1
K
F
H
E
H
I
G
D
E
I
C
G
D
C
J
B
B
A
F
A

TABLE 21

Principal components analysis of Esker soil data

Environmental variables	Eigenvectors Component 1	Component 2	
SAND%	-0.40	0.05	
CLAY%	0.18	0.20	
OM%	0.39	0.05	
pH	-0.16	-0.27	
SALT	-0.04	0.48	
Na	0.13	0.46	
Ca	-0.33	0.29	
Mg	-0.13	0.50	
ESP	0.26	0.31	
P	0.37	0.04	
N	0.37	-0.11	
K	0.38	0.02	
Eigenvalue	6.07	3.26	Total
% variance explained	51	27	78

linity, Na, Mg and ESP show the highest positive loadings while CLAY%, P and N show the highest negative loadings on the first axis. Organic matter percentage, Ca, and K show high positive loadings while SAND% and pH show high negative loadings on the second axis. Soils of low elevations are on the right of the plot with soils of increasingly higher elevation upshore located to towards the left of the plot (Figure 21).

Figure 20: Principal components analysis of Esker soil data. Letters in sequence progress from the hydrolittoral to the epilittoral zones.

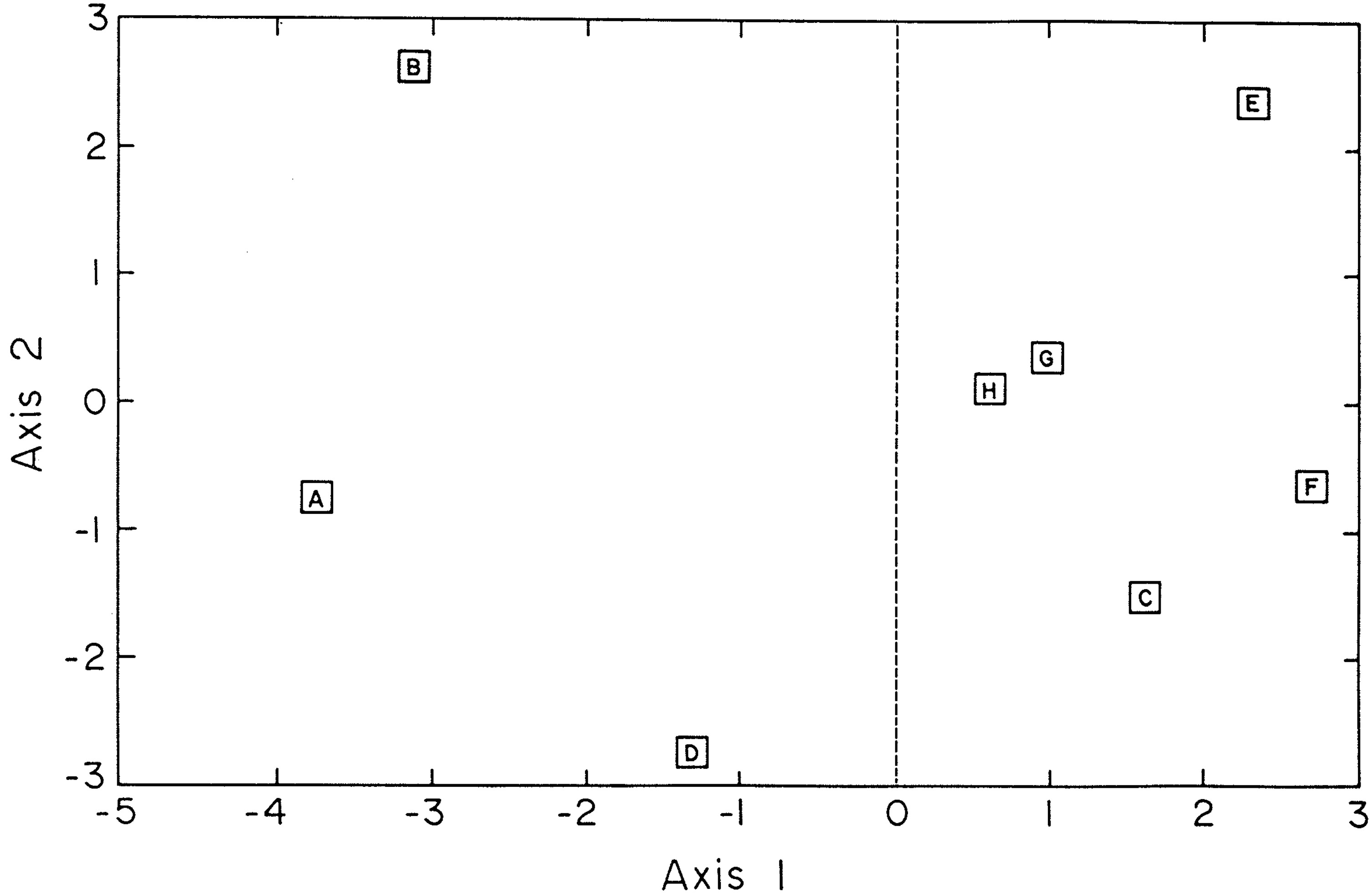

Axis 2
Axis 1
3
2
1
0
-1
-2
-3
-5
-4
-3
-2
-1
0
1
2
3
A
B
C
D
E
F
G
H

TABLE 22

Principal components analysis of Pumphouse soil data

Environmental variables	Eigenvectors Component 1	Component 2	
SAND%	0.27	-0.33	
CLAY%	-0.30	0.25	
OM%	-0.28	0.33	
pH	-0.18	-0.38	
SALT	0.30	0.29	
Na	0.30	0.28	
Ca	0.29	0.31	
Mg	0.30	0.29	
ESP	0.31	0.20	
P	-0.33	0.13	
N	-0.30	0.26	
K	-0.27	0.34	
Eigenvalue	8.06	3.44	Total
% variance explained	67	29	96

5.3.2 Detrended correspondence analysis of vegetation data

5.3.2.1 Site ordination (total vegetation matrix)

Ordination scatter plots of the four transects for 1983 and 1984 produce similar distributions (Figure 22). 1984 data are discussed since they are based on a larger sample size (131 elevation classes and 54 species).

There is a clear separation of elevation classes along DCA axis 1 with Sandspit and Akudlik on the left side of the plot, Esker classes in the middle and Pumphouse classes on the right side (Figure 22, 1984). The eigenvalues for the

Figure 21: Principal components analysis of Pumphouse soil data. Letters in sequence progress from the hydrolittoral to the epilittoral zones.

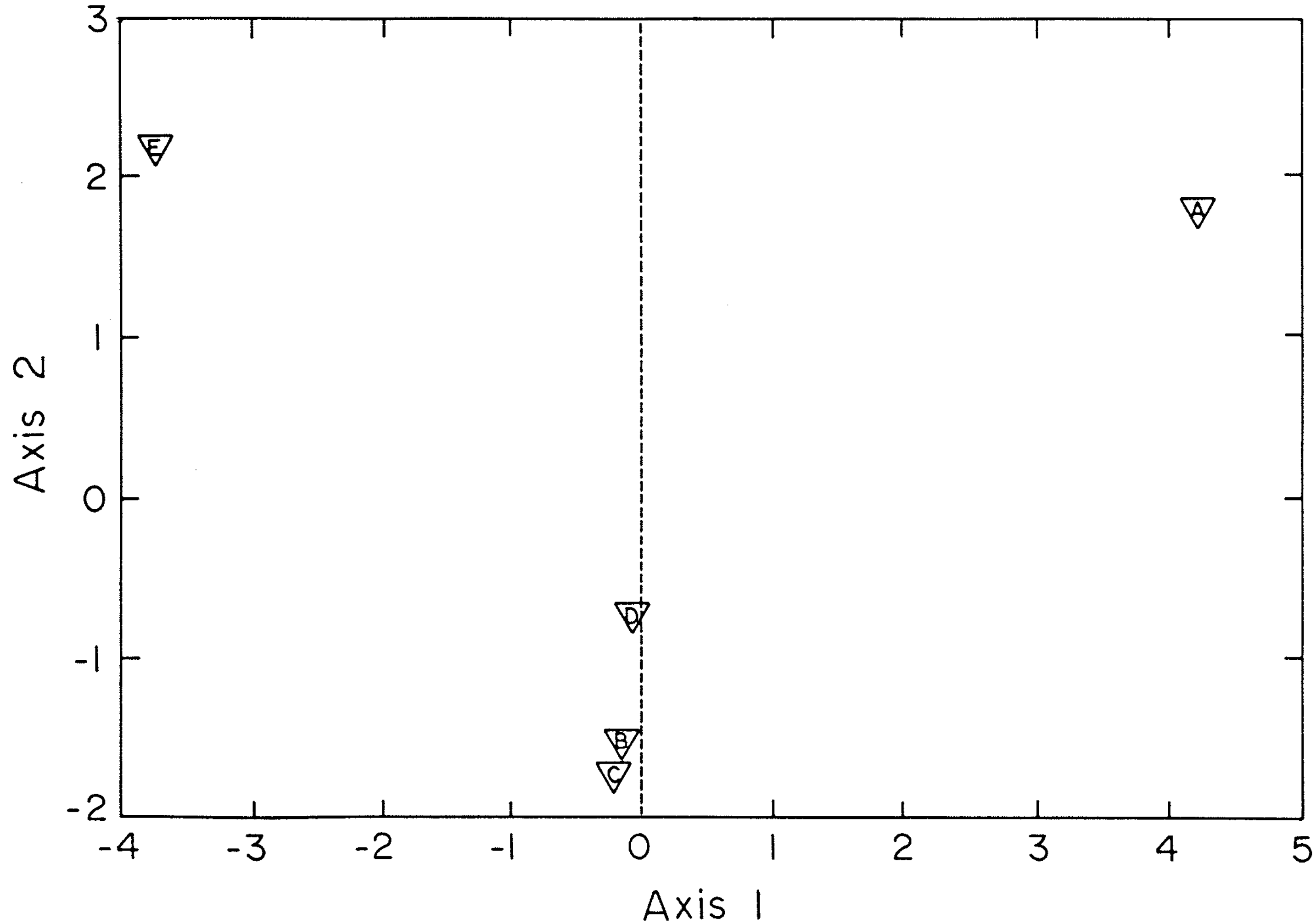
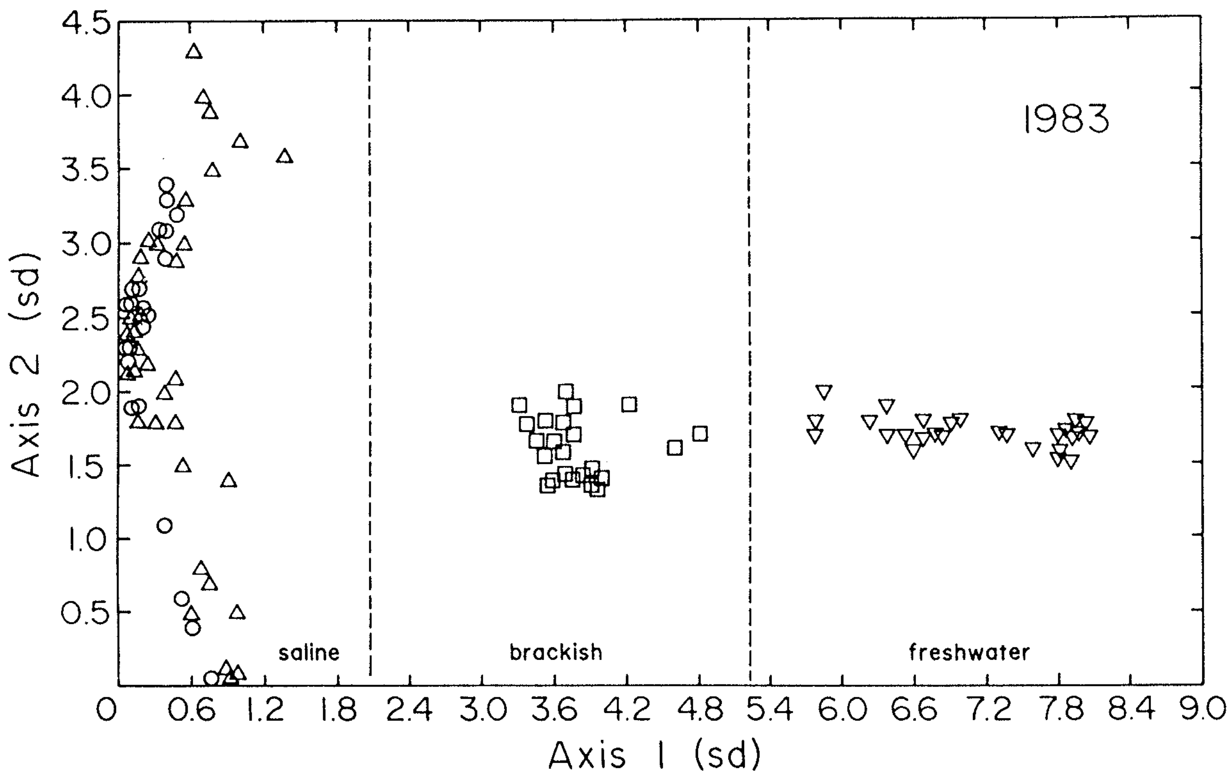
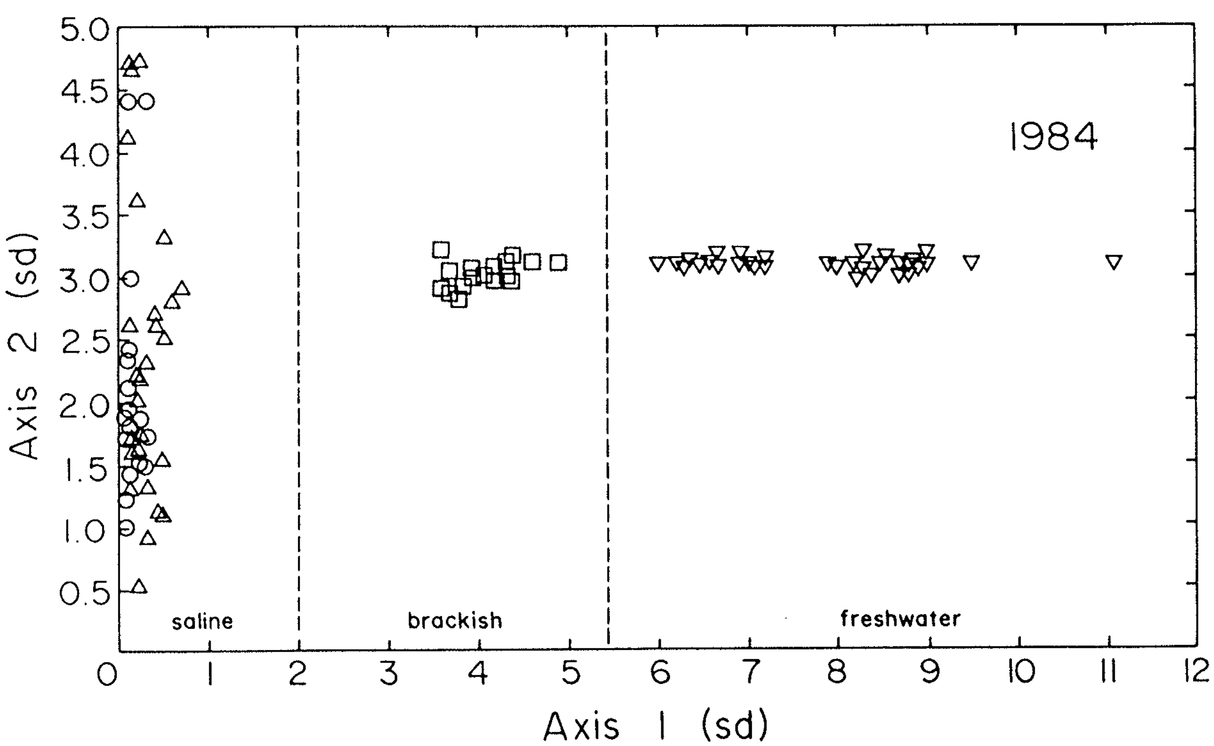

E
A
D
B
C
3
2
1
0
-1
-2
-4
-3
-2
-1
0
1
2
3
4
5
Axis 2
Axis 1

Figure 22: Detrended correspondence analysis of samples for 1983 and 1984. Axes are labeled in units of standard deviations (sd).
(o)-Sandspit (Δ)-Akudlik (□)-Esker
(▽)-Pumphouse


1983
saline
brackish
freshwater
Axis 2 (sd)
Axis 1 (sd)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
0.6
1.2
1.8
2.4
3.0
3.6
4.2
4.8
5.4
6.0
6.6
7.2
7.8
8.4
9.0


1984
saline
brackish
freshwater
Axis 2 (sd)
Axis 1 (sd)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
1
2
3
4
5
6
7
8
9
10
11
12

first two axes are 0.966 and 0.722 and explain 38% and 30% of the variation respectively.

Correlations of species composition of the elevation classes (ordination sample scores from axis 1, Figure 22, 1984) with the environmental parameters show that pH ($r=0.53$, $p<0.001$) is positively correlated with detrended correspondence analysis (DCA) axis 1 and Mg ($r=-0.64$, $p<0.0001$), salinity ($r=-69$, $p<0.0001$), Na ($r=-0.75$, $p<0.0001$), K ($r=-0.86$, $p<0.0001$), and ESP ($r=-0.88$, $p<0.0001$) are negatively correlated with the axis 1 scores. These are the same variables that have significant loadings on component 1 in the PCA of the total soil data matrix (Table 19). ESP has the highest correlation with the DCA axis 1 scores as it is a derived salinity value and incorporates Na, Mg, and Ca. Correlation of axis 1 of the vegetation DCA with axis 1 of the soil PCA shows that PCA axis 1 is similar to exchangeable sodium percentage in its ability to predict axis 1 of the DCA ($r=-0.87$, $p<0.0001$).

A stepwise regression of the six soil variables (pH, Mg, salinity, Na, K and ESP) and PCA axis 1 on DCA axis 1 shows that a multiple regression of K and ESP on DCA axis 1 significantly improves the predictive power over the use of ESP or PCA axis 1 alone. Detrended correspondence analysis axis 1 therefore represents a salinity gradient from saline samples on the left side of the axis to freshwater samples on the right side.

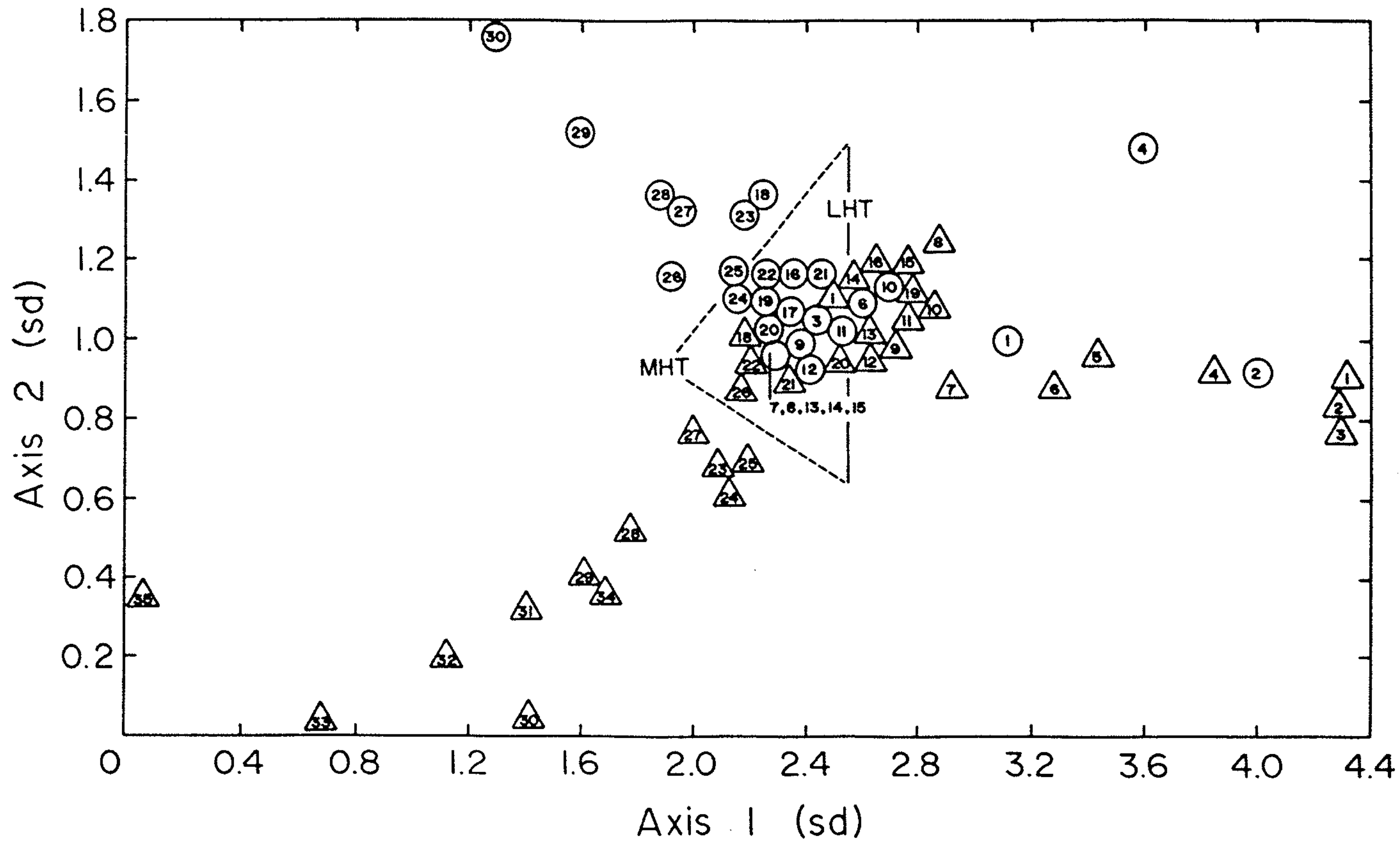
Three major plant communities are identified according to salinity. The saline communities (Sandspit and Akudlik) are typified by an exchangeable sodium percentage range of 63-74 and by a potassium range of 243-657ppm, the brackish community (Esker) by an ESP range of 41-54 and a K range of 121-261ppm and the fresh community (Pumphouse) by a ESP range of 1-58 and a K range of 40-144ppm.

The next step is to examine subsections of the total vegetation data matrix by dividing it into the above three main plant communities.

5.3.2.2 Saline ordination (Sandspit and Akudlik)

To examine possible definitions of the second axis, an ordination was performed using Sandspit and Akudlik data. The eigenvalues for axes 1 and 2 are 0.730 and 0.213 and explain 66% and 19% of the variation. The scatter plot of axes 1 and 2 show a sideway 'Y' configuration (Figure 23, elevation sample number and corresponding elevation are tabulated in fold out page 140). The top right arm of the 'Y' consists of Sandspit data, the bottom right arm of the 'Y' of Akudlik data, while the base is composed of a mixture of data from the two sites. Both arms consist of high elevation classes (o-23 to o-30 and Δ-23 to Δ-35) while the base consists of mid and low elevation classes from the both sites. The concordance of elevation classes with the MHT and LHT boundaries suggests a relatively high degree of similarity among

Figure 23: Detrended correspondence analysis of Sandspit and Akudlik samples for 1984. Axes are labeled in units of standard deviations (sd). Each sample is identified by a symbol and a number, refer to fold out page (140).



Axis 2 (sd)
Axis 1 (sd)
LHT
MHT
7, 8, 13, 14, 15

the mid-elevation classes in Sandspit and Akudlik. The grouping includes elevation classes with a high percentage of Carex subspathacea. There is a decrease in elevation from left to right, and it is assumed that axis 1 represents an elevation gradient and therefore inundation effects. Axis 2 represents a gradient of increasing salinity with Sandspit elevation classes located at the bottom and Akudlik classes at the top.

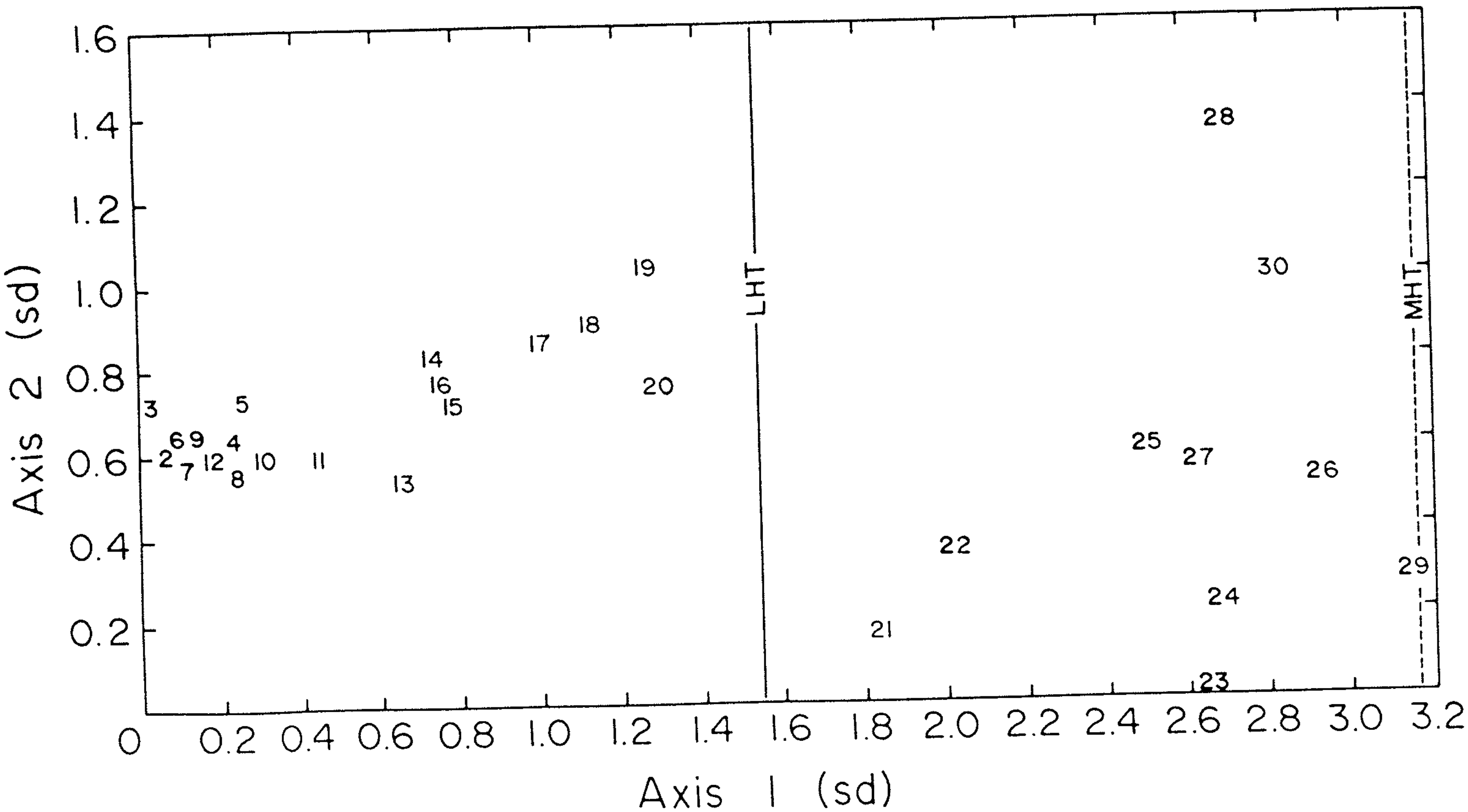
5.3.2.3 Brackish ordination (Esker)

Plotting Esker data separately, the eigenvalues for the two derived axes are 0.703 and 0.088 explaining 80% and 10% of the variation respectively. The main separator of the samples is elevation (tidal pattern). All the samples on the right side of the ordination plot (elevation classes 21 through 30) lie below MHT and above LHT (mid geolittoral zone) while samples on the left (2-20) are below LHT (lower geolittoral zone) with a nearly sequential increase from left to right (Figure 24). Elevation could be the controlling influence for axis 1 reflecting the effects of tidal inundation.

5.3.2.4 Freshwater ordination (Pumphouse)

The eigenvalue for axis 1 is 0.926 and that for axis 2 is 0.228. Axis 1 accounts for 63% of the variance and axis 2 for 20%. Two major divisions emerge. These coincide with the separation of upland classes (elevation classes 23

Figure 24: Detrended correspondence analysis of Esker samples for 1984. Axes are labeled in units of standard deviations (sd). Each sample is identified by a number, refer to fold out page (140).


Axis 2 (sd)
Axis 1 (sd)
LHT
MHT
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
3.2
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30

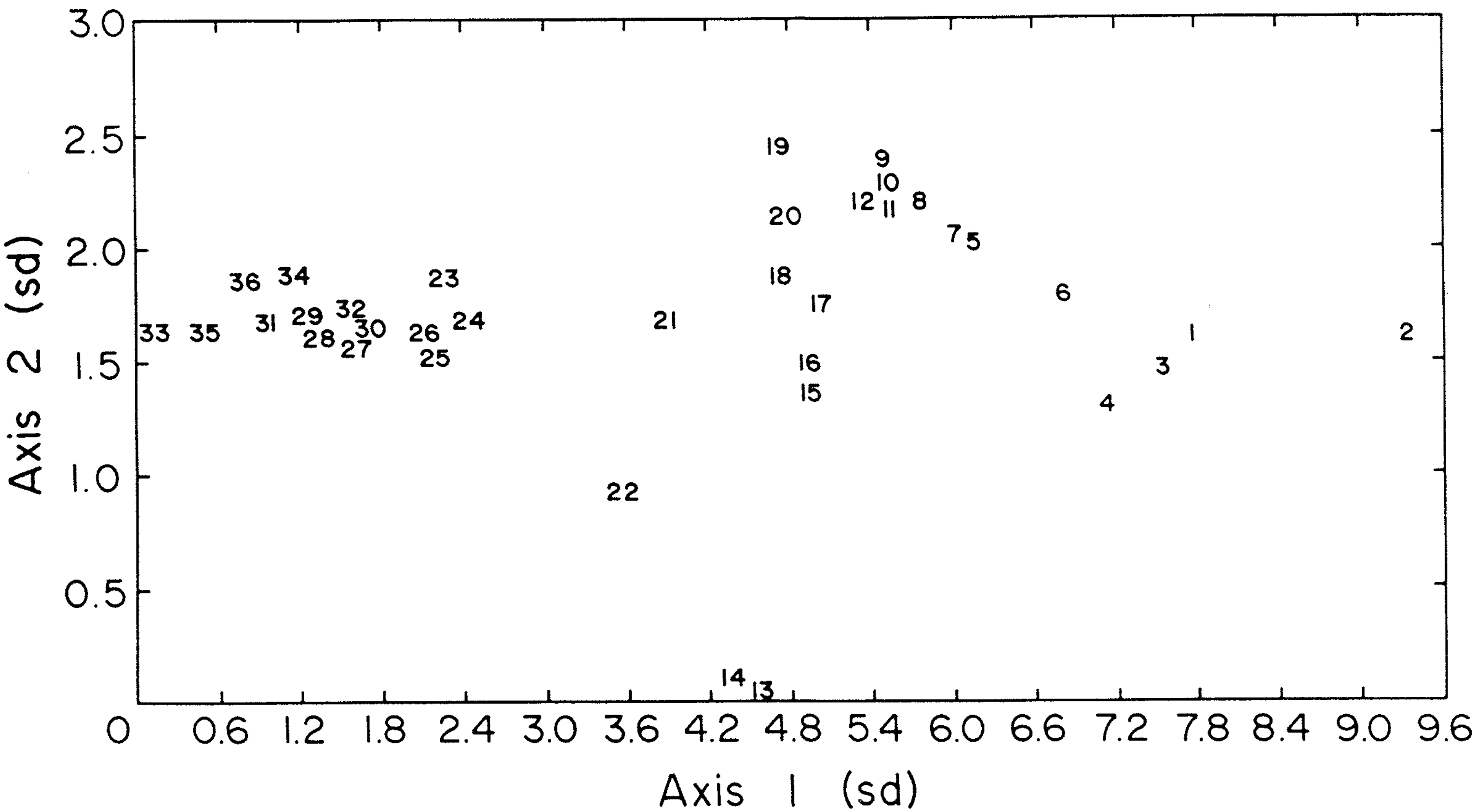
through 36), and freshwater aquatic classes (1-22). There is a general trend of decreasing elevation towards the right of the plot (Figure 25). Elevation is also related to a soil moisture gradient with relatively dry conditions at high elevations and mesic conditions at low elevations. Elevation samples 13 and 14 separate out as they are colonized by only one species, Juncus bufonius.

5.3.2.5 Species ordination

When the eigenvalues of the DCA of the total species matrix are plotted along axes 1 and 2 (Figure 26), one of the most obvious points is the increase in species richness from left to right of the scattergram. There is a primary trend of saline species clustering to the left, freshwater to the right with brackish located in the central area. There are also secondary groupings of plants; saline species can be divided into upper and lower tidal species classes, and freshwater species separated into upland and aquatic species classes.

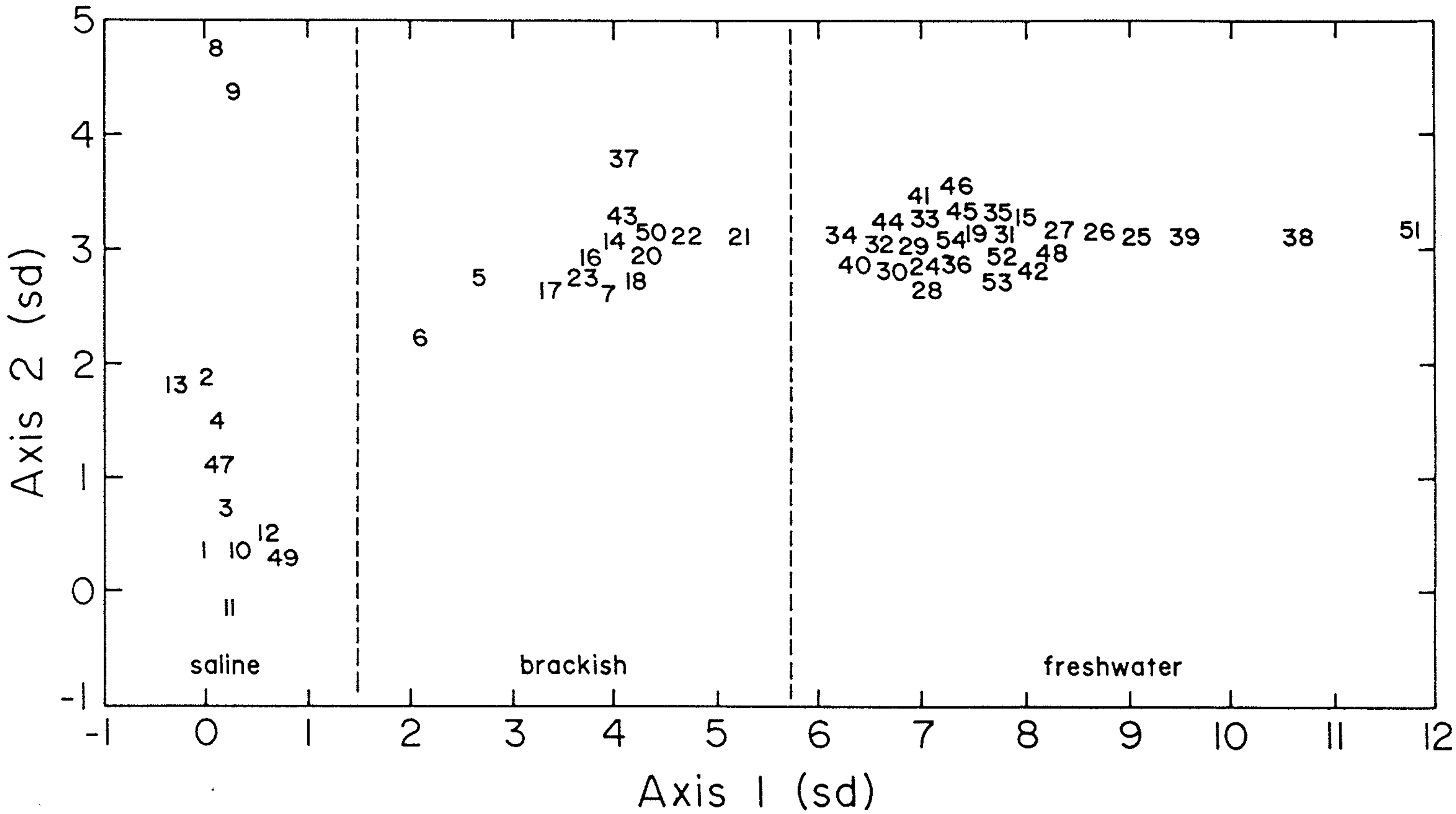
Species are numbered (in parenthesis) in the following paragraphs to aid in their identification on the DCA plots; a complete list is given on the fold-out page 140. Puccinellia phryganodes (8) and Hippuris tetraphylla (9), grow only in the lower geolittoral zone, and are located at the top left of the scatter plot (Figure 26), while species occurring in the epilittoral zone such as Chrysanthemum arcti-

Figure 25: Detrended correspondence analysis of Pumphouse samples for 1984. Axes are labeled in units of standard deviations (sd). Each sample is identified by a number, refer to fold out page (140).



Axis 2 (sd)
3.0
2.5
2.0
1.5
1.0
0.5
0
0.6
1.2
1.8
2.4
3.0
3.6
4.2
4.8
5.4
6.0
6.6
7.2
7.8
8.4
9.0
9.6
Axis 1 (sd)
19
9
10
12
11
8
20
7
5
36
34
23
18
6
17
31
29
32
30
24
21
33
35
28
26
1
2
27
16
25
3
15
4
22
14
13

Figure 26: Detrended correspondence analysis of all species for 1984. Axes are labeled in units of standard deviations (sd). Species are numbered for purposes of identification, refer to fold out page (141).

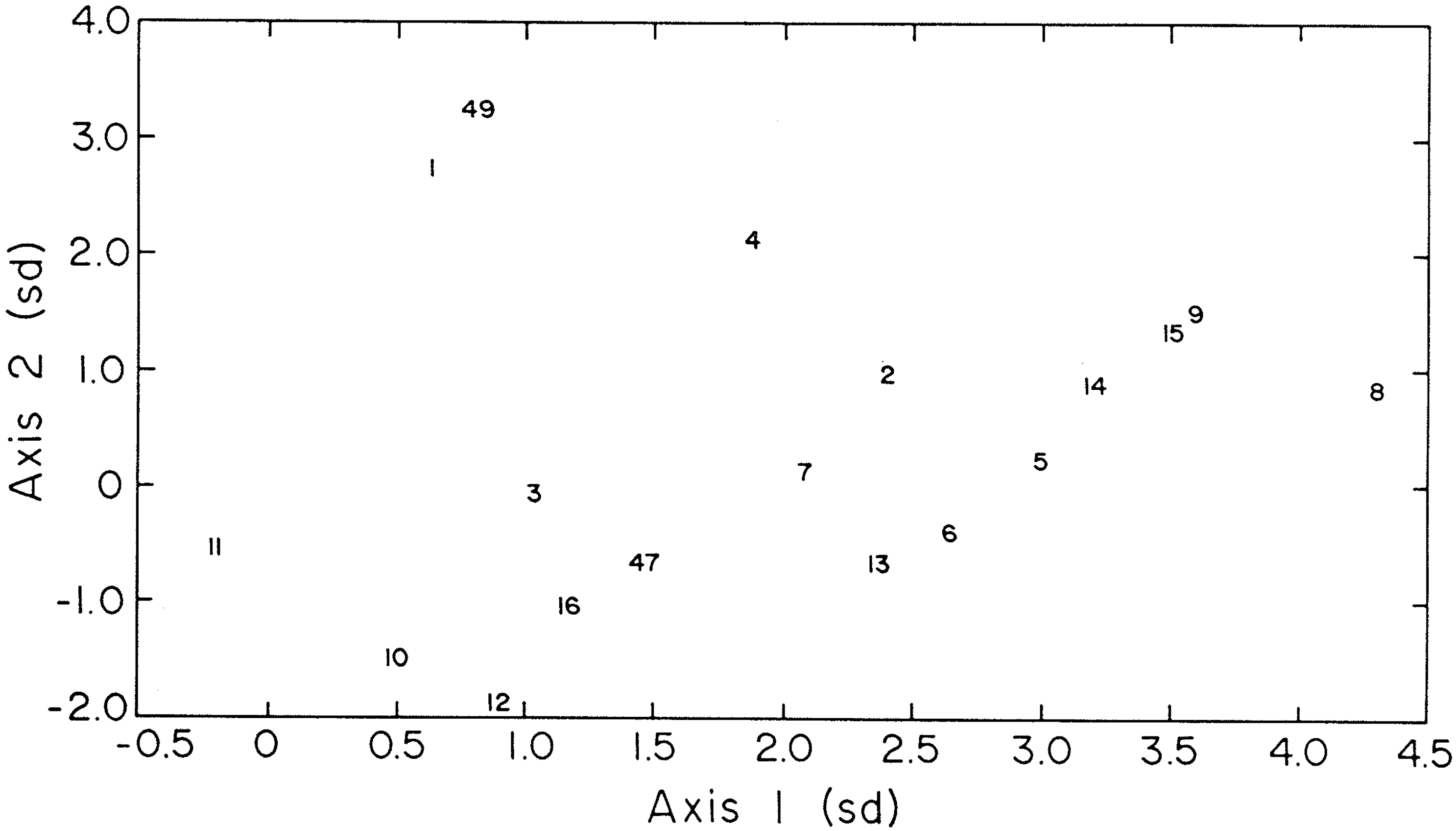

saline
brackish
freshwater
Axis 1 (sd)
Axis 2 (sd)

cum (1), Calamagrostis deschampsioides (3) and Festuca rubra ssp. rubra (11), are at the bottom left. Moving towards the center of the plot, constituent species are characteristically less salt tolerant. Brackish species such as Carex aquatilis (21), Calamagrostis neglecta (43) and Descampsia ceaspitosa var. littoralis (22), are in the centre of the plot. Freshwater aquatic species such as Sagitttaria cuneata (25), Potamogeton richardsonii (38), P. vaginatus (39), and P. pusillus var. minor (51) are at the far right. Lomatogonium rotatum (34), and Primula egaliksensis (40), from the fresh upland area, are clustered just to the left of the aquatic species.

A more detailed ordination of Sandspit and Akudlik separates saline species (Figure 27). Axis 1 places the species according to inundation tolerance. Puccinellia phryganodes (8), Hippuris tetraphylla (9), Eleocharis uniglumis (14) and Potamogeton filiformis (15), tolerate long periods of inundation. They are on the right of the plot and Festuca rubra ssp. rubra (11), Chrysanthemum arcticum (1), Puccinellia nuttalliana (49) and Salix brachycarpa (10), species intolerant of inundation are on the left of the plot. Species located in the center of the plot are moderately tolerant of inundation.

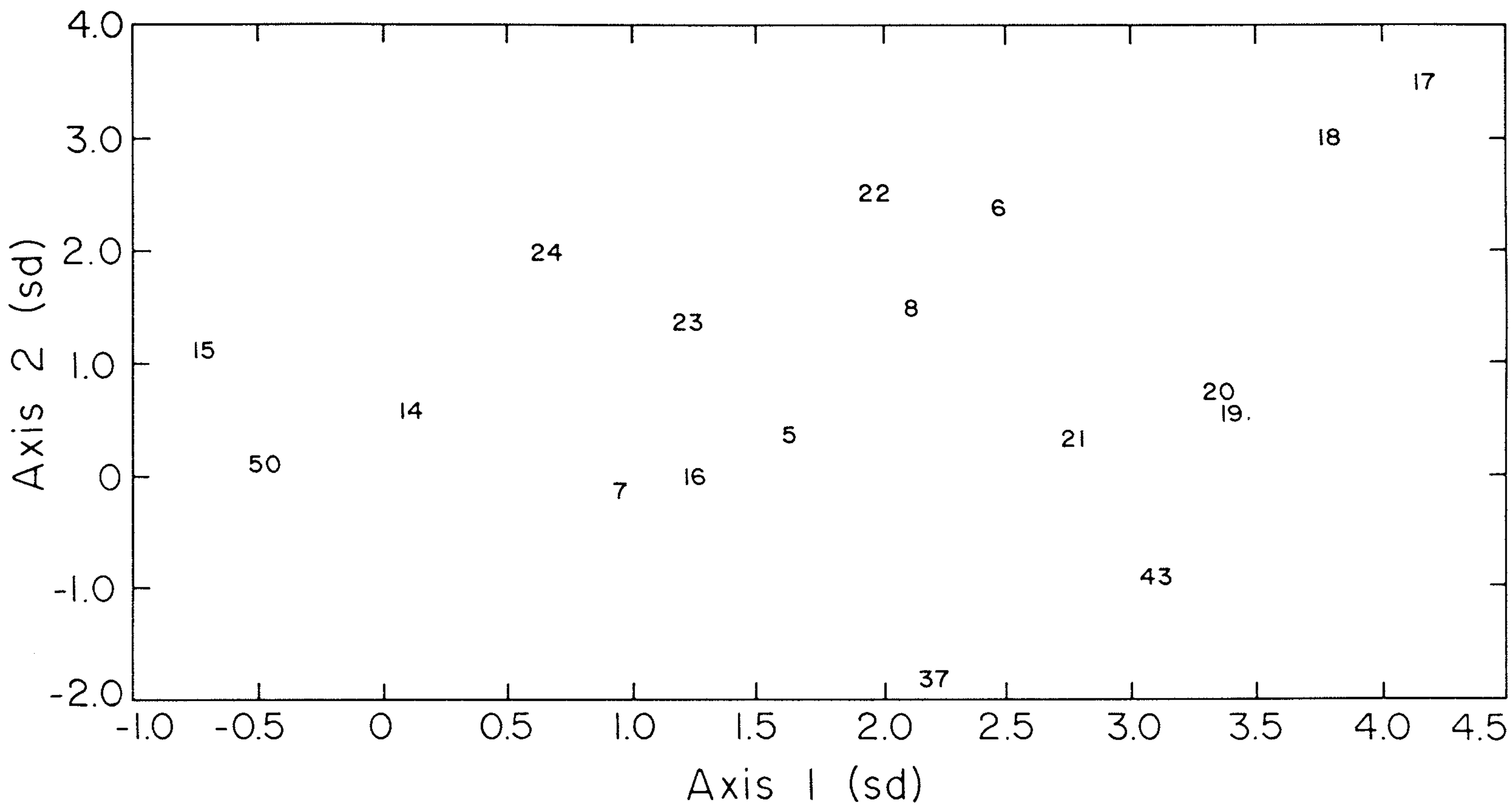
An ordination plot of Esker species shows similar distribution patterns along axis 1 according to the period of inundation (Figure 28). From left to right there is a de-

Figure 27: Detrended correspondence analysis of Sandspit & Akudlik species for 1984. Axes are labeled in units of standard deviations (sd). Species are numbered for purposes of identification, refer to fold out page (141).



4.0
3.0
2.0
1.0
0
-1.0
-2.0
-0.5
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Axis 1 (sd)
Axis 2 (sd)
49
1
4
9
15
2
14
8
7
5
3
6
11
47
13
16
10
12

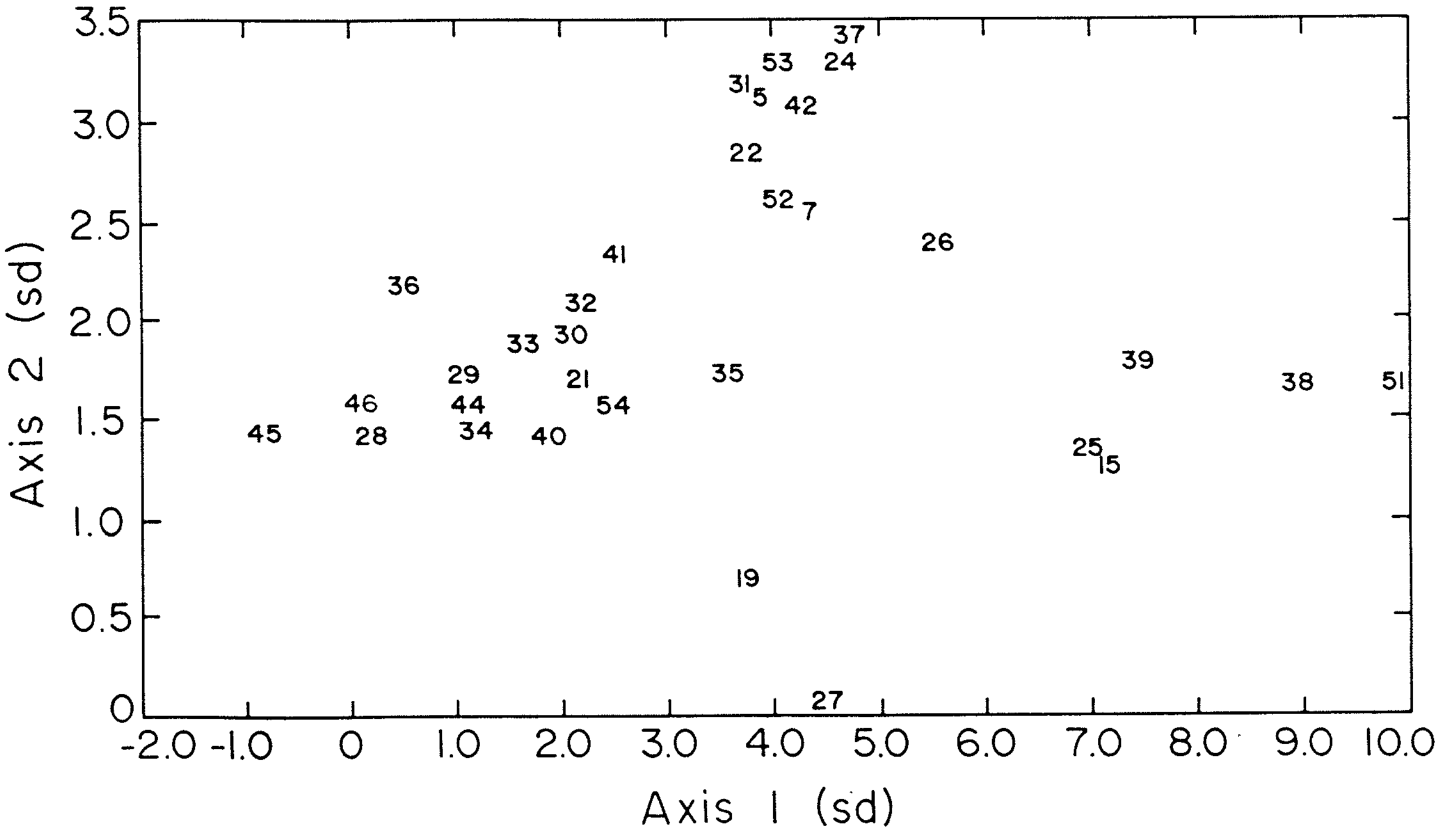
Figure 28: Detrended correspondence analysis of Esker species for 1984. Axes are labeled in units of standard deviations (sd). Numbers represent species numbers (refer to fold out page (141)).



Axis 2 (sd)
4.0
3.0
2.0
1.0
0
-1.0
-2.0
-1.0
-0.5
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Axis 1 (sd)
17
18
22
6
24
23
8
15
20
19
14
5
21
50
7
16
43
37

crease in period of inundation, with *Eleocharis uniglumis* (14), *Potamogetom filiformis* (15) and *Puccinellia langeana* (50) at the lower reaches and *Eriophorum angustifolium* (17), *Aster junciformis* (18), *Rumex occidentalis* (19), *Cicuta mackenziana* (20) and *Calamagrostis neglecta* (43) at the highest elevations. Species located in the central area have a moderate inundation period. Axis 2 cannot be interpreted ecologically.

The Pumphouse plot shows an elevational trend with axis 1 (Figure 29). Species dominant in low areas, *Potamogeton filiformis* (15), *Sagitaria cuneata* (25), *P. richardsonii* (38), *P. vaginatus* (39) and *P. pusillus* var. *minor* (51) are at the right, and species dominant at high elevations, *Parnassia palustre* var. *neogaea* (28), *Potentilla anserina* (36), *Polygonum amphibium* var. *stipulaceum* (45) and *Calamagrostis lapponica* (46) are on the left of the plot.



3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
Axis 2 (sd)
-2.0 -1.0 0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0
Axis 1 (sd)
37
53
24
31
5
42
22
52
7
26
41
36
32
30
33
29
21
35
39
38
51
46
44
54
45
28
34
40
25
15
19
27

Figure 29: Detrended correspondence analysis of Pumphouse species for 1984. Axes are labeled in units of standard deviations (sd). Species are numbered for purposes of identification, refer to fold out page (141).

Chapter VI

DISCUSSION

6.1 VEGETATION

Three groups of communities were recognized in the lower, 17km of the Churchill River estuary. Saline communities were dominated by *Puccinellia phryganodes* in the lower geolittoral zone, *Carex subspathacea* in the mid and upper geolittoral zone and *Calamagrostis deschampsioides* in the epilittoral zone. The brackish community was dominated by *Eleocharis uniglumis* in the lower geolittoral zone and *Carex aquatilis* in the mid geolittoral zone. The freshwater community was dominated by *Eleocharis acicularis*.

In general, species composition changes gradually along each transect with increasing elevations, and several distinct vegetation zones can be identified by the dominant species. Some species occur in all zones along a transect but in most cases their percent cover is low.

The lower and mid geolittoral zones of the two saline transects (Sandspit and Akudlik) are colonized by similar species while the upper geolittoral and epilittoral zones species diverge.

At the two saline transects, Puccinellia phryganodes colonized consolidated areas in the lower geolittoral zone. This species is a characteristic pioneer on tidal flats in arctic and sub-arctic salt marshes. It is tolerant of tidal and wave action, and can presumably withstand the ice scour which limits the establishment of other invading species (Hanson 1951; Chapman 1960). Unconsolidated sediments in the same zone and spreading into the mid geolittoral zone are colonized by Hippuris tetraphylla. Similar observations are noted by Jefferies et al. (1979), Ringius (1980) and Taylor (1981).

From the zone of Puccinellia phryganodes and Hippuris tetraphylla, the plant sequence from lower geolittoral to epilittoral zones at Sandspit and Akudlik is similar to other arctic and sub-arctic salt marshes (Hanson 1951; Kershaw 1976; Glooscenko 1978; Jefferies et al. 1979; Mason 1981a; Taylor 1981; Vince & Snow 1984).

Carex subspathacea has a wide distribution at Sandspit and Akudlik, it does not extend below LHT (the boundary between the mid and lower geolittoral zones), presumably because it cannot tolerate two daily tidal inundations, thus decreasing the exposure time of the plants. In addition, this area below low high tide is suseptible to disturbance by ice scour in the spring causing the tearing up and subsequent removal of the roots and rhizomes. In the middle of its range, C. subspathacea reaches its greatest luxurance and has culms up to 30+cm in height. Other species such as Stellaria humifusa, Ranunculus cymbalaria and Potentilla egedii var. groenlandica occur sporadically as single plants or in clumps. In areas such as this, species diversity generally is very low and occasionally drops to zero when only Carex subspathacea is present. At MHT (boundary between upper geolittoral and epilittoral zones), there is a conspicous reduction in height of C. subspathacea plants and presumably competition with Calamagrostis deschampsioides, but the upper limits of Carex subspathacea are not marked by a clear boundary.

At Sandspit (Table 6), the restricted ranges of Hippuris tetraphylla in the mid geolittoral zone and Puccinellia nuttalliana, Chrysanthemum arcticum, Calamagrostis deschampsioides in the epilittoral zone are superimposed on the broad distribution of Carex subspathacea. Similarly at Akudlik, Hippuris tetraphylla, Eleocharis uniglumis and Potamogeton filiformis are restricted to the mid geolitoral zone (Table 7), while Chrysanthemum arcticum, Fectuca rubra spp. rubra, Calamagostis deschampsioides, Salix brachycarpa and Stellaria longipes are restricted to the epilittoral zone. Potentilla egedii var. groenlandica, Stellaria humifusa, Ranunculus cymbalaria and Carex subspathacea have a broad distribution along the elevation gradient for both transects.

At Esker, the brackish transect, *Eleocharis uniglumis* colonizes and dominates the consolidated sediments in the lower geolittoral zone. As conditions become less extreme a greater range of species occurs. *Carex aquatilis* and *Deschampsia caespitosa* take over in the mid geolittoral zone. *Eriophorum angustifolium*, *Aster junciformis* and *Calamagrostis neglecta* are limited to the upper mid geolittoral zone. This may be due to the freshwater runoff from higher areas inland. Most of the other species have a broader range and occur in all of the mid geolittoral zone. Plant zonation at the brackish site is similar to that found in a James Bay brackish marsh (Ringius 1980).

There are a number of dead shrubs (identified as *Salix* spp. with insufficient morphological characteristics to identify to species) present in the upper portions of the Esker transect (mid geolittoral) and upper geolittoral and epilittoral zones which lie beyond the transect. The cause of death of the willows is unknown, but if the willows are freshwater taxa, an increase in the salinity of tidal water since 1976 could have been responsible. Further study of this area (specifically the identification of the dead willows) would be necessary to substantiate this suggestion.

Pumphouse is a non tidal transect but nevertheless shows a shift of species from high to low elevations. The change in species long this transect &mayirectly influenced by the increased soil moisture from low to high elevations since the species at the lower end are aquatic while those at the top of the transect are terrestrial.

At Pumphouse the river water level dropped markedly from 1983 to 1984 with the result that the transect had to be extended 200m to reach the edge of the river in 1984. Even then the water level dropped more than 50cm during the course of the growing season. The aquatic plants in the lower 200m of the transect are in an area which would normally be under water. This decrease in river water level and exposure of river flats caused drying of soil, stunting of growth and eventual death of some species (eg. Potamogeton spp.).

Most species in the Churchill estuarine tidal sites (Sandspit, Akudlik and Esker) are herbaceous perennials that reproduce vegetatively. In the lower and mid geolittoral zones the lack of annuals may be due to their poor adaptation to an environment subject to inundation and periods of hypersalinity that may seriously depress the uptake of minerals (Jefferies et al. 1977) as well as mechanical disturbance (Ranwell 1972). Mechanical disturbance caused by ice scour is observed mainly below and in the lower geolittoral zone.

Vegetative reproduction is more important than seedling establishment in producing and maintaining zoned patterns within sites in the upper geolittoral and the epilittoral zones. A salt marsh provides hemi-cryptophyte habitat, there is little open ground for annuals (Ranwell 1972).

The effects of salinity on salt marsh plants has been studied experimentally. Most species will not germinate in sea-water but will in very dilute salinities (Chapman 1960). Germination is a critical period in the plant life cycle and inhibition of germination by high salt concentrations may exclude certain species from large segments of their potential habitat.

Pigott (1969) suggested that nitrogen and phosphorus are exploited in the spring by the roots of perennial plants and thereby reduce the nutrients available for annuals. He found higher nitrogen and phosphorus levels in bare areas compared with upper vegetated marsh areas. This type of exploitation may also occur at the three tidal sites thereby decreasing the ability of annuals to survive.

Due to the nature of vegetative growth at the tidal sites, only long-term persistent changes of environmental parameters would cause a shift in vegetation zonation. Change in species at a specific location would be governed by both the expansion of existing species and the influx and establishment of vegetative propagules.

At Pumphouse where salinity is low and there are extensive areas of bare ground, annuals contribute significantly to the plant community, eg. Juncus bufonius and Limosella aquatica grow abundantly in the sands.

Diversity increases as stress is reduced (Krebs 1972). In the Churchill estuary average site species diversity increases from Sandspit at the mouth of the river upstream to Pumphouse. This could be related to a decrease in mean salinity, a cause of stress (Table 5). Tidal inundation within each site is also considered a stress, with a decrease in stress with increasing elevation. Sandspit, Esker and Pumphouse "elevation class" species diversities are positively correlated with elevation. Eilers (1975) and Dawe and White (1982) found a similar positive correlation between elevation and species diversity. Vogl (1966) and Vince and Snow (1984) reported very simple plant communities at lower elevations increasing to more complex communities at high elevations.

Species richness in salt marsh communities is often low (about 10-20 species; MacDonald & Barbour 1974). The three tidal marsh sites (Sandspit, Akudlik and Esker) have 16, 25 and 23 species respectively. In contrast, 59 species were identified at the Pumphouse site. In areas of the salt marsh where there was a combination of stress factors such as high salinity and low elevation or high salinity and low soil redox potential, no species were found (eg. salt pans).

The mean above-ground standing crop values along the four transects ranged from 103 to 215g m^{-2} (Table 10) and were comparable with other reported ranges of 22-564g m^{-2} (Glooschenko 1978), 18-610g m^{-2} (Jones & Hanson 1983) and 218-466g

m^{-2} (Vince & Snow 1984). The above-ground standing crop values were generally lower in 1984 than in 1983 perhaps as a result of the many repercusions of decrease in precipitation in 1984.

On average, there is a&nncrease in above-ground standing crop from low to high elevations (Figure 6). Lower elevations are subject to longer and more frequent inundations. Photosynthesis is reduced because of decreased light intensity caused by suspended silt in the water and restricted atmospheric gas exchange. As a result, plants at lower elevations are limited in available energy for growth. In 1984, at Pumphouse, aquatic plants at lower elevations were at a disadvantage due to the decrease in river water levels that caused exposure. This probably resulted in lower above-ground standing crop.

Mean below-ground standing crop values for the four transects ranged from 798 - 2,015g m^{-2} (Table 11), overlapping the 500 - 1,000g m^{-2} range of Cargill & Jefferies (1984a) and the 1,520 - 2,185g m^{-2} range of Dennis & Johnson (1970). The above-ground:below-ground standing crop ratios ranged from 1:1 to 1:23.4 (Table 12). These ratios fall within cited ranges, 1:1 to 1:23 (Wielgolaski 1972). This low ratio of above-ground to below-ground biomass has been interpreted as an indication of the more stable conditions within the soil resulting in a greater accumulation of standing crop. It could also reflect the need for an extensive root system to tap the meagre supply of nutrients in the soil (Haag 1974; Chapin 1978).

6.2 ENVIRONMENTAL PARAMETERS

The Churchill tidal salt marshes vary in the composition and diversity of communities as well as the productivity and reproduction of individual species. Variation in soil properties such as drainage, pH, salinity, texture, organic matter, nutrients, and redox potential, as well as tidal inundation along the three tidal transects contribute to the vegetation zonation.

The highest mean water salinities were measured at Sandspit, and decreased up the river to Pumphouse, the non-tidal site (Table 13). Many factors affect the salinity gradient and its variations in the estuary (eg. tide weather and river flows). River mean daily discharge decreased 70% 409m^3 s^{-1} in 1983 to 136m^3 s^{-1} in 1984 (Table 1). This coupled with a decrease in precipitation and subsequent reduction in runoff from higher areas surrounding the tidal marsh resulted in an increase in tidal water flowing up the estuary. Salinity at Akudlik increased by 67% and at Esker by 196% (Table 13). River flows have been reduced since 1976 (Table 1) and this has affected the salinity gradient resulting in an increase in salinity at the three tidal sites. In the Churchill River, a 60% decrease in mean annual flow from 1343m^3 s^{-1} (pre-diversion) to 573m^3 s^{-1} (post-diversion) would considerably increase the water salinity in the estuary.

Interstitial water salinities had the highest mean values at Sandspit and the lowest at Pumphouse (Table 16). The salinity of the interstitial water in salt marsh sediments is influenced by the salinity, frequency and duration of tidal flooding, precipitation rain, evaporation and sediment properties that affect the rate of exchange across the sediment-water interface (Lindberg & Hariss 1973). If decreased mean daily discharge in the river resulted in an increase in tidal water salinity, interstitial water salinities in the sediment-water interface would also increase. During the relatively dry summer of 1984, precipitation was 135.6mm, which was 78% of the mean annual precipitation, while mean temperatures during June, July and August were on average 1.6°C above normal (Table 4). These factors combined not only to reduce leaching by freshwater runoff and groundwater recharge, but to increase rates of evaporation and contribute to increases in interstitial salinity.

The low relief of the marsh, fine sediments, reduced drainage due to slight levees along the channels and low evaporation rates favor retention of tidal water on the marsh.

In 1984, a 20 day delay in the higher spring tides gave plants an initial period for growth in mid and upper geolittoral zones before they were subjected to effects of influent saline water (Figure 13). As the summer progressed the tide height increased and therefore flooded the upper geolittoral and epilittoral zones. Two-thirds of the Sandspit and Akudlik transects were inundated 50% of the time at high tide, while almost all of the Esker transect was inundated 50% of the time during the growing season (Figure 14). In Esker, two-thirds of the transect was inundated 100% of the time at high tide, with the result that vegetation was exposed for only brief periods. Consequently, plants in the lower and mid geolittoral zones had appreciably less time to carry on photosynthesis and gas exchange than plants in the upper and epilittoral zones.

Although water pH did not play an important part in vegetation zonation, unusually high pH values for river water were found at Pumphouse (Table 15) this may be due to the calcareousness of the sediment load in the water. The increased mixing of the tidal water (pH 7.7), with the river water (pH 8-9) would tend to decrease the pH values downstream.

Sandspit, Akudlik and Esker have similar soil textures while Pumphouse is sandier (Table 17). This is probably due to the reduced carrying capacity of the river as it reaches the mouth of the estuary. The lower geolittoral zone of each transect is sandier (Figure 15) than the mid and upper geolittoral zones. This reduction in grain size is related to tidal and river deposition. Similar results were found by Hantzchel (1939), Martini & Protz (1978), and Clarke et al. (1982).

Soil organic matter decreases from Sandspit to Pumphouse (Table 17). Organic matter data for all four transects (range 1.3-16.3%) is similar to that of Glooschenko & Capobiano (1979) with 1.4-17.0%, Clarke et al. (1982) 1.7-26%, and Vince & Snow (1984) with 2.3-16.6%. Within each site, there is an increase in organic matter from the lower geolittoral to the epilittoral zone. Howes et al. (1977), Glooschenko & Capobiano (1980), Clarke et al. (1982) and Ewing (1983) found similar trends in organic matter. This relates to the increase in above and below-ground plant standing crop from the lower geolittoral to the epilittoral zone. More organic matter therefore occurs in the soil. Organic matter may also be more readily removed from sandy sediments in the lower geolittoral zone by tidal activity.

Mean soil pH at the four sites ranges from 7.3 to 7.5 (Table 17) (probably buffered around neutrality by high calcium carbonate contents of the soils). This range is higher than the 6-6.5 range of Clarke et al. (1982) but overlaps the 6.2-7.4 range of Vince & Snow (1984). Mean pH values for soils vary along the river (Table 17) although the differences are not significant. The small differences indicate that soil pH is not a factor influencing vegetation zonation. Similar results were found in other salt marsh studies (Zedler 1977; Dawe & White 1982).

Mean values for soil salinity are highest at Sandspit and lowest at Pumphouse (Table 17). The conductivity range observed (1 to 22.0dS m^{-1}) is much higher than the 0.2-0.8dS m^{-1} range of Clarke et al. (1982) and the 0.3-4.0dS m^{-1} range of Glooschenko & Harper (1982), who worked at North Point, Ontario in the less saline James Bay which would have lower nutrient concentrations.

Sodium levels in soils from along the four transects range from 15 - 4,000ppm. This range is higher than the 25-290ppm range reported by Glooschenko & Clarke (1982) but overlaps the range of 164 - 24,000ppm of Jones & Hanson (1983). The ranges of calcium (59-725ppm), magnesium (28-605ppm) and potassium (20-700ppm) are also higher than those reported for the west coasts of Hudson and James Bay (Jones & Hanson, 1983). They reported a Ca range of 332-353, a Mg range of 11-465 and a K range of 3-300ppm. Phosphorus concentrations (3.8-59ppm) compare favorably with the 5-70ppm range of Jones & Hanson (1983).

Exchangeable sodium percentages range from 1 to 74, compared with the 7 to 71 range reported by Glooschenko & Clarke (1982). In general, ESP values greater than 15% are considered toxic to plants (with some exceptions) and detrimental to soil structure (Richards 1954). The plants at the Sandspit, Akudlik and Esker sites must be tolerant of such toxic conditions. Sandspit and Akudlik both have mean ESP values of 69 (Table 17) and similar species. At Esker where the mean ESP value is 47 there is a shift to less salt tolerant species such as _Eleocharis uniglumis_ and _Calamagrostis neglecta_.

Salt marshes are generally eutrophic (Teal 1962; Jefferies 1972). Micro-nutrients are usually not limiting (Valiela & Teal 1974) being constantly replenished by tidal water. There is a continual cycling of nutrients within the salt marsh which is linked to biological activity and maintains a relatively high overall level of productivity (Teal 1962).

In the Churchill River estuary, sodium, calcium, magnesium, potassium and exchangeable sodium percentage all decrease upstream while nitrogen increases (Table 17). In salt marshes, available nitrogen is generally limited, and increases in freshwater areas (Pigott 1969; Valiela & Teal 1974). This study followed a similar trend, Sandspit has a mean of only 2.6ppm nitrogen but this increases upstream to 5.8ppm at Pumphouse. Cargill & Jefferies (1984) documented a mineral nitrogen deficiency for _Carex subspathacea_ and _Puccinellia phryganodes_ in a salt marsh near Churchill.

Phosphorus concentration is high at the three tidal sites and lower at the freshwater site (see also Boyd & Hess 1970; Patrick & DeLaune 1976). Wolf & Fucik (1981) documented that higher phosphorus content in tidal salt marshes was due to the influx of marine phosphate with the tides. Cargill & Jefferies (1984) reported no phosphorus limitation in a salt marsh near Churchill. In the present study however, increases in mean standing crop parallel increases in phosphorus suggesting that phosphorus is limiting.

The higher salinity in saltpans is the result of several factors. The margins of pans are usually slightly elevated with the result that outflow is restricted. Pans are replenished with tidal water during extreme high tides. The elevation of many saltpans is high enough to reduce the number of tidal inundations. Consequently evaporation periods are long enough to result in higher salt concentrations than in the lower and more frequently flooded areas of the marsh.

Oxidation-reduction potential (redox) is a convenient measure of soil aeration (Brereton 1971). Values less than 200mV indicate poor drainage and anaerobic conditions (Stolzy & Fluhler 1978). At Sandspit mean redox potential values throughout the growing season were below 200mV indicating that Sandspit vegetation must tolerate long periods of anaerobic conditions. The same applies to Akudlik and Esker except for short periods early and late in the season. At Pumphouse the soil was well drained and aerated throughout the growing season and the soil redox potentials were consistently above 200mV.

Redox potentials at Sandspit were higher in the root zone than in the sediments below or in the unvegetated sediments (Figure 17). Within the top 4cm, where most of root biomass is located, the redox potential was above 200mV. Plants oxidize the sediments around their roots thereby increasing the redox potential in the root zone. Other studies have shown that wetland grasses can oxidize sediments in their root zone (Teal & Kanwisher 1966; Armstrong 1975; Howes et al. 1981). At lower depths however, there were fewer roots and less oxidation of the sediments. Similar results are found by Howes et al. (1981) in a Spartina salt marsh.

6.3 VEGETATION AND ENVIRONMENTAL PARAMETER INTERACTIONS

To compare one environmental factor with vegetation zonation a direct relationship can be used. When using 12 independently varying environmental factors a direct comparison with vegetation is impossible. Principal components analysis was therefore used to compare soil data from along the four transects. Salinity, Na, Mg, ESP, K and pH show high loadings on the first PCA axis (Table 19). Texture, organic matter, and three soil nutrients, Ca, P and N have high loadings on the second axis (Table 19).

Organic matter and texture have a high correlation with elevation and the latter directly influences the inundation pattern, which in turn affects soil texture. Elevation is probably the most frequently acknowledged factor influencing vegetation zonation in salt or brackish marshes (Johnson & York 1915; Gray & Bunce 1972; Redfield 1972; Provost 1976) although its influence is modified by interactions with sediments.

The first PCA axis (Table 20) separates Sandspit and Akudlik soils according to salinity, while the second PCA axis divides the soils according to texture, organic matter, phosphorus and potassium. In the case of Esker, with a salinity range of only 1ppt the effects of salinity are assumed to be negligible. The first PCA axis of Esker (Table 21) reflects an 'elevation' gradient (texture, organic matter, N, P, K, & Ca). At Pumphouse, however salinity and texture are the most important factors separating the soils (Table 22).

Three distinct floristic groups were identified with detrended correspondence analysis of the total vegetation matrix (Figure 22). The correlation of relative species composition (ordination samples from axis 1 - Figure 22, 1984) with five environmental parameters shows that salinity of the soil (quantified by the exchangeable sodium percentage and the potassium concentration) is important in segregating these three plant communities along the first DCA axis. The ordination defines three major plant communities, saline, brackish and fresh.

The detrended correspondence analysis proves to be an effective technique for simplifying the field data and emphasises the essential attributes of the vegetation. The similarity of the floristic DCA and the environmental PCA indicates the overriding influence of edaphic parameters on the flora.

Secondary ordinations of the three plant communities show that species composition up river from Sandspit to Pumphouse is controlled largely by salinity while zonation from the sublittoral to epilittoral is determined by elevation which controls inundation and sediment characteristics. Species distribution indicates that salinity determines the presence or absence of a species, while elevation determines the vertical range and abundance of species.

Many studies (Kershaw 1976; Ringius 1980) have used elevation to explain vegetation zonation although most studies assume that micro-elevation is constant at a specific distance and location along a transect. They consider the mean macro elevation at the point of sampling. In the present study, the elevation of each vegetation sample (point frame) was determined. Data analysis showed that the elevation of a point frame was more important in determining the species present than the position of the point frame along the transect. A particular elevation is colonised by the same species and this is independent of the position along the transect. Elevations indicate inundation preferences of the various species.

Although there have been previous vegetation studies of the saline communitites examined in this thesis, the data collected were generally of a qualitative nature (Ritchie 1956; Schofield 1959). There have however, been no studies of the brackish and freshwater areas examined here. If the long term effects of reduced flows in the Churchill River, on vegetation in the estuary are to be assessed it is essential to have the type of data provided in this thesis. Admittedly it would have been preferable for such research to have been undertaken prior to the diversion of the Churchill River, but no such study took place. The information presented here should provide adequate data for comparison with future vegetation studies especially if the same transects and methods were to be used. It would be advisable to resample the four transects every 5-10 years for comparative purposes.

Since the diversion of the Churchill River in 1976, there have been marked increases in several water chemistry parameters (hardness, total inorganic carbon, calcium, total phosphorus and aluminum (page 6)) which may have long term effects on the biota in the lower reaches of the estuary. Many biological systems react to cumultive changes, but this cannot be determined without adequate monitoring or surveilance. The data in this thesis provides the most comprehensive source of information for comparison with future research.

This study and subsequent work could also provide valuable information for establishing management guidelines for similar river diversion projects. When the impact of the Churchill River Diversion is assessed the effects of future hydro electric and other water diversion programs in the sub-arctic and arctic areas in North America could be inferred.

Chapter VII

SUMMARY

1. Three major plant communities, distributed according to salinity (quantified by the exchangeable sodium percentage value and the potassium concentration) are identified from the four transects studied. Saline transects are dominated by *Puccinellia phryganodes* in the lower geolittoral zone, *Carex subspathacea* in the mid and upper geolittoral zone and *Calamagrostis deschampsioides* in the epilittoral zone. The brackish transect is dominated by *Eleocharis uniglumis* in the lower geolittoral zone and *Carex aquatilis* in the mid geolittoral zone. The freshwater transect is dominated by *Eleocharis acicularis*.
2. Land elevation, which controls inundation regimes for the three tidal transects and soil moisture for the freshwater transect determines the vertical distribution of species.
3. Species richness and diversity increases up river and increases with elevation within each transect.
4. Reproduction is predominantly vegetative at the saline and brackish transects, while sexual reproduction is important at the freshwater transect.

5. Mean above-ground standing crop values for the four sampled transects ranged from 103 to 215g m^{-2} comparing favorably with other sub-arctic sites. Above-ground standing crop values were 16 to 48g m^{-2} lower in 1984, probably as a result of the many repercussions of decreased precipitation.
6. Mean below-ground standing crop values from the four sampled transects ranged from 798 to 2015g m^{-2}.
7. Above-ground:below-ground standing crop ratios ranged from 1:1 to 1:23.
8. Mean salinities of tidal water for the 1983 and 1984 growing seasons decreased up river from 16ppt at Sandspit to 7.0ppt at Esker and was 0.5ppt at Pumphouse which is non-tidal.
9. Mean transect soil salinity values for the 1983 growing season showed a similar trend with 4.0ppt at Sandspit and 0.7ppt at Pumphouse.
10. The soils were characterized by a decreasing salinity gradient upstream from the mouth of the river. Salinity, sodium, magnesium, exchangeable sodium percentage and potassium showed high positive loadings on principal component analysis axis 1.

SANDSPIT		AKUDLIK		ESKER		PUMPHOUSE	
Sample	Elevation	Sample	Elevation	Sample	Elevation	Sample	Elevation
○-1	0.00	△-1	0.00	□-1	0.00	▽-1	0.00
○-2	0.05	△-2	0.05	□-2	0.05	▽-2	0.05
○-3	0.10	△-3	0.10	□-3	0.10	▽-3	0.10
○-4	0.15	△-4	0.15	□-4	0.15	▽-4	0.15
○-5	0.20	△-5	0.20	□-5	0.20	▽-5	0.20
○-6	0.25	△-6	0.25	□-6	0.25	▽-6	0.25
○-7	0.30	△-7	0.30	□-7	0.30	▽-7	0.30
○-8	0.35	△-8	0.35	□-8	0.35	▽-8	0.35
○-9	0.40	△-9	0.40	□-9	0.40	▽-9	0.40
○-10	0.45	△-10	0.45	□-10	0.45	▽-10	0.45
○-11	0.50	△-11	0.50	□-11	0.50	▽-11	0.50
○-12	0.55	△-12	0.55	□-12	0.55	▽-12	0.55
○-13	0.60	△-13	0.60	□-13	0.60	▽-13	0.60
○-14	0.65	△-14	0.65	□-14	0.65	▽-14	0.65
○-15	0.70	△-15	0.70	□-15	0.70	▽-15	0.70
○-16	0.75	△-16	0.75	□-16	0.75	▽-16	0.75
○-17	0.80	△-17	0.80	□-17	0.80	▽-17	0.80
○-18	0.85	△-18	0.85	□-18	0.85	▽-18	0.85
○-19	0.90	△-19	0.90	□-19	0.90	▽-19	0.90
○-20	0.95	△-20	0.95	□-20	0.95	▽-20	0.95
○-21	1.00	△-21	1.00	□-21	1.00	▽-21	1.00
○-22	1.05	△-22	1.05	□-22	1.05	▽-22	1.05
○-23	1.10	△-23	1.10	□-23	1.10	▽-23	1.10
○-24	1.15	△-24	1.15	□-24	1.15	▽-24	1.15
○-25	1.20	△-25	1.10	□-25	1.20	▽-25	1.20
○-26	1.25	△-26	1.25	□-26	1.25	▽-26	1.25
○-27	1.30	△-27	1.30	□-27	1.30	▽-27	1.30
○-28	1.35	△-28	1.35	□-28	1.35	▽-28	1.35
○-29	1.40	△-29	1.40	□-29	1.40	▽-29	1.40
○-30	1.45	△-30	1.45	□-30	1.45	▽-30	1.45
		△-31	1.50			▽-31	1.50
		△-32	1.55			▽-32	1.60
		△-33	1.60			▽-33	1.80
		△-34	1.65			▽-34	1.85
		△-35	1.70			▽-35	1.90
						▽-36	2.00

Species number	Species name
1	*Chrysanthemum arcticum* *
2	*Carex subspathacea* *
3	*Calamagrostis deschampsioides* *
4	*Stellaria humifusa* *
5	*Ranunculus cymbalaria* *
6	*Potentilla egedii* var. *groenlandica* *
7	*Triglochin palustris*
8	*Puccinellia phryganodes* *
9	*Hippuris tetraphylla* *
10	*Salix brachycarpa*
11	*Festuca rubra* ssp. *rubra*
12	*Plantago junciodes* var. *glauca*
13	*Carex glareosa* var. *amphigena*
14	*Eleocharis uniglumis* *
15	*Potamogeton filiformis* *
16	*Dupontia fisheri* var. *psilosantha*
17	*Eriophorum angustifolium*
18	*Aster junciformis*
19	*Rumex occidentalis*
20	*Cicuta mackenzieana*
21	*Carex aquatilis*
22	*Deschampsia caespitosa* var. *littoralis* *
23	*Myriophyllum exalbescens*
24	*Limosella aquatica*
25	*Sagittaria cuneata* *
26	*Eleocharis acicularis* *
27	*Juncus bufonius* *
28	*Parnassia palustris* var. *neogaea*
29	*Euphrasia arctica*
30	*Ranunculus aquatalis* var. *capillaceus*
31	*Potentilla palustre* var. *parvifolia*
32	*Epilobium palustre*
33	*Salix planifolia* *
34	*Lomatogonium rotatum* spp. *rotatum*
35	*Eleocharis palustris*
36	*Potentilla anserina* *
37	*Ranunculus gmelinii* var. *hookeri*
38	*Potamogeton richarsonii* *
39	*Potamogeton vaginatus* *
40	*Primula egaliksensis*
41	*Juncus balticus*
42	*Polygonum boreale*
43	*Calamagrostis neglecta* *
44	*Equisetum arvense* *
45	*Polygonum amphibium* var. *stipulaceum*
46	*Calamagrostis lapponica* *
47	*Stellaria longipes*
48	*Polygonum lapathifolium*
49	*Puccinellia nuttalliana*
50	*Puccinellia langeana*
51	*Potamogeton pusillus* var. *minor*
52	*Poa alpigena* *
53	*Stellaria crassifolia*
54	*Salix* spp. *

* Species with a 20% or greater percent cover

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Appendix A

SPECIES LIST

A total of 81 macrophytic species or species groups were identified during the 1983-1984 growing seasons at the four sampling sampling sites (Figure 2). Nomenclature follows Porsild and Cody (1980). Sandspit (S) Akudlik (A) Esker (E) Pumphouse (P).

SPECIES	S	A	E	P
EQUISETACEAE				
Equisetum arvense L.				X
POTAMOGETONACEAE				
Potamogeton filiformis Pers.		X	X	X
Potamogeton pusillus L. var. minor				X
Potamogeton richardsonii (Benn.) Rydb.				X
Potamogeton vaginatus Turcz.				X
SCHEUCHZERIACEA				
Triglochin maritima L.	X	X		
Triglochin palustris L.	X	X	X	X
ALISMATACEAE				
Sagittaria cuneata Sheld.				X
GRAMININEAE				
Alopecurus aequalis Sobol				X
Beckmannia syzigachne (Steud.) Fern.				X
Calamagrostis deschampsioides Trin.	X	X		
Calamagrostis lapponica (Wahlenb.) Hartm.				X
Calamagrostis neglecta (Ehrh.) Gaertn., Mey. and Schreb.		X	X	X
Deschampsia caespitosa (L.) Beauv. var. littoralis (Reut.) Richter.			X	X
Dupontia fisheri R. Br. var. psilosantha (Rupr.) Polunin	X	X	X	
Festuca rubra L. ssp. rubra		X		

Hierochloe odorata (L.) Beauv.				X
Hordeum jubatum L.				X
Poa alpigena (Fr.) Lindm.		X		X
Puccinellia phryganodes (Trin.) Scribn. & Merr.	X	X	X	
Puccinellia langeana (Berl.) Th. Sor.			X	
Puccinellia nuttalliana (Schultes) Hitchc.	X	X	X	X

CYPERACEAE

Carex amblyorhyncha Krecz.	X			
Carex aquatilis Wahlenb.			X	X
Carex bicolor All.				X
Carex glareosa Wahlenb. var. *amphigena* Fern.	X	X		
Carex subspathacea Wormskj.	X	X		
Eleocharis acicularis (L.) R.& S.				X
Eleocharis palustris (L.) R.& S.			X	X
Eleocharis uniglumis (Link) Schult		X	X	
Eriophorum angustifolium Honck.			X	
Eriophorum scheuchzeri Hoppe				X

JUNCACEAE

Juncus alpinus Vill. var. *rariflorus* (Hartm.) Hartm.				X
Juncus bufonius L. s. lat.				X
Juncus balticus L.				X

SALICACEAE

Salix alaxensis (Anderss.) Cov.				X
Salix brachycarpa Nutt.	X	X		
Salix myrtifolia Andress.				X
Salix planifolia Pursh				X

MYRICACEAE

Myrica gale L.				X

BETULACEAE

Betula glandulosa Michx.				X

POLYGONACEAE

Polygonum amphibium L. var. *stipulaceum* (Coleman) Fern.				X
Polygonum boreale (Lange) Small				X
Polygonum lapathifolium L. *s. lat.*				X
Polygonum viviparum L.				X
Rumex occidentalis S. Wats			X	X

CHENOPODIACEAE				
Chenopodium glaucum L. var. *palustris*			X	X
CARYOPHYLLACEAE				
Stellaria crassifolia Ehrh.				X
Stellaria humifusa Rottb.	X	X		
Stellaria longipes Goldie. *s. str.*		X		
RANUNCULACEAE				
Caltha palustris L. var. *palustris*				X
Ranunculus aquatilis L. var. *capillaceus* (Thuill.) DC.			X	X
Ranunculus cymbalaria Pursh	X	X	X	X
Ranunculus gmelinii D.C. var. *hookeri* (Don) Benson			X	
CRUCIFERAE				
Barbarea orthoceras Ledeb.				X
Cochlearia officinalis L. ssp. *groenlandica*	X	X		
Rorippa islandica (Oeder) Borbas				X
SAXIFRAGACEAE				
Parnassia palustris L. var. *neogaea* Fern.		X		X
ROSACEAE				
Potentilla anserina L. *s. lat.*				X
Potentilla egedii Wormskj var. *groenlandica*	X	X	X	
Potentilla palustris (L.) Scop. var. *parvifolia* (Raf) Fern & Long.				X
Rubus acaulis Michx.				X
CALLITRICHACEAE				
Callitriche hermaphroditica L.				X
ONAGRACEAE				
Epilobium glandulosum Lehm. var. *adenocaulon* (Haussk.) Fern.				X
Epilobium palustre L.				X

HALORAGACEAE				
Hippuris tetraphylla L. f.	X	X	X	
Hippuris vulgaris L.				X
Myriophyllum exalbescens Fern.			X	X
UMBELLIFERAE				
Cicuta mackenzieana Raup				X
PRIMULACEAE				
Primula egaliksensis Wormsk.		X		
GENTIANACEAE				
Lomatogonium rotatum (L.) Fries spp. *rotatum*		X		X
LABIATAE				
Mentha arvensis L. var. *villosa* (Benth.) Stewart				X
SCROPHULARIACEAE				
Euphrasia arctica Lge.				X
Limosella aquatica L.			X	X
Rhinanthus borealis (Sterneck) Chab.				X
PLANTAGINACEAE				
Plantago juncoides Lam. var. *glauca* (Hornem.) Fern.		X		
RUBIACEAE				
Galium brandegei Gray				X
COMPOSITAE				
Achillea millefolium L. var. *borealis*				X
Aster junciformis Rydb.			X	
Chrysanthemum arcticum L.	X	X		
Senecio congestus (R. Br.) D.C.			X	X

Appendix B

SUMMARY OF SOIL CHEMISTRY FOR EACH SAMPLING STATION

Mean soil data for each sampling station along Sandspit (S), Akudlik (A) Esker (E) and Pumphouse (P) transects (Tr). Location (Loc) letters in sequence from the hydrolittoral to the epilittoral zone. organic matter (OM) salinity (ppt) (Salt) conductivity (dS m^{-1}) (Cond) sodium (ppm) calcium (ppm) magnesium (ppm) exchangable sodium percentage (ESP) sodium absorption ratio (SAR) potassium (ppm) nitrogen (ppm) phosphorus (ppm)

TR	LOC	Sand(%)	Silt(%)	Clay(%)	OM(%)	pH	Salt	Cond	Na	Ca	Mg	ESP	SAR	K	N	P
S	A	15.2267	65.9049	18.8685	4.3856	7.34000	6.03333	19.4667	3225.00	716.667	485.833	65.7056	131.684	313.200	0.6667	13.2400
S	B	26.3856	56.4209	17.1936	4.6095	7.26667	4.30000	16.4333	3591.67	210.500	435.000	74.3359	200.276	327.167	2.4667	13.6667
S	C	16.3534	66.4319	17.2147	5.7902	7.20000	3.60000	21.8667	3716.67	725.000	578.333	68.0860	146.507	375.000	1.8667	13.9667
S	D	9.2753	76.1587	14.5660	7.5901	7.31250	5.26667	17.9667	2470.60	253.500	404.000	64.3079	144.149	475.000	1.4333	16.7000
S	E	4.8264	82.5045	12.6691	8.9195	7.30000	4.40000	14.4000	2446.67	366.667	401.667	66.2949	141.243	590.167	1.6000	20.9000
S	F	10.3023	79.8965	9.8013	8.2758	7.31667	3.03333	16.8000	3016.67	342.167	425.000	71.1149	169.232	629.167	3.4667	28.7667
S	G	4.9778	81.8209	13.2013	8.5095	7.20000	2.71667	19.8000	4000.00	645.667	605.833	70.7756	166.054	609.667	3.2000	22.0000
S	H	7.2921	70.1151	22.5928	9.2216	7.20000	4.46667	14.0667	2460.00	321.333	387.500	67.6787	144.836	451.000	7.1333	10.0000
S	I	14.5559	68.2659	17.1782	13.2489	7.45000	4.15000	17.7000	2440.00	111.500	297.500	71.5065	172.332	640.000	2.2000	31.2000
S	J	10.4095	75.7444	13.8460	13.3111	7.30000	1.70000	12.9250	2300.00	95.333	242.500	72.1034	177.688	565.167	2.8000	20.8667
S	K	24.7457	49.1125	26.1418	11.1833	7.60000	0.70000	9.1667	1640.00	58.500	148.750	70.2742	162.110	415.750	3.5333	29.5500
S	L	3.3125	76.7818	19.9057	16.3493	7.15000	5.91667	17.5000	3126.67	354.667	481.667	69.6663	157.995	656.500	1.0667	24.9333
A	A	38.5259	46.1327	15.3414	2.9162	7.31667	3.95000	11.3667	2113.33	183.667	291.667	66.6533	139.198	299.833	2.5333	18.0667
A	B	15.9763	71.1419	12.8818	6.4986	7.20000	4.05000	13.6667	2423.33	133.667	299.167	70.8373	166.942	362.857	3.6667	21.5143
A	C	14.4610	63.7629	21.7761	7.0968	7.20000	3.80000	12.8333	2451.50	106.625	273.125	72.1619	178.000	447.000	2.2000	20.0000
A	D	7.0941	74.6939	18.2120	8.7355	7.25714	3.81667	10.9000	2235.00	92.750	230.000	72.0541	177.044	430.571	1.9000	24.8857
A	E	6.4343	73.2147	20.3510	7.1143	7.18333	5.00000	13.2000	2493.33	150.333	355.000	69.3798	156.484	439.167	4.6667	19.1333
A	F	8.6890	67.4800	23.8311	5.5225	7.22857	3.00000	10.3167	1797.50	117.625	236.875	64.3473	135.739	242.571	5.4000	13.0286
A	G	3.0479	80.5262	16.4259	14.0937	7.21667	3.65000	11.3333	2023.33	187.500	382.500	63.4069	120.341	499.500	1.8667	15.3667
A	H	2.4622	76.1660	21.3718	11.9109	7.31429	3.92000	15.4167	2416.00	141.200	363.500	69.1340	156.634	488.571	8.0000	29.0286
A	I	4.7882	71.3299	23.8819	11.8545	7.41429	3.10000	8.7500	1607.50	79.375	171.250	67.6628	143.889	380.286	6.1000	27.0857
E	A	40.3023	44.1238	15.5739	2.8043	7.51429	0.71667	3.6817	583.20	130.000	115.000	42.5791	52.521	121.714	3.8333	10.8286
E	B	36.3337	48.7250	14.9413	3.7174	7.41429	1.46667	5.3667	775.00	131.875	146.875	47.6047	64.493	121.143	2.6667	11.8571
E	C	11.5417	70.4641	17.9942	6.0648	7.35714	0.86667	3.5933	520.00	70.500	96.667	44.6510	56.630	217.857	5.0000	23.4571
E	D	23.4576	60.3373	16.2052	4.9663	7.45714	0.45000	2.9900	429.00	82.000	94.375	40.8894	49.275	162.000	2.3000	13.4571
E	E	10.8293	65.2877	23.8830	7.3487	7.27143	1.10000	5.2067	839.50	97.875	126.250	53.4283	80.829	261.000	4.1667	21.3429
E	F	7.3902	79.1603	13.4495	6.9464	7.54000	0.83333	4.2250	806.25	67.250	104.375	54.6746	85.228	252.800	5.4333	26.6400
E	G	12.7564	64.3411	22.9025	6.7295	7.34286	0.70000	4.3167	700.50	84.125	116.875	50.3247	69.979	173.571	4.9000	16.3429
E	H	12.9289	67.1825	19.8886	6.5098	7.40000	0.86667	3.7583	600.50	103.000	125.625	44.5487	55.959	235.286	5.0000	16.8286
P	A	70.6506	18.9241	10.4253	1.3155	7.27143	3.46667	11.9500	2085.50	483.375	353.125	58.5438	100.108	40.000	0.9333	5.1429
P	B	64.3422	23.9067	11.7511	1.7548	7.68333	0.00000	0.8967	117.00	63.000	28.333	19.5182	17.409	41.333	3.8000	10.2000
P	C	70.0569	15.8992	14.0440	1.6428	7.71667	0.00000	0.7867	41.33	75.833	44.167	6.1408	5.329	43.667	2.7333	8.4000
P	D	68.3545	18.9469	12.6986	2.3005	7.41667	0.16667	1.0633	38.67	119.333	46.667	4.6395	4.194	53.667	4.8000	8.6000
P	E	21.7431	56.0457	22.2112	9.4954	7.51667	0.00000	0.7600	15.00	99.667	35.833	1.3814	1.814	144.000	16.7333	15.2667