THE UNIVERSITY OF CALGARY

PRE- AND POSTSETTLEMENT PALYNOLOGY OF SOUTHERN ALBERTA

by

WAYNE L STRONG

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

DEPARTMENT OF GEOGRAPHY

CALGARY, ALBERTA

May, 1975

THE UNIVERSITY OF CALGARY

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Pre- and Postsettlement Palynology of Southern Alberta" submitted by Wayne L Strong in partial fulfillment of the requirements for the degree of Master of Science.

Dr. L.D. Cordes, Supervisor
Department of Geography

Dr. D.G. Smith
Department of Geography

Dr. L.V. Hills
Department of Geology

April, 1975

ABSTRACT

This study was undertaken to determine changes in the vegetation of southern Alberta since European settlement. Palynological and limnic sediment analysis of nine short cores show the impact of settlement on the vegetation. Secondary work with extra-regional pollen or wind transported pollen from long distance, indicates the carrying distance and volume of such pollen types.

An analysis of modern regional pollen spectra identified the four vegetation formations of the study area: 1) the Short Grass Prairie, 2) Mixed Grass Prairie, 3) the Groveland Belt of the Aspen Parkland, and 4) the Aspen Parkland proper. Subsequent analysis of presettlement pollen spectra identified the first three vegetation formations and a Fescue Grassland; however, their boundaries were not all located in the same areas as the modern vegetation. The Short Grass Prairie has expanded at the expense of the Mixed Grass Prairie. The Fescue Grassland is represented in modern times by the grassland component of the Groveland Belt of the Aspen Parkland, while the presettlement Groveland Belt has developed into the modern Aspen Parkland proper.

The expansion of the Short Grass Prairie has been attributed to increased grazing pressure, whereas the Aspen Parkland appears to have expanded as a result of fire control. The response individual types of plants were varied, but marked increaes were observed in Chenopodiaceae/Amaranthaceae and <u>Taraxacum</u>, <u>Selaginella densa</u> and <u>Artemisia</u> in the Mixed and Short Grass Prairie, and Cyperaceaes in the Aspen Parkland.

Study of the sediment grain sizes suggests a change in the mode of erosion. The Aspen Parkland showed statistically significant increases in sand and clay, indicating a change from wind erosion to water erosion, in the form of increased runoff. In contrast, the Groveland Belt sediments increased in silts, indicating greater wind erosion associated with the breaking of the prairie sod. The modern Mixed and Short Grass Prairie lake sediments tended to follow the trends of the Parkland proper, although not statistically different from presettlement sediments. This increase in sand and clay is thought to be the result of sparser vegetation allowing a larger runoff. This condition may have been brought about through increased grazing pressure and exposed mineral surfaces.

Pollen spectra were dominated by extra-regional pollen with *Picea*, *Pinus* and *Betula* composing from 40 to 80 percent of the pollen. The data indicates *Betula* and *Picea* could be carried 300 to 400 and 400 to 500 kilometers, respectively. Pinus could be transported by wind more than 1000 kilometers from its source, if a linear rate of decrease could be assumed. However, preliminary analysis indicates the decrease of pollen from its source occurs at a curvilinear rate.

In summary, settlement in southern Alberta has resulted in vegetation composition and formation changes with alterations in the mode and rates of erosion.

ACKNOWLEDGEMENTS

I would like to thank the following people for their assistance in the completion of this thesis. Drs. L.D. Cordes and L.V. Hills, who initially suggested the topic, provided many helpful comments, and loaned necessary field equipment.

Dr. Charles D. Bird, Department of Biology, allowed me to use an unpublished vegetation map of southern Alberta which depicts the present-day Aspen Parkland boundary.

Dr. Robert E. Bailey, Department of Biology at Central Michigan University, provided an unpublished pollen diagram from a settlement study in Indiana.

Mr. Charles Pilger assited in many ways and made necessary laboratory and field equipment available.

Mrs. Gillian Crowley edited the manuscript and Mrs. Florence Knight typed the final version.

I would especially like to thank Miss Kathryn Winterbottom, who assisted me in the coring of the lake sediments and patiently processed the pollen samples which were used in the eventual construction of the various pollen diagrams.

Also my friends who contributed in some way to the successful completion of this thesis: Joe Cathey, Peter Herrem, Shan Jones, Bev Thomson and Rod Thompson.

This study was supported through an Intersessional Bursary and Graduate Teaching and Research Assistantships from the Department of Geography under the direction of Dr. Mario B. Giovinetto.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Changes have occurred in the grassland vegetation of southern Alberta since European settlement, but questions exist as to the degree and type of change (Hardy, 1971). Little is known about the composition of the prairie prior to settlement. Early explorers kept few notes on plants, making the study of man's influence difficult (Warkentin, 1964). Other sources of information such as palynological or paleobotanical studies are limited or nonexistent. Knowing the composition of presettlement vegetation may allow a better understanding of man's effect on the "natural" environment.

Objectives

The objectives of this study are: 1) to determine, through the use of pollen analysis techniques, the major components of the grassland prior to European settlement; 2) to determine the spatial distribution characteristics of extra-regional pollen; and 3) to examine the composition and mineral texture of pre- and postsettlement limnic sediments.

Presettlement vegetation is defined as the "natural" vegetation prior to major European influences on the landscape. The principal plants occurring in the modern grassland probably composed the presettlement grasslands as well, but the proportions are unknown. It is known that exotic weed species have been introduced to Alberta (Bird and Halladay, 1971), but the response of native species to settlement can only be speculative.

Most pollen profiles contain pollen originating from outside the expected source region (50 to 100 kilometers). This pollen can create problems in interpretation and result in false conclusions. As grasslands have a distinctive type of vegetation, this allows for the separation of extra-regional (wind transported pollen from long distances) and regional pollen, providing clues to the distance of transport and volume of which such pollen types are carried.

It is hypothesized that changes in land-use and terrestrial vegetation have resulted in changes in the rate of production of organic sediments and in the grain size of sediment deposited. The increase in grain size and mineral input would be the result of sparser vegetation and increased exposure of the mineral surface, whereas increased organic productivity would be a response to nutrient input.

Observations of Presettlement Vegetation

Although many explorers traversed southern Alberta prior to settlement, John Palliser (1863) was one of the few who explored and inventoried the geology and vegetation. Mention is made throughout his journal and reports of unusual plants encountered and effects of fire and wildlife. However, specific notes on plant composition were lacking.

Palliser did recognize three vegetation formations: the "Palliser Triangle" or modern Short Grass Prairie which he described as a near desert; the true prairie or Mixed Grass Prairie; and the northern prairie or Fescue Grassland which was described as a rich area of grasses and *Carex* (Palliser, 1863). A more detailed botanical study was conducted by Bourgeau (Palliser, 1863). Commissioned to collect and identify plant species found in British North America, his collection numbered in the hundreds, but his publications consisted only of species lists. Other botanists, such as Macoun and Dawson, made extensive studies of prairie vegetation. However, few quantative values are available for comparison with modern vegetation (Macoun, 1882; Dawson, 1875).

After the late 1870's, changes in both flora and fauna were increasingly influenced by European ranchers and farmers in the region. Observations of the "natural" vegetation after this time period may not necessarily be representative since some important changes may have already taken place.

Palynological Review for Alberta and Related Presettlement Pollen Studies

Work using pollen analysis has been limited in southern Alberta. Hansen (1949 a,b), analyzed several bogs near Edmonton in central Alberta, attempting to study postglacial forests for the purpose of making paleoclimatic interpretations. Two of Hansen's conclusions were that the climate in postglacial times was drier and warmer in southern Alberta than the present, and that *Pinus contorta* was an important invasion species after deglaciation (Hansen, 1949 a,b). Hansen's work prepared the ground work for future study but little effort was spent until the 1970's.

The record of a full length, carbon dated core from central Alberta was published on Lofty Lake in 1970 (Lichti-Federovich, 1970). This core provided a continuous record from 11,400 years ago to the present, making it one of the more important contributions to pollen analysis in Alberta.

Since the publication of Lofty Lake's data, only three studies have been completed: Callum Bog, Alley (1972); Linnet Lake, Christensen and Hills (1971); and Goat and Lost Lakes, Bujak (1974).

Alley (1972) concluded from his work that the climate, at his particular site, had warmed and dried after deglaciation but reversed its trend approximately 5,000 years before the present (B.P.). Christiansen and Hills (1971), in studying the sediments of Linnet Lake (Waterton Lakes National Park), provided basic information on the paleoecology and vegetation history of the area. A major conclusion of this study was that Pinus contorta and fire were an intricate part of Waterton Park's history. Bujak's (1974) work indicated that a cooling and moistening of the climate occurred approximately 1,600 years B.P. She showed Picea engelmannii and Abies lasiocarpa were co-dominant, and added evidence to support Christiansen's and Hills' conclusions that fire has played an important role in Waterton Lakes National Park's history over a long period of time.

A considerable amount of work has been done outside Alberta using pollen analysis in North America. Many of these studies were concerned with the movement and depression of forests before, during and after glacial retreat and/or climatic interpretation.

Recent work by Webb (1973a,b,c) has taken a different approach from previous work. Webb, using short cores taken the mud-water interface, has been able to study presettlement vegetation, its spatial distribution, and man's effect after settlement (Webb, 1973a,b,c). In the lower peninsula of Michigan, Webb (1973b) demonstrated that since settlement a relative increase has occurred in herbs, Betula, Ulmus and Salix with decreases in Fagus, Acer and Tsuga, but concluded that the basic spatial patterns of pre- versus postsettlement vegetation were similar. Additional studies in Iowa and northern Wisconsin by Webb (1973a,b) and in Indiana by Bailey (unpublished data) had results showing similar changes in the vegetation, primarily increases in herbs: Ambrosia, Rumex and Chenopodium. Such studies illustrate man's influence on the environment, though little work has been conducted.

Another researcher, McAndrews (1967, 1968), has used early survey records and notes in addition to pollen stratigraphy to determine the presettlement vegetation pattern. However, such an approach is not possible if adequate records and notes are lacking.

CHAPTER II

STUDY AREA

The area under consideration is located in the southern portion of the province of Alberta (Figure 1). Alberta's eastern boundary serves as one border for the study area, whereas the remaining three sides are based on latitude and longitude: 49° 50' and 52° 30' north and 114° 15 west. Comprising approximately 98,000 square kilometers (40,000 square miles), the area can be described as a plain, grading from 600 to 1200 meters in an east-west direction. This slope influences climate and dictates the regional drainage pattern. The Bow, Oldman, Red Deer and Battle Rivers, all part of the Saskatchewan drainage basin, comprise the principle drainage system.

Bio-physical Environment

Three vegetation formations cover southern Alberta: the Short Grass Prairie, Mixed Grass Prairie and Aspen Parkland (Figure 1). Each of these formations is characterized by a particular soil type, climatic conditions and species composition. All show distinctive changes in the vegetation as a result of cultural use.

Geology

Situated in the Interior Plateau physiographic region, this province lies between the Canadian Shield and the Rocky Mountains. Geological strata within the study region dips gently southwest to west and is of Cretaceous and Lower Cenozoic age (Stalker, 1960). Paleocene

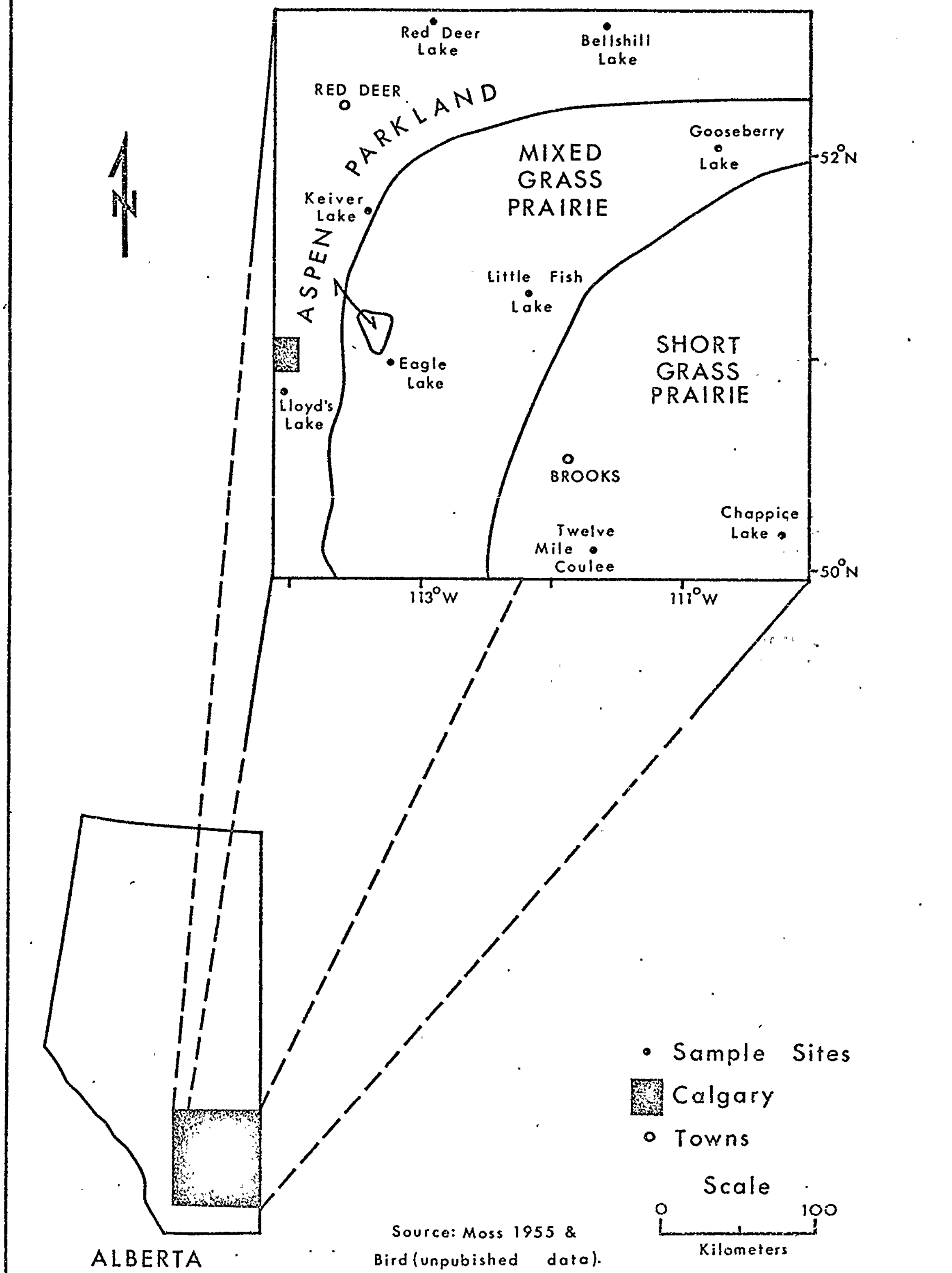


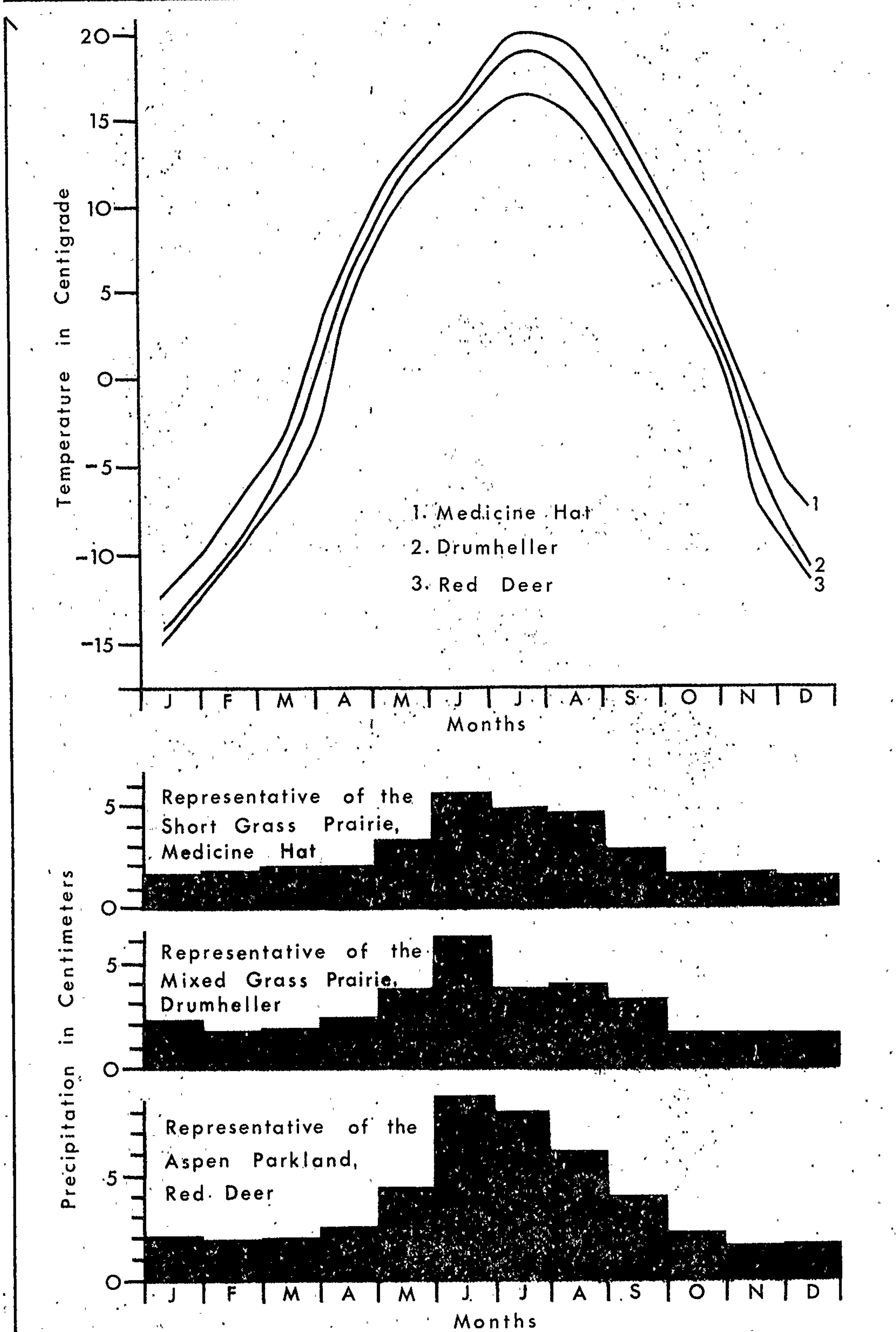
Figure 1: Study Area Location.

formations are found in the western portion of the study region, while older Cretaceous rocks are exposed in the eastern two-thirds, with both composed of alternation sandstone and shale beds. Overlaying the bedrock is glacial debris from Pleistocene glaciations that ended approximately 12,000 years ago. The area is predominantly covered with Laurentian glacial ice deposits, although the western fringe is Cordilleran (Glendinning, 1974). Laurentian ice movements occurred from north-northeast to south-southeast with Cordilleran ice moving from a north-northwesterly direction. Laurentian deposits, with many of these deposits dissected by meltwater channels (Douglas, 1970).

Climate

Koeppen's climatic classification system rates the Short Grass and Mixed Grass Prairie formations as "Bsk" or mid-latitude steppe climates which are semiarid and cool. The Short Grass Prairie receives approximately 25 to 36 centimeters of precipitation annually with most occurring during the summer months (Lodge et al, 1971). Maximum summer temperatures occur in July and August, two months after the maximum precipitation period (Figure 2). Late summer temperatures reach an average maximum of 20 degrees centigrade and when combined with low precipitation, a precipitation/evaporation ration (P/E) of 0.4 results, indicating a moisture deficiency. Such deficiencies are characteristic of grasslands and produce dormancy in the vegetation in late summer.

The Mixed Grass Prairie has a climate similar to the Short Grass, but precipitation is three centimeters greater, with average temperatures one degree centigrade cooler. The P/E ratio is also lower, ranging



Source: Environment Canada.

Figure 2: Mean Temperature & Precipitation

from 0.5 to 1.0 (Lodge et al, 1971). This slightly moister situation is the result of increased elevation reducing evaporation, thus making more moisture available for plant growth.

The Aspen Parkland has been classified as a "Dfb" climate or a humid continental climate with adequate moisture year around, short warm summers and severe winters (Critchfield, 1966). Precipitation ranges from 46 to 56 centimeters per year with 60 percent falling during the summer growing season (Figure 2). Annual temperatures parallel those experienced by the aforementioned vegetation formations, but are consistently lower year around. This combination of increased precipitation and lower mean temperatures is responsible for a P/E ratio of 1.0, indicating a balance between factors (Lodge et al, 1971).

The physical environment can modify moisture budgets through variations in aspect, exposure, and soil texture. North-facing aspects receive less solar radiation due to their protected position, resulting in less evaporation and increased available moisture. Aspen generally require moister conditions than that provided by the grassland environment, but can successfully colonize in microclimatic situations. This is evident in many areas of the Aspen Parkland.

Winds

Wind directions are controlled by atmospheric circulation patterns and pressure systems, and play an important role in the movement of pollen. Wind readings from Coronation, Calgary, Lethbridge, and Medicine Hat indicate the mid-latitude storm track determines wind directions in this region (Figure 3). Air masses moving from the Pacific High pressure

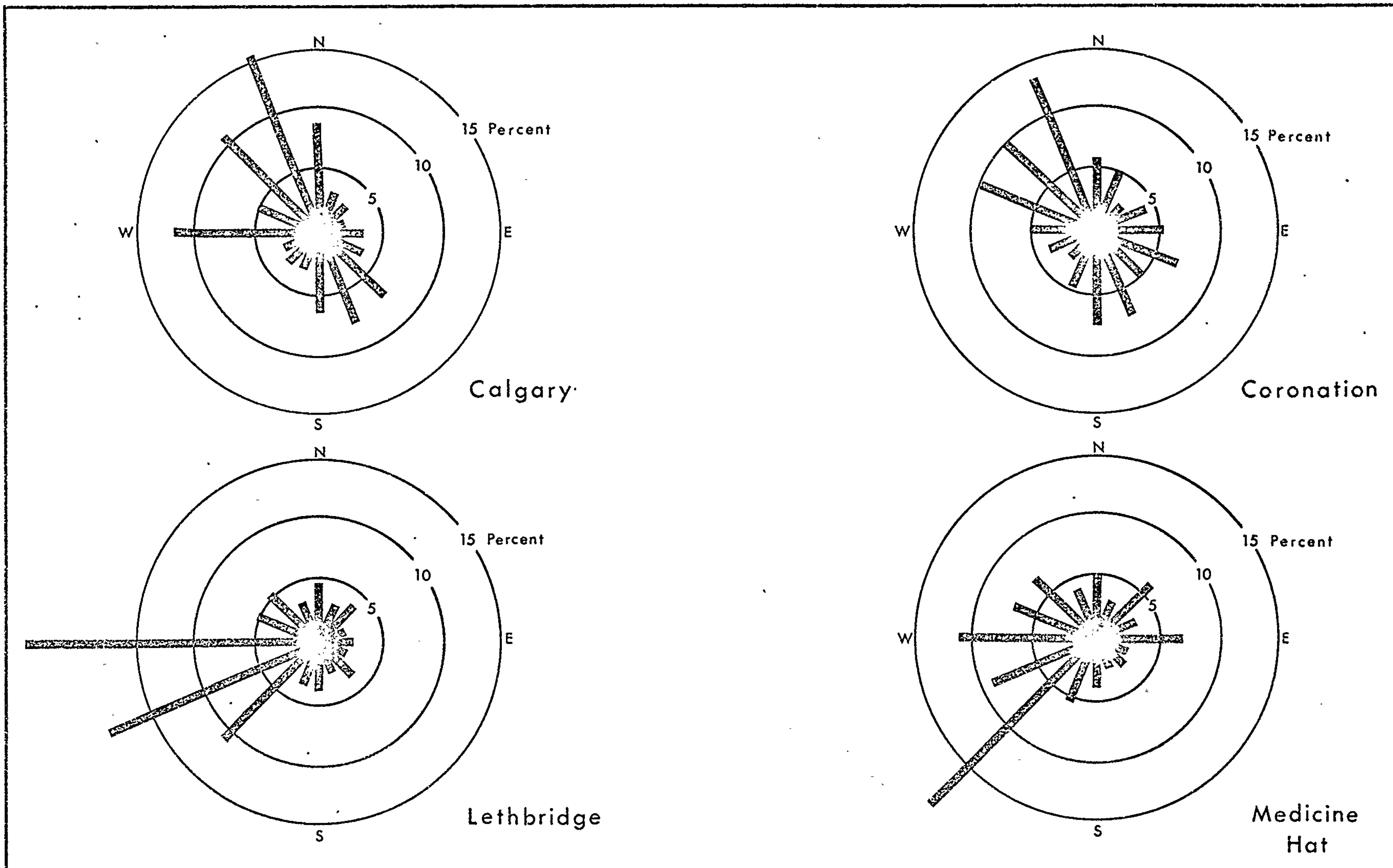


Figure 3: Summer Wind Directions.

system eastward, down the mid-latitude storm track, produce the majority of summer winds in the southern portion of this region. The majority of winds are from a westerly direction, but 54 and 40 percent of all winds at Lethbridge and Medicine Hat, respectively, are from a west to southwest sector (Department of Transport, 1968). Winds in the northern portion are primarily from a northwesterly direction. Calgary and Coronation both receive 40 percent of their winds from a sector on the west side of north to west. Air moving from the Polar High southward to the mid-latitude storm track is an important factor in producing these winds, with Calgary under the direction influence of winds moving over the Rocky Mountains.

Soils

Soils in this region, based on the Canadian Soils Classification System, are Brown, Dark Brown, and Black Chernozems, and correspond closely to the Short Grass Prairie, Mixed Grass Prairie, and Aspen Parkland formations, respectively. These soil types are very similar in their morphology except the darker soils are better developed in terms of depth which is controlled by available moisture. Four horizons are characteristic of Chernozemic soils: "Ah", "Bm", "Bt" or "Btj", "C" and occasionally a "Cca" (Canada Department of Agriculture, 1974).

An "Ah" horizon develops from the recycling of decayed organic matter by grasses near the surface of the soil. Less than 30 percent of the "Ah" is composed of organic matter, but this results in the high nutrient availability and cation exchange capacity that makes these soils very fertile. The annual water deficiency inhibits the development of an eluviated "A" horizon characteristic of most soils. The underlying "Bm" horizon is illuviated with developed prismatic structure and varying amounts of calcium carbonate. The quantity of and depth to which calcium carbonate is found within this horizon varies inversely with the precipitation/evaporation ratio. Under maximum conditions a caliche layer (Cca) develops beneath the "Bm" horizon (Foth and Turk, 1972). A second variation is the weak development of a clay horizon (Bt) at the base of the "B" horizon (Canada Department of Agriculture, 1974).

Chernozem soil degradation occurs in the southern fringe of the Aspen Parkland. The Black Chernozems developed under *Festuca* may become podzolized after *Populus tremuloides* is established in suitable microclimatic situations (Moss, 1955). Podzolization results from the moister and cooler conditions produced under the canopy of the *Populus* clone. Morphologically, these degraded Chernozems are similar to the true Black Chernozems, except an "Ae" horizon is developed and a slight reduction in alkalinity occurs (Canada Department of Agriculture, 1974).

Vegetation

1. Short Grass Prairie

The Short Grass Prairie and its species within the study area reflect the severe summer moisture deficiency present in this region (Figure 1, Table 1). *Bouteloua gracilis* and *Stipa comata* are the dominant vascular plant species, accounting for approximately 69 percent of the total herb cover. *Carex* (9 percent) and *Artemisia* (12 percent) comprise the majority of the remaining vegetation. *Selaginella densa*,

Table 1: Plant Composition in Percent

	Short Grass Prairie	Mixed Grass Prairie	Grassland Component of the Aspen Parkland
Agropyron	3	7	–
Anternaria	–	–	1
Artemisia	12	7	2
Aster	–	–	1
Bouteloua	52	25	–
Carex	9	15	23
Cerastium arvense	–	–	1
Festuca scrabrella	–	–	36
Koeleria	3	7	6
Phlox hoodii	2	4	–
Solidago missouriensis	–	–	1
Stipa	17	30	12
Selaginella densa	13*	15*	–*

– indicates a low percentage * percent ground cover not percent composition

Based on Coupland, 1950; Moss and Campbell, 1947.

a club moss, was not included in the determination of percent composition; the rationale being that this life form is different from the other grassland plants and thus uncomparable. Nine percent of the ground cover is occupied by this species which represents one-third of the total cover in this region (Coupland, 1950).

Stipa is a decreaser species, meaning it is eliminated by constant grazing, whereas *Bouteloua*, *Koeleria*, *Selaginella*, *Phlox* and *Artemisia* are increaser species (Smoliak, 1965; Lodge *et al*., 1971). Overgrazing of the Short Grass Prairie can result in the invasion of exotic weeds such as members of the Chenopodiaceae (Russian Thistle and Goosefoots) and Compositae (Goatsbeard, Gumweed, Dandelion, Canadian Thistle) (Wroe *et al*., 1972).

2. Mixed Prairie

The species composition of the Mixed Grass Prairie is similar to that of Short Grass Prairie, the dominant species being *Stipa* rather than *Bouteloua* (Table 1). Domestic grazing produces a decrease in *Stipa* and an increase of *Bouteloua* (Smoliak, 1965). Other responses are similar to those seen in the Short Grass Prairie.

3. Aspen Parkland

The most northerly and westerly vegetation formation in the study area is the Aspen Parkland (Figure 1). This formation represents a transitional zone between dry grassland to the south and more mesic boreal forests to the north. The Aspen Parkland formation can be subdivided into the Groveland Belt and Parkland proper, but the latter is a more mature stage.

The Groveland Belt is represented on the landscape by Populus tremuloides which occupies aspects and depressions where adequate moisture is available to sustain tree growth. Grasses such as Festuca scabrella form the matrix on dry and more exposed sites. Predominantly, the matrix is composed of grasses (65 percent) and Carex (23 percent), with herbs and shrubs occupying only a small percent of the total composition (Coupland, 1961) (Table 1).

Populus tremuloides dominates the wooded and clonal areas with secondary quantities of shrubs (Table 2). Bird (1930) suggested that these shrubs existed prior to the establishment of the Populus and provided a suitable environment for succession.

Table 2: Common Species Composing Wooded Patches and Depressions of the Aspen Parkland.

Populus tremuloides	Symphoricarpos occidentialis
Salix spp.	Elaeagnus argentea
Rosa spp.	Rubus strigosus
Galium boreale	Lathyrus ochroleucus
Solidago spp.	Anemone spp.

Based on Moss, 1932.

The expansion of Populus since settlement has been attributed to the elimination of bison and the control of prairie fires that restricted shrub community development (Bird, 1930).

The relative species composition changes when Festuca scabrella grassland is domestically grazed. Mowing results in the increase of Agropyron, Koeleria, Stipa, Carex and some forbs. Heavy grazing eliminates Festuca scabrella but hastens the expansion of Potentilla, Rosa, Artemisia, Carex and Lupinus (Moss and Campbell, 1947).

A small area located near the town of Red Dear in the northwest corner of the study area has been classified by Moss (1932) as a Populus area, now commonly referred to as the Aspen Parkland proper. The Aspen Parkland proper and Groveland Belt are similar in vegetative composition, except the Parkland Proper contains a greater proportion and a more continuous cover of Populus than the Groveland Belt (Moss, 1932).

Local and Regional Vegetation

The regional vegetation within the vicinity of a lake influences the pollen rain collected in limnic sediments as does the local or seral vegetation. In many situations the change from prairie vegetation to open water is abrupt, limiting the influence of the local vegetation. However, in the Aspen Parkland a much wider band of ecotone vegetation was observed.

The regional vegetation surrounding Twelve Mile Coulee, Chappice, Eagle and Little Fish Lakes was similar. A very narrow transition zone (less than one meter) existed between the lake and prairie vegetation. Twelve Mile Coulee and Eagle Lake possessed scattered patches of Typha latifolia and an occasional shrub bordering the lake, as did Little Fish and Chappice. The land use consisted of grain farming and grazing of native grasslands. The presence of Populus was an additional element in the area of Eagle Lake. The Chappice Lake vicinity was represented by extensive areas of grassland with approximately 20 percent of the land use for farming. The total quantity of agricultural land was greater in the Eagle Lake, Little Fish Lake, and Twelve Mile Coulee areas, although much of the area was still native grassland used for the grazing of cattle.

The Keiver Lake area was the most disturbed of the areas under consideration. Over 90 percent of the area surrounding the lake was used for grain farming with very little native prairie remaining. As the lake is part of the Aspen Parkland, the ecotone consisted of Populus and various shrubs.

Red Deer, Bellshill, Gooseberry and Lloyd's Lake were similar in regional vegetation and located in the Aspen Parkland or marginal to this formation. Populus in the areas of Gooseberry and Bellshill Lakes has invaded depressions and north facing aspects where adequate moisture is available for growth. Populus within these areas occupies approximately 20 percent of the landscape. Moss (1932) found Salix, Alnus, Rubus and Juncus were common genera within the ecotone areas of sloughs and depressions and would contribute to the pollen rain of these areas. In the vicinity of Lloyd's, Bellshill and Gooseberry Lakes, much of the land (less than 40 percent) was used for farming, with forested and native grassland occupying the remaining area. However, in the Red Deer area wooded Populus areas were more predominate and extensive than grassland.

In most situations, the local or ecotone vegetation is not an important component of the vegetation, except in the Aspen Parkland where Populus occupies ecotone situations and is thus an important constituent.

Settlement

Europeans first entered Alberta in 1754 with the Henday expedition (Warkentin, 1964). A period of exploration and fur trading existed in the prairie from this time until the mid-1870's (Bird, 1961). Although fur trading predominated, farming and grazing were scattered throughout the study area during the latter part of this period (MacGregor, 1972). These activities probably produced few changes in the "natural" vegetation. However, the elimination of the bison from 1860 to 1878 and the development of the Canadian Pacific Railroad in the early 1880's, may have aided in changing the vegetation through the removal of a natural grazer and by increased settlement (Nelson, 1973; Gershaw, 1956). The elimination of bison and the slow encroachment of agriculture may also have allowed the grasslands to develop a lusher vegetation than would be normally expected. Nelson (1973) illustrates this point,

> "Many early ranchers and settlers in the grasslands and parkland ... remarked on the richness and length of the grass, which some said reached 'the horse's bellies' " (p. 139).

This extract is in contrast to the description by Palliser in 1857 which indicates the grass was heavily grazed (Nelson, 1973).

Following the completion of the railroad, grazing and grain farming became increasingly important (MacGregor, 1972). By 1906, the western half of the study area had been settled, and during the 1910's agriculture advanced into the eastern portion, but later declined (MacGregor, 1972). It appears the study area by this time was largely under the control of European settlers. Much of the prairie had been broken by the plow and large areas of native grass were grazed by cattle.

CHAPTER III

METHODS

The initial problem of the study was the collection of sediment that contained preserved pollen. Only limnic sediments from permanent lakes were used. The length of time the lakes under study continuously contained water may be questiond, but based on interviews with local residents as well as map and aerial photograph interpretation, they appear to have contained substantial amounts of water for at least 50 years. Additional criteria used in selecting sample sites was: the depth of water, indications of disturbance, and the presence of preserved pollen. Deep lakes (over nine meters) could not be cored from the water surface, whereas shallow waterbodies (less than 1.5 meters) were avoided for reasons of possible sediment disturbance. Lakes containing coarse textured sands were not used because of associated poor polynomorph preservation.

Nine lakes were selected to study the pre- and postsettlement vegetation pattern. A minimum of two sites were located within each vegetation formation. Nine lakes may appear too few to study such patterns, but it has been estimated that regional pollen originates within 50 to 100 kilometers of its deposition site (Davis and Goodlet, 1960). This suggests large portions of each formation will be represented by the lakes under study.

Field Methods

Coring or sampling of lake sediments involved using a hand operated Livingston stationary piston sampler. Samples were taken from the central portion or deepest area in the lake basin, with these two factors normally coinciding. Seventy-five centimeters was the maximum penetration depth of the sampler, although much more sediment existed. Once filled, the core barrel was held in a vertical position to avoid stratigraphic disturbance until frozen. Freezing was accomplished by surrounding the core barrel with dry ice (solid CO_2) that froze the sediment quickly. Freezing by dry ice appears to produce less disturbance from ice crystal formation than conventional freezing methods which are much slower, and produce ice crystals that displace the sediment, destroying the stratigraphy. After freezing the core was extruded, wrapped and refrigerated.

Laboratory Methods

Palynomorph Processing

A relative time series was produced by subsectioning individual cores into one centimeter slices, starting from the mud-water interface and proceeding down the core. These subsections were used as stratigraphic units and provided the basis for analysis of sediment, pollen and texture.

Processing of palynomorphs involved the removal of one cubic centimeter sample from each stratigraphic level. Palynomorphs were then concentrated by the chemical elimination of excess organic matter,

Table 3: Palynomorph Processing Procedure.

Step	Chemical	Time	Hot Water Bath	Stir	Centifuge	RPM's
1.	Potassium hydroxide	6 minutes	X	X	4 minutes	3800 ± 5%
2.	Hydrochloric Acid	(-)	X	X	4 minutes	3800 ± 5%
3.	Hydrofluoric Acid	(-)	X	X	4 minutes	3800 ± 5%
4.	Hydrochloric Acid	10 minutes	X	X	4 minutes	3800 ± 5%
5.	Glacial Acetic Acid			X	4 minutes	3800 ± 5%
6.	Acetolysis Solution	60 seconds	X	X	4 minutes	3800 ± 5%
7.	Glacial Acetic Acid			X	4 minutes	3800 ± 5%
8.	Calgon Solution*			X	45 seconds	2700 ± 5%
9.	Water and Safrain θ			X	4 minutes	3800 ± 5%
10.	Water					

(-) continued until mineral is removed

* repeated as needed.

carbonates and silicates through the use of potassium hydroxide and acetolysis solution, followed by hydrochloric and hydrofluoric acid (Table 3). This procedure was followed by differential centrifuging that removed excess organic matter. Safrain θ was added as the final step to stain and improve the visibility of the individual grains and their structure.

Counting slides were prepared by placing a small quantity of pollen residue on 22 X 40 milimeter coverslips with Evanol, mixing thoroughly, and spreading over the entire coverslip surface. After drying, coverslip was inverted and bonded to a 25 X 100 milimeter microscope slide with Lakeside 70. These slides provided the basic information for pollen analysis. A preset number of 400 pollen grains and spores were identified at each stratigraphic level examined, except for very sparse levels where 200 grains were counted.

Identification of pollen and spores were to the family level for difficult to separate types such as Gramineae, Cyperaceae, Chenopodiaceae/ Amaranthaceae and Polypodiaceae, but most were taken to genus.

Pollen Diagram Construction

A pollen profile is a diagram indicating regional pollen percentages in relationship to depth or time. Included within the pollen counts under consideration are local, regional and extra-regional (wind transported from long distances) pollen. To obtain a more representative picture of the true vegetation, local and extra-regional pollen were excluded from the percentage calculations (Wright and Patten, 1963) as in Formula 1:

Formula 1:

$$PPV = \frac{Xj}{\Sigma X} * 100.$$

PPV = Percent Prairie Vegetation
Xj = Number of Pollen Grains for each Prairie Pollen Type.
ΣX = Total Number of Prairie Pollen Grains and Spores.
j = 1, 8 or each Pollen Type.

To illustrate other pollen types, percentages were calculated on the total number of grains counted at each stratigraphic level (Formula 2).

Formula 2:

$$PEP = \frac{Yj}{\Sigma Y} * 100.$$

PEP = Percent Extra-Regional and Local Pollen.
Yj = Number of Pollen Grains per Type.
ΣY = Total Number of Pollen Grains and Spores Counted at Each Stratigraphic Level.
j = Each Individual Pollen Type.

The exclusion of these pollen types from the regional pollen rain can be justified as they are not representative and obscure the regional pollen which is more important. Extra-regional pollen sometimes composes from 30 to 60 percent of the pollen counted.

Regional pollen was selected by analyzing vegetation studies characteristic of Prairie vegetation, identifying habitat and geographic ranges (Moss, 1959) (Table 4).

Absolute pollen frequencies or grains per cubic centimeter were determined by adding a known quantity of *Eucalyptus* pollen to each stratigraphic level prior to processing (Formula 3).

Table 4: Major Identified Pollen Types.

Regional Pollen	Extra-Regional and Local Pollen
Ambrosia	Alnus
Artemisia	Betula
Chenopodiaceae/Amaranthaceae	Monoletes
Cyperaceae	Picea
Gramineae	Pinus
Populus	Salix
Taraxacum	Elaeagnus
Triletes	

Formula 3:

$$Yj = \frac{\Sigma X}{\Sigma Yj} * Nj$$

Yj = Number of Grains per Cubic Centimeter.
ΣX = Total Number of Exotics Added.
ΣYj = Number of *Eucalyptus* Counted at each Stratigraphic Level.
Nj = Number of Pollen Grains Counted per Type at Each Level.
j = Each Individual Pollen Type.

This method functions as an independent method of determining the absolute number of pollen grains per cubic centimeter, irrespective of other pollen types (Bonny, 1972).

Sediment Analysis

Volumetric samples (1 - 2 cc.) for determining percent organic matter and carbonate content were removed from each stratigraphic level and oven dried at 105° centigrade. Organic constituents of the sediment were removed by igniting the samples in a muffle furnace for one hour at 550° centigrade. Subsequent burning at 950° centigrade for two and a half hours resulted in the loss of carbon dioxide held chemically bonded to carbonates. The weight loss due to carbon dioxide removal was then multiplied by 2.273 to compensate for the weight of calcium and magnesium which were not removed by burning (Bailey 1972 and personal communication, Frey 1960).

Non-organic constitutents of limnic sediments were textured for grain size by pipette mechanical analysis (Kilner and Alexander, 1949). Samples for mechanical analysis were prepared by extracting a constant volume of sediment from each stratigraphic level above and below the settlement rise. Levels were then combined to form a pre- and post-settlement sample for each lake with an equal number of levels in each sample. Organic components were eliminated by submerging samples in hydrogen peroxide. A twenty gram dry, organic free sample was measured and combined with ten mililiters of 38 percent Calgon solution, which was mixed thoroughly with 1000 mililiters of distilled water in a measuring cylinder.

The proportion of different grain sizes was determined by taking two 25 mililiter samples for a liquid suspension as described by Kilner and Alexander (1949) at present depths and time intervals: 46 seconds for silt and clay (0.5 - 0.002 mm in diameter) and 8 hours for clay (less than 0.002 mm in diameter). After oven drying, the percent sand, silt and clay was calculated by subtracting the Calgon residual weight from each sample, the weight of clay from sample one, and dividing the final weight of each sample by 0.005. This fraction represents one percent of the mineral matter when subdivided into 40 parts of the original 1000 mililiter liquid suspension (i.e. $((20 \div 100) \div (1000 \div 25)) = 0.005$).

Statistical Methods

Cluster Analysis

Cluster analysis is a statistical method for grouping sets of variables. Ward's (1963) Error Sum of Squares method was used as the technique for grouping and can be generally described as the grouping of sets of variables that produce the least error when combined (Formula 4):

$$\text{Formula 4:} \quad \text{Error Sum of Squares} = \Sigma\,(X_i^2) - \frac{1}{n}\,(\Sigma X_i)^2$$

X = the variables
N = number of variables

Once sets of variables were paired, the mean of each variable was used to represent that newly formed group. Grouping was continued until all sets of variables were combined to form one cluster (Everitt, 1974). However, unless all sets of variables are identical, the error produced by clustering will increase as clusters are formed. Variables that were mathematically similar produced low quantities of error when grouped, and clustering was stopped when the error became excessive. This cut-off point can be evaluated graphically by plotting the groupings and error; where a sharp break occurs clustering is stopped. If the error does not increase sharply, the selection of the break point may be subjective, but under the existing situation this was not a problem.

Trend Surface Analysis

Trend surface analysis is a technique for determining the general direction of flow or pattern of spatially distributed variables. Three variables were used in the quadratic analysis of extra-regional pollen: 1) an X coordinate, 2) a Y coordinate, and 3) a pollen percentage for the location marked by the X and Y coordinates. By solving for the parameters, a, b_1, b_2, b_3, b_4 and b_5, a regression model (Formula 5), a regression coefficient (r), and coefficient of determination (r^2) were determined.

Formula 5:

$$X = a + b_1Y + b_2Z + b_3Y^2 + b_4YZ + b_5Z^2$$

X - Coordinate
Y - Coordinate
Z - Pollen Percentage
a - Y intercept
b_j - Slope j = 1,5

Chorley and Haggett, 1968.

The coefficients "r" and "r^2" were used to indicate the degree of explanation produced by the three variables, X, Y and Z. The validity of such an analysis was then tested by an F ratio (Formula 6).

Formula 6:

$$\frac{\text{Sum of Squares Due to Regression*}}{\text{Sum of Squares Due to Residues*}} = \text{Calculated F ratio}$$

* These are interchanged so the largest occurs as the numerator.

If statistically significant, the calculated F ratio exceeds the expected F value which was determined from an F Ratio Table.

t - Statistic Test

A t - statistic test was used to determine if a significant difference existed between pre- and postsettlement pollen deposition rates. Formula 7 represents the method used for calculating the t - statistic.

Formula 7:

$$t - \text{statistic} = \frac{S_x^2}{n_x} + \frac{S_y^2}{n_y}$$

S^2 = variance
x = a variable
y = a variable
n = number of variables in each set

(Freund, 1967).

To test for significance of the t - statistic, the number of degrees of freedom ($n_x + n_y - 2$) were determined and compared with a t - value at $\alpha_{0.025}$ level. If the t - statistic exceeded the t - value the two samples were considered statistically different.

CHAPTER IV

LIMNIC SEDIMENTS

Limnic sediments are the result of an accumulation of organic and inorganic materials. Clastic sediments originating from the action of wind and water are the most frequently encountered inorganic component of sediment. Streams and runoff are frequent movers of clastic material which is transported mechanically as bedload, in saltation or in suspension. Coarse clastics are lost immediately when a standing water-body is entered, but finer materials are carried until they settle to the bottom in deeper, quieter waters. Clays are the last to settle and are carried furthest from the source. Dissolved carbonates and salts are carried in solution and become incorporated into the sediment when a saturation point is reached in the solute, forcing excess quantities to be precipitated (Krumbein and Sloss, 1963). Winds aid in the accumulation of sediment by picking up loose minerals from the ground surface and carrying them directly to a lake basin. Silt is the predominant grain size moved by wind, though lesser quantities of other separates may be moved.

Organic matter is contributed to the sediment annually as a result of seasonal plant cycles. The type of plants found in an aquatic environment range from vascular to micro-organisms but all eventually become incorporated into the sediment. The productivity of a lake is a function of available nutrients and suitable growing conditions. Organic decomposition itself adds nutrients for additional plant development (Allen and Kramer, 1972).

Lake Dimensions

Lake size and depth varied between lake basins (Table 5). Water depths ranged from 1.8 to 7.2 meters in the central portions of the lake basins. However, measurements were taken during early summer and seasonal variations may result in fluctuating depths. Surface drainage which maintains the water level is restricted to local surface runoff, except Twelve Mile Coulee which is stream fed. Lake size based on contour map calculations ranged from 0.7 to 14.0 square kilometers. All lakes except Red Deer were less than 5.8 square kilometers in area.

Sediment Composition

Organic Content

Organics comprised from 0.3 to 1.3 percent by weight of the sediment. However, the low bulk density of organic matter produces a misconception: by volume, organic matter would represent between 10 and 15 times its weight. In many samples, the organic component was fine algal matter that formed a matrix around minerals which predominated in most sediments. Twelve Mile Coulee and Lloyd's Lake were exceptions to this general statement. These two lakes contained abundant multicellular aquatic plants that were well represented in the sediment. Reducing conditions, represented by dark bluish - black sediments which oxidized to a grayish color, suggest that the preservation of organic matter was high due to a limited oxygen supply.

The quantity of organic matter present in the sediment has decreased since settlement (Table 6). Several possible factors may

Table 5: Lake Site Characteristics

Lake	Location	Vegetation Formation Based on Moss, 1955.	Area in Square Kilometers	Water Depth in Meters
Bellshill	52°36'N 111°33'W	Groveland Belt of the Aspen Parkland	2.2	1.8
Chappice	50°10'N 110°23'W	Short Grass Prairie	1.4	2.7
Eagle	51°00'N 113°18'W	Mixed Prairie (or Groveland Belt of the Aspen Parkland)	5.8	3.9
Gooseberry	52°08'N 110°45'W	Mixed Grass Prairie	2.4	2.6
Keiver	51°42'N 113°34'W	Marginal Mixed Grass and Aspen Parkland Groveland Belt	0.7	1.8
Little Fish	51°23'N 112°15'W	Mixed Grass Prairie	5.2	7.2
Lloyd's	50°53'N 114°10'W	Aspen Parkland	1.4	2.1
Red Deer	52°44'N 113°05'W	Aspen Parkland Proper	14.0	4.8
12 Mile Coulee	50°08'N 111°55'W	Short Grass Prairie	1.2	2.0

Table 6: Percent Limnic Sediment Composition and Changes Since Settlement

	Carbonate Content			Organic Content			Grain Size								
							Sand			Silt			Clay		
	Pre-	Post	% Change	Pre-	Post	% Change	Pre-	Post	% Change	Pre-	Post	% Change	Pre-	Post	% Change
Aspen Parkland															
Bellshill Lake	2.00	1.08	-46	0.65	0.54	-17	65.7	39.0	-28.5	16.5	45.3	+28.5	16.0	15.7	-0.3
Eagle Lake	1.30	0.86	-34	0.33	0.44	+33	73.0	47.6	-25.4	16.9	37.3	+20.4	10.1	15.0	+4.9
Keiver Lake	1.20	0.47	-61	0.45	0.29	-36	42.5	22.8	-19.7	27.9	59.2	+31.3	29.5	18.0	-11.5
Lloyd's Lake	2.10	1.20	-43	1.10	0.73	-34	12.1	12.3	+ 0.2	67.6	65.9	- 1.7	20.3	21.8	+ 1.5
Red Deer Lake	2.00	1.30	-38	0.30	0.24	-20	19.1	31.5	+12.4	70.1	52.4	-17.7	10.8	16.1	+ 5.3
Mixed Grass Prairie															
Gooseberry Lake	Confused by salt			Confused by salt			2.0	8.4	+ 6.4	61.9	36.2	-25.7	36.1	55.4	+19.3
Little Fish Lake	0.06	0.03	-50	0.37	0.32	-14	51.0	63.0	+12.0	36.1	24.3	-11.8	12.8	12.7	- 0.1
Short Grass Prairie															
Chappice Lake	1.95	1.08	-39	0.82	0.65	-21	75.3	81.7	+ 6.4	10.0	4.5	- 5.5	14.8	13.8	- 1.0
Twelve Mile Coulee	0.50	0.18	-7.5	0.67	0.62	-8	29.9	31.2	+ 1.3	18.7	55.1	+36.4	51.4	13.6	-37.8

- indicates a decrease in volume
+ indicates an increase in volume

Percent change in Grain Size was determined by subtracting Postsettlement from Presettlement Percentage.

explain this decline: an increased inorganic sedimentation rate, and a constant rate of organic production; an increased inorganic input but with a much higher rate of sedimentation of inorganics; or the rate of organic production has decreased while the inorganic input has remained similar. The second possibility seems the most plausible. Eagle Lake is the only site which did not show to a decreased organic content. It may represent an increased rate of organic input, although the inorganic input may be higher than in presettlement times as well.

Carbonates

The quantity of carbonates present in the limnic sediment has decreased since settlement (Table 6). Carbonates are significant in the nutrient cycle of aquatic plants and represent one of the easier to measure nutrients (Carpenter, 1928). This compound is poorly represented within the sediment, composing a maximum presettlement content of two percent by weight. Other studies in the eastern United States show limnic sediments have a carbonate content of 20 to 30 percent (Fast and Wetzel, 1974; Murray, 1956). The low quantity in Alberta may be the result of less of solution action due to reduced precipitation. A decline in carbonates is evident in all lakes under study, with carbonate content following the same pattern of decrease as organic matter.

Clastic Content

Marked changes have occurred in the texture of limnic sediments, although this has not affected the total quantity present. All nine lakes cored contained a mineral content of not less than 97 percent by weight, with quartz the dominant mineral.

Mixed Prairie Lakes, Little Fish and Gooseberry show increases in sand since settlement (Table 6). This increase may be associated with sparser vegetation which would allow increased runoff. Gooseberry Lake may follow more closely the trends of Little Fish Lake, but the pipette results are influenced by a high salt content in the sediment.

The two lakes within the Short Grass Prairie, Chappice and Twelve Mile Coulee, exhibit increases in medium and coarser grain sizes since settlement. Presettlement sediments in Twelve Mile Coulee contained 51 percent clay, whereas postsettlement contained only 14 percent. The higher presettlement clay content originated from suspended stream load carried by Twelve Mile Creek, but with settlement and the development of an irrigation system that empties into Twelve Mile Coulee, the size of material deposited increased. Postsettlement sediments are composed of silts and lesser quantities of sand.

Bellshill, Keiver and Eagle Lakes, all located in the Groveland Belt of the Aspen Parkland, show increases in the silt content ranging up to thirty percent higher than that in presettlement sediments (Table 6). A change from water to wind erosion, associated with the breaking of land and the resulting increased mineral exposure, may account for this change. Silt showed the greatest increase and is the most frequent separate carried by wind (Pecsi, 1968).

Both Red Deer and Lloyd's Lakes have had an increase in sand and clay since settlement began. Prior to settlement, these areas possessed approximately 55 percent silt, indicating water erosion has replaced wind erosion in these particular areas.

Evidence for an Increased Sedimentation Rate

Evidence that indicates an increased sedimentation rate since settlement is varied. If a constant rate of pollen production and deposition existed in the study area, changes in the number of grains per cubic centimeter should indicate changes in the sedimentation rate. All the lakes within the Aspen Parkland, except Lloyd's Lake, show statistically significant decreases in the number of pollen grains per cubic centimeter. This indicates an increased sedimentation rate. This change in sedimentation rate is illustrated by the pollen deposition rates of Keiver and Red Deer Lakes (Figure 4). Sedimentation rates of lakes in the Mixed and Short Grass Prairie may have also changed, but not substantially. The sedimentation rates of Red Deer and Keiver Lakes appear to have increased by 100 to 150 percent, whereas Bellshill and Eagle Lakes have only increased by 35 and 15 percent, respectively. These different rates of increase may be directly related to the quantity of exposed mineral surface within each area.

Changes in the deposition rate and mode of sediment transport have also produced proportional decrease in the carbonate and organic components. For example, the carbonate content of postsettlement sediments has decreased by half as the result of an apparent doubling of the sedimentation rate. This increased sedimentation rate may have been the result of a change from water to wind erosion. However, changes in sedimentation rates can not be positively proven without accurate dating.

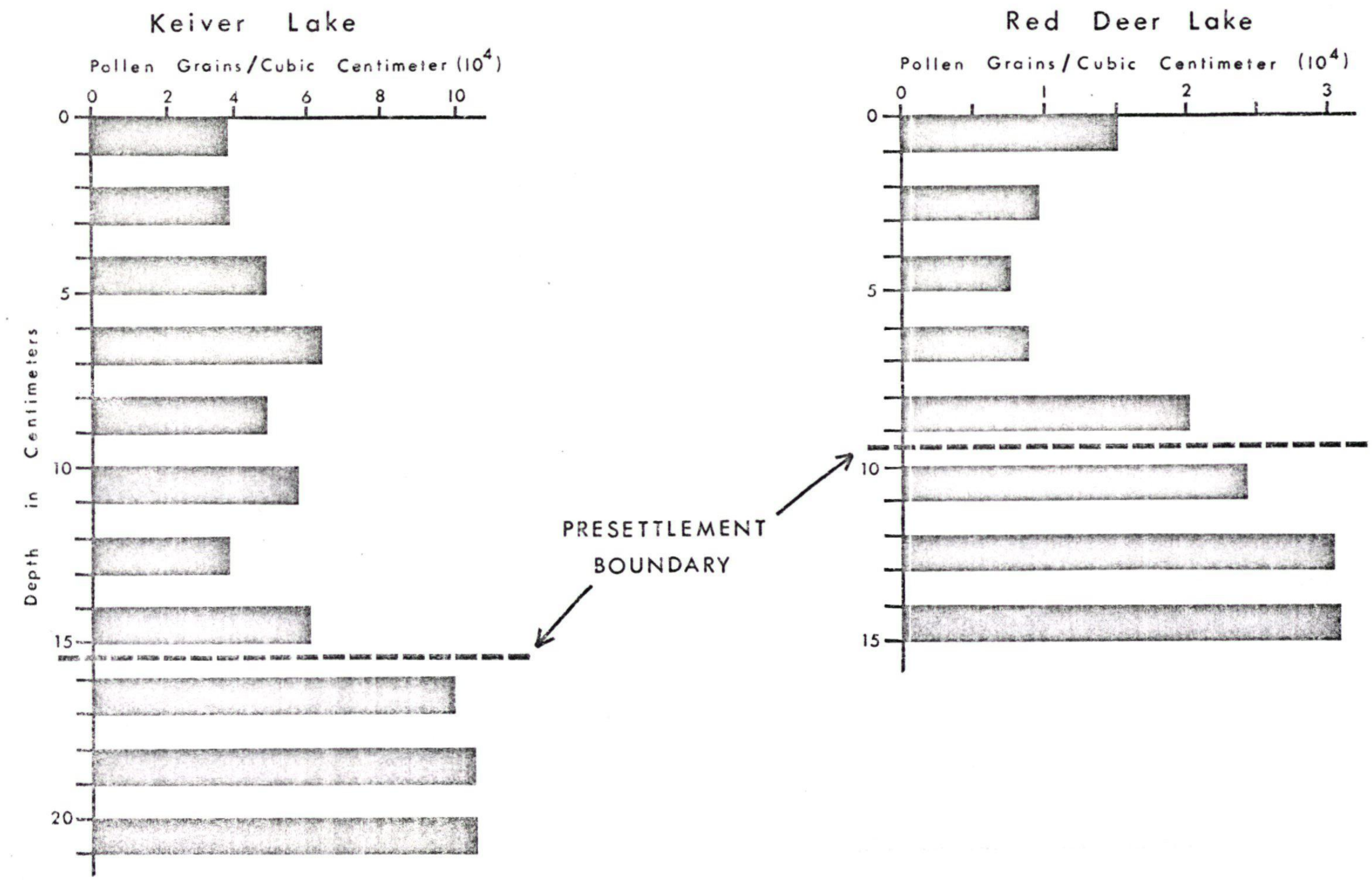


Figure 4: Pollen Deposition Rates.

CHAPTER V

EXTRA-REGIONAL POLLEN

Wind transported pollen is a common phenomenon and essential for palynological studies, but when carried beyond the area that it represents, problems are created. This is referred to in this paper as extra-regional and can be defined as wind transported pollen originating outside the expected source region. The problems created are those of interpretating the pollen spectrum and vegetation; however, if pollen were not transported by wind, pollen sequences would be very limited.

Few studies have been directed toward the examination of extra-regional pollen or its carrying distance. During the early 1900's European workers showed that certain pollen types were capable of being carried long distances (Faegri and Iverson, 1966). Recently, McAndrews and Wright (1969) analyzed pollen samples collected along two transections, from the Rocky Mountains eastward, and suggested _Pinus_ was capable of being carried to a distance of 300 kilometers at a volume of 20 percent. Ritchie and Lichti-Federovich (1967), in their study of pollen spectra of the Arctic and Subarctic regions of northern Canada, observed _Quercus_, _Jugulans_ and other deciduous forest pollen types. As these species are not normally found in these regions it indicates pollen can be transported long distances. However, Andersen (1967) found the majority of deciduous tree pollen was restricted to the local forest.

A better knowledge of the distance travelled by extra-regional pollen and the volume carried may aid in producing a clearer picture of fossil pollen spectra. An attempt was made to describe or model the extra-regional pollen rain by trend surface analysis (See Chapter III). This analysis proved not to be statistically significant as a result of too few sample sites. However, a description of the results is appropriate and provides some basis for future work on the subject.

Extra-regional Pollen Types

Extra-regional pollen is usually produced by anemophilous pollinators which transfer pollen by wind, as opposed to entomphilous pollinators which are dependent on insects and hence less commonly transported long distances by wind. Anemophilous pollinators are characteristically prolific pollen producers with grains adapted to wind transfer.

The lakes under consideration contained from 40 to 80 percent extra-regional pollen. Pinus, Picea and Betula were the major contributors with Pinus dominating over the others in volume deposited. These three pollen types should be accurately represented spatially due to similar sediment types and good preservation qualities (Faegri and Iverson, 1966).

Pinus, Picea and Betula composed, respectively, a maximum of seventy, nine and three percent of the extra-regional pollen in surface samples. All three species tend to decrease as they move out from their sources. Source directions, in relationship to the study area, are west and northwest for Pinus and Picea and west for Betula. Picea (glauca and englemannii) appears to decrease at a rate of approximately 30 percent of its volume per hundred kilometers, whereas Betula decreases at a rate of approximately 25 percent of its volume per hundred kilometers. Pinus (contorta) appears to have the greatest carrying capacity, with a fallout rate of approximately 10 percent of its volume per hundred kilometers. The significance of these carrying rates is in the distances the pollen grains can be transported. By using Formula 8, as follows, these rates of decrease can be extended to discover the potential carrying distance.

Formula 8:

$$\text{Potential Carrying Distance} = \frac{100 \text{ percent}}{\text{Carrying Rate in Percent}} * \text{100 Kilometers}$$

Thus, Picea, Betula and Pinus should be carried a minimum distance of 300 to 400, 400 to 500, and 1000 kilometers, respectively. Figure 5 graphically illustrates the carrying distances of these three types, based on distance and rate of loss. The graph assumes the relationship between these variables is linear, although it is probably a curvilinear function.

McAndrews and Wright (1969), in their study of wind transported pollen, showed results similar to those above. However, in the present study lower rates of fallout were observed for Pinus and higher for Picea than those found by McAndrews and Wright.

Observed Pollen Carrying Rates

As anemophilous pollen types are carried further from their source, a general trend of decreasing extra-regional pollen is evident. Rates of decrease are not consistent within this study, and may be the

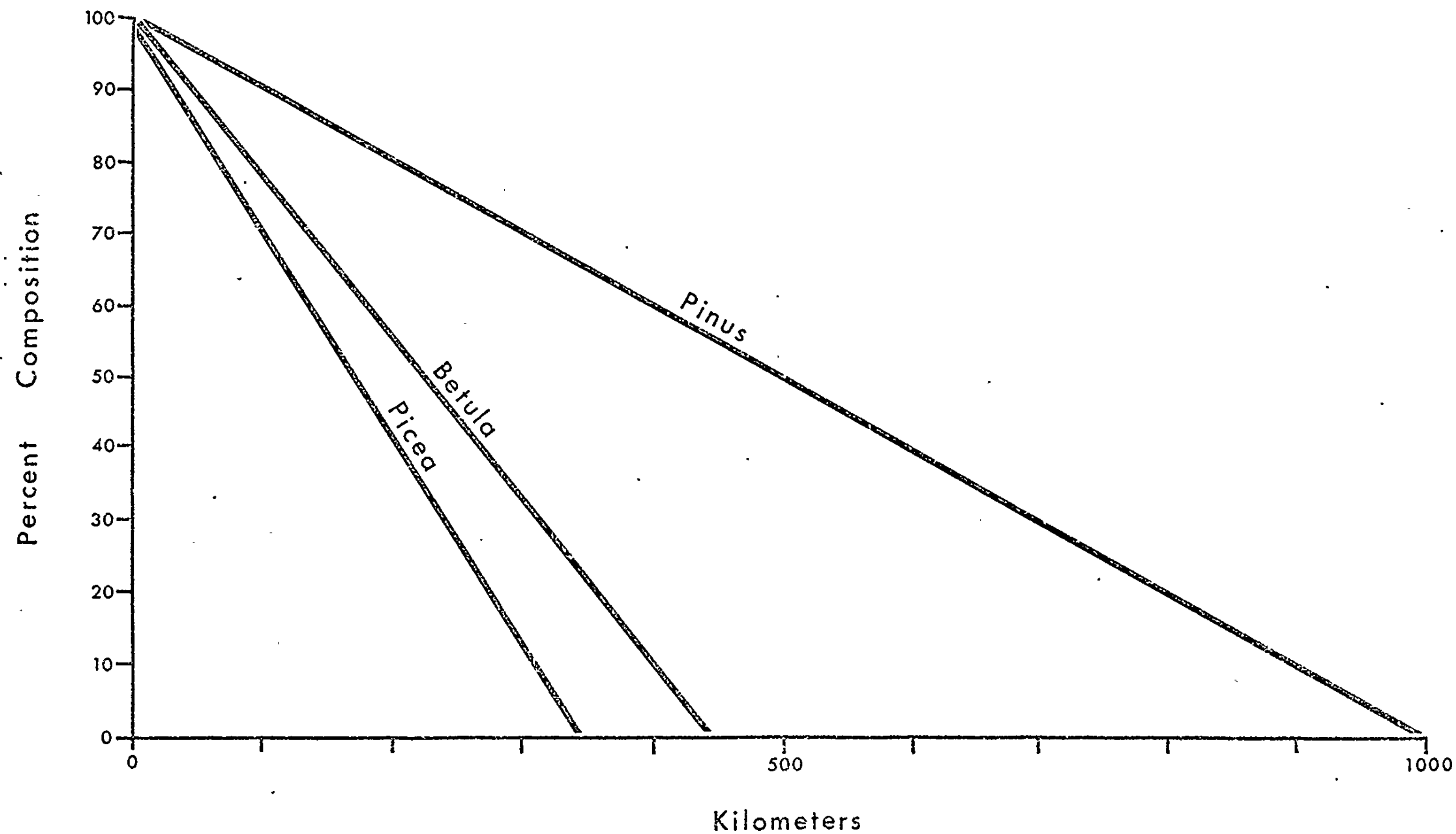


Figure 5: Potential Pollen Carrying Rates.

result of variations in determining the percent pollen composition and varying distances from the source region. However, a description of the actual pollen fallout rates will be given to provide a basis for additional work in the future.

The fallout rate of *Picea* from Bellshill to Gooseberry Lake was 36 percent over a distance of 80 kilometers, which is greater than the previously suggested carrying rate of *Picea*. Figure 6c illustrates *Picea*'s fallout rate as opposed to other pollen types such as *Pinus* and *Betula*. *Betula* shows a much lower rate of fallout than the predicted 25 percent per hundred kilometers. However, a transect from Lloyd's Lake east to Eagle and Little Fish Lakes shows a decreasing rate for *Betula* of 30 percent per hundred kilometers from west to east, which is similar to the predicted rate (Figure 6d). *Pinus* shows various fallout rates (Figure 6a and b). A transect from Lloyd's Lake to Eagle Lake has a *Pinus* decrease of 86 percent per hundred kilometers, whereas a transect from Keiver Lake to Little Fish and Twelve Mile Coulee has a 20 percent decrease. Although variable, the fallout rates do indicate a curvilinear rate of decrease.

Two problems are evident in the study of extra-regional pollen. First, a large spatial data base is needed to produce an adequate picture of the distribution of extra-regional pollen. Secondly, a method for measuring the percentage of extra-regional pollen is needed because the pollen productivity of the local and regional vegetation can influence the percentage of extra-regional pollen counted. For example, a highly productive regional vegetation would contain fewer extra-regional elements than a low pollen-producing vegetation, if a constant

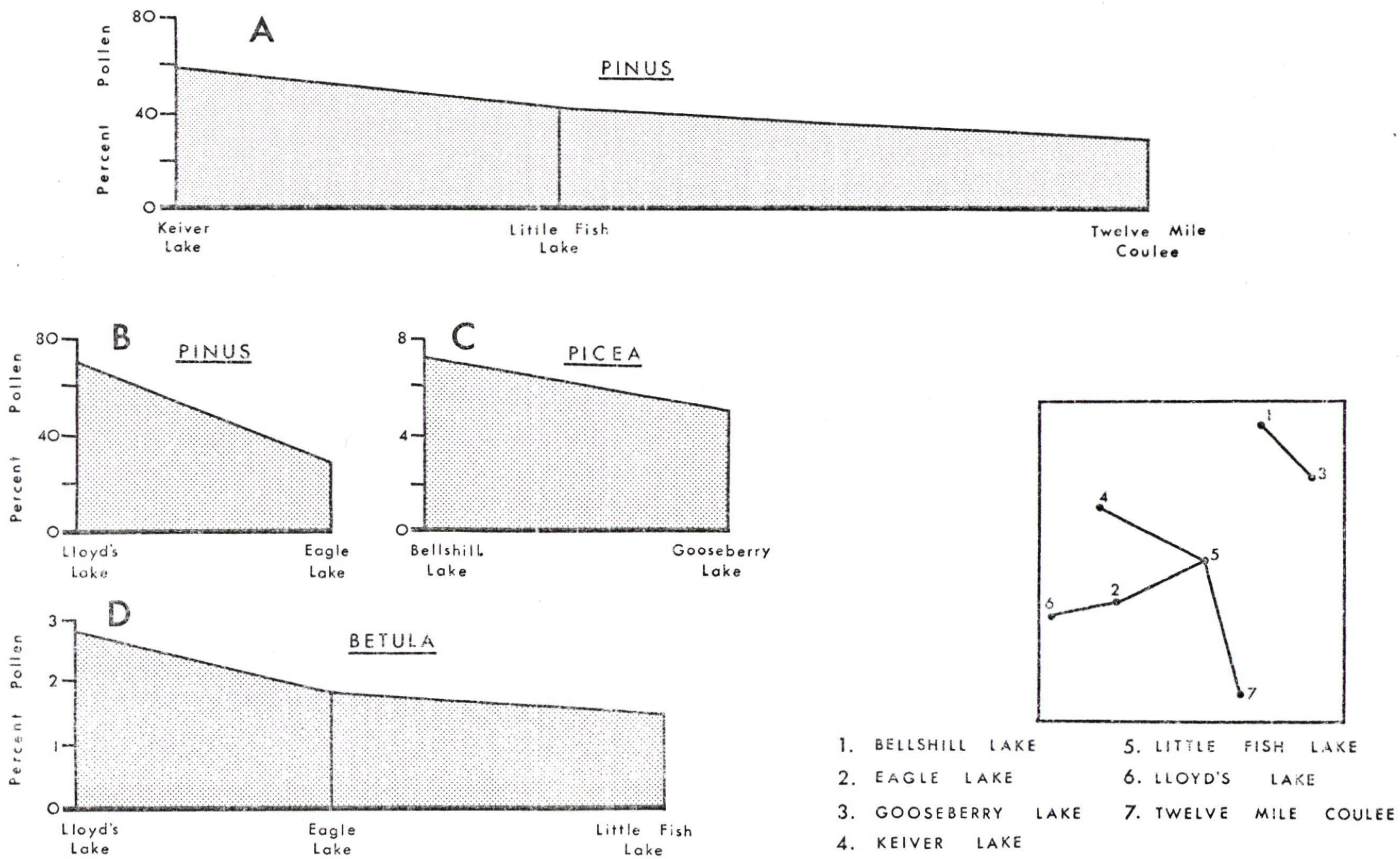


Figure 6: Pollen Fallout Rates.

extra-regional pollen rain existed in both situations. These variations in regional pollen productivity could also affect the relative quantity of extra-regional pollen found in the pollen profile over time.

CHAPTER VI

VEGETATION AND POLLEN STRATIGRAPHY

The identification of vegetation at particular sites over time has been employed by palynologists and paleoecologists for many years, but the identification of the spatial distribution of vegetation only started in the sixties. A few palynologists (Davis and Goodlet 1960, Lichti-Federovich 1965 and Ritchie 1963, Bright 1966, Mott 1969, Janssen 1966 and Webb 1973a,b,c) have attempted to relate pollen rains to vegetation distribution patterns. Most of their results indicate a general relationship between these variables. However, if pollen stratigraphy is to be used for the interpretation of prehistoric plant distributions and changes, pollen should clearly differentiate vegetation types. Recently, Webb (1973a,b,c) has shown vegetation formations can be statistically separated and has attempted to use this principle to study changes in the vegetation resulting from European settlement.

Identification of the Settlement Boundary

To study the presettlement vegetation using pollen spectra, a settlement boundary must be located. The location of the pre- and postsettlement vegetation boundary was based on changes in the pollen deposition rate and pollen percentages that generally coincided with changes in the texture of clastic sediments and carbonate and organic content. *Taraxacum officinale*, an introduced weed, was an important indicator. This weed has a distinctive morphology, making it easily identified. Being entomphilous, the occurrence of its pollen is under represented and limited but conclusive. The increase in Chenopodiaceae/ Amaranthaceae (Cheno/Am) and _Selaginella densa_ spores was also considered an indicator of settlement and land-use change. Cheno/Ams tend to be more abundant in areas of disturbance, and _Selaginella densa_ and _Artemisia_ increase as a result of grazing. Changes in the absolute pollen frequency were not considered direct response by the vegetation but possibly the result of an increaed sedimentation rate (See Chapter IV).

The pre- and postsettlement boundary was based on no single factor. Lloyd's, Bellshill, Keiver and Eagle Lakes were marked by the appearance of _Taraxacum_ (Figure 7). Another change included the sharp increase in Cheno/Ams at Lloyd's and Keiver Lakes. This increase was interpreted as an increase in disturbance. Keiver Lake also showed a corresponding decrease in the absolute pollen frequency after settlement. Eagle Lake is an exception to the increase in Cheno/Ams, showing instead a consistantly lower percentage after settlement.

Little Fish, Twelve Mile Coulee, Gooseberry and Chappice Lakes demonstrated similar changes at the time of settlement. All showed increases in Cheno/Am pollen. Chappice exhibited a decrease in _Artemisia_, whereas Twelve Mile Coulee, Little Fish, and Gooseberry Lakes increased. The absolute pollen frequency decreased in Gooseberry Lake after settlement and also in Red Deer Lake, where the settlement rise was conclusively dated using _Taraxacum_ as an index pollen (Figure 7). Changes within the pollen profile of Red Deer Lake were not as distinct as those found in other lakes. A general increase in Cheno/Am pollen and a decrease in _Artemisia_ was evident, and was used to indicate settlement. Changes in the pollen percentages appears to be the result of the expansion or

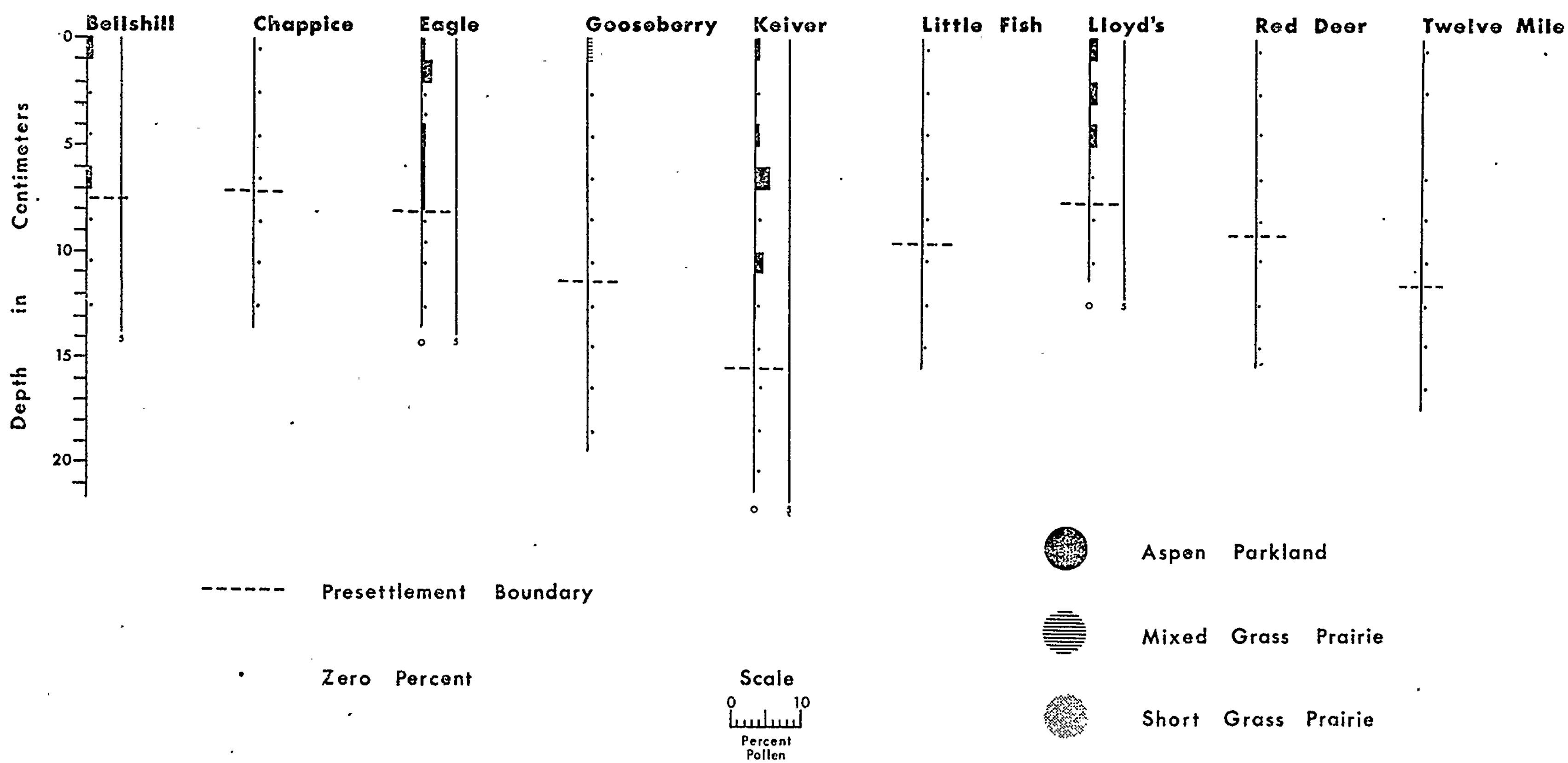


Figure 7: Lake Pollen Spectrums of <u>Taraxacum</u> <u>officinale</u>.

reduction of plants in response to settlement.

Pollen Identification of Present Vegetation Formations

Modern vegetation formations in southern Alberta can be identified from pollen percentage by using surface samples (0 - 1 centimeter levels in sediment cores). Ward's Error Sum of Squares Method of Cluster Analysis was used to identify each formation (Wishart, 1968). Cluster Analysis has the advantage of grouping comparable sets of variables (pollen percentages) in a step-by-step fashion until all lake sites are grouped to form one cluster (Everitt, 1974). Clustering or grouping was stopped when the error incurred became excessive or a discontinuity occurred in the quantity of error resulting from grouping.

Figure 8a represents the successive groups developed by cluster analysis; Figure 8b illustrates graphically the error resulting from the fusing of similar lakes. Clustering was stopped after the fifth step due to the change from a low two digit increment increase to a three digit, which represents a severe increase in error (Rummel, 1970). The groups occurring to the left of the break in slope will provide the basis for the following discussion of modern pollen in relation to vegetation formations.

Modern Vegetation Formations

Four vegetation formations were identified, based on nine lake sites and eight variables, and correspond closely to the vegetational boundaries drawn by Moss (1955) and modified by Bird (unpublished data). The variables included were considered representative of the prairie

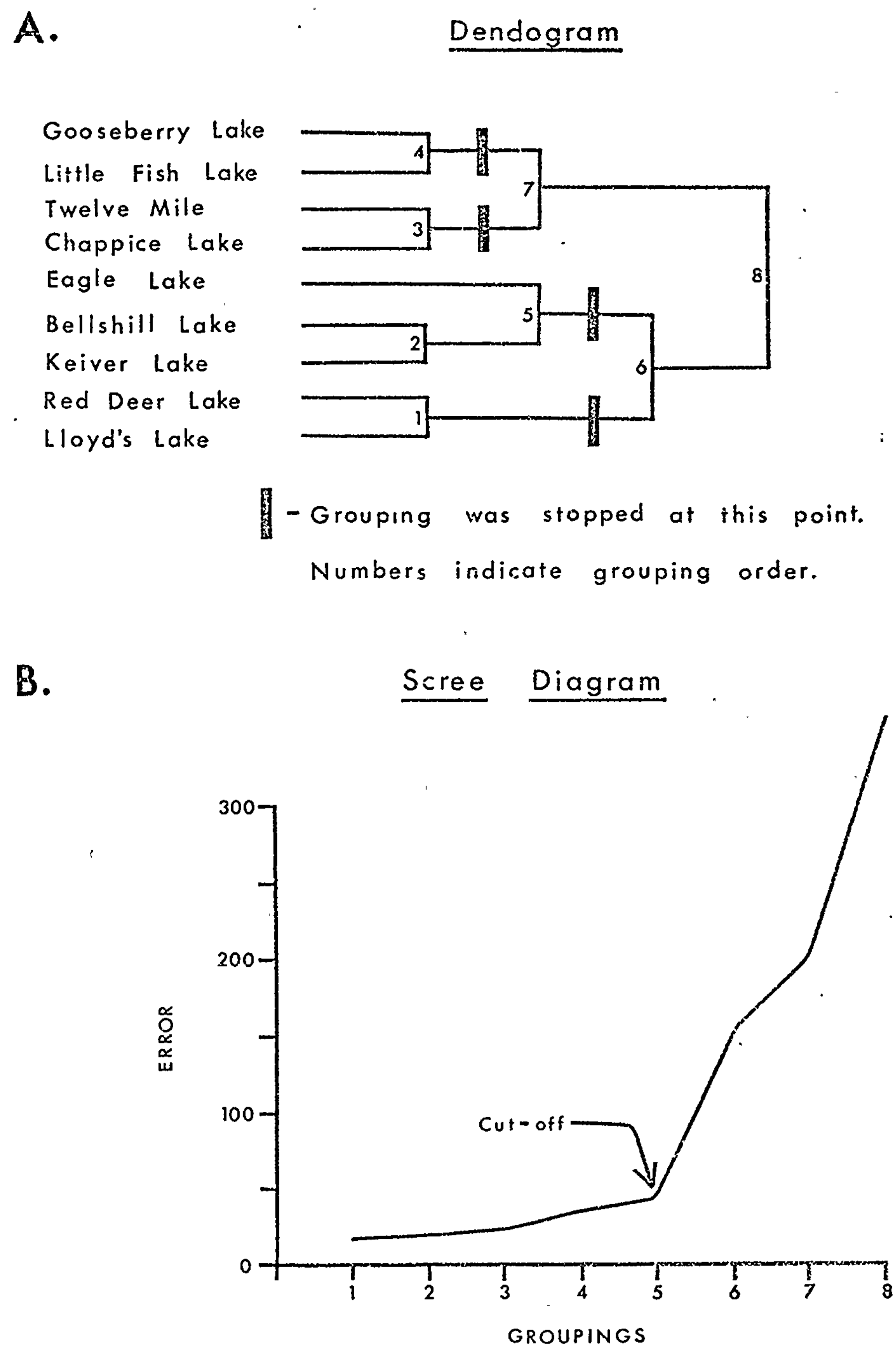


Figure 8: Dendogram for Postsettlement Pollen Spectra and Associated Scree Diagram.

vegetation: Artemisia, Ambrosia, Chenopodiaceae/Amaranthaceae, Cyperaceae, Gramineae, Populus, Taraxacum and Selaginella. The four groups identified were: 1) the Short Grass Prairie, 2) the Mixed Grass Prairie, 3) the Groveland Belt of the Aspen Parkland, and 4) the Aspen Parkland proper (Figure 9).

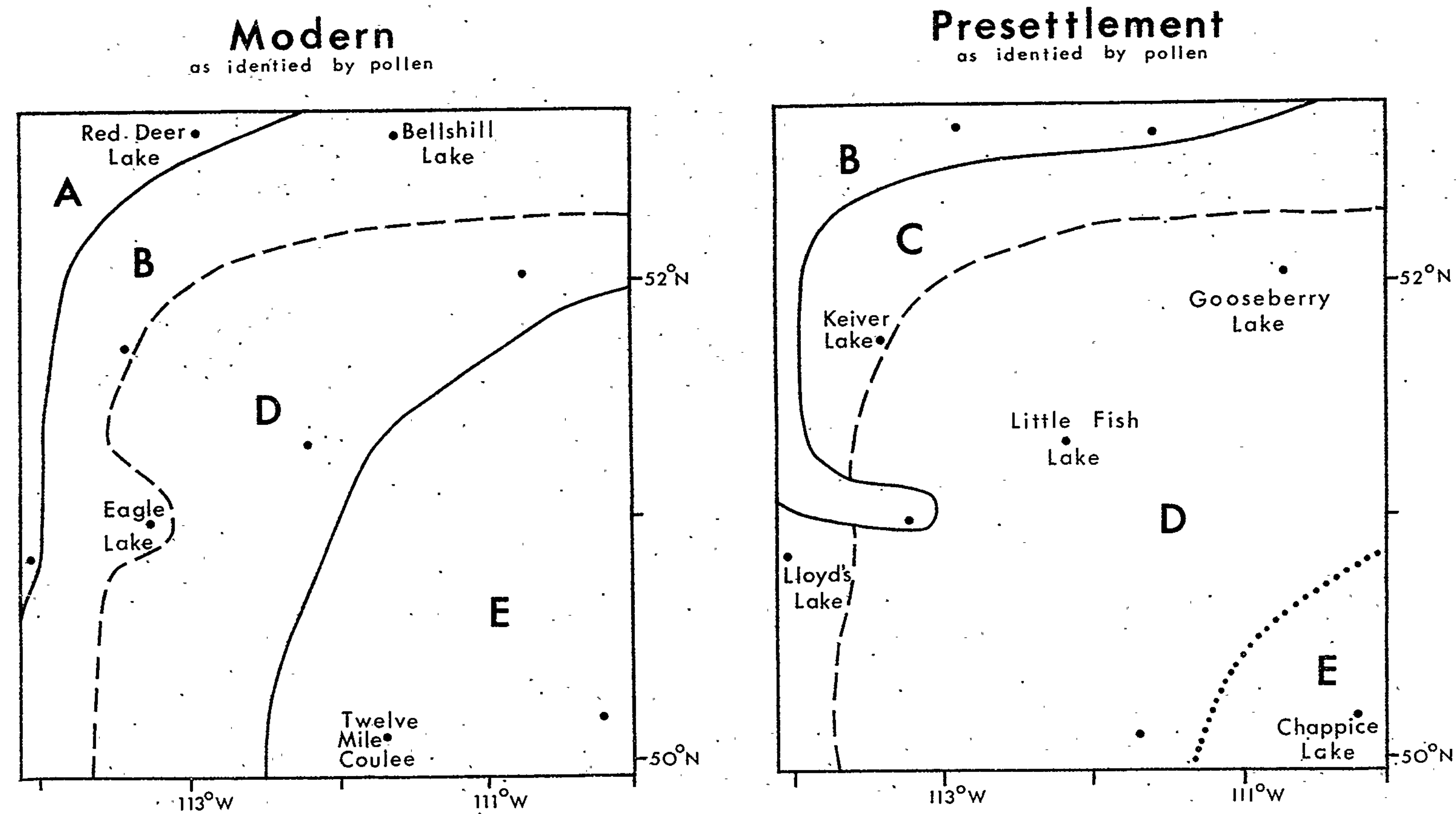
The modern Short Grass Prairie represented by Chappice Lake and Twelve Mile Coulee occupies an area mapped by Moss (1955) (Figure 8, Table 7). Artemisia (25 to 30 percent), Cheno/Ams (15 percent), Gramineae (20 to 25 percent), and Selaginella (20 to 30 percent) are the predominant pollen types, with secondary quantities of Ambrosia and Cyperaceae. (These figures were obtained following the removal of extra-regional pollen from the prairie pollen spectra). These pollen types and quantities are similar to those obtained by Mott (1969) in a study of the palynology of Saskatchewan. However, Mott did not consider or recognize the predominance of Selaginella densa. Selaginella spores appear to be an excellent indicator of Short Grass Prairie when occurring in high percentages. These percentages of palynomorphs and percent vegetation composition are not proportional. For example, Gramineae and Artemisia are under represented approximately three times, whereas Selaginella is under represented by four times based on the vegetation composition (Table 1).

The Mixed Grass Prairie pollen composition is similar to that of the Short Grass except Artemisia is twice as abundant, Gramineae is slightly higher in percentage, and Selaginella is under represented approximately ten times. The higher composition of Artemisia pollen relative to the actual vegetation composition indicates a very high

Table 7: Pre- and Postsettlement Pollen Percentages

	AMBROSIA		ARTEMISIA		CHENO/AM		CYPERACEAE		GRAMINEAE		POPULUS		SELAGINELLA		TARAXACUM	
	Pre-	Post	Pre-	Post	Pre-	Post	Pre-	Post	Pre-	Post	Pre-	Post	Pre-	Post	Pre-	Post
Aspen Parkland																
Bellshill Lake	2.8	3.2	32.4	31.7	11.1	12.7	12.0	21.4	35.2	26.2	0.0	1.6	6.5	2.4	0.0	0.8
Eagle Lake	1.7	1.7	30.8	33.1	23.9	17.4	0.0	4.5	41.0	34.3	0.0	7.3	2.6	1.1	0.0	0.6
Keiver Lake	3.4	1.0	15.3	29.4	5.1	20.6	18.6	14.3	49.2	31.4	0.0	1.0	8.5	1.0	0.0	1.0
Lloyd's Lake	2.3	1.4	22.1	24.3	8.1	8.6	16.3	11.4	51.2	48.6	0.0	1.4	0.0	2.9	0.0	1.4
Red Deer Lake	1.5	1.6	33.8	15.6	6.9	11.5	6.2	13.1	44.6	48.4	1.5	6.6	5.4	3.3	0.0	0.0
Mixed Grass Prairie																
Gooseberry Lake	0.9	2.8	59.3	45.4	2.7	7.4	8.8	9.3	21.2	23.1	0.0	0.0	7.1	11.1	0.0	0.9
Little Fish Lake	2.4	0.0	51.8	54.1	4.8	15.6	10.8	3.0	24.1	24.9	0.0	0.0	6.0	3.0	0.0	0.0
Short Grass Prairie																
Chappice Lake	2.7	1.9	27.4	31.1	6.8	17.5	1.4	2.9	24.7	25.2	0.0	0.0	37.0	21.4	0.0	0.0
Twelve Mile Coulee	3.4	1.8	14.2	25.6	2.8	13.0	13.6	6.7	44.9	22.4	0.0	0.0	21.0	30.5	0.0	0.0

Pre- presettlement Pollen Percentages   Post - Postsettlement Pollen Percentages (Surface Samples)



A – ASPEN PARKLAND PROPER

B – GROVELAND BELT of the ASPEN PARKLAND

C – FESCUE GRASSLAND

D – MIXED GRASS PRAIRIE

E – SHORT GRASS PRAIRIE

Presettlement Boundaries Subjectively Determined

Figure 9: Vegetation Formations.

degree of disturbance from grazing and agriculture. The slight increase in Gramineae may be the result of more pollen-productive grasses replacing native species. The sharp drop in the composition of Selaginella spores in the Mixed Grass Prairie when similar to the vegetation content of the Short Grass Prairie, suggests the Mixed Grass Prairie is two and half times more productive in terms of pollen than the Short Grass Prairie. This was confirmed by absolute pollen frequencies at Twelve Mile Coulee and Little Fish Lake.

The Groveland Belt of the Aspen Parkland is composed of Gramineae (25 to 35 percent), Artemisia (30 percent), Cheno/Ams (10 to 20 percent), Cyperaceae (5 to 20 percent), and Populus (0 - 10 percent) pollen (Table 7). The major differences between the Mixed Prairie and Groveland Belt are the thirty percent decrease in Artemisia, the slightly higher Gramineae composition, and the more abundant Populus and Taraxacum. Populus seems to demarcate the Aspen Parkland, although the quantity of pollen is under represented.

The presettlement Aspen Parkland proper was identified as existing in the area of Red Deer Lake and Lloyd's Lake (Figure 9, Table 7). The vegetation composition is marked by higher Gramineae and lower Artemisia pollen values. The presettlement Groveland Belt, now the Aspen Parkland proper, contained Populus pollen percentages comparable to the modern Groveland Belt pollen spectra, although under represented in both time periods. This reduction may be the result of poor Populus preservation during early stages of deposition.

Sangster and Dale (1961, 1964), Ritchie (1963), Lichti-Federovich (1965), and Havinga (1967) have show Populus pollen is destroyed in the sediment by oxidation and microbial activities during the early stages of deposition. However, the degree of Populus preservation after it becomes incorporated into the sediment is unknown. Lichti-Federovich (1970) identified a Populus maximum (60 percent) approximately 11,400 years ago in Lofty Lake. If Populus were not preserved after becoming invorporated into the sediment, this maximum probably would not have been identified. Most of the sediments under study show evidence of reducing conditions, suggesting minimal oxidation and microbial activity with maximum Populus preservation after it is incorporated into the sediment. In addition, most lakes under study within the Aspen Parkland contained sediments Cushing (1967) considered best for the preservation of pollen.

It is evident from the preceeding discussion that different vegetation formations can be separated by using pollen analysis, and their geographic distribution confirmed, so long as the true regional pollen spectrum is represented. Applying the techniques used with modern vegetation and pollen spectra to presettlement fossil pollen should simulate the presettlement vegetation with reliable results.

Pollen Identification of Presettlement Vegetation Changes

Changes in Vegetation Composition

Gramineae or grasses show fluctuating pollen percentages throughout their profiles (Figure 10). Actual changes in the prairie vegetation are confused by varying responses to grazing and by cultural grasses replacing native species. In general, a slight increase has

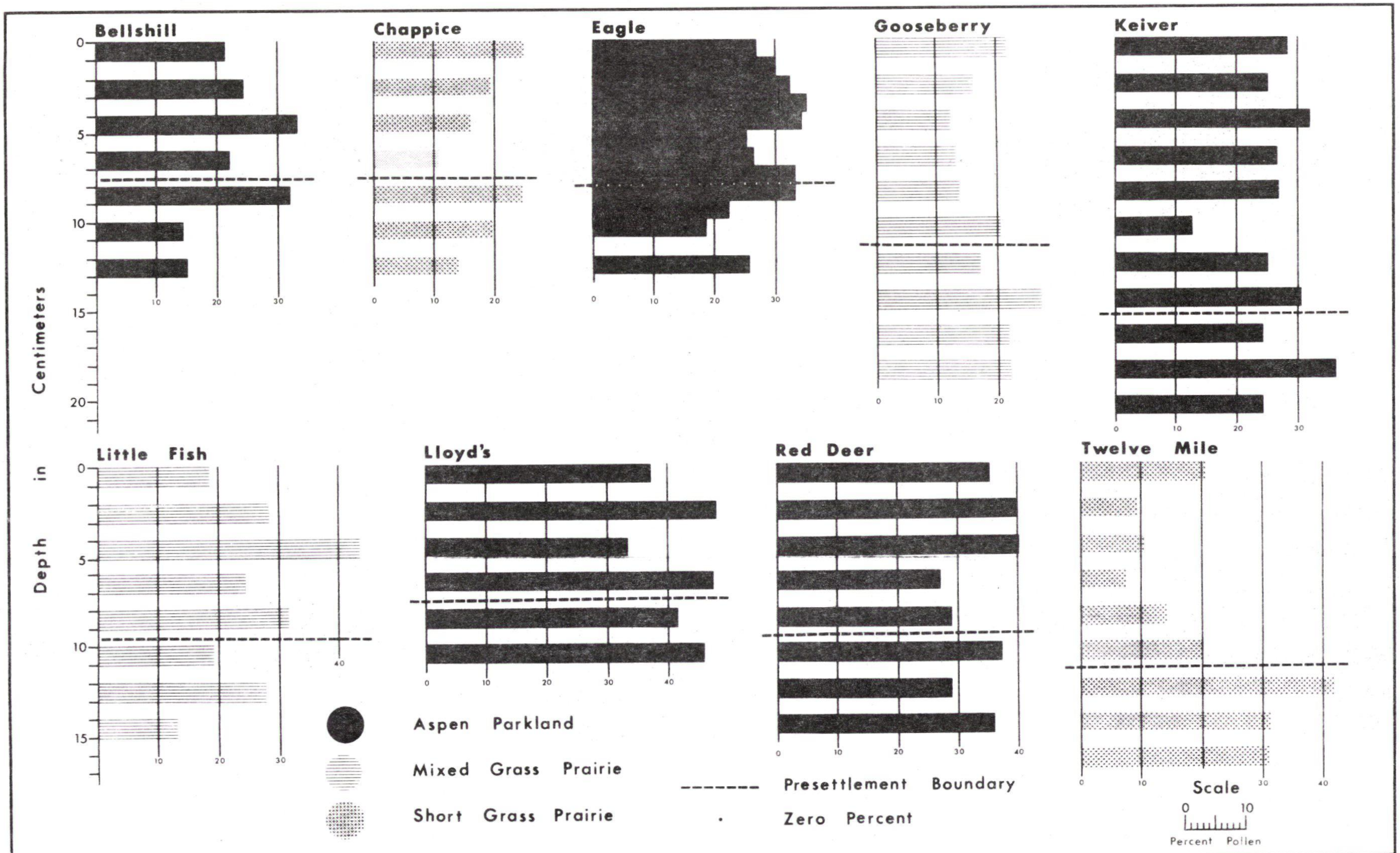


Figure 10: Lake Pollen Spectrums of Gramineae.

occurred in the percentage of Gramineae pollen since settlement. However, Twelve Mile Coulee shows the greatest change with a 50 percent decrease in the Gramineae composition.

In contrast Chenopodiaceae/Amaranthaceae have increased since settlement (Figure 11). Occurring only in disturbed areas, these plants have increased up to four times their presettlement composition. Prior to settlement the variation in species of Cheno/Am was limited, but pore frequency and grain diameter observations show an increase in introduced species has occurred rather than an increase in native species. One exception to an increase in Cheno/Am is Eagle Lake, which possessed a higher than normal count prior to settlement and decreased only slightly after settlement. If Cheno/Ams are indicators of disturbance, then the area of Eagle Lake was highly disturbed prior to settlement. Such disturbance could have been created by bison.

Artemisia frigida was an important herb in the presettlement prairie but was also over represented in the pollen spectrum. Since settlement, *Artemisia absinthium*, A. *cana*, A. *frigida* and others have increased in the Aspen Parkland and Short Grass Prairie but decreased in the Mixed Prairie (Figure 12). *Artemisia* tends to increase with grazing. Therefore, the reason for its decrease in the Mixed Prairie is not clear; possibly the plant is being destroyed by farming. The greatest quantity of *Artemisia* pollen occurs in the Mixed Prairie, although the greatest vegetative composition occurs in the Short Grass Prairie. This may indicate *Artemisia* is better suited to the Mixed Grass Prairie environment and flowers more frequently than in the Short Grass Prairie.

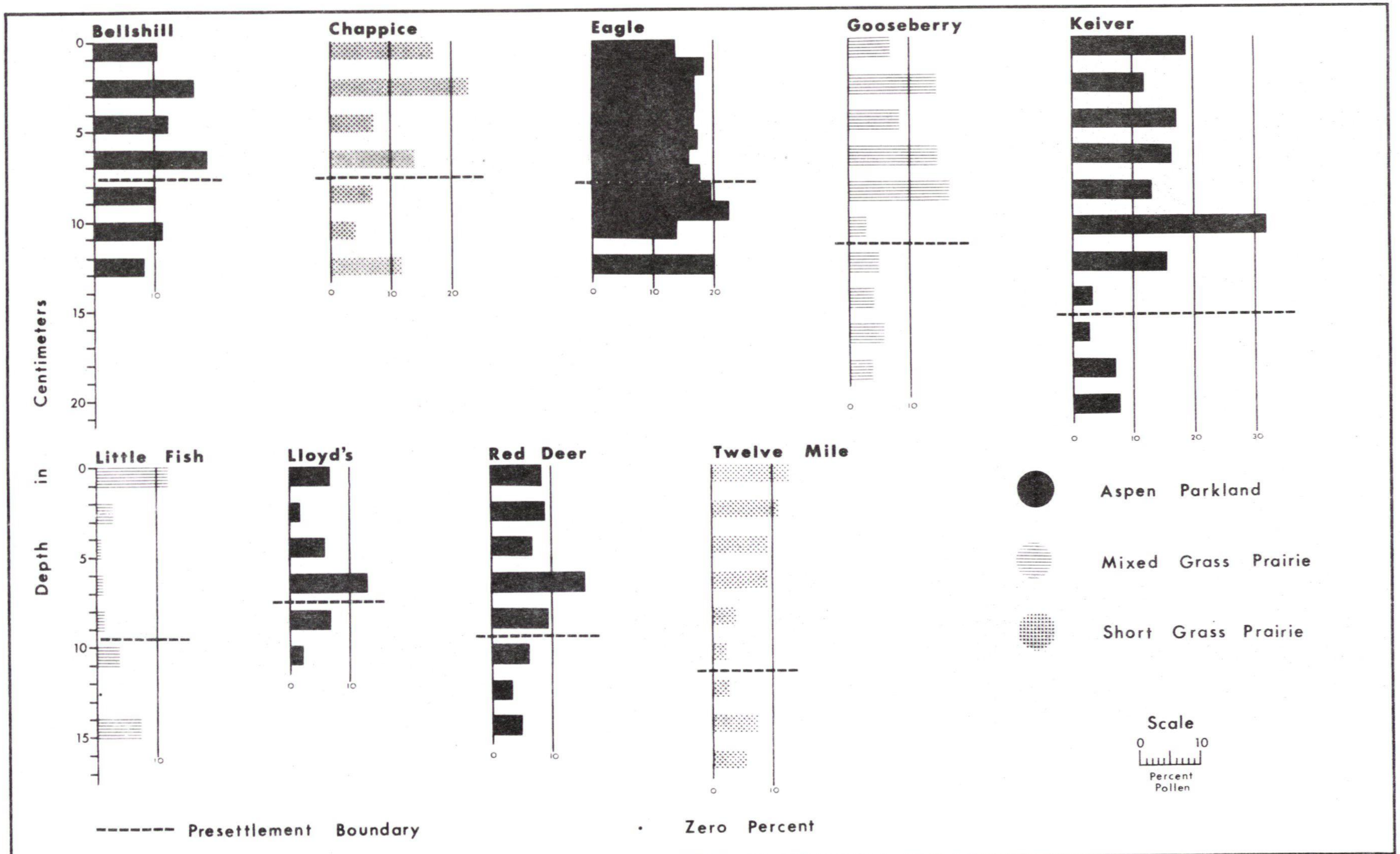


Figure 11: Lake Pollen Spectrums of Chenopodiaceae/Amaranthaceae.

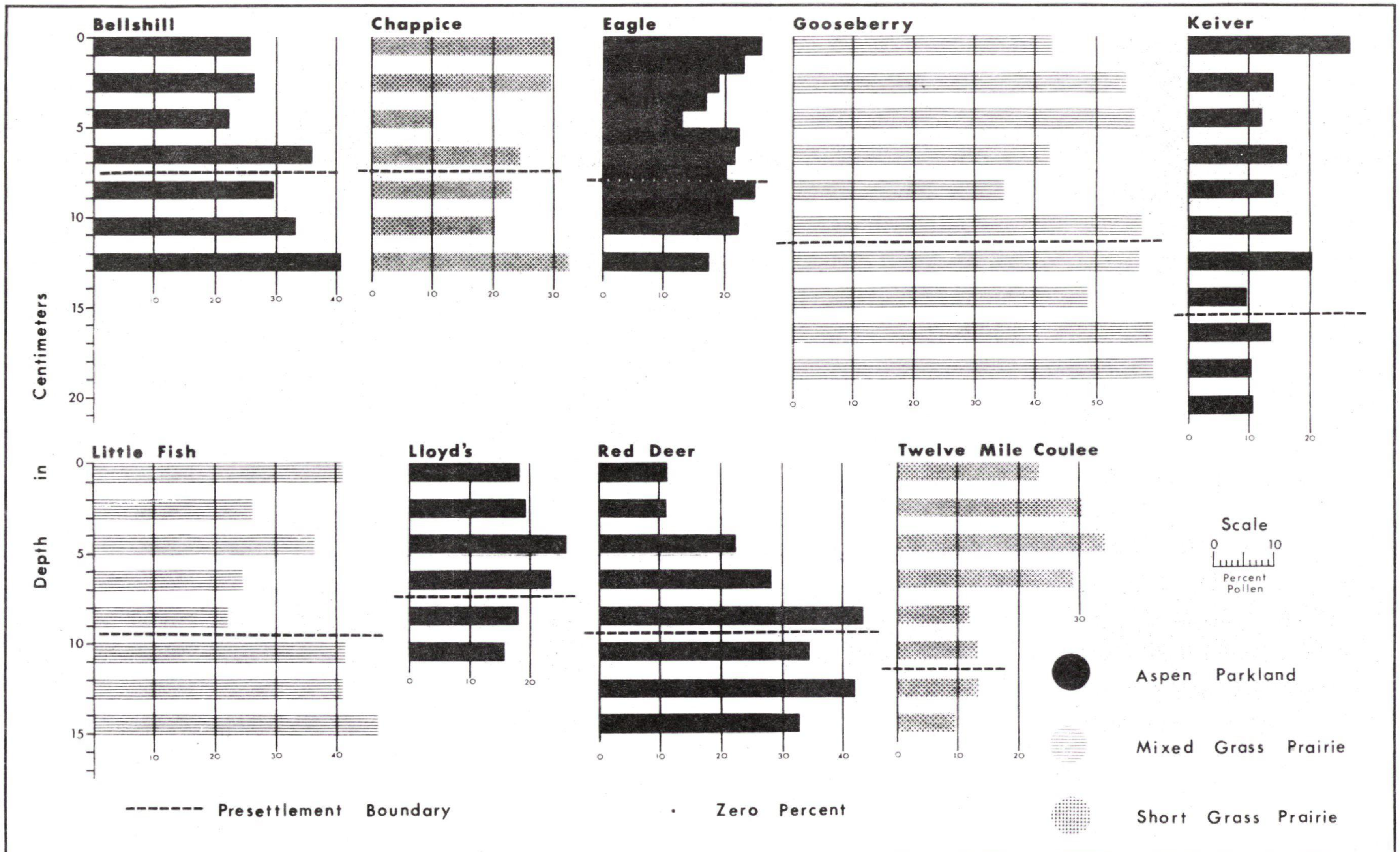


Figure 12: Lake Pollen Spectrums of _Artemisia_.

Most lakes in the southern portion of the study area show increases in *Selaginella densa* after settlement, whereas northern areas are similar to their presettlement quantity (Figure 13). Such an increase indicates a more intense use of the grassland areas since settlement.

All lakes except Keiver and Bellshill Lake show an overall decrease in Cyperaceae pollen since settlement (Figure 14). The reason for this change is not obvious. The reduction could be due to disturbance of the plant's habitat, while the increases at Keiver and Bellshill Lakes may be the expansion of wetlands.

Ambrosia composed only a small percent of the regional pollen rain in presettlement times and appears to have changed little in composition after settlement (Figure 15). This is a complete reversal of observations in eastern Canada and the United States where *Ambrosia* increases abruptly as a result of forest clearance and settlement (McAndrews 1968, Webb 1973a,b,c). The absence of change in *Ambrosia* after settlement may be the result of Alberta's dry climate not providing an adequate moisture regime for its expansion.

Populus has gradually increased since settlement in the northern regions of the study area which is associated with the migration of *Populus*. *Populus* is an important component at Red Deer, Lloyd's, Keiver, Bellshill and Eagle Lakes (Figure 16). The latter four have changed from grassland to groveland through the invasion of *Populus* since settlement. This change was not abrupt but a gradual increase. The Red Deer Lake area contained *Populus* for a period of time prior to settlement, suggesting it was part of the Groveland Belt or near a source of *Populus* pollen.

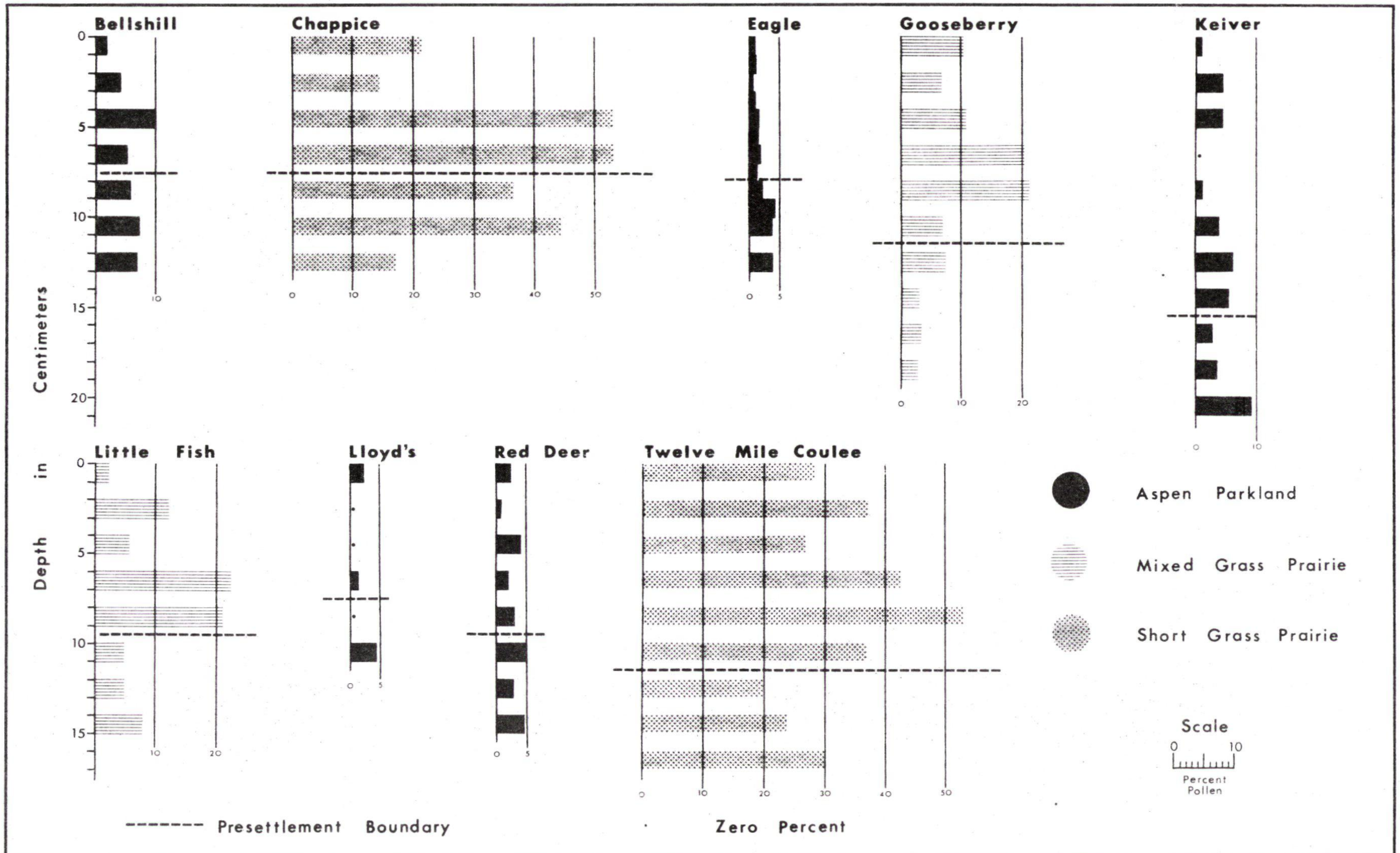


Figure 13: Lake Spore Spectrums of Selaginella densa.

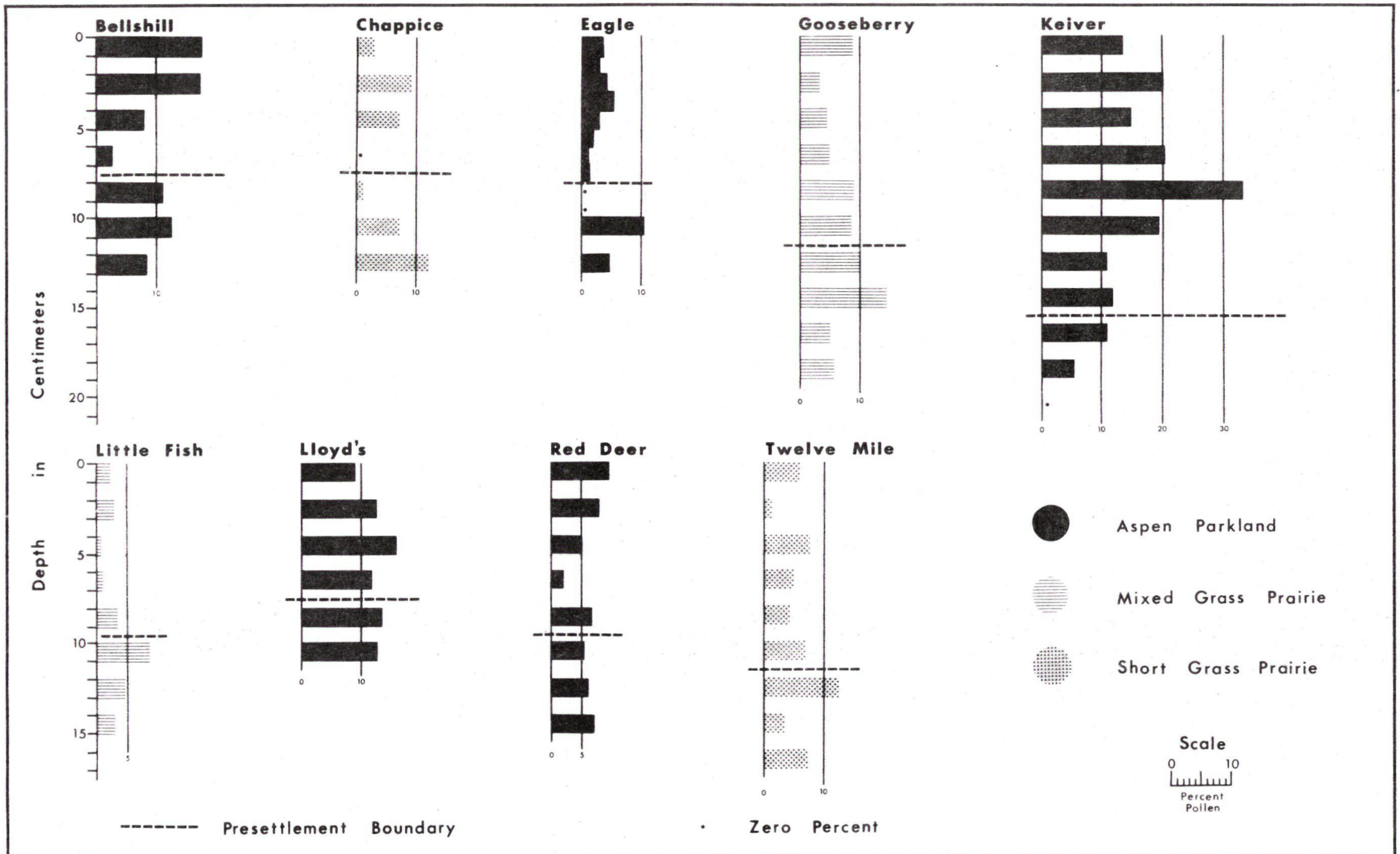


Figure 14: Lake Pollen Spectrums of Cyperaceae.

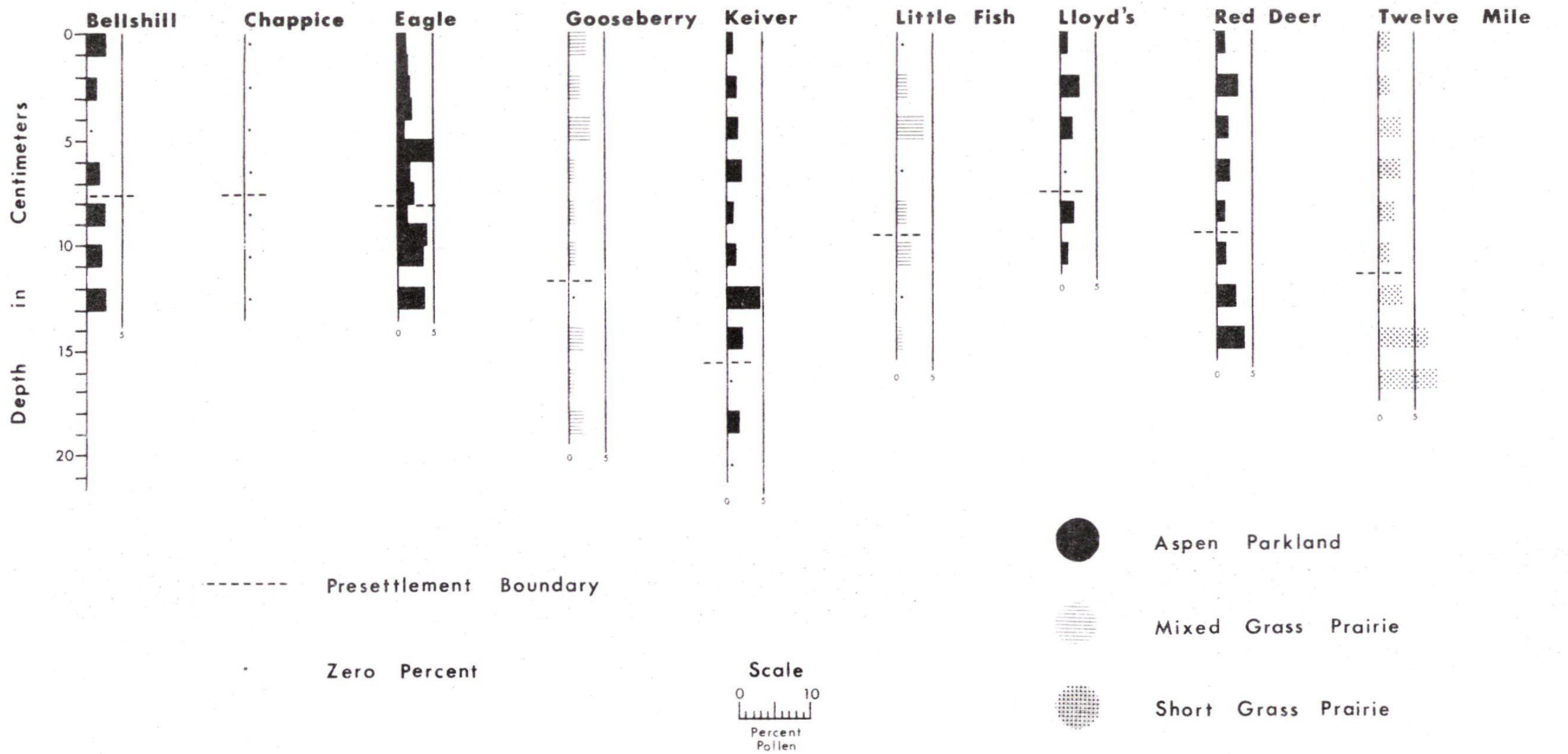


Figure 15: Lake Pollen Spectrums of Ambrosia.

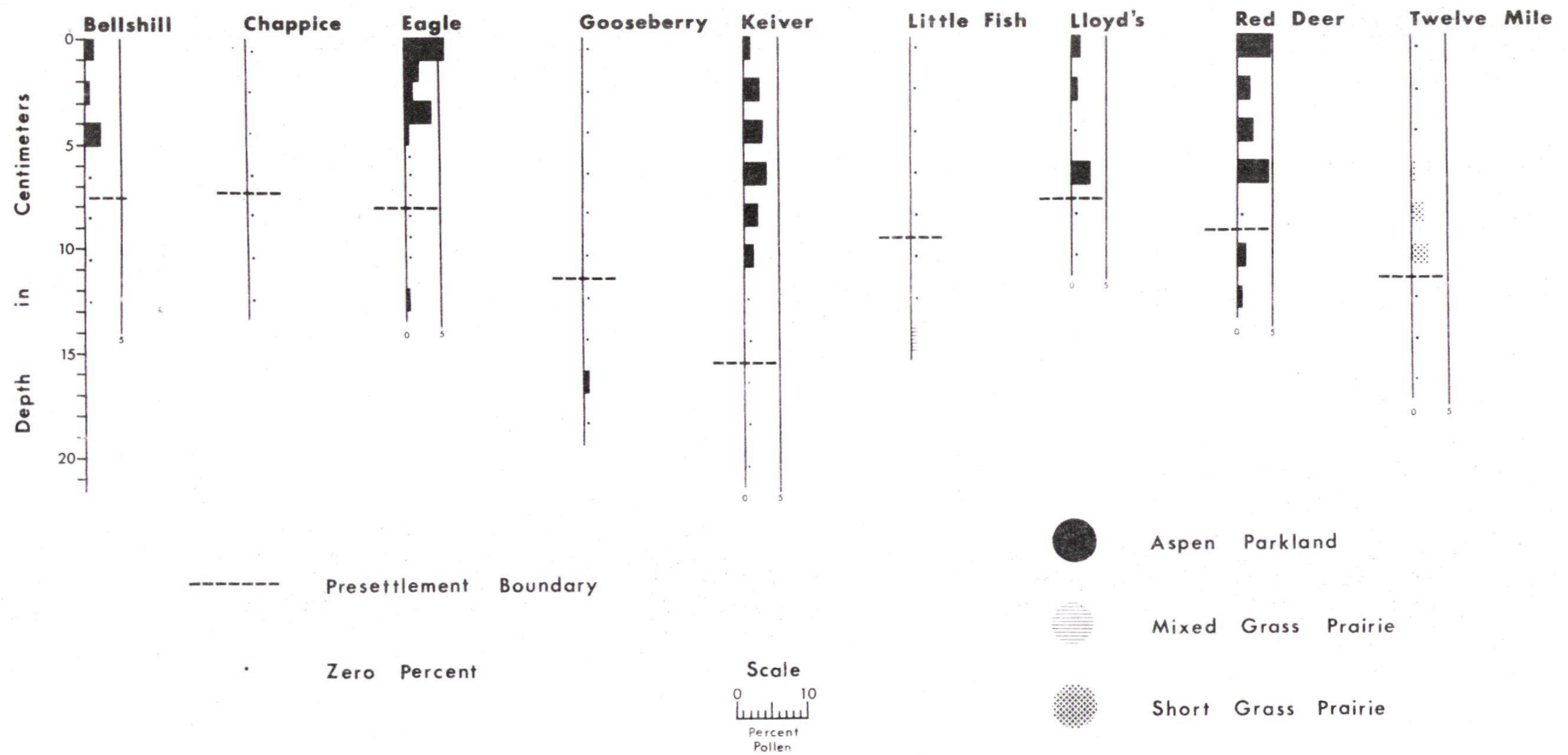


Figure 16: Lake Pollen Spectrums of Populus.

Twelve Mile Coulee show the occurrence of _Populus_ just after settlement. This is interpreted as _Populus_ growing along the Bow River and local tributaries.

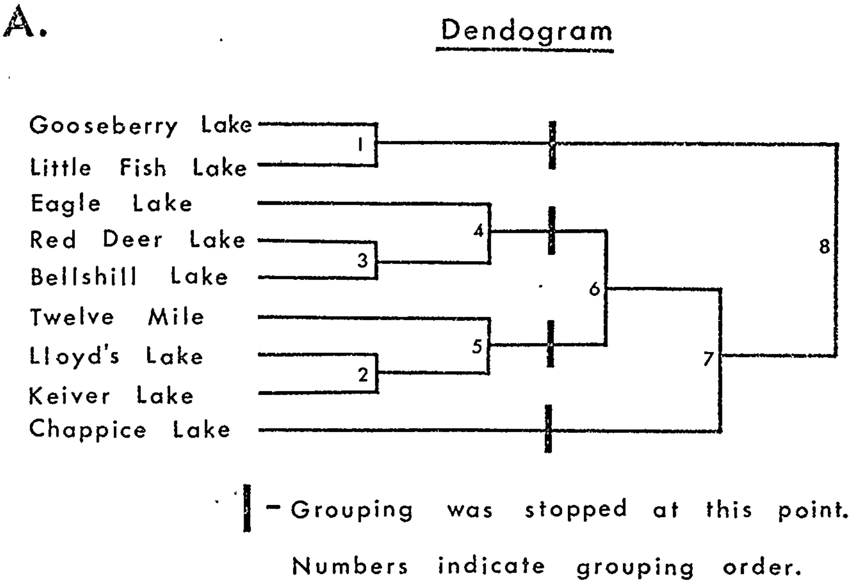
Changes in Vegetation Formation

Presettlement vegetation formations were identified from pollen samples taken directly below the settlement boundary. Identical clustering procedures were employed to identify presettlement vegetation formations as in the study of postsettlement formations. However, only seven of the eight variables in the postsettlement study were used: _Ambrosia_, _Artemisia_, Cheno/Ams, Cyperaceae, Gramineae, _Populus_ and _Selaginella_. _Taraxacum_, an introduced species, was excluded from the analysis. The various groups formed by cluster analysis are represented in Figure 17a and the resulting error is illustrated in Figure 17b. Clustering was stopped after the fifth grouping due to severe increases in error. These clusters are spatially represented in Figure 8. However, the boundaries between each grouping should not be considered fixed as they were subjectively determined.

Prior to settlement, the vegetation within the study area consisted of four vegetation formations: 1) the Short Grass Prairie, 2) the Mixed Grass Prairie, 3) the Fescue Grassland, and 4) the Groveland Belt of the Aspen Parkland. The first most obvious change is the inclusion of a Fescue Grassland which was not identified in the modern vegetation.

The Fescue Grassland does exist in the modern vegetation, but only as a component of the Aspen Parkland. The Aspen Parkland proper was not identified in the presettlement vegetation but may have existed north

A.



B.

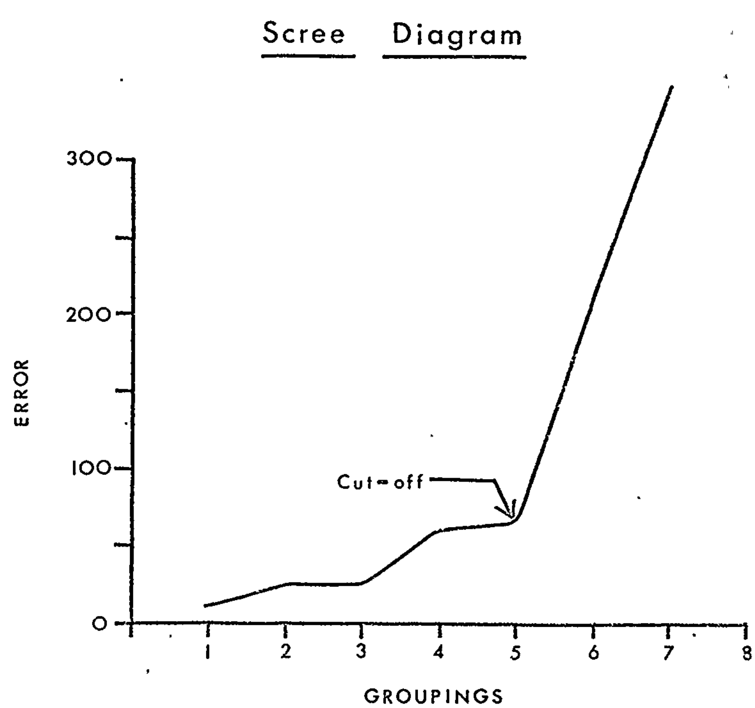


Figure 17: Dendogram for Presettlement Pollen Spectra and Associated Scree Diagram.

and west of the study area.

At present, the Short Grass Prairie occupies the southern quarter of the study area. In presettlement times it consisted of an area approximately one-third its present size, based on the Twelve Mile Coulee sample (Figure 9). The expansion moved in a northwesterly direction at the expense of the Mixed Grass Prairie. The area of expansion was characterized by an increase in Artemisia and Selaginella with a decrease in the Gramineae composition.

The modern Mixed Prairie is located in the same position that it occupied prior to settlement, although reduced in areal extent (Figure 9). Its northern boundary appears to be located in the same area, although Populus may be encroaching. The presettlement Mixed Grass Prairie was similar in composition to the modern version but contained fewer Cheno/Ams.

The Fescue Grassland, located north of the Mixed Prairie in presettlement time, is represented today by the grassland component of the Groveland Belt of the Aspen Parkland. The largest change in the vegetation was the migration of Populus into the area after settlement. Other changes included an increase in Artemisia and Cheno/Ams and a decrease in Gramineae and Selaginella. Other changes that occurred in the Fescue Grassland included a decrease of Artemisia and an increase of Cheno/Ams and Cyperaceae.

The presettlement Groveland Belt occupied an area to the north of the Fescue Grassland and bordered the north and west edges of the study area (Figure 9). The justification for identifying this region as Groveland and not Parkland is the low incidence of Populus pollen in the stratigraphic profiles of this area, indicating this tree was not a major component of the vegetation at that time. Although *Populus* does not preserve well, the pollen profiles indicate this is not a severe problem (Figure 16). The gradual increase in *Populus* pollen illustrates a continueal increase in the frequency of *Populus* trees within the area.

Eagle Lake is an unusual case in both pre- and postsettlement periods with respect to the general arc pattern of the vegetation formations (Figure 9). The Eagle Lake area was classified by the author (using pollen analysis) as Groveland in pre- and postsettlement times, although Moss (1955) and Bird (unpublished data) classified the area as Mixed Prairie. Figure 8 illustrates the strong statistical relationship which exists between Eagle Lake and other Aspen Parkland pollen spectrums.

Major Factors Influencing Vegetation Change

European settlement appears to have had a major effect on the vegetation of southern Alberta. Fire control, elimination of the bison, grazing and agriculture were the basic factors which modified vegetation.

Disturbance appears to have increased and has resulted in changes in vegetation composition and formation. Weed species such as *Taraxacum* and Cheno/Ams increased as a result of this greater disturbance since settlement. Webb (1973a,b,c) and Bailey (unpublished data) observed similar changes in Cheno/Ams with marked increases in *Ambrosia*. However, *Ambrosia*, has not changed significantly in southern Alberta. *Selaginella* and *Artemisia*, both indicators of overgrazing, have also increased in the

Mixed Grass Prairie, suggesting this area is much more intensively grazed than it was before settlement. Chappice Lake, the only sampling site in the presettlement Short Grass Prairie, decreased in _Selaginella_, suggesting less grazing pressure exists here. This completely contradicts Watts (1969) who states that the Short Grass Prairie has been "radically altered by present day grazing" through modification of the vegetation composition.

A large areal expansion of the Short Grass Prairie at the expense of the Mixed Grass Prairie was interpreted in the southeastern portion of the study area. It is hypothesized to have occurred due to from Mixed Grass to Short Grass Prairie and was characterized by a decrease in Gramineae and an increase in _Selaginella_ and _Artemisia_ pollen, all of which are indicators of increased grazing pressure. Overgrazing may have allowed the expansion of what appears to be a Short Grass "type"; however, if left undisturbed for a period of time, the area may revert to the original Mixed Grass Prairie.

The concept of more intense grazing in modern times is in contrast to that of Nelson (1973), who contends that the bison "grazed the grass very heavily" and Palliser's (1863) description of the grass as heavily grazed. England and de Vos (1969) speculate that overgrazing was only a localized phenomenon. Such speculation seems to be more probable than widespread overgrazing. The Eagle Lake site may be representative of such localized disturbance prior to settlement. The presettlement Cheno/Am pollen content of 24 percent decreased only slightly after settlement, indicating severe disturbance prior to settlement, possibly by bison.

The greatest and most obvious change in the vegetation after settlement was in the northern portion of the study area, where _Populus_ migrated southward into the Fescue Grassland. Such an expansion is attributed to fire control which allowed _Populus_ to invade areas of undulating topography that provided moist microclimatic conditions. Fire is believed to have been an integral part of maintaining the interface between the grassland and _Populus_ invasion prior to settlement (Bird, 1961). It does not appear that climatic fluctuations to moister conditions have resulted in the migration of _Populus_ as Moss (1932), and Moss and Campbell (1947) have suggested. If this were the situation, the Short Grass Prairie probably would not have shifted northward and expanded. Other than the invasion of _Populus_, only decreases in _Artemisia_ and increases in Cheno/Ams have occurred in the Fescue Grassland Formation since settlement (Table 7).

CHAPTER VII

SUMMARY

This study was conducted in an effort to determine the effects of European settlement on the native vegetation of southern Alberta. The changes observed were varied and consisted of floristic and environmental changes. The study area was composed of three major vegetational formations: 1) the Short Grass Prairie, 2) the Mixed Grass Prairie, and 3) the Groveland Belt of the Aspen Parkland with a small area of Aspen Parkland proper in the Red Deer Lake area. In addition, extra-regional pollen and limnic sediments were studied. Limnic sediments provided evidence that indicates changes in erosion rates and increased sedimentation rates while extra-regional pollen analysis indicated the potential travelling distance of <u>Betula</u>, <u>Picea</u> and <u>Pinus</u>.

The study of limnic sediment composition and grain sizes indicates changes have occurred in the erosion rate and subsequently influenced the sedimentation rate found within lakes. Prior to settlement, sediments were composed of a minimum of 97 percent clastic material, a maximum of two percent carbonate and one percent organic matter content. A decrease in the nonclastic fraction took place after settlement. The reduction was approximately 20 percent in organic matter and 40 percent in carbonate content. The only exception to a decreased organic content was Eagle Lake which increased in organic productivity.

Changes in grain size were also observed. The Mixed Grass Prairie, Short Grass Prairie and Aspen Parkland proper show increases in sand content associated with increased runoff from agricultural land breaking, and sparser vegetation which is the result of increased grazing pressure. The Groveland Belt of the Aspen Parkland has shown a change from sandy to silty lake sediments and an increased sedimentation rate. These changes are thought to be caused by increased wind erosion related to the high incidence of exposed mineral matter following the breaking of the prairie sod.

The prairie pollen rain was composed of 40 to 80 percent extra-regional pollen. The analysis of extra-regional pollen suggests anemophilous pollen types can be carried long distances; however, a much larger data base is needed to develop accurate generalizations. The data indicates *Betula* and *Picea* could be carried 300 to 400 and 400 to 500 kilometers, whereas *Pinus* could be transported by wind more than 1000 kilometers from its source.

The greatest changes found to have occurred were the shifting of the major vegetation formations. The Short Grass Prairie appears to have expanded to approximately three times its presettlement size, resulting in the reduction of the area occupied by the Mixed Grass Prairie. It is hypothesized that this expansion was caused by increased grazing pressure. The second major shift noted was the migration of the Groveland Belt of the Aspen Parkland south and eastward into the area formerly occupied by the Fescue Grassland. The data indicates this migration was not climatically induced, but possibly the result of fire control combined with the existence of available moist sites. If the expansion of the Groveland Belt were the result of moister conditions, the Short Grass Prairie probably would not have expanded. Such adaptive sites are the result of undulating terrain and the lack of severe disturbance or land clearance by man.

Changes in the vegetation composition due to settlement were varied, depending on the vegetation formation. The Short Grass Prairie, still consisting of large areas of native grassland, increased in Cheno/Ams but decreased in *Selaginella densa*. This change in plant composition is thought to be a response to decreased grazing since settlement. The present day Groveland Belt was formerly Fescue Grassland, but with settlement and fire control, *Populus* invaded the area and secondary increases in Cheno/Ams and decreases in *Artemisia* were observed. Gramineae were an important component of the grassland prior to settlement but did not show drastic changes in percent composition as a result of settlement. The only exception is in the area where Mixed Prairie was replaced by Short Grass Prairie and a sharp decrease occurred. The major change was in species composition, an exchange of native grasses for cultural grasses. The introduction of weeds such as *Taraxacum officinale* and members of the Cheno/Ams have also contributed to changes in the vegetation composition.

Palynologically, this study has confirmed the idea that modern and past vegetation formations can be identified by regional pollen rains, although the extra-regional pollen must be removed from the pollen spectrum. The removal of extra-regional pollen provides a much clearer picture of changes within the prairie vegetation. Cluster analysis was found to be an excellent tool for the separation and identification of formations and avoided the problem of multicollinearity common with principle component and factor analysis (Webb, 1973b).

Settlement can be identified in the prairie pollen spectrum of southern Alberta by increases in Cheno/Ams and the introduced weed, Taraxacum officinale. Grasslands are composed of high percentages of Gramineae and Artemisia pollen while Short Grass Prairie, in particular, can be separated by the presence of a high concentration of Selaginella densa spores. However, these pollen types are not necessarily proportional to the vegetation composition.

Several limitations and short comings are present within this study: 1) the arid climate of southern Alberta minimized the number of potential sampling sites and restricted the intensity of the sampling pattern; 2) the identification of pollen was at times limited to the family level because of the difficulty of separation; and 3) accurate dating of sediments was not possible for technical and financial reasons.

A more intense pattern of sampling may allow a more detailed picture of vegetational changes such as the migration of the Aspen Parkland and the expansion of the Short Grass Prairie. In addition, refined identification of pollen types may provide a more detailed idea of the actual species changes. The lack of accurate dating methods will always bring the identification of the settlement boundary and sedimentation rates into question. The results from the analysis of extra-regional pollen were limited because of the lack of an adequate data base. Also, a method for accurately determining the quantity of extra-regional pollen must be developed before precise analysis of extra-regional pollen from sediments is possible.

REFERENCES

Allen, H.E. and J.R. Kramer. 1972. Nutrients in Natural Waters. Environmental Science and Technical Series. 457 pp.

Alley, A.N. 1972. "Quaternary History of Southwestern Alberta." Unpublished Ph.D. Thesis, The University of Calgary. 201 pp.

Andersen, S.T. 1967. "Tree-Pollen in a Mixed Deciduous Forest in South Jutland (Denmark)," Review of Palaeobotany and Palynology, 3:267-275.

Bailey, R.E. 1972. "Late and Post Glacial Environmental Changes In Northwestern Indiana." Unpublished Ph.D. Thesis, Indiana University. 109 pp.

Bird, R.D. 1930. "Biotic Communities in the Aspen Parkland of Canada," Ecology, 11(2):356-442.

________. 1961. Ecology of the Aspen Parkland. The Queen's Printers, Ottawa. 155 pp.

Bird, C.D. and I.A.R. Halladay. 1971. "The Cypress Hills." In Alberta: A Natural History. (W.G. Hardy, Editor), M.G. Hurtig, Publishers, Edmonton, Alberta, p. 117-133.

Bonny, A.P. 1972. "A Method for Determining Absolute Pollen Frequencies in Lake Sediments," New Phytologist, 71:393-405.

Bright, R.C. 1966. "Pollen and Seed Stratigraphy of Swan Lake, Southeastern Idaho: Its Relation to Regional Vegetational History and to Lake Bonneville," Tebiwa, 9:1-47.

Bujak, C.A. 1974. "Recent Palynology of Goat Lake and Lost Lake, Waterton National Park." Unpublished M.Sc. Thesis, The University of Calgary. 60 pp.

Canada Department of Agriculture. 1974. The System of Soil Classification for Canada. Ottawa. 255 pp.

Carpenter, K.E. 1928. Life in Inland Waters. (Edited by J.S. Huxley), Sedgwich and Johnston, Ltd. England. 267 pp.

Chorley, R.J. and Haggett, P. 1968. "Trend Surface Mapping in Geographical Research." In Spatial Analysis: A Reader in Statistical Geography. (B. Berry and D.F. Marble, Editors), Prentice Hall, Englewood Cliffs, New Jersey, p. 195-215.

Christensen, O.A, and L.V. Hills. 1971. "Palynological and Paleoclimatic Interpretation of Recent Sedmiments, Waterton Lakes National Park, Alberta." In Western Regional Office Operation Library, Accession No. 2692. 34 pp.

Coupland, R.T. 1961. "A Reconstruction of Grassland Classification in the Northern Great Plains of North America," Ecological Monographs, 20:272-315.

Critchfield, H.J. 1966. General Climatology. Prentice Hall, Inc., Englewood Cliffs, New Jersey. 420 pp.

Cushing, E. 1967. "Evidence for Differential Pollen Preservation in Late Quaternary Sediments in Minnesota," Review of Palaeobotany and Palynology, 4:87-101.

Davis, M. and J. Goodlet. 1960. "Comparison of the Present Vegetation with Pollen Spectra on Surface Samples from Brownington Pond, Vermont," Ecology, 51:346-357.

Dawson, S.J. 1875. Report on the Geology and Resources of the Region in the Vicinity of the Forty Ninth Parallel from the Lake of the Woods to the Rocky Mountains. British North American Boundary Commission. unpaged.

Department of Transport, 1968. Winds: Climatic Normals. Toronto, Ontario. 95 pp.

Douglas, R.J.W. 1970. Geology and Economic Minerals of Canada. Geological Survey of Canada, Department of Energy, Mines, and Resources. 838 pp.

England, R. and A. de Vos. 1969. "Influence of Animals on Pristine Conditions on the Canadian Grasslands," Journal of Range Management, 22(2):87-94.

Environment Canada. 1973. Temperatures and Precipitation 1941-1970, Prairie Provinces. Downsview, Ontario. 159 pp.

Everitt, B. 1974. Cluster Analysis. Heimemann Education Books, Ltd., London. 122 pp.

Fast, A.W. and R.G. Wetzel. 1974. "A Close-Interval Fractionator for Sediment Cores," Ecology, 55:202-204.

Faegri, K. and J. Iverson. 1964. Textbook of Pollen Analysis. Munksgaard, Copenhagen. 237 pp.

Foth, H.D. and L.M. Turk. 1972. Fundamentals of Soil Science. (Edition 5), John Wiley and Sons, Inc., New York. 454 pp.

Freund, J.E. 1967. Modern Elementary Statistics. (Edition 3), Prentice Hall, Englewood Cliffs, New Jersey. 432 pp.

Frey, D.G. 1960. "The Ecological Significance of Cladocern Remains in Lake Sediments," Ecology, 41(4):684-699.

Gershaw, F.W. 1956. "A Brief History of Southern Alberta, The Short Grass Prairie." (Unpublished ?).

Glendinning, G.R. 1974. "The Glacial Geomorphology of an Area Near Calgary, Alberta, Between the Bow River and Fish Creek Valley." Unpublished M.Sc. Thesis, The University of Calgary. 145 pp.

Hansen, H.B. 1949a. "Postglacial Forests In South Central Alberta, Canada," American Journal of Botany, 36:54-65.

________. 1949b. "Postglacial Forests in West Central Alberta, Canada," Bulletin of the Torrey Botanical Club, 76:778-789.

Hardy, W.G. 1971. Alberta: A Natural History. M.G. Hurtig, Publishers, Edmonton, Alberta. 343 pp.

Havinga, A.J. 1967. "Palynology and Pollen Preservation," Review of Palaeobotany and Palynology, 2:81-98.

Janssen, C.R. 1966. "Recent Pollen Spectra from the Deciduous and Coniferous-Deciduous Forest of Northeastern Minnesota, A Study of Disperal," Ecology, 47:804-825.

Kilner, V.J. and L.T. Alexander. 1949. "Methods of Making Mechanical Analysis of Soils," Soil Science, 68:15-24.

Krumbein, W.C. and L.L. Sloss. 1963. Stratigraphy and Sedimentation. (Edition 2), W.H. Freemand and Company, San Francisco. 660 pp.

Lichti-Federovich, S. 1970. "The Pollen Stratigraphy of a Dated Section of Late Pleistocene Lake Sediments from Central Alberta," Canadian Journal of Earth Sciences, 7:938-945.

________. and J.C. Ritchie. 1965. "Contemporary Pollen Spectra in Central Canada, II: The Forest Grassland Transition in Manitoba," Pollen et Spores, 7(1):61-87.

Lodge, R.W., J.B. Campbell, S. Smoliak, and A. Johnson. 1971. Management of the Western Range. Canadian Department of Agriculture, Publication 1425. 34 pp.

Macoun, J.M. 1882. Manitoba and the Great Northwest. World Publishing Company, Guelph, Ontario. 692 pp.

MacGregor, J.G. 1972. A History of Alberta. Hurtig Publishers, Edmonton, Alberta. 335 pp.

McAndrews, J.H. 1967, "Pollen Analysis and Vegetation History of the Itasca Region," In Quaternary Paleoecology. (E.J. Cushing and H.E. Wright, Jr., Editors), Yale University Press, New Haven, Connecticut, p. 219-236.

________. 1968. "Pollen Evidence for the Protohistoric Development of the "Big Woods" in Minnesota (USA)," Review of Palaeobotany and Palynology, 9:201-211.

________. and H.E. Wright. 1969. "Modern Pollen Rain Across the Wyoming Basin and the Northern Great Plains, USA," Review of Palaeobotany and Palynology, 9:14-34.

Moss, E.H. 1932. "The Vegetation of Alberta, IV: The Populus Association and Related Vegetation of Central Alberta," Journal of Ecology, 20:381-415.

________. 1955. "The Vegetation of Alberta," Botanical Review, 21(9):493-567.

________. 1959. Flora of Alberta. University of Toronto Press, Toronto. 546 pp.

________. and R.T. Campbell. 1947. "The Fescue Grasslands of Alberta," Canadian Journal of Research, Section C, 25:209-227.

Mott, R.J. 1969. "Palynological Study in Central Saskatchewan: Contemporary Pollen Spectra from Surface Samples," Geological Survey of Canada, Department of Energy, Mines, and Resources, Paper 69-32.

Murray, R.C. 1956. "Recent Sediments of Three Wisconsin Lakes," Bulletin of the Geological Society of America, 7:803-910.

Nelson, J.G. 1973. The Last Refuge. Harvest House, Montreal. 230 pp.

Palliser, J. 1863. Journals, Detailed Reports and Observations Relative to Captain Palliser's Exploration in British North America, During the Years 1857, 1858, 1859 and 1860. George Edward and William Spottiswoode, London.

Pecsi, M. 1968, "Loess." In Encyclopedia of Geomorphology. (R.W. Fairbridge Editor), Reinhold Book Company, New York, p. 674-679.

Ritchie, J.C. and S. Lichti-Federovich. 1963. "Contemporary Pollen Spectra in Central Canada, 1. Atmospheric Samples at Winnipeg, Manitoba," Pollen et Spores, 5:95-113.

________. 1967. "Pollen Dispersal Phenomena in Arctic-Subarctic Canada," Review of Palaeobotany and Palynology, 3:255-266.

Rummel, R.J. 1970. Applied Factor Analysis. Northwestern University Press, Evanston. 617 pp.

Sangster, A.G. and H. Dale. 1961. "A Preliminary Study of Differential Pollen Grain Preservation," Canadian Journal of Botany, 39:35-43.

________. 1964. "Pollen Grain Preservation of Underrepresented Species in Fossil Spectra," Canadian Journal of Botany, 42(4):437-449.

Smoliak, S. 1965. "A Comparison of Ungrazed and Lightly Grazed Stipa-Bouteloua Prairie in Southern Alberta," Canadian Journal of Plant Science, 45:270-275.

Stalker, A.M. 1960. "Surficial Geology of the Red Deer, Stettler Map Area, Alberta," Geological Survey of Canada, Department of Mines, and Technical Surveys, Memoir 306. 140 pp.

Ward, J.H. 1963. "Heirarchical Grouping to Optimize and Objective Function," American Statistical Association Journal, 58:236-244.

Warkentin, J. 1964. The Western Interior of Canada, McClelland and Stewart, Toronto. 309 pp.

Watts, F.B. 1969. "The Natural Vegetation of the Southern Great Plains of Canada." In Vegetation, Soils and Wildlife. (J.G. Nelson and M.J. Chambers, Editors), Methuen, Toronto, p. 93-112.

Webb, T. 1973a. "Pre- and Postsettlement Pollen from a Short Core, Trout Lake, North Central Wisconsin," Wisconsin Academy of Sciences, Arts and Letters, 61:141-148.

________. 1973b. "A Comparison of Modern and Presettlement Pollen from Southern Michigan (USA)," Review of Palaeobotay and Palynology, 16:137-156.

________. 1973c. "Pre- and Postsettlement Pollen from a Short Core, Blackhawk Lake, West-Central Iowa," Proceedings of Iowa Academy of Science, 80(1):41-44.

Wishart, D. 1968. Clustan, a computer program. St. Andrews Computing Laboratory, United Kingdom.

Wright, H.E. and L.H. Patten. 1963. "The Pollen Sum," Pollen et Spores, 5(2):445-450.

Wroe, R.A., S. Smoliak, A. Johnson and L.M. Forbes. 1972. Alberta Guide to Range Condition and Stocking Rates. Alberta Department of Lands and Forests, Publication No. 11. 18 pp.