Géographie physique et Quaternaire

Isopoll Maps and an Analysis of the Distribution of the Modern Pollen Rain, Eastern and Central Northern Canada
Les cartes isopolles et l'analyse de la répartition des pluies polliniques modernes dans l'est et le centre du Nord canadien
карты изограмм пыльцы и анализ распределения современного дождя пыльцы на востоке п в центре севера Канады

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Citer cet article

Elliot-Fisk, D. L., Andrews, J. T., Short, S. K. & Mode, W. N. (1982). Isopoll Maps and an Analysis of the Distribution of the Modern Pollen Rain, Eastern and Central Northern Canada. *Géographie physique et Quaternaire*, *36*(1-2), 91–108. https://doi.org/10.7202/032471ar

Résumé de l'article

L'analyse pollinique d'un grand nombre d'échantillons de mousses et de lichens prélevés à la surface de 39 sites du centre et de l'est du Nord canadien a été faite. Même si on a pu identifier de 20 à 30 taxons dans les échantillons provenant de chacun des sites, 8 types polliniques (Alnus, Betula, Picea, Pinus, Salix, Gramineae, Cyperaceae, Ericaceae) se partagent habituellement entre 90 et 100% de la pluie pollinique. On présente ici les cartes isopolles de ces taxons, basées sur les pourcentages moyens des nombreux échantillons prélevés sur les 39 sites. L'analyse statistique des données qui a été faite avait pour but de dégager des assemblages polliniques distincts et de déterminer si les paramètres climatiques actuels ainsi que les régions floristiques pouvaient être mis en corrélation avec les sommes polliniques. Une analyse de grappes et de scores des composantes principales et des données brutes a permis de dégager 6 assemblages polliniques distincts qui ont fait l'objet d'une analyse discriminante. Les cartes de concentration pollinique de l'est du Canada, qui ont été dressées, ont servi à l'interprétation des données en pourcentage.

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ISOPOLL MAPS AND AN ANALYSIS OF THE DISTRIBUTION OF THE MODERN POLLEN RAIN, EASTERN AND CENTRAL NORTHERN CANADA

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ABSTRACT At 39 sites in eastern and central northern Canada, multiple samples of surface moss and lichens have been analyzed for their pollen content. Although pollen from 20 to 30 taxa were identified in the samples from each site, 8 pollen types (*Alnus, Betula, Picea, Pinus, Salix,* Gramineae, Cyperaceae and Ericaceae) usually comprise 90 to 100% of the pollen rain. We present isopoll maps of these taxa based on mean percentages of multiple samples from the 39 sites. The data are further analyzed by a number of statistical methods to determine whether there are specific pollen assemblages within this region and to what extent present day climatic parameters and floristic/vegetation zones correlate with pollen counts. Cluster analysis on raw data and on principal component scores yields six distinct pollen assemblages which are further examined by discriminant analysis. Pollen concentration maps for eastern Canada are also presented here and used as an aid in interpreting the percentage data.

RÉSUMÉ *Les cartes isopolles et l'analyse de la répartition des pluies polliniques modernes dans l'est et le centre du Nord canadien.* L'analyse pollinique d'un grand nombre d'échantillons de mousses et de lichens prélevés à la surface de 39 sites du centre et de l'est du Nord canadien a été faite. Même si on a pu identifier de 20 à 30 taxons dans les échantillons provenant de chacun des sites, 8 types polliniques *(Alnus, Betula, Picea, Pinus, Salix,* Gramineae, Cyperaceae, Ericaceae) se partagent habituellement entre 90 et 100% de la pluie pollinique. On présente ici les cartes isopolles de ces taxons, basées sur les pourcentages moyens des nombreux échantillons prélevés sur les 39 sites. L'analyse statistique des données qui a été faite avait pour but de dégager des assemblages polliniques distincts et de déterminer si les paramètres climatiques actuels ainsi que les régions floristiques pouvaient être mis en corrélation avec les sommes polliniques. Une analyse de grappes et de scores des composantes principales et des données brutes a permis de dégager 6 assemblages polliniques distincts qui ont fait l'objet d'une analyse discriminante. Les cartes de concentration pollinique de l'est du Canada, qui ont été dressées, ont servi à l'interprétation des données en pourcentage.

РЕЗЮМЕ *Карты изограмм пыльцы и анализ распределения современного дождя пыльцы на востоке и в центре севера Канады.* На 39 участках на востоке и в центре севера Канады были взяты на анализ на содержание пыльцы многочисленные образцы поверхностных мхов и лишайников. Хотя от 20 до 30 таксонов пыльцы были обнаружены в образцах с каждого участка, 8 видов пыльцы (Alnus, Betula, Picea, Pinus, Salix, Gramineae, Cyperaceae и Ericaceae) обычно составляют от 90 до 100% дождя пыльцы. Мы представляем карты изограмм пыльцы этих таксонов, составленные на основании среднего процентного содержания многочисленных образцов с 39 участков. Данные были далее анализированы рядом статистических методов, чтобы определить, есть ли в этом районе ассоциации особых видов пыльцы и в какой степени современные климатические параметры и растительные зоны соответствуют содержанию пыльцы. Групповой анализ необработанных образцов и главных составных видов дает шесть отчетливых групп пыльцы, которые подвергаются далее дискриминационному анализу. Здесь представлены карты концентрации пыльцы восточной Канады, которые используются в качестве пособия для толкования процентных данных.

INTRODUCTION

Over the last several years, we have amassed data that enabled us to characterize the modern pollen influx of eastern and northern Canada. Most existing data sets (LICHTI-FEDEROVICH and RITCHIE, 1968; DAVIS and WEBB, 1975; WEBB and McANDREWS, 1976) extend only a short distance beyond the modern limit of coniferous trees (Fig. 1A). An adequate comprehension of Late Pleistocene "tundra" episodes in pollen spectra from south of the Laurentide Ice Sheet margin and of changes of vegetation and/or climate within the Arctic tundra itself, requires a firmer understanding of the nature of the present distribution of pollen types and their possible association with underlying vegetation/climatic constraints. Our aim in this paper is to analyze the pollen that we have gathered.

THE POLLEN DATA

The pollen samples analyzed here (Fig. 1B) were collected by: (1) Nichols in 1972-73 along a transect from southwestern Keewatin to Baffin Island (ANDREWS and NICHOLS, 1981); (2) Andrews, Mode, and assistants in the 1970's in Baffin Island (MODE, 1980), and (3) Elliott, Short, Stravers and Nichols in 1973, 1975, and 1978-79 in Labrador-Ungava (ELLIOTT, 1979; STRAVERS, 1981). Using these data, the surface pollen data for northwest Ungava reported by BARTLEY (1967), and the climatic data for selected variables (Table I), transfer function equations have been developed (ANDREWS and NICHOLS, 1981; Short, unpublished) for estimating the degree of climatic change for the region.

NICHOLS (1975), SHORT (1978) and MODE (1980) described the preparation of pollen slides from surface moss and lichen polsters. Counts inside the sum (with exclusions of spores and pollen from local peat producers) varied between 100 and 300 grains, but statistical analysis indicates that counts of 100 adequately represent the "true" proportion of pollen at a particular site (DAVIS, 1980; ANDREWS, et al., 1980a). Because pollen from polsters may have a considerable "local" vegetational signal (BARTLEY, 1967; ADAM and MEHRINGER, 1975; WEBB, et al., 1978; ELLIOTT, 1979; ANDREWS and NICHOLS, 1981), we chose to extract the regional signal by computing means of the pollen percentages from several samples at each site (Table II). Eight taxa: *Alnus* Hill., *Betula* L., *Picea* Dietr., *Pinus* L., *Salix* L., Gramineae (Poaceae), Cyperaceae and Ericaeae[1] comprised 90 to 100% of the pollen counts in most samples. It is these basic pollen types that we report on in this paper. At all our sites, pollen percentage and pollen concentrations (grains/gm dry weight) were computed

by methods outlined in ECCLES *et al.* (1979). Our paper focuses on the percentage data, although we do present and comment on the pollen-concentration data from Labrador-Ungava and Baffin Island. Because of skewness in the distribution of pollen percentages among the several samples at each site, the sum of the means for the individual pollen types was not equal to 100% (variation between 80 to 150%). We, therefore, adjusted the averages proportionally to yield a sum of the 8 taxa equal to 100%.

The pollen concentration data for Labrador and Baffin Island are also presented as means for multiple polsters at forty-four sites; these sites have been grouped into nine composite sites to smooth values for collection in the same geographic area but from very different topographic settings — factors which influence the local vegetation (ELLIOTT, 1980) (Fig. 2). Concentration counts for the Keewatin transect are available and are currently being evaluated (Nichols, unpublished).

ENVIRONMENTAL DATA

Climate varies considerably among our study sites (Table I). The interior of Keewatin (such an Ennadai and Baker Lakes) experiences lower average annual temperatures (even with its higher average summer temperatures, as these are offset by its low winter temperatures so typical of a continental climate) and lower annual precipitation than vegetationally comparable sites in eastern Canada (such as Fort Chimo and Frobisher Bay), which are more mesic in nature and often maritime in setting. In the Arctic, the ranges of many species are strongly correlated with climate, especially summer warmth (YOUNG, 1971). Climate also influences the growth form of vegetation. The question remains whether the geographic distribution of our pollen data is related to regional climate.

Floristic and vegetation zonation schemes for the North American Arctic referred to in this paper include YOUNG's (1971) arctic floristic delineation (with zone 4 Low Arctic, zone 3 Transitional Arctic and zone 2 High Arctic). Although the above zone boundaries do not precisely match those of PORSILD's (1957) and POLUNIN's (1960) vegetation zones, they are similar and are used for discussion purposes herein. Our pollen data is therefore discussed in reference to both floristic and vegetation zones, with Figure 1A modified from the above studies and other investigations of the vegetation and flora of our study area (LARSEN, 1972; SHORT, 1978; ELLIOTT, 1979; MODE, 1980).

DATA ANALYSIS

Our major objective is to present a series of isopoll maps for pollen percentages and concentrations across the region of interest (Figs. 3, 4, 5 and 6; Tables II, III,

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1. The English equivalents are: *Alnus*, alder; *Betula*, birch; *Picea*, spruce; *Pinus*, pine; *Salix*, willow; Gramineae *(Poaceae)*: grass; Cyperaceae: sedge; Ericaceae: heath.

IV, V and VI). We are also interested in examining any underlying structure to the data by methods similar to those used by BIRKS *et al.* (1975), DAVIS and WEBB (1975), WEBB and McANDREWS (1976) and BERNABO and WEBB (1977). Our data set from the Low and High Arctic tundras extends north of the data presented in these earlier studies.

ISOPOLL MAPS

Isopoll maps, and indeed all the contoured maps used in this paper (excluding the concentration maps), have been prepared using a program developed by L.D. Williams (see, for example, DAVIS, 1973, p. 310-316). À 9 × 14 grid was established over the area and at each grid point a weighted estimate was calculated based on the two nearest data points. The resulting grid of values was then automatically contoured. Because of the uneven spread of our data points within the

9 × 14 grid, the final maps we show here have been adjusted and estimates of percentages in areas far removed from a data point are excluded. Contoured maps of pollen concentration were constructed by hand and the contours were positioned by linear-gradient techniques applied to the actual data points. In addition, we use an uneven contour interval (appropriately labeled) for certain taxa to illustrate important aspects of their distribution.

Alnus

Alnus pollen is an important component of the modern surface pollen and may be an important indicator of paleowinds (NICHOLS *et al.*, 1978 ; BARRY *et al.*, 1981). Percents drop non-linearly beyond the northern limit of the shrub species *(Alnus crispa).* Values of above 5% in southeastern Baffin Island appear to reflect transport from northern Labrador (Fig. 3A). The region
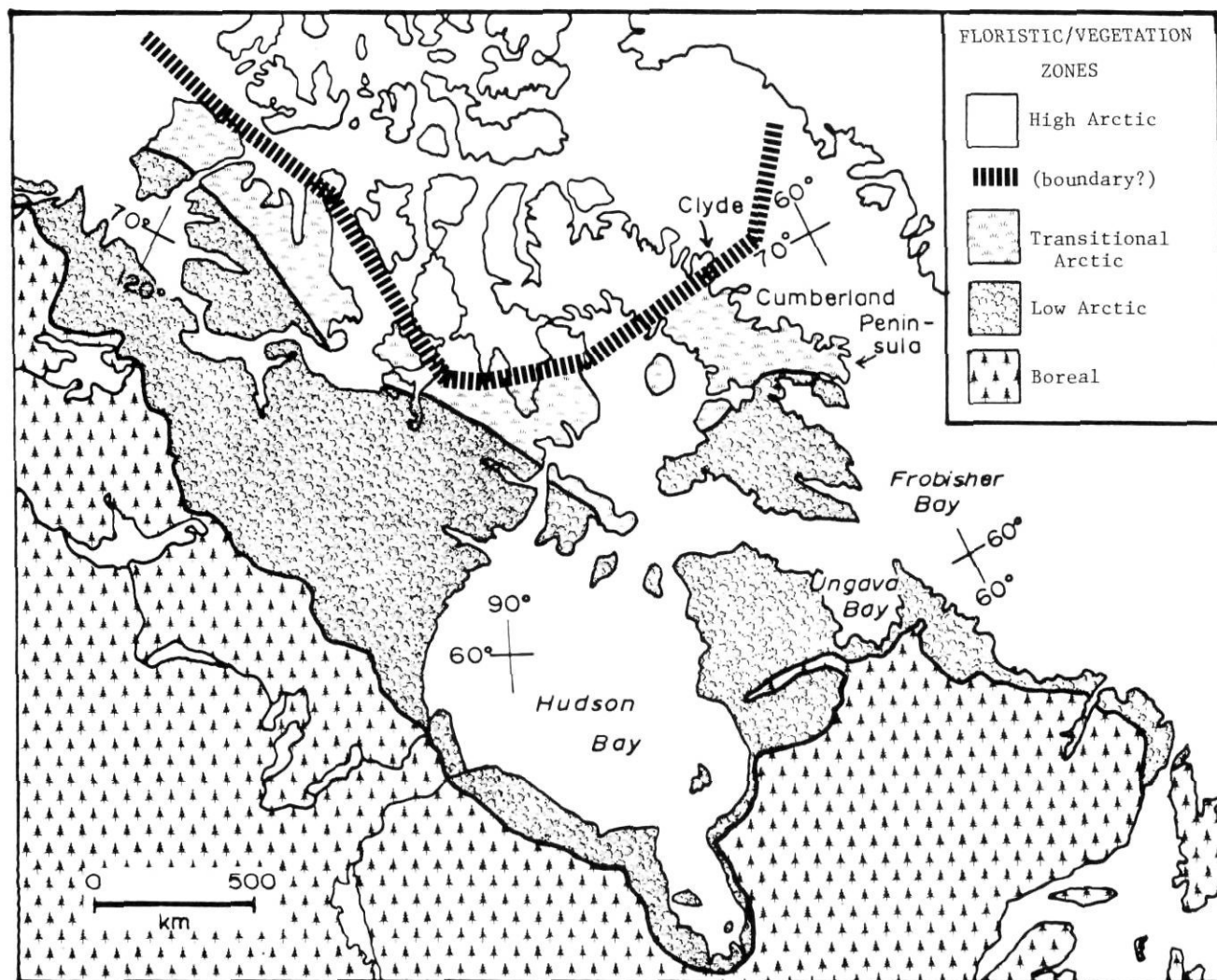

FIGURE 1A. Major floristic zones of northern Canada.   *Principales régions floristiques du nord canadien.*

of low values (<2%) occupies the central area surrounding the Foxe Basin and, thus, is neither receiving large influxes from the west (Mackenzie) and southwest (Keewatin), nor from the southeast (Labrador) and east (Greenland).

We believe that almost all of the *Alnus* pollen is from *Alnus crispa*, though occasional influxes of other species growing further south may also occur (Fig. 3A). *Alnus crispa* is principally a boreal species, and occurs just north of the limit for *Picea* along the forest-tundra ecotone of the Northwest Territories (Fig. 1B), whereas it occurs quite far north of these trees on the Labrador-Ungava Peninsula (ELLIOTT, 1979), even extending to Greenland (KUC, 1974).

The distribution of *A. crispa* populations along the Keewatin transect confirms the boreal affiliation of this species, at it is seldom found outside of any but the

largest remnant patches of the boreal forest still existing in the forest-tundra ecotone. As *A. crispa* is not only common in the forest-tundra ecotone of eastern Canada, but is very extensive, forming high, dense shrublands many kilometers in extent north of the tree limit in Labrador (ELLIOTT, 1979; ELLIOTT and SHORT, 1979), we believe that it may be an indicator of the climatic potential tree limit, although it is likely that conifers would only exist in a vegetative state at these northernmost locations.

Alnus (crispa) pollen reaches its highest concentrations (and intuitively, productivity as based on pollen values and the size of individual plants) along the north-central Labrador coast between Nain and Saglek (Fig. 5A). Here, it forms extensive mixed shrublands, often associated with *Betula glandulosa* Michx. and *Salix* L. spp. It is also found within and above boreal woodland patches.
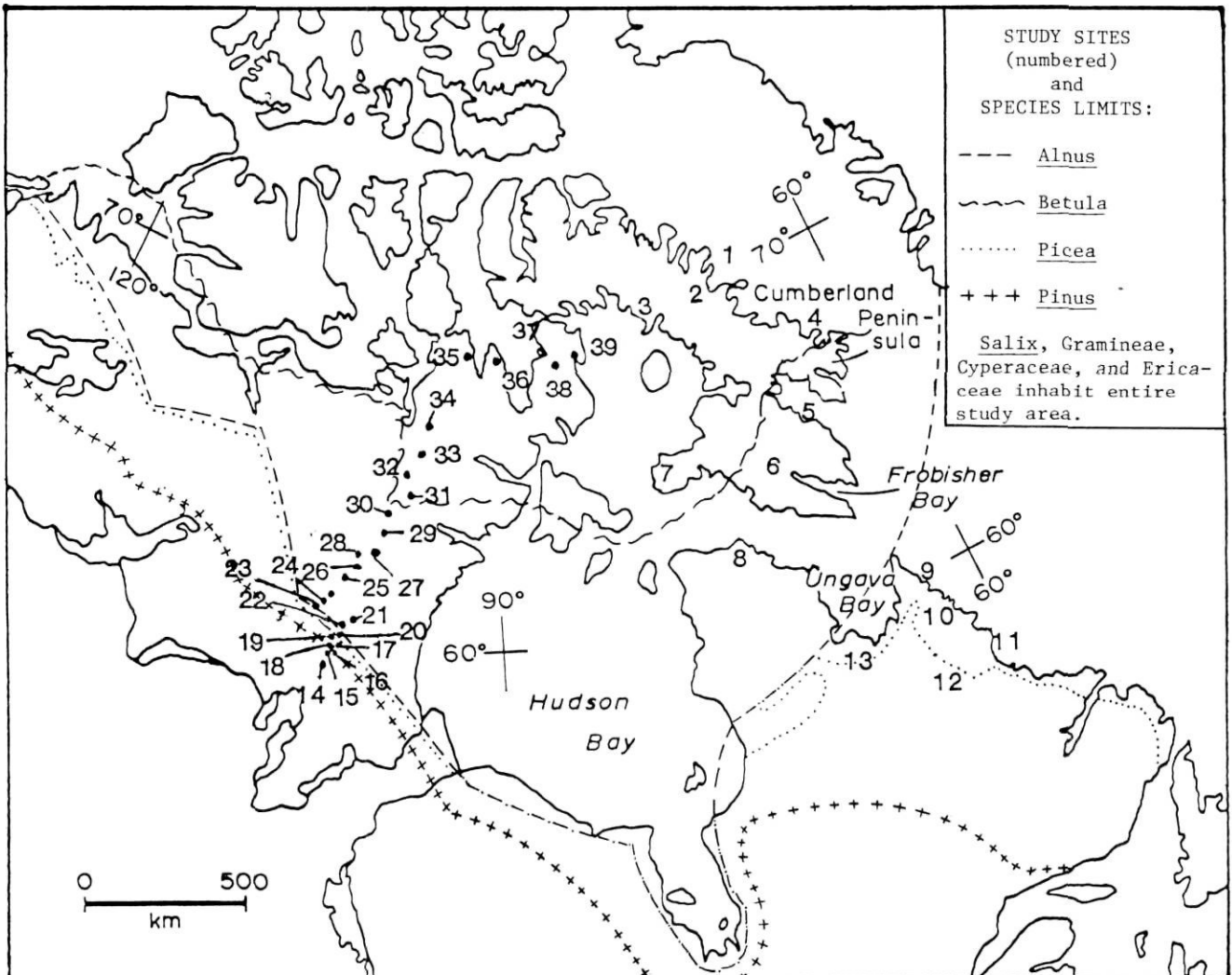

FIGURE 1B. Location of the 39 sites used in this study and the major genera limits.

Localisation des 39 sites étudiés et des limites des principaux genres.

Table I

Climatic Data (variably between 1942-1971AD) from Selected Stations (Fig. 1)

	Avg. Ann. T°C	July T°C	Jan T°C	Total precip. (cm)	Summer* precip. (cm)
Indian House Lake	− 5.1	12.2	−23.6	54.3	21.9
Fort Chimo	− 5.4	11.3	−23.5	48.4	16.0
Ennadai Lake	− 9.5	12.7	−31.6	28.6	12.0
Baker Lake	−12.3	10.7	−33.5	20.7	8.5
Cape Hopes Advance+	− 7.1	5.5	−21.5	31.8	11.9
Cape Dorset+	− 9.7	6.9	−25.6	37.4	7.1
Frobisher Bay	− 9.1	7.8	−26.2	40.9	14.8
Broughton Island	−11.3	4.4	−23.6	28.0	6.5
Pelly Bay	−15.3	6.7	−33.1	20.0	9.4
Hall Beach	−14.3	5.5	−31.2	20.0	7.7
Longstaff Bluff	−12.6	7.0	−27.6	20.0	7.8
Dewar Lake	−13.1	5.7	−26.8	21.4	9.7
Clyde River	−12.2	4.4	−27.1	20.4	6.2

*Summer — June, July, August
+ Infrequent records
Data obtained from tapes in the National Climate archives, Nashville.

Table II

Modern pollen percents for 8 taxa adjusted to sum to 100%

Sample No.	Alnus	Betula	Picea	Pinus	Salix	Grass	Sedge	Heath
1	.100	.100	.100	.300	6.300	89.300	2.400	1.000
2	1.700	3.100	1.300	7.300	5.600	56.900	5.000	18.800
3	2.600	2.300	.900	5.100	5.700	2.200	37.700	43.500
4	.800	1.600	.400	.800	35.800	6.800	29.300	24.400
5	5.300	6.200	.800	9.800	19.500	8.800	17.700	31.900
6	5.900	20.000	0.000	12.400	13.400	9.200	24.000	14.700
7	1.700	4.300	2.800	5.200	18.900	60.400	4.300	2.000
8	1.400	6.100	2.500	5.700	25.400	31.700	21.800	5.300
9	8.100	19.600	20.100	2.200	10.400	4.300	11.600	23.700
10	17.400	33.500	10.000	3.700	12.900	10.600	6.500	5.500
11	21.200	29.400	11.700	2.500	6.700	7.400	18.000	3.100
12	19.300	15.800	49.300	3.300	.600	1.600	4.100	5.800
13	9.100	14.600	40.900	4.400	3.500	1.400	21.500	4.500
14	7.800	11.800	37.700	30.100	.200	.500	1.300	10.800
15	16.300	23.200	30.200	19.500	.600	1.500	.900	7.800
16	39.600	13.700	16.400	18.900	.400	.900	7.600	2.600
17	11.500	15.100	29.900	28.700	.400	.200	.800	13.600
18	14.000	15.800	20.000	26.300	.600	.400	2.100	21.000
19	6.100	15.800	17.600	15.300	24.100	4.100	2.700	14.300
20	9.200	19.200	14.900	19.400	2.100	.300	13.300	21.600
21	7.900	34.300	15.900	21.600	.800	.500	2.900	16.100
22	4.600	43.200	16.900	14.500	.800	.800	10.900	8.400
23	13.400	35.800	10.800	20.300	.600	3.900	6.200	8.900
24	10.900	39.800	9.800	18.400	3.900	2.000	2.600	12.500
25	5.400	33.000	12.800	24.100	5.600	.800	4.000	14.300
26	10.900	16.500	9.000	29.800	16.100	3.700	1.500	12.500
27	7.200	64.500	4.900	14.100	.400	2.500	1.500	5.000
28	13.300	31.200	11.300	18.200	1.700	.300	4.600	19.300
29	15.000	26.500	13.400	23.000	1.800	.300	2.200	17.600
30	8.000	17.900	5.500	27.200	6.900	6.000	21.100	7.200
31	10.600	25.100	5.500	23.900	1.400	4.300	2.600	26.600
32	15.800	21.700	3.200	16.000	.400	2.200	3.700	37.000
33	5.800	9.300	1.100	6.100	25.100	5.300	17.300	30.100
34	9.200	7.800	3.900	10.200	32.000	8.500	20.900	7.300
35	4.100	6.800	2.400	17.500	6.200	14.400	18.000	24.400
36	2.700	5.600	1.400	21.700	44.900	2.100	20.400	1.200
37	4.800	5.100	1.900	17.100	19.000	6.700	6.000	41.200
38	.500	1.400	1.000	6.000	40.500	2.900	45.200	1.100
39	.010	.800	.010	.700	8.300	65.500	8.700	16.000

The high values (in excess of 12,800 grains/gram dry weight of polster material) decline both to the north and south and onto the plateau, as the taxon declines in dominance over the area (Table VI). At sites west of the coast, as for example, along the George River, *A. crispa* is found in a shrub belt above the woodland that occupies the valley bottoms. This accounts for its lower dominance and, therefore, pollen concentrations inland.
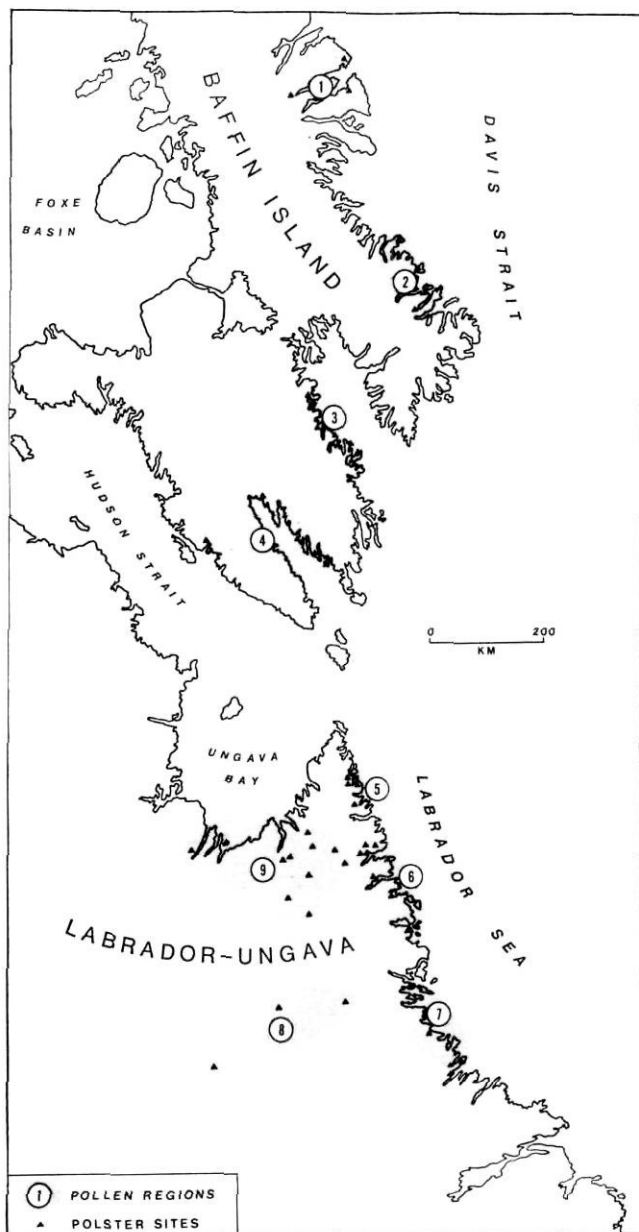

FIGURE 2. Pollen regions used in computing average pollen concentration data.

Régions polliniques qui ont servi au calcul des données de concentration pollinique moyenne.

North of the alder dominated region on the coast, *A. crispa* is found in moderately moist sites along valley floors and up to 100 m above on the valley walls. Pollen values on Baffin Island rapidly decrease to the north (since the taxa is not present on the island : Fig. 1B), with exotic transport from the south apparent.

As discussed in NICHOLS *et al.* (1978) and BARRY *et al.* (1981), it is likely that pollen influx of *A. crispa* into Baffin Island is predominately from Labrador, as pollen from central Canada would have to traverse much longer distances, with the decline in exotic influx apparent. This is also well illustrated in the percentage isopoll map (Fig. 3A).

Although our actual data values from which isopolls have been constructed are not shown on our figures, *the values for the percentage map are also higher along the coast than in the interior* (see Table VI); to portray this would necessitate contours not only 20 and 10, but 19, 18, ... and 11%.

Betula

Both *B. nana* and *B. glandulosa* are found on Baffin Island (ANDREWS *et al.*, 1980) with the northernmost individuals restricted to south-facing slopes at elevations above the pronounced influence of the ocean waters. In Labrador, *B. glandulosa* is nearly a ubiquitous component of the vegetation, occurring within woodland stands, as a major component of the very important shrub tundra, and further north and at high elevations as a more minor component of the lichen-heath tundra in protected locations. Although the extensive shrublands north of the tree limit diminish as one moves west through Canada (ELLIOTT, 1979), *B. glandulosa* continues to be an important local component of the vegetation for 100 to 200 km beyond outlying conifer populations.

In Keewatin, *B. glandulosa* is the major component of the low arctic shrub tundra, other shrub species being very much subdominants. Its importance here as a pollen producer is reflected in Figures 3B, 3A and 4A, comparing *Betula* with *Alnus* and *Salix* isopolls. We do not distinguish between tree and shrub pollen on Figure 3B. A distinct pollen maximum with values close to 40% and usually between 20 and 40% extends between treeline and the northern limit of dwarf birch in Keewatin. This bulge northward corresponds to the northern range extensions of both the shrubs and trees along the major rivers, such as the Kazan and the Dubawnt. This *Betula* pollen-dominated area is identical with YOUNG's (1971) floristic Zone 4. In Labrador, *Betula* pollen has high values (>20%) along the northeastern coast, with the contours aligned approximately north-south. In southeastern Baffin Island, high values of *Betula* pollen represent local patches of prostrate shrubs and our data suggests (ANDREWS *et al.*, 1980 ; MODE,

TABLE III

Mean and standard deviations for taxa in the 6 clusters

Taxa	Cluster 1		2		3		4		5		6	
Alnus	0.9	.9	5.2	1.7	10.7	3.3	2.9	3.6	11.6	5.4	17.3	11.8
Betula	2.1	2.0	9.7	6.7	19.1	3.4	4.5	2.9	37.1	10.8	15.7	4.0
Picea	1.1	1.3	1.8	1.8	12.9	10.0	1.8	1.3	11.8	3.4	34.1	11.3
Pinus	3.4	3.4	13.6	7.7	19.0	9.1	8.9	7.9	16.0	7.6	17.4	11.5
Salix	9.8	6.2	13.7	7.8	7.9	9.3	35.7	7.5	3.5	4.0	1.0	1.2
Gramineae	68.0	14.6	7.5	3.8	2.8	1.8	10.4	12.2	2.9	5.1	1.0	0.6
Cyperaceae	5.1	2.6	20.3	9.5	5.4	4.9	27.5	10.5	5.9	5.1	6.0	8.0
Ericaceae	9.5	9.3	27.5	13.2	22.4	8.2	7.9	9.6	11.1	5.7	7.5	4.1

Pollen Assemblage	Vegetation/floristic zone
Cluster 1 : Grass/willow/heath	Transitional to High Arctic tundra
Cluster 2 : Heath/sedge/willow (pine)	Transitional (Low to High) Arctic tundra
Cluster 3 : Heath/birch/pine	Low Arctic tundra (dry?)
Cluster 4 : Willow/sedge/grass	Low to Transitional Arctic tundra (wet?)
Cluster 5 : Birch/pine/spruce	Forest-tundra ecotone (Boreal to Low Arctic tundra)
Cluster 6 : Spruce/pine/alder	Northern Boreal forest-woodland

TABLE IV

*General climatic conditions for
the six Regional Pollen Assemblages (RPA)*
(values derived from Table 1 and other climate station records)

	Avg. Ann. T°C	July °C	Summer Precip. (cm)	Seasonality*
RPA 1	−12° to −14°	4°- 7°	6-12	28°-36°
2	− 9° to −12°	8°-11°	8-15	34°-42°
3	−10° to −12°	9°-11°	9-16	25°-42°
4	−10° to −15°	6°- 9°	9-16	35°-42°
5	− 6° to −10°	9°-11°	12-25	35°-44°
6	− 5° to −10°	11°-13°	12-22	36°-44°

* Seasonality defined as : July T°C-Jan T°C

1980; DAVIS, 1980) that in this area, *Betula* pollen travels only limited distances in the air. Percentages of 6% or more are indicative that the shrub is growing within 10 m of the site. The trend of contours around Foxe Basin suggests that this cold, inland sea creates a trough in the *Betula* pollen percentages. The coastal effect is also present along the coast of Hudson Bay (Fig. 3B).

In our isopoll map, *Betula* declines to the northwest across Labrador-Ungava, with highest values reached along the north-central coast in the vicinity of Nain (Fig. 3B). In contrast, the highest concentration values are found in the interior of Labrador-Ungava near the northern treeline along the George and Koroc Rivers (Fig. 5B). It is possible that the increased pollen production for *Picea, Salix* and other understory plants,

as well as the relatively important influx of *Pinus*, contributes to the decline of the percentage values here in the interior relative to the Labrador coast. The pollen concentration maps for Baffin Island correspond to the isopoll map and both correlate with the genus' distribution.

Picea

The limit of *Picea* today (Fig. 1B) represents the combined northern limit of both *P. glauca* (Moench) Voss and *P. mariana* (Mill.) B.S.P. In general, *P. glauca* occurs north of *P. mariana* in coastal locations and in the interior in more xeric habitats (*e.g.*, eskers, outwash plains, etc.). Their pollen is similar enough in size and morphology to be hypothesized to be capable of being transported equal distances.

Pollen percentages for *Picea* (Fig. 3C) partly reflect the limits of the tree species. Over central Labrador-Ungava values exceed 40% and fall off rapidly toward the northeast and northwest. These values extend furthest north along the George River drainage. In Keewatin, maximum values reach 30% and tail off exponentially toward the north and northeast. This difference in pollen percentages is influenced by the relative importance of *Pinus* pollen in the area. As can be seen from both the *Pinus* isopolls and its northern limit, *Pinus* populations are more extensive in the northern boreal forest of central than of eastern Canada. In addition, the 5% (exotic influx) isopoll lies further north of the genus limit in Keewatin than in northeastern Labrador. This may reflect an additional influx of *Pinus* pollen exotics from the western boreal forest (Mackenzie District) as well as from forest to the south. Values along the eastern coast of Baffin Island do not vary

TABLE V

Factor Loadings on R-mode Principal Component Analysis

Taxa	Factors					% Variance of each taxa on first five P.C.
	1	2	3	4	5	
Alder	.397	−.009	−.267	−.302	−.189	36%
Birch	.396	.016	−.008	.553	−.561	78%
Spruce	.376	−.128	−.336	−.492	.267	58%
Pine	.349	.314	.181	.352	.651	80%
Willow	−.425	.206	−.351	.251	.259	48%
Grass	−.294	−.666	.315	−.013	.069	63%
Sedge	−.385	.348	.421	−.090	−.226	51%
Heath	−.074	.527	.619	−.406	−.175	86%
Cumulative % Variance	39	56	70	81	89	

TABLE VI

Adjusted means for concentration pollen data
(grains/gm dry weight)

Region Name	Region No.	No. of sites	Alnus	Betula	Picea	Pinus	Salix	Gramineae	Cyperaceae	Ericaceae
Clyde, BI	1	3	34	23	16	34	2020	1114	838	794
Qivituq, BI	2	4	50	1190	11	39	2595	1143	1389	1945
Cumberland Sound, BI	3	6	119	432	32	164	897	573	656	2531
Frobisher Bay, BI	4	5	460	11898	136	458	2484	877	1212	4483
Torngat Mtns., L-U	5	3	1846	8600	1297	465	4422	2212	2206	891
North-Central Coast, L-U	6	7	18993	12379	3854	679	2607	5214	9950	1676
Central Coast, L-U	7	3	7540	5293	9122	684	78	302	1001	2351
Interior Plateau, L-U	8	3	4992	8412	13923	3043	4344	686	14343	2467
Northern Plateau, L-U	9	10	4771	16691	13913	1033	3969	1017	4170	1182

greatly between Frobisher Bay in the south and Clyde River in the north.

The concentration and isopoll maps for *Picea* in eastern Canada correspond closely (Fig. 3C and 5D). Both show the highest values in the interior of Labrador-Ungava (Region 9, Fig. 2) which parallels the taxon's distribution, density and dominance. These high values extend furthest north along the George River valley, the floor of which is occupied by a dense spruce forest.

Pollen values on both maps decline away from the northern *Picea* population limit (Fig. 1B), as exotic influx decreases with increasing distances.

Pinus

The importance of *Pinus* as a local and exotic component of the pollen rain is well illustrated by the spatial variation in isopolls (Fig. 3D). As was stated in the discussion of *Picea* populations, *Pinus* occurs closer to the northern conifer tree line in western and central than in eastern Canada (Figs. 3D and 1B). This may be due to a combination of the following factors: (1) competition, (2) differences in the timing/rate of deglaciation, and (3) differences in the climate of the two areas (temperature, moisture, cloudiness, etc.).
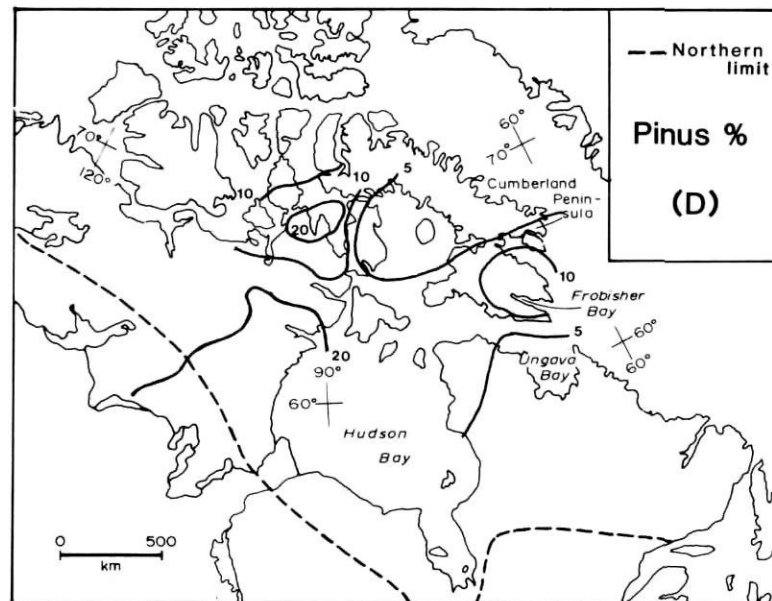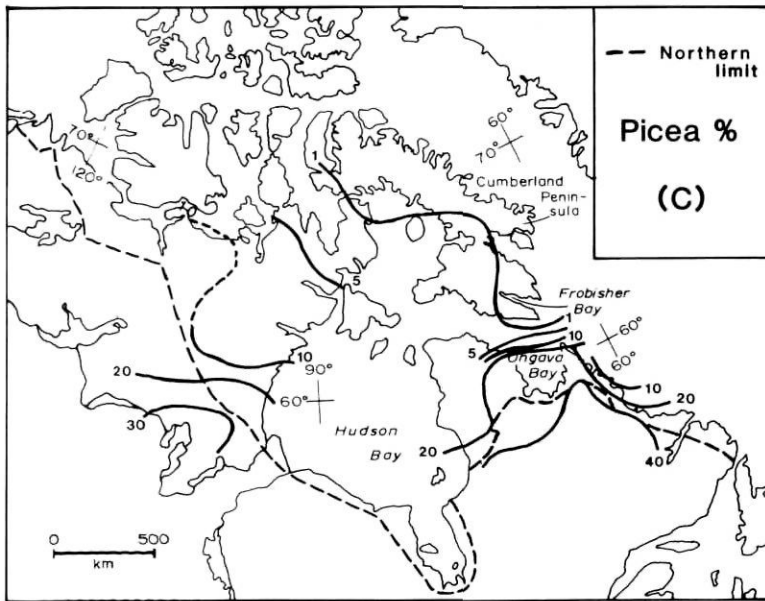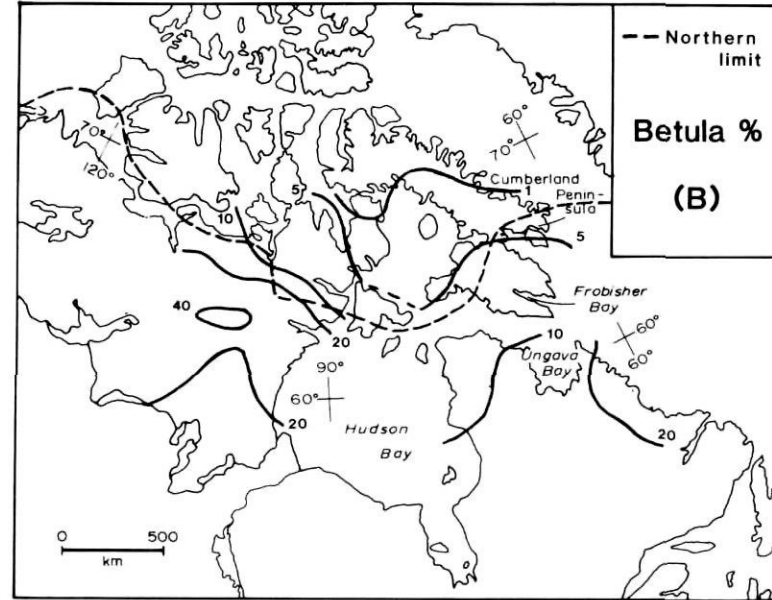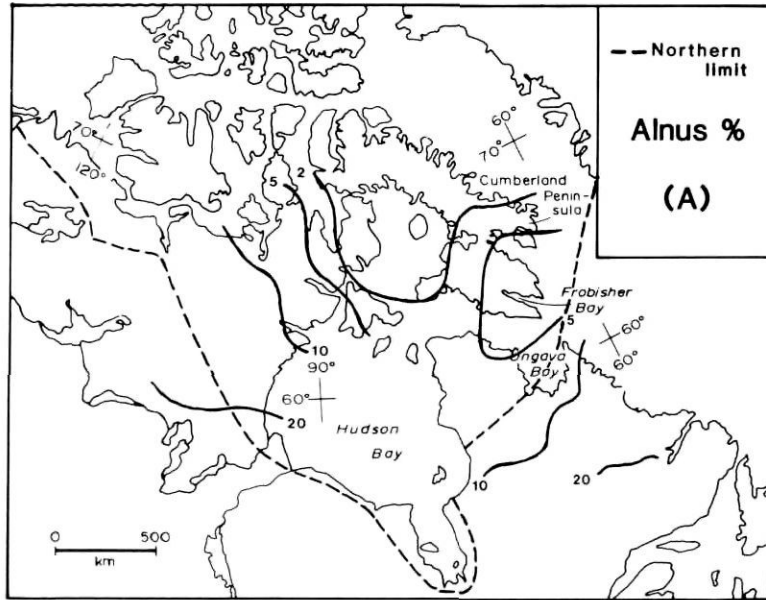
FIGURE 3. Isopoll maps for the study region (contour intervals may not be even). A: *Alnus*, B: *Betula*, C: *Picea*, D: *Pinus*.

Cartes isopolles de la région à l'étude (les intervalles entre les isolignes ne sont pas nécessairement égaux). A: Alnus, B: Betula, C: Picea, D. Pinus.
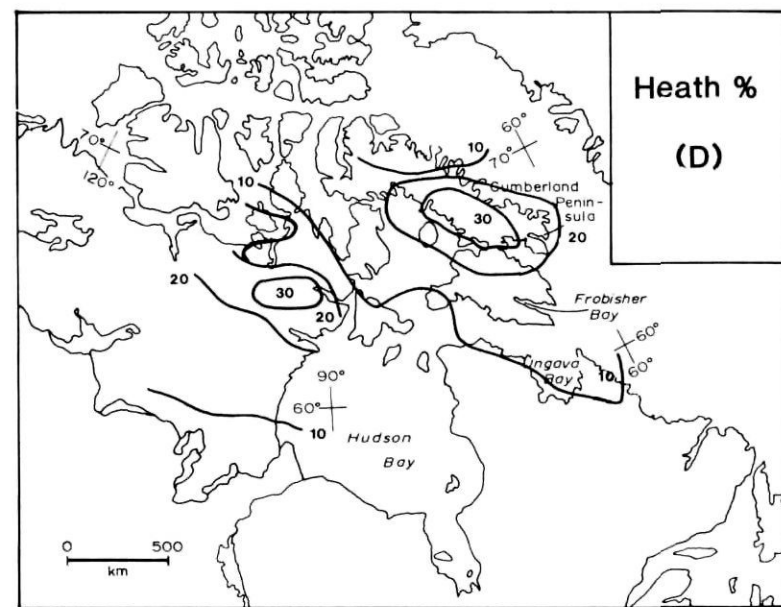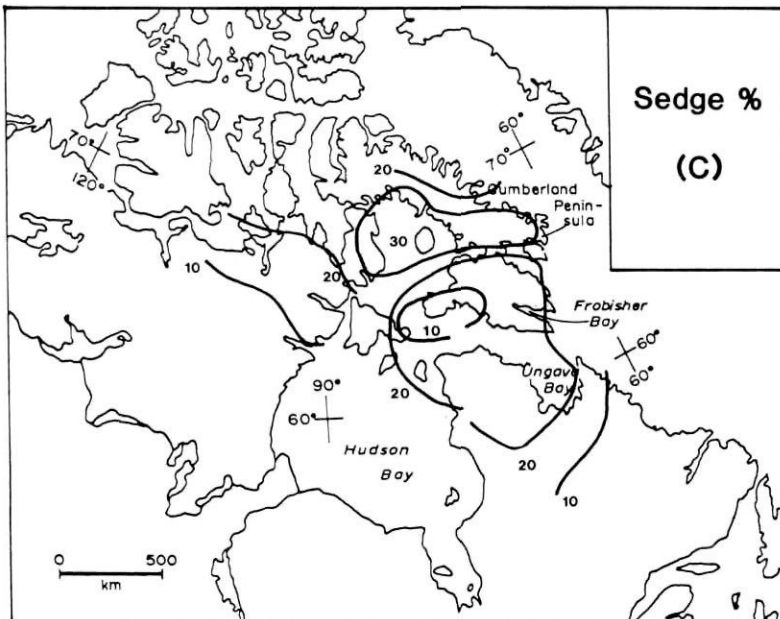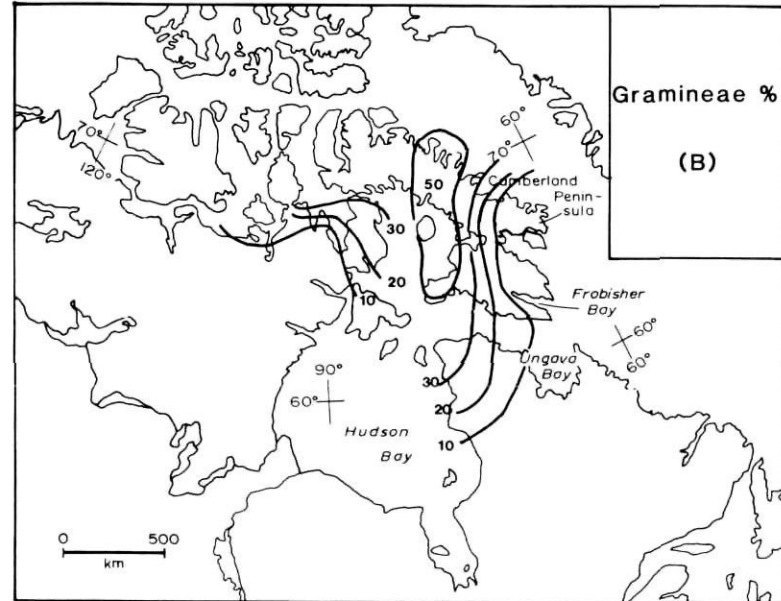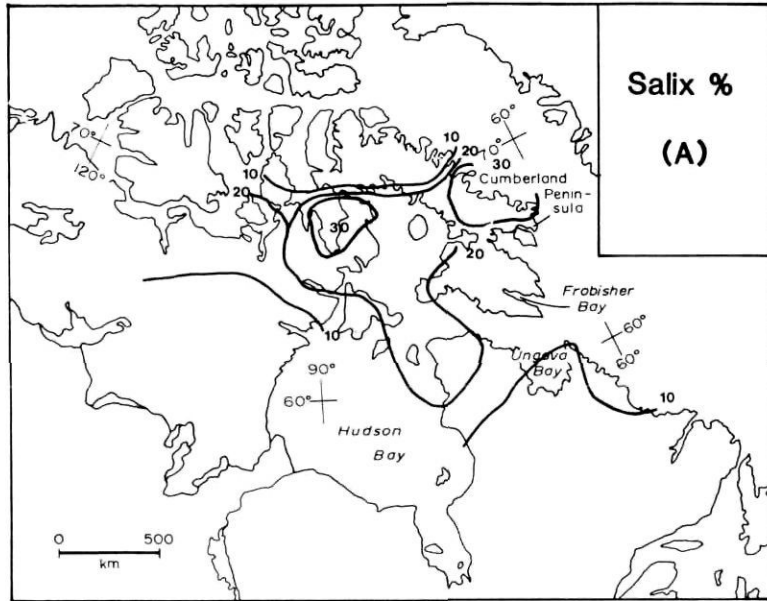
FIGURE 4. Isopoll maps for study area (contour intervals may not be even). A: *Salix*, B: *Gramineae*, C: Sedge, D: Heath.

Cartes isopolles de la région à l'étude (les intervalles entre les isolignes ne sont pas nécessairement égaux). A: Salix, B: Gramineae, C: laîches, D: bruyères.

The surface pollen spectra of the area west of Hudson Bay consists of between 20 and 30% *Pinus* (Fig. 3D). In contrast sites in Labrador-Ungava record less than 5% pine pollen. This is a result of the distribution of the genus, with the northern limit of *Pinus* populations only 50 km from the northern *Picea* forest limit in central Canada, whereas they are as much as 400 km apart in eastern Canada (Fig. 1B). It, therefore, continues to be a dominant component of the pollen rain further north of the tree line in central than

in eastern Canada. However, the values increase to the northwest and north, and the values of *Pinus* pollen average 5% at Cape Dorset (#7) and are between 5 and 12% at sites #5 and #6. Another interesting feature of the *Pinus* isopoll map is the increase of *Pinus* percentages near the coast of the Arctic Mainland, where values rise to 20%. This isopoll "high" probably reflects the decrease in local *Betula* pollen production and testifies to the long-distance transport of *Pinus* pollen 10^2 km beyond its northern limit. However, it is also possible that the high values along the Arctic Coastal plain reflect transport of *Pinus* pollen eastward from the northern tree limit near the coast in the vicinity of Coppermine in the Mackenzie District (Figs. 1A and 1B). The relatively large pollen value over southeastern Baffin Island cannot be explained by this transport path and it may reflect northeastward airflow from the population's northern limit in southern Keewatin.

It is apparent from the pollen concentration map for *Pinus* (Fig. 5C) that these low values reflect exotic influx from the south and west, decreasing with increasing distances away from the northern pine limit. Although the pollen values for *Pinus* are higher in southeastern Baffin Island than for sites to the north, values here are lower than those for Labrador-Ungava, a trend that is not shown on the isopoll map (Fig. 3D). This higher percentage value may be a function of the decreased influx of *Picea* to Baffin Island. It can be seen from Figure 5C and 5D that *Pinus* has higher concentration values in Baffin than *Picea* does. As the pollen production of all tundra taxa is relatively low, it seems reasonable that it is simply the favored influx of the more easily transportable *Pinus* grains that explain the high percentage value for southeastern Baffin Island.

Salix

Salix populations extend throughout the study area and are common in most arctic habitats. In the Low Arctic tundra zone (as well as the northern boreal forest) in protected locations, willows can be tall whereas further north, the same or different species become prostrate and are frequently found in association with heath (Ericaceae) communities. The stressful conditions which lead to the dwarfing of growth forms at high latitudes also lead to a decrease in the productivity of individuals (*e.g.*, decrease of growth-ring width).

Salix populations contribute relatively few pollen grains to the modern surface pollen spectra in Keewatin (Fig. 4A) from treeline northward to the limit of the Low Arctic floristic zone (Fig. 1A). This distribution contrasts with Labrador-Ungava and Baffin Island where willow is important within the Low Arctic. Pollen concentrations actually reach their highest values here, with *Salix* becoming a major element in pollen samples along the coast of eastern Baffin Island, on Hall Peninsula, and in
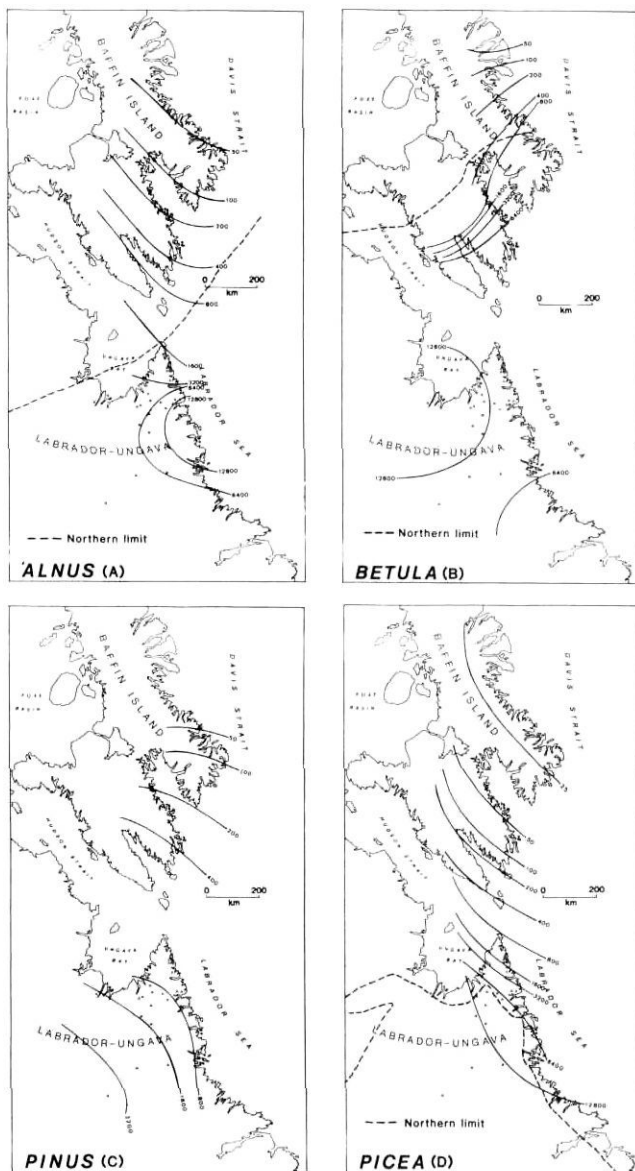

FIGURE 5. Pollen concentration maps for the sites in Labrador and Baffin Island. A: *Alnus*, B: *Betula*, C: *Pinus*, D: *Picea*. For site locations see Figure 2. Data in Table VI.

Carte de concentration pollinique des sites du Labrador et de l'île de Baffin. A: Alnus, B: Betula, C: Pinus, D: Picea. Voir la figure 2 pour la localisation des sites. Le tableau VI présente les données pertinentes.

the sites immediately west (Fig. 6A). It will be important to obtain samples from northern Baffin Island and the High Arctic islands of Canada to determine the role of *Salix* in the surface pollen counts in High Arctic and Polar Desert environments, as it appears to be one of the more productive tundra taxa.

In the pollen concentration map (Fig. 6A), *Salix* is seen to reach its highest productivity in the Low Arctic tundra, as well as some interior forest-tundra ecotone

FIGURE 6. Pollen concentration maps for the sites in Labrador and Baffin Island. A. *Salix*, B: *Gramineae*, C: *Cyperaceae*, D: *Ericaceae*. For site locations see Figure 2. Data in Table VI.

Cartes de concentration pollinique des sites du Labrador et de l'île de Baffin. A: Salix, B: Gramineae, C: Cyperaceae, D: Ericaceae. Voir la figure 2 pour la localisation des sites. Le tableau VI fournit les données pertinentes.

sites in Labrador. Values decrease somewhat in south-eastern Baffin Island, reaching a low for the island along the southern fringes of Cumberland Sound, then increasing to the north toward Broughton Island (Cumberland Peninsula).

These high values (greater than 3200 grains/gram dry weight) in northern Labrador correspond to dense and productive willow communities in river valleys. Species such as *S. planifolia* Pursh., which are very large and biologically productive individuals, are most likely the dominant contributors to the *Salix* pollen rain. The increase in *Salix* pollen concentration for the Cumberland Peninsula is more difficult to explain; perhaps true arctic species are increasing in importance here, a switch from the northward declining influx of boreal species from the south. Again, the high percentage values of *Salix* are in many cases a result of the decline of pollen production, especially for *Betula*, which is no longer an important component of the local vegetation, as well as a decline in the influx of exotics from the boreal forest/woodland.

Gramineae

Gramineae (grass) is the dominant pollen type at sites aligned north to south between Clyde River (#1) and Ungava (#8) (Fig. 4B). Grass contributes relatively little pollen to the surface pollen spectra in most of northern Labrador and it only becomes important in Keewatin in the vicinity of the Hall Peninsula. The highest pollen concentration values for grass occur within the coastal forest-tundra ecotone and shrub tundra of Labrador (Fig. 6B); this may be partly due to the large topographic and, hence, vegetational variability here, along with increased pollen and vegetative productivity of plants.

This occurrence of maximum grass percentage values in the most stressed environments fits well with our fossil pollen spectra for more southerly locations following deglaciation (SHORT, 1978). The increased dominance of grass northward may be partly a response to the decrease in precipitation toward higher latitudes and the increased tendency toward Polar Desert conditions in northern and western Baffin Island.

The percentage and concentration maps show very different trends (Figs. 4B and 6B) for the grass family. This is perhaps related to not only the change in pollen production of both the grasses and other components of the vegetation, but to the difference in our number of plotted sample sites for the two types of maps. Our concentration diagram does not have enough northern and western points to show these lineations. As stated earlier, the grass pollen suggests that the highest pollen production is in the coastal forest-tundra ecotone and shrub tundra sites along the north-central Labrador coast. There is no question that grass is a dominant
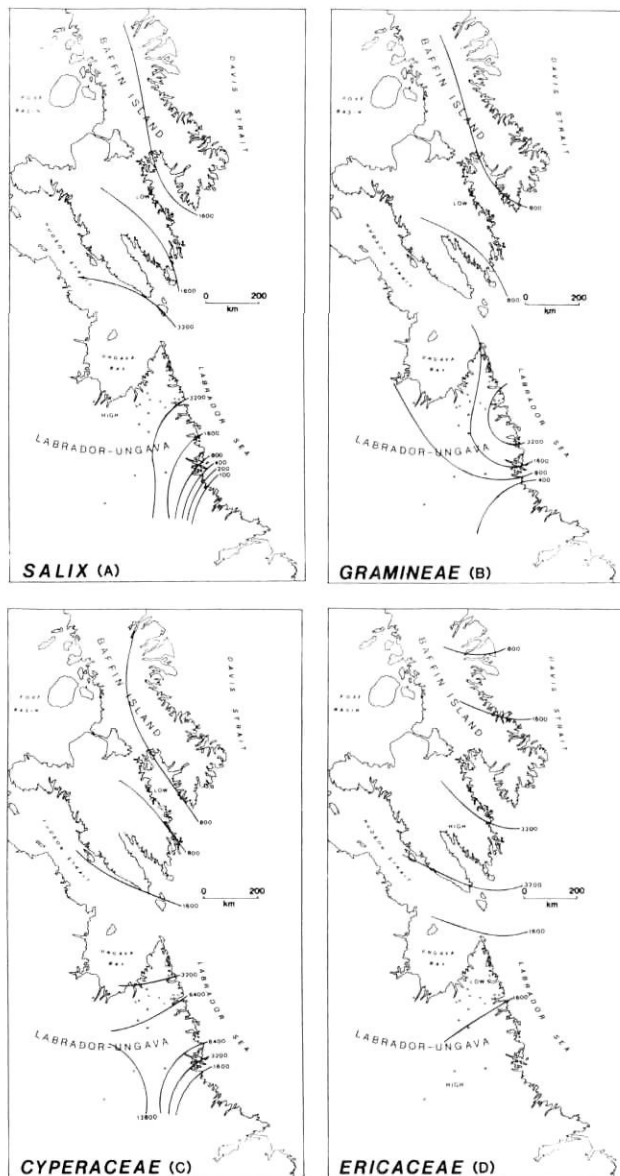
component of the vegetation immediately above the woodland and shrub communities here. It stands to reason that its pollen production would be highest here (climates are so ameliorated along this coastal region that even conifers sexually reproduce at their northern limit [ELLIOTT, 1979]), where it is first able to colonize large tracts of land and not excluded by the more productive and competitively superior forest species at lower elevations and to the south.

Pollen concentrations decline away from this region, with a decline in dominance of grass as a component of the vegetation to the south, to the immediate, more mesic interior, and to the north, which experiences an increase in the severity of climatic conditions. These appear to be the most feasible explanations for this decline. The low in the southern part of Cumberland Sound corresponds to a low also in *Salix* and the Cyperaceae (Figs. 6A and 6C). This general decline in pollen production of the vegetation may be due to this relatively narrow peninsula being affected by the cold, Foxe Basin to the northwest and Cumberland Sound to the southeast; in other words, the maritime influence is very pronounced.

Cyperaceae

As a generalization (*c.f.*, ANDREWS *et al.*, 1979), most arctic sedges grow in wet sites, although occasionally they are found in mesic and xeric sites. Thus, the ratio of grass to sedge pollen in arctic pollen profiles may be a signature of changes in local moisture conditions. The isopoll map for Cyperaceae indicates that sedge populations contribute between 10 to 34% of the pollen at our 39 sites (Fig. 4C). Again, the position and location of the isopolls with respect to the floristic and climatic boundaries differ between Labrador and Keewatin. The 10% isopoll lies close to the Low Arctic boundary in Keewatin, whereas in the eastern arctic, the values of sedge pollen are much higher and range from ca. 20% in Ungava to 30% in north-central Baffin Island. This difference probably reflects more mesic (maritime) climates in eastern Canada, as well as more topographic depressions due to differences in topography and glacial erosion between the two areas.

The pollen concentration map (Fig. 6C) illustrates that sedge pollen production increases in "warm", wet habitats. Cyperaceae reaches its highest values in the interior boreal forest/woodland of Labrador-Ungava, declining to the north through the Torngat Mountain region and to Baffin Island. The decrease in pollen concentration south of the north-central coast may be due to solely the topographic position and habitats in which the polster materials were collected (with sedge being excluded) or to a true decrease in pollen production due to climatic factors.

The isopoll map shows Cyperaceae reaches its highest values much further north (Fig. 4C). This probably reflects the favored pollen production of sedge over other tundra plants in hygric habitats.

Ericaceae

Two discrete "highs" of heath (Ericaceae) pollen characterize the surface pollen spectra (Fig. 4D). In north-central Baffin Island and the Cumberland Peninsula, heath percentages vary between 30 and 40%, then decrease both to the south and the west. A second area of high values is located south of the Keewatin Arctic Coastal plain. Heath pollen is a more important component of the modern spectra in Keewatin than it is in Labrador. This may reflect the greater dominance of ericaceous species in the drier environs of Keewatin.

Our pollen maps for the heath family are difficult to interpret climatically and ecologically. This family contains a large number of boreal and arctic species which are difficult to differentiate in terms of pollen morphologies without tedious examination of well-preserved grains. As can be seen from the pollen concentration map (Fig. 6D), pollen production for this family is relatively low at all of our sites (this is also true in the majority of the fossil pollen diagrams), although most important in the Low Arctic of southern Baffin Island. This agrees with our pollen percentages which show that Ericaceae is a more important part of the pollen rain in certain Low Arctic areas rather than it is in boreal woodland or forest-tundra ecotone sites (Fig. 4D), most likely due to the decreased production of other taxa.

Picea/Pinus ratio

The contours for *Picea/Pinus* (Fig. 7A) show that within the tree limit the pollen spectra of Labrador differ from those in Keewatin. The ratios are 4:1 to 9:1 in Labrador whereas they are approximately 1:1 in Keewatin. Again, this reflects the differences in the distribution of these taxa, with *Pinus* populations occurring far south of the northern tree limit in eastern Canada. However, the ratios in the Low Arctic and High Arctic areas are all less than 1:1 even in Ungava. This fact reflects the better dispersion of *Pinus* pollen. Beyond the contour for the 1:1 ratio, two areas of "high" ratios occur. In Keewatin a discrete ridge with ratios of 1.3:1 occurs south of the Arctic Mainland coast whereas in southwestern Baffin Island, a zone of ratios ca. 1.4:1 to 0.5:1 trends southwest-northeast from Cape Dorset to Cumberland Sound. To the north of these highs, ratios fall off to 0.1:1. The relatively small amounts of *Picea* pollen reaching southeastern Baffin Island indicate that the likely trajectories for pollen transport are, as suggested by BARRY *et al.* (1981), primarily from Keewatin (central Canada) and south of Hudson Bay
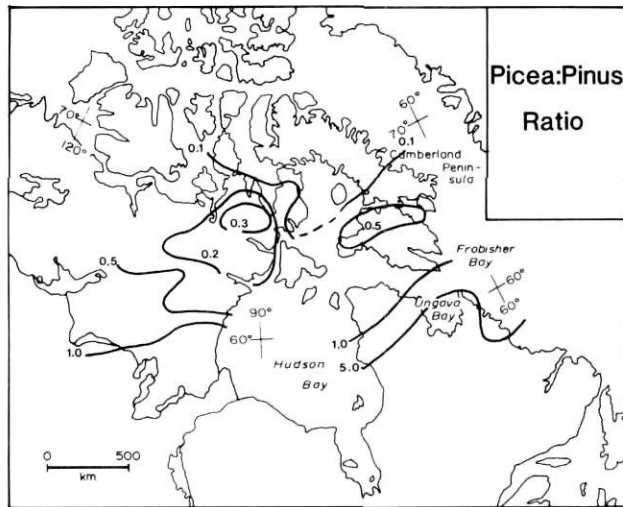
FIGURE 7A. Spruce/Pine ratios mapped over the study area.

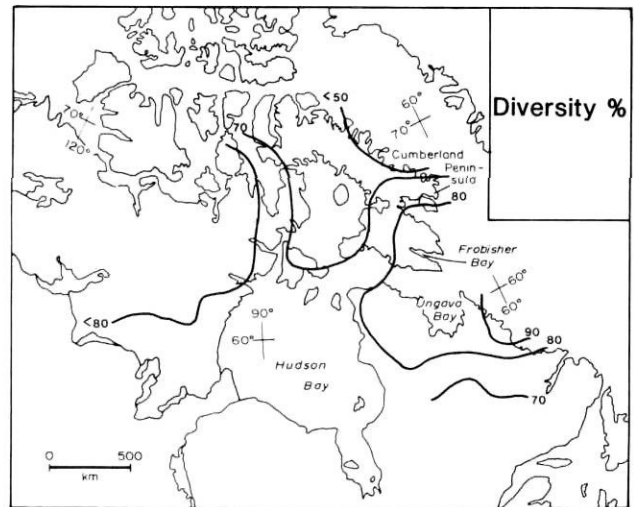*Cartographie des rapports épinette/pin dans la région à l'étude.*

FIGURE 7B. Diversity of the 39 sites based on Shannon's H over the 8 taxa.

Taux de diversité des 39 sites calculés à partir du test H de Shannon fait sur les 8 taxons.

rather than the closer pollen source of Labrador-Ungava.

MEASURES OF THE MODERN POLLEN DISTRIBUTION

One final way of mapping our data is to examine the "diversity" or "evenness" of the pollen spectra. Because we have limited our analysis to 8 taxa, we cannot compute several measures of diversity. We have calculated a measure of "evenness" as outlined below. We use the Shannon Information measure H and evaluate this for the 8 taxa only. H is defined as:

$$H = - \left(\sum_{i=1}^{k} p_i 1np_i \right)$$

where p_i is the proportion of taxa in the ith class and k=8. We can define the maximum entropy as:

$$H_{mx} = -(8[0.125 \ln 0.125])$$

which equals 2.079. "Relative diversity" as mapped in Figure 7B is then:

$$\frac{H}{H_{mx}} \times 100$$

A value of 100% indicates that each of the 8 taxa have an equal occurrence. A value of 0% indicates that only one taxa occurs in the pollen spectra. Figure 7B indicates that the relative evenness of our 39 sites varies mainly between 60 and 90%. Values below 60% only occur around Clyde River and the western Foxe Basin. The highest relative diversity occurs in the Low Arctic floristic zone (Fig. 1A) where the pollen spectra illustrates the importance of both the exotic tree genera

and Low Arctic shrubs as pollen producers, as well as the graminoids and heath species. Relative diversity decreases both southward toward the boreal forest, where the pollen spectrum is dominated by the pollen production of one or two tree species (and possibly *Alnus* and *Betula*), and to the north where the High Arctic pollen rain becomes increasingly a mix of grass, sedge and willow pollen in various proportions. Thus changes in relative diversity of pollen spectra cannot be interpreted as a simple expression of variations along an environmental gradient. The relatively high diversity of the Low Arctic zone represents the mixing of pollen signals and vegetation of the tundra and the boreal forest.

CLUSTER AND DISCRIMINANT ANALYSIS

We used the cluster program algorithm of DAVIS (1973) on the pollen percentage data and clustered the 39 pollen sites on the basis of the measure of distance between each and every site[2]. This resulted in the identification of six discrete clusters. However, cluster analysis is a one-dimensional representation of n-dimensional space, and this can result in some distortion of the relationships between sites. For these reasons we also examined the integrity of the clusters through discriminant analysis. Figure 8 illustrates the spatial distribution of the cluster membership, with each

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2. Distance(d) is defined as: $d_{ij} = \sqrt{\sum_{k=1}^{m} \frac{(x_{ik} - x_{jk})^2}{m}}$

where k_{ik} is the kth variable on site i and x_{jk} is the kth variable on site j, evaluated over m variables (taxa).

cluster appropriately labelled. The resulting map indicates a systematic and understandable pattern of pollen assemblages. Cluster 1 consists of sites #1, 2, 7 and 39 which are High Arctic/Transitional Arctic sites. Cluster 2 sites lie south of these whereas Cluster 4 occupies that region to the east and west. Cluster 3 is the most difficult to explain, possibly because of the influence of local tundra vegetation. Cluster 5 occurs at and just beyond treeline and the sites in Cluster 6 occur within the tree limit.

Table III indicates the mean and standard deviations for the eight taxa grouped over the six clusters which enables us to generalize the six pollen assemblages of Figure 8.

Discriminant Analysis

The cluster program suggested the presence of 6 pollen assemblages within the area of our survey

(Fig. 8). However, cluster analysis is not a particularly powerful method of analysis, so we tested the "goodness of fit" of the cluster memberships by multiple stepwise discriminant analysis (MSDA) (e.g., DAVIS, 1973). This statistical procedure tests how well a priori groups (clusters) can be discriminated one from another on the basis of a specified number of variables (taxa). The stepwise part of the procedure enables the researcher to ascertain which variable is the most important in discriminating between the groups, which is second, which is third, etc.

The discriminant analysis indicated that the important taxa are, in order: Gramineae, Picea, Betula, Salix, Alnus, Cyperaceae, Pinus and Ericaeae. Discrimination between the 6 clusters was 100% after the first 5 steps, and even after 3 steps, 30/39 sites were correctly classified. This indicates that the clusters and the re-
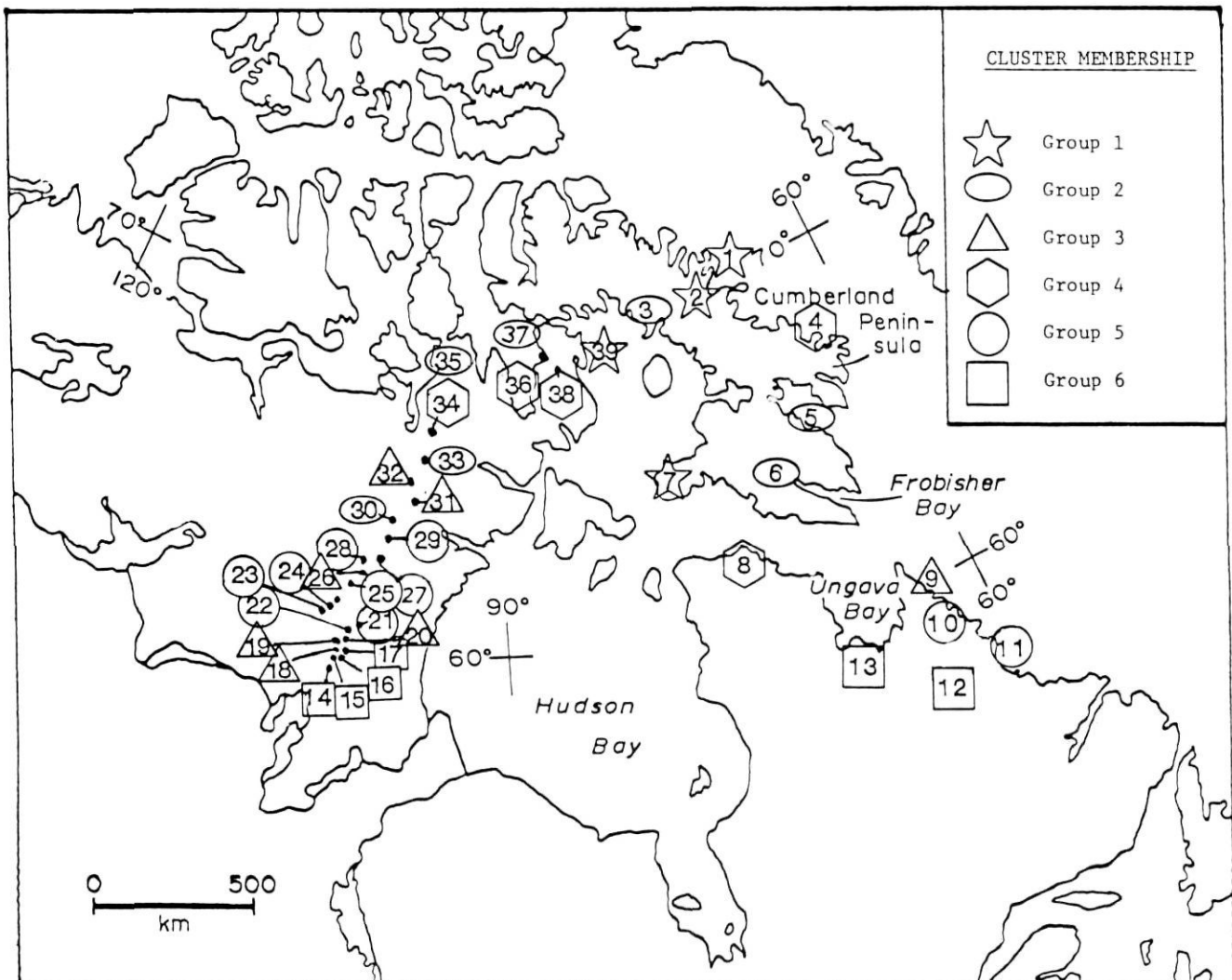

FIGURE 8. Map of the cluster membership for each of the 39 sites.   Cartographie des regroupements pour les 39 sites.

gional pollen assemblages (RPA) of Table III and Figure 8 are statistically quite distinct.

The pollen assemblages (Table III) change progressively from the relatively warm and wet environments at or below the treeline to the cool, dry summer conditions that prevail over eastern Baffin Island at the end of our transects (Fig. 8). These assemblages reflect the interactions between climatic conditions that control the growth of each genus and the variations that reflect changes in vegetation along both temperature and moisture gradients. However, it is also clear from the average values of Table III that exotic tree and shrub pollen have an imprint on the pollen spectra well beyond the geographical limits of each species (see previous discussions on the isopoll maps).

If climatic data were available at each of our 39 sites, we could quantitatively express these relationships. However, such data are not available (e.g., Table I), but even so, interpolation from climatic stations or atlases can be used to give a reasonable *first* estimate of controlling summer variables: namely, temperature and precipitation. On Table IV we estimate the average and range of July T°C that are experienced within each pollen assemblage region as well as estimates for summer precipitation. These do indicate that the modern pollen assemblages on the regional scale have some relationship to climate, albeit not simple.

Principal Component Analysis

The description of the isopoll maps indicates that there may be regional assemblages of modern surface pollen spectra. This hypothesis can be evaluated by the examination of the spatial coherence of Principal Component Scores (e.g., IMBRIE and KIPP, 1971; CLINE and HAYS, 1976). In this study we used a Principal Components program (BMD01M). The program is a R-mode analysis which has some problems associated with analysis of a closed data array (pollen values sum to 100%). We selected for study the first five components which explains 89% of the variance (Table V). The loadings (= correlations) between the original variables and the Principal Component (PC) axes (Table V) indicate that the first component is associated with *Salix*(−), *Alnus*(+) and *Betula*(+), the second component with Cyperaceae(−) and Ericaceae(+), the third with Gramineae(+) and Ericaceae(+), the fourth factor is negatively associated with *Picea* and positively with *Betula*, and the fifth factor is dominated by a strong association with *Pinus*, and to a lesser extent, *Betula*(-). The importance of *Betula* in the PC analysis is clear. Regression of the PC scores from the 39 sites against July T°C indicates that the scores on the first component alone account for 89% of the variation in July temperature. Maps of PC scores at the different sites for each PC produce patterns that partly mimic the dominant

taxon of each component (Table V). Ericaceae, *Betula* and *Pinus* are "best explained" by the first five principal components. The first five PC scores were also used as input into the Davis (1973) clustering routine but no substantial difference was noted between this approach and the one discussed earlier (e.g., Fig. 8).

SUMMARY

The utility of isopoll maps for reconstructing postglacial and other vegetational migrations has been well stated by researchers (c.f., BERNABO and WEBB, 1977). In order to reconstruct past vegetation, floristic, and climate changes using these maps, we need to be confident that isopoll maps reflect particular vegetation, floristic and climatic types. The isopoll maps from surface polster materials show that: (1) there are regional assemblages of pollen taxa, (2) that these pollen assemblages have regional coherence (as shown by factor loadings), and (3) that these assemblages are further numerically distinct (as shown using cluster and discriminant analyses).

Our use of cluster and discriminant analyses on our data delineated a progression of pollen assemblages from warm, wet summer climates of the northern boreal forest/woodland (Cluster 6: *Picea, Pinus, Alnus* ≈ boreal floristic zone) through the forest-tundra ecotone (Cluster 5: *Betula, Pinus, Picea*) and Low Arctic mesic shrub communities (Cluster 3: Ericacea, *Betula, Pinus*; Cluster 4: *Salix*, Cyperaceae, Gramineae ≈ Low Arctic floristic zone), to the cool, dry summer climates of the transitional and high arctic tundra communities (Cluster 1: Gramineae, *Salix*, Ericaceae; Cluster 2: Ericaceae, Cyperaceae, *Salix (Pinus)* ≈ Transitional and High Arctic floristic zones) (Table III).

These regional pollen assemblages reflect not only the regional pollen rain and long distance transport, but also local vegetational units (as shown by our standard deviation values) and a topographic diversity of habitats, and hence, vegetation types. Our relative diversity values show this, with the greatest diversity found in the low arctic pollen assemblages, which experience an important influx of exotic boreal (tree) pollen, as well as relatively high local pollen production from various low arctic shrub, heath and graminold components of the vegetation.

The concentration maps are especially useful in explaining anomalies within some of the percentage pollen data, particularly in regard to the masking of the local vegetation signal by the exotic influx. Although various workers use different techniques in obtaining "absolute" pollen data (grains/cm², grains/cm³, grains/ gm dry weight, etc.), our concentration maps give a picture of the zones most likely to have high pollen values for various taxa. It is ecologically important to

understand that although, for example, the grasses are the most important or dominant taxon in high arctic modern percentage pollen assemblages, they show their greatest pollen productivity (as reflected by concentration numbers) in less climatically harsh environments much further south. Concentration pollen numbers for the grasses from fossil pollen spectra immediately following deglaciation at southern sites may therefore not 'match' the modern, higher latitude tundra community. It is simply the decrease in the diversity of pollen taxa and the decreased pollen production of all these taxa that allows Gramineae to dominate the percentage pollen rain here. Still, it is the most important component of the vascular vegetation of the region (see MODE, 1980), and therefore shows the usefulness of the isopoll maps.

The resolution of our maps will also be improved in the future by further collection of polster materials, especially along all shores of Hudson Bay, in western Ungava (Nouveau-Québec), from the High Arctic Dew Line stations, and on all of the High Arctic islands. This would allow us to attempt to delineate a High/Transitional Arctic boundary.

There are other potential problems with all pollen data, such as the differential productivity and preservation of various taxa, and the use of polster versus surface lake sediment materials to delimit the modern pollen rain; these have been well discussed by WEBB et al. (1978) and MODE (1980). We do, however, want to stress the fact that the pollen rain for a site reflects regional, local and exotic pollen components; palynologists must take a careful look at the importance of these various contributors to pollen surface samples in order to determine the relations of pollen types to the modern vegetation, flora and climate.

ACKNOWLEDGEMENTS

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