

Postglacial Vegetation at the Northern Limit of Lichen
Woodland in Northwestern Québec

La végétation postglaciaire à la limite septentrionale de la
pessière à lichens du nord-ouest du Québec

Postglaziale Vegetation an der nördlichen Grenze des
Flechten-Tannenwalds in Nordwest-Québec

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Article abstract

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POSTGLACIAL VEGETATION AT THE NORTHERN LIMIT OF LICHEN WOODLAND IN NORTHWESTERN QUÉBEC

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ABSTRACT Three pollen diagrams from the northern part of the lichen woodland in northwestern Québec show broadly similar Holocene vegetation sequences. Following deglaciation, shortly after 6000 yr BP, shrub and herbaceous tundra plants dominated briefly; *Larix laricina*, *Populus* and *Juniperus* were also important elements of the landscape. A maximum of *Alnus crispa* and *Betula* was followed by a period dominated by *Picea*. In the northernmost site, the forests opened in response to neoglaciation during the past 1000 years. Today only black spruce (*Picea mariana*) grows in northwestern Québec and there is no evidence that white spruce (*P. glauca*) ever migrated into the region.

RÉSUMÉ La végétation postglaciaire à la limite septentrionale de la pessière à lichens du nord-ouest du Québec. Trois diagrammes polliniques provenant de la limite septentrionale de la pessière à lichens du nord-ouest du Québec montrent des séquences en grande partie similaires durant l'Holocène. Après la déglaciation, survenue vers 6000 BP, la végétation de la région a été dominée par les plantes herbacées et arbustives de la toundra. *Larix laricina*, *Populus* et *Juniperus* ont aussi constitué des éléments importants du paysage. Un maximum d'*Alnus crispa* et de *Betula* a été suivi par une période dominée par *Picea*. Dans le site le plus nordique, les forêts se sont ouvertes durant les 1000 dernières années en réponse au refroidissement néoglaciation. Actuellement, seule l'épinette noire (*Picea mariana*) croît au nord-ouest du Québec, et les résultats laissent croire que l'épinette blanche (*P. glauca*) ne s'est jamais établie dans la région.

ZUSAMMENFASSUNG Postglaziale Vegetation an der nördlichen Grenze des Flechten-Tannenwalds in Nordwest-Québec. Drei Pollen-Diagramme vom nördlichen Teil des Flechten-Tannenwalds in Nordwest-Québec zeigen in großen Zügen ähnliche Vegetations-Sequenzen während des Holozän. Nach der Enteisung, kurz nach 6000 Jahren v.u.Z., dominierten eine kurze Zeit lang Pflanzen der Busch- und Gras-Tundra; *Larix laricina*, *Populus* und *Juniperus* waren auch wichtige Elemente der Landschaft. Auf ein Maximum von *Alnus crispa* und *Betula* folgte eine von *Picea* beherrschte Periode. Im nördlichsten Teil Öffneten sich die Wälder während der letzten 1000 Jahre als Reaktion auf eine neoglaziale Abkühlung. Heute wächst nur die schwarze Fichte (*Picea mariana*) in Nordwest-Québec und es gibt keinen Beleg dafür, daß die Weißtanne (*Picea glauca*) jemals in die Region wanderte.

INTRODUCTION

Studies of past positions of arctic treeline of North America have indicated that significant displacements occurred in western Canada during the Holocene. These changes include a northward advance of *Picea* in the MacKenzie Delta region in the early Holocene (10 000 yr BP), followed by a retreat after 7000 yr BP (Spear, 1983, 1993; Ritchie, 1984). A similar sequence has been found in central Canada, but it occurred later, with an advance and subsequent retreat between 5500 and 3500 yr BP (Nichols, 1975; Moser and MacDonald, 1990). In eastern Canada, *Picea* arrived at its present-day limit shortly after deglaciation less than 6000 yr BP. Treeline has not since retreated southward, although pollen records indicate opening of the forest-tundra during the past 2000 years (Richard, 1981; Gajewski *et al.*, 1993). Lamb (1985) found a decrease in the altitude of treeline in the past 3000 years in Labrador.

Climatic changes can be inferred from these variations, as the location of treeline is associated with the mean position of the arctic front in July (Bryson, 1966). However, estimating past climates from the reconstruction of treeline movement has proven difficult. Due to difficulties of access, few paleoecological sites have been analyzed and there are large intervening areas with no treeline data. At most sites, sedimentation rates are low and the sediments are relatively inorganic, limiting the temporal resolution and precision of the pollen record. Consequently, only broad-scale inferences can be made when correlating vegetation changes between sites. Our work provides additional sites in northwestern Québec to improve the spatial resolution of the regional vegetation reconstructions.

In a previous study (Gajewski *et al.*, 1993) we presented four pollen diagrams from the region, one from each of the vegetation zones making up the forest - tundra transition (lichen woodland, forest-tundra forest subzone, forest-tundra shrub subzone, shrub-tundra). The broad-scale similarities of the three diagrams from the lichen woodland and forest-tundra were noted. A fourth pollen diagram from the tundra showed no changes during the past 6000 years, and further studies confirmed that *Picea* had never been north of its present day limit in the past 6000 years (Gajewski and Garralla, 1992). One of the questions to be addressed here is: how representative is one pollen diagram of the vegetation history of its vegetation zone? Does the low density of available pollen diagrams at treeline limit the resolution of reconstructions of the past vegetation and climate?

Gajewski *et al.* (1993) did not discriminate spruce pollen to species. All of the pollen was assumed to derive from black spruce (*Picea mariana*), as it is the only species present in the region today. Payette (1993) has argued, on biogeographic grounds supplemented by extensive macrofossil and some pollen evidence, that white spruce (*Picea glauca*) never expanded in northwestern Québec in the Holocene. This contrasts with the situation in Labrador, where *P. mariana* and *P. glauca* are both present today. However, *P. glauca* apparently arrived first and was replaced as the dominant tree by *P. mariana* (Engstrom and Hansen, 1985). We will here provide pollen evidence supporting Payette's hypothesis.

A late Holocene cooling (Neoglaciation) is interpreted from proxy-climate data from a number of sites in the northern part of North America. Richard (1981), Lamb (1985) and Gajewski *et al.* (1993) have identified an opening of the forest-tundra in response to this cooling in eastern North America. The data presented here will further detail how this cooling influenced the vegetation at the transition from lichen woodland to forest-tundra.

METHODS

Sediment cores were collected with a Livingstone square-rod piston sampler from a raft which was anchored at three points in the lake. The uppermost sediment was collected with a clear plastic tube which had been fitted with a piston. The tube was kept vertical until sediments were extruded in the laboratory at the field station.

Weight-loss-on-ignition was estimated by drying one-mL subsamples overnight at 100 °C and then igniting them for three hours at 550 °C. Bulk sediment samples were submitted for radiocarbon dating after carefully cleaning the core surface. One-mL subsamples of the sediment were processed for pollen analysis using standard methods as described in Gajewski *et al.* (1993). This includes treatment of the sediment with 10% HCl, 10% KOH, HF and acetolysis solution, and mounting the residue in silicon oil. The pollen sum varies between 480 and 955 grains per spectrum. Species discrimination of *Picea* pollen is discussed in Appendix 1.

STUDY AREA

In northwestern Québec, the present-day transition from open forest to tundra occurs over two degrees of latitude through a broad forest-tundra, which is a mosaic of tundra and forest communities (Payette, 1983). This forest-tundra is further subdivided into a northern shrub and a southern arboreal subzone (Fig. 1), depending on the predominant form of the spruce trees present. The density of trees on the landscape decreases irregularly from south to north (Payette, 1983).

Lake GB1 (informal name) is located on top of a hill just to the south of the valley of the Grande Rivière de la Baleine. The regional forests are an open lichen woodland dominated by black spruce (*Picea mariana*); larch (*Larix laricina*) is also present although less abundant. Jack pine (*Pinus banksiana*) reaches its northern limit in this region, where it is restricted to sandy river terraces (Despots, 1990). Paper birch (*Betula papyrifera*) also reaches its northern limit a little to the north (Payette *et al.*, 1989). The area surrounding the lake was burned in the 1940's (Payette *et al.*, 1989) but there is a band of unburnt spruce around the lake. Here, as at the other two sites, the density of trees is low and there is a ground cover of lichens and heaths (Ericaceae). This small lake has almost no drainage basin and little pollen is transported to the sediment by streams.

Lake BN7 is in a low-relief area just to the southwest of Lac Bienville. Lake BN7 is larger and shallower than the other two (Table I), and there is streamflow into and out of the lake. The regional vegetation is an open lichen woodland.

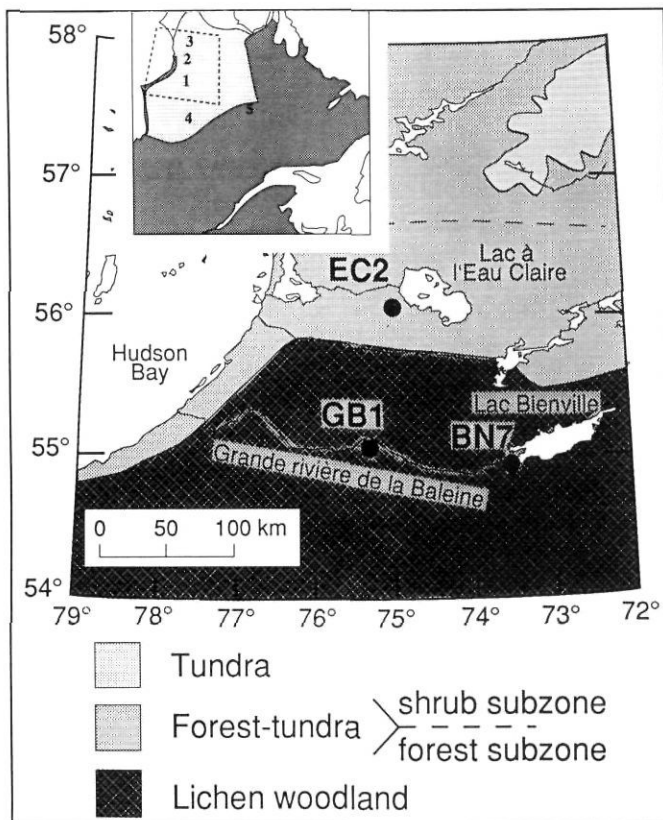


FIGURE 1. Map showing the location of three lakes in northern Québec. Vegetation zones follow Payette (1983). Inset: (1) GB2, (2) EC1, (3) LB1, (Gajewski *et al.*, 1993); (4) Bereziuk, Chism-I, Chism-II (Richard, 1979); (5) Delorme, Daumont (Richard *et al.*, 1982). The present range of *Picea glauca* is indicated by the dark tint, whereas *P. mariana* occurs also in the area of light tint.

Carte de localisation du nord du Québec. Les zones de végétation sont de Payette (1983). Encart: (1) GB2, (2) EC1, (3) LB1, (Gajewski *et al.*, 1993); (4) Bereziuk, Chism-I, Chism-II (Richard, 1979); (5) Delorme, Daumont (Richard *et al.*, 1982). La répartition de *Picea glauca* est donnée par la trame foncée; *P. mariana* se trouve aussi dans la région identifiée par la trame pâle.

Lake EC2 is a small lake, which, as at lake GB1, has almost no drainage basin. There is one outlet draining into a larger lake only a few metres away. The regional vegetation consists of an open lichen woodland, except for hilltops, which are open shrub tundra with occasional krummholz and tree black spruce. The steep slopes immediately surrounding the lake are covered by an open black spruce-lichen woodland, except for an area supporting an *Alnus crispa* shrubland.

RESULTS

The sediment from GB1 (Table I) was a uniform gyttja except for the section from 101 to 107 cm which was a lighter-coloured silt-clay and gyttja mixture. The entire postglacial sequence is apparently contained in this short sedimentary sequence, as the basal date (Table II) is comparable to others from the region (Dyke and Prest, 1987; Gajewski *et al.*, 1993). The sediment accumulation rate at GB1 was nearly constant during the past 6000 yr BP (Fig. 2). Weight-loss-on-ignition

TABLE I
Location of sites in northern Québec

| | Latitude (°N) | Longitude (°W) | Elevation (m) | Sfc Area (ha) | Water depth at core site (cm) | Depth of sediment (cm) |
|-----|------------------|-------------------|------------------|------------------|-------------------------------------|------------------------------|
| GB1 | 55° 07.0' | 75° 15.0' | 325 | 7.0 | 482 | 107 |
| EC2 | 56° 01.4' | 74° 56.7' | 260 | 2.5 | 885 | 155 |
| BN7 | 55° 00.2' | 73° 31.0' | 395 | 34.0 | 280 | 80 |

TABLE II
Radiocarbon dates from lakes GB1, EC2 and BN7

| Sediment depth (cm) | Age (¹⁴ C yrs BP) | Laboratory No. |
|------------------------|----------------------------------|----------------|
| GB1 | | |
| 18-30 | 1710 ± 90 | Beta-34467 |
| 49-61 | 3230 ± 110 | Beta-34468 |
| 95-106 | 5610 ± 160 | GSC-4736 |
| EC2 | | |
| 35-47 | 3530 ± 80 | Beta-36248 |
| 69-80 | 3900 ± 80 | Beta-36249 |
| 120-130 | 4920 ± 100 | Beta-36250 |
| 152-163 | 5610 ± 100 | Beta-34466 |
| BN7 | | |
| 8-18 | 2390 ± 100 | Beta-43867 |
| 35-45 | 4130 ± 110 | Beta-43868 |
| 65-75 | 6020 ± 100 | Beta-43869 |

(an index of organic matter of the sediment) was also constant at 40%, except for one sample analyzed from the basal silt-clay layer (Fig. 2).

A short core of only 80 cm was collected from BN7. The weight-loss-on-ignition was relatively low, and varied around 20%, except for the uppermost samples (Fig. 2). The sedimentation rate was constant until the late Holocene, when it decreased.

The sediment recovered at EC2 consists of 155 cm of uniform gyttja overlying 25 cm of silt-clay. The weight-loss-on-ignition curve (Fig. 2) is more complex than that of GB1 and shows an initial rise from low values to nearly 60% at 135 cm, a decrease to values around 40% between 105 and 35 cm, and a subsequent increase to greater than 60%. The sedimentation rate, as estimated from the radiocarbon dates (Fig. 2) decreased in the past 3000 yr BP, as occurred in Lake BN7. Similar decreases are found in many northern Québec and Labrador lakes (Short and Nichols, 1977; Richard, 1981; Richard *et al.*, 1982; Lamb, 1985; Gajewski *et al.*, 1993).

As the pollen diagrams of GB1 and BN7 are quite similar, they will be discussed together. *Picea*, *Alnus crispa* and *Betula* dominate the percentage pollen diagrams (Figs. 3 and 4). Spectra at the base of the sequence had high values of *Larix*, *Cupressineae* (probably *Juniperus communis*), *Populus* and NAP (non-arboreal pollen) percentages. *Alnus crispa* and *Betula* pollen percentages increased and remained high until

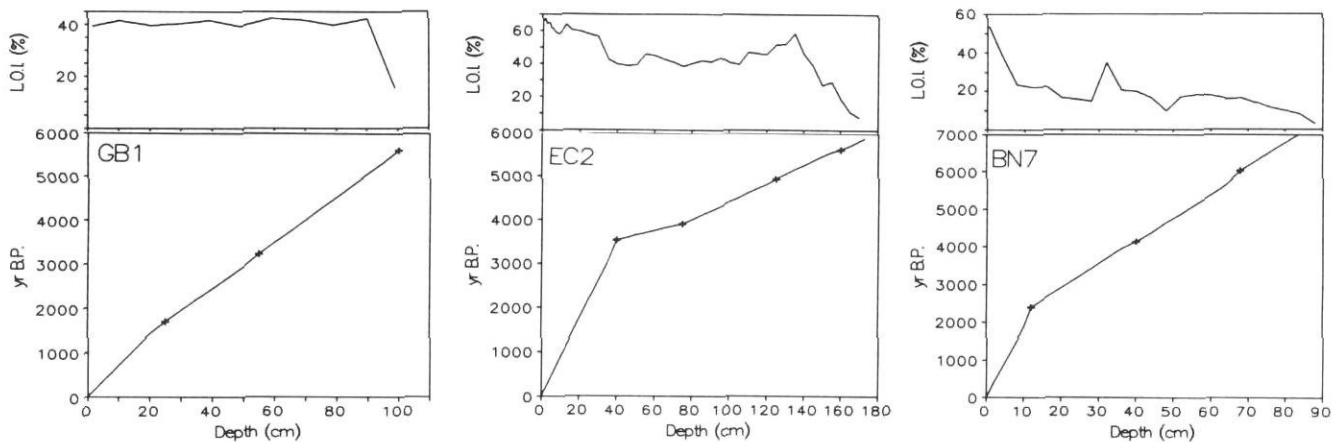


FIGURE 2. Radiocarbon chronologies for the three lake-sediment sequences. Percentage weight-loss-on-ignition (% L.O.I.) as a function of depth.

Courbes de l'âge en fonction de la profondeur des trois séquences. Courbe en pourcentages de la perte au feu (% L.O.I.) en fonction de la profondeur.

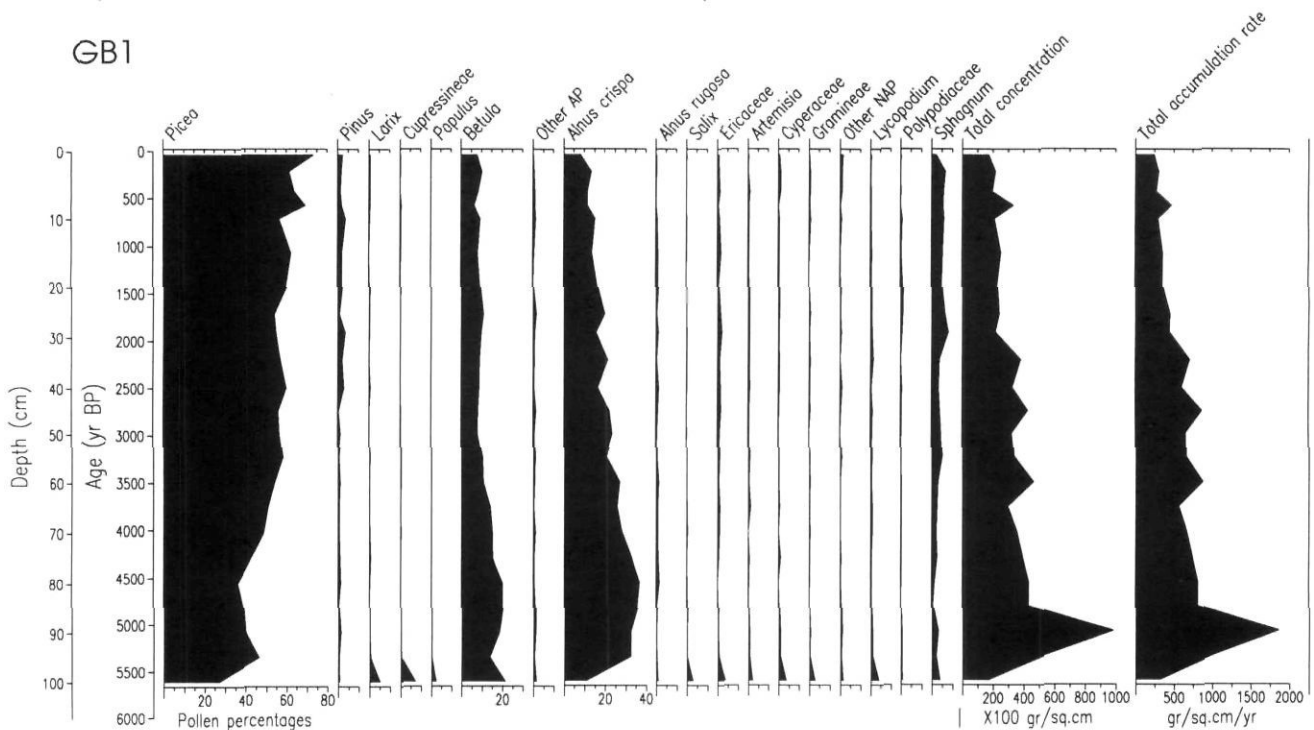


FIGURE 3. Percentage pollen diagram for Lake GB1. Vertical axis based on age-depth relationship of Figure 2. Pollen sum includes all pollen and spores, excluding aquatic taxa.

Diagramme pollinique en pourcentages du site GB1. L'axe vertical est fondé sur la relation âge-profondeur de la figure 2. La somme pollinique se compose de tous les grains de pollen et des spores, excluant les taxons aquatiques.

around 4500 yr BP. *Alnus crispa* and *Betula* pollen percentages then steadily declined while those of *Picea* increased. Spores of *Sphagnum* were more abundant during the past 2000 yr BP. Around 2500 yr BP pollen of *Pinus* type diploxylon (probably *P. banksiana*; see Despons, 1990; Gajewski *et al.*, 1993) increased; values were slightly higher at BN7 than at the other sites and over 5% in many spectra. Other pollen types showed few changes and rarely rose above trace values. The *Picea* pollen (see Appendix) were predominantly *P. mariana* (Table III) at all three sites. *P. glauca* pollen remained between 5% and 20%, and there were no trends through time.

The pollen percentage diagram of EC2 (Fig. 5), although broadly similar to those of GB1 and BN7, is different in several significant details. *Alnus crispa* pollen percentages were consistently higher, while those of *Picea* were lower at EC2 than at GB1 or BN7. There were high percentages of *Alnus crispa* between 5500 and 4000 yr BP as in the other two sites. However, the *Betula* pollen curve at EC2 is different from those of GB1 and BN7. Minor peaks in *Betula* pollen percentages occurred at 5000 and 3800 yr BP at the expense of *Alnus crispa*, and *Betula* remained relatively abundant in the late-Holocene. *Picea* pollen increased after 4000 yr BP,

K. Gajewski, analyst

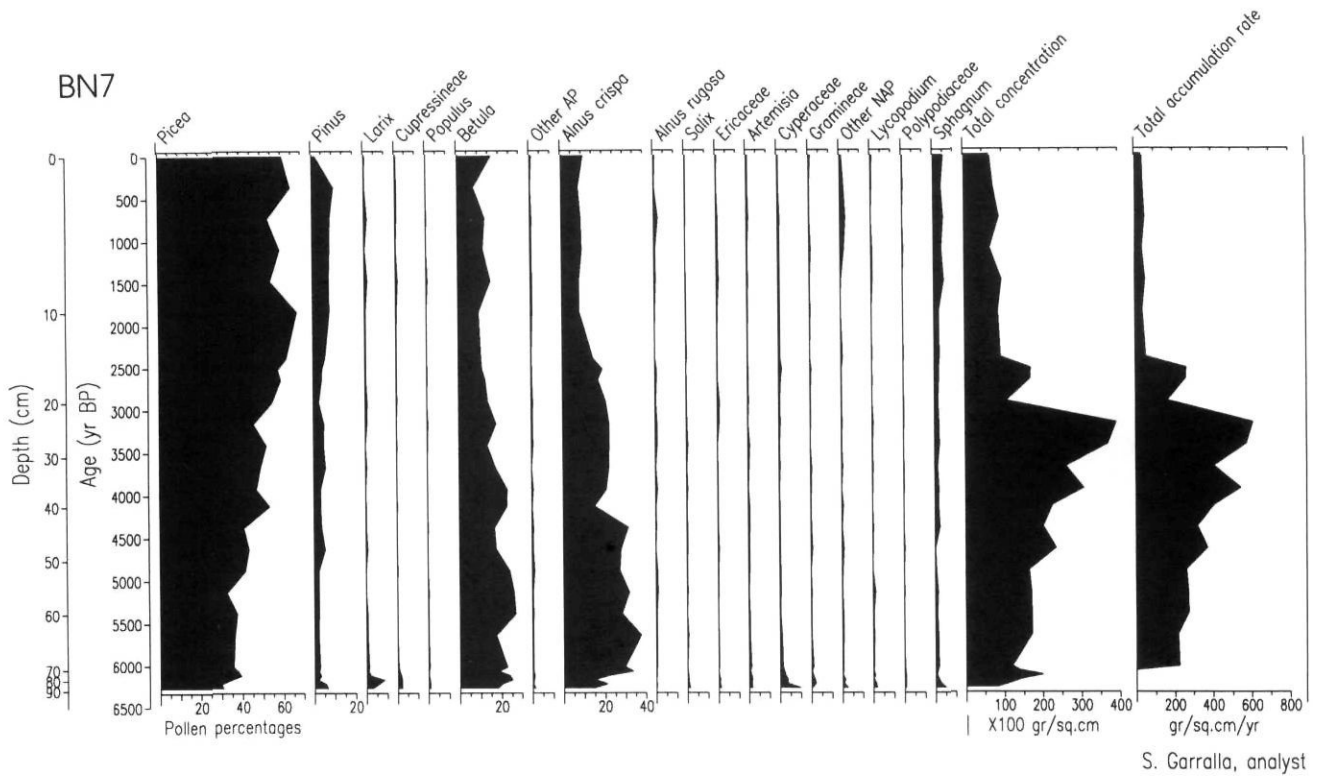


FIGURE 4. Percentage pollen diagram for Lake BN7. Several levels below the basal ¹⁴C date were arbitrarily assigned dates 50 years apart for the purposes of plotting the diagram.

Diagramme pollinique en pourcentages du site BN7. Quelques niveaux sous la datation au ¹⁴C de base ont arbitrairement été séparés par un intervalle de 50 ans pour les besoins du diagramme.

TABLE III

Discrimination of *Picea* pollen using qualitative and quantitative methods. Percent of grains from selected levels assigned to *P. glauca* and *P. mariana* (depth in cm)

| Lake/ Depth | Qualitative | | | | Quantitative | | | |
|----------------|-----------------------|------------------------|-----------|----|-----------------------|------------------------|-----------|----|
| | % <i>Picea glauca</i> | % <i>Picea mariana</i> | % unident | n | % <i>Picea glauca</i> | % <i>Picea mariana</i> | % unident | n |
| GB1 | | | | | | | | |
| 01 | 20 | 80 | 0 | 20 | 0 | 85 | 15 | 20 |
| 20 | 15 | 85 | 0 | 20 | 15 | 65 | 20 | 20 |
| 40 | 10 | 90 | 0 | 20 | 10 | 65 | 25 | 20 |
| 60 | 20 | 80 | 0 | 20 | 25 | 65 | 10 | 20 |
| 80 | 10 | 90 | 0 | 20 | 15 | 80 | 5 | 20 |
| 95 | 4 | 84 | 12 | 50 | — | — | — | — |
| EC2 | | | | | | | | |
| 01 | 14 | 74 | 12 | 50 | — | — | — | — |
| 40 | 5 | 95 | 0 | 20 | 15 | 70 | 15 | 20 |
| 80 | 10 | 90 | 0 | 20 | 15 | 80 | 5 | 20 |
| 120 | 20 | 80 | 0 | 20 | 15 | 80 | 5 | 20 |
| 140 | 22 | 68 | 10 | 50 | — | — | — | — |
| 160 | 6 | 71 | 23 | 34 | — | — | — | — |
| 174 | 8 | 82 | 10 | 50 | — | — | — | — |
| BN7 | | | | | | | | |
| 02 | 15 | 85 | 0 | 20 | 15 | 80 | 5 | 20 |
| 20 | 10 | 90 | 0 | 20 | 5 | 85 | 10 | 20 |
| 40 | 25 | 75 | 0 | 20 | 30 | 55 | 15 | 20 |
| 60 | 0 | 100 | 0 | 20 | 0 | 95 | 5 | 20 |
| 80 | 20 | 80 | 0 | 20 | 15 | 85 | 0 | 20 |

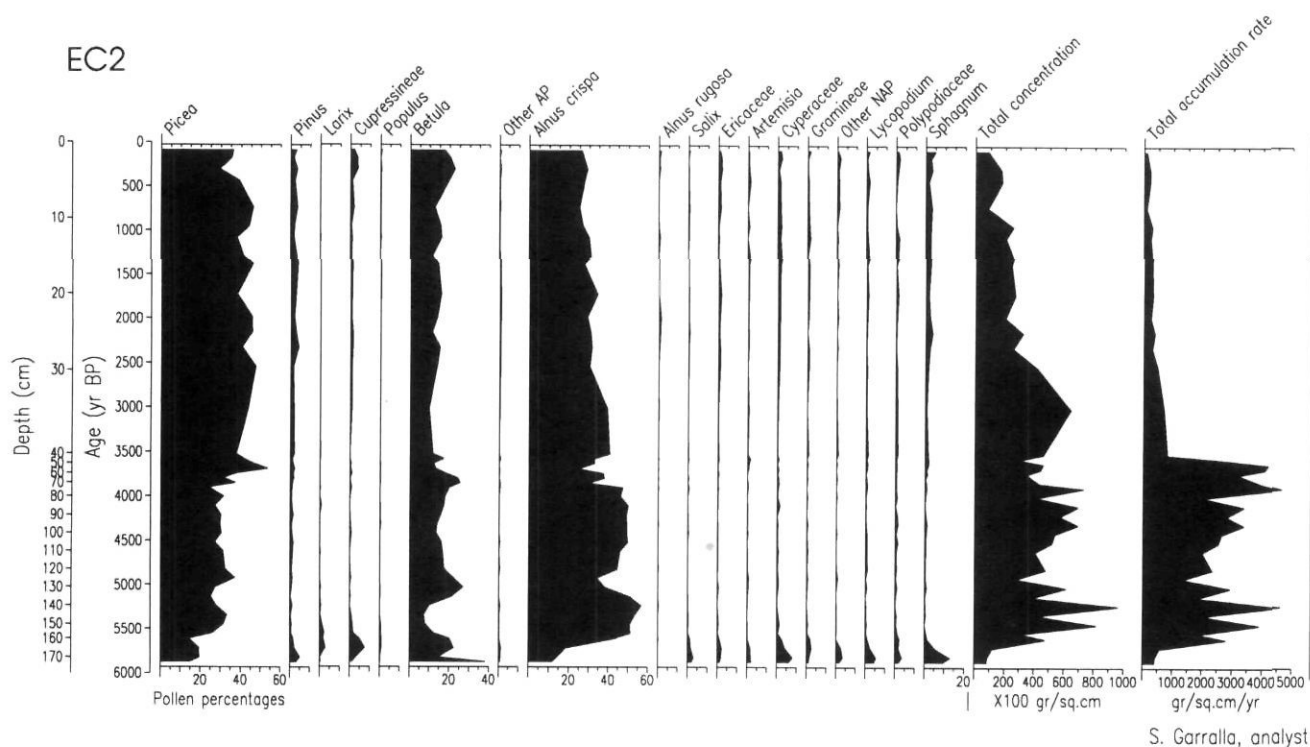


FIGURE 5. Percentage pollen diagram, for Lake EC2.

Diagramme pollinique en pourcentages du site EC2.

remained between 40-50% until around 800 yr BP, and then decreased. This contrasts with the continued increase observed at GB1 and BN7.

Total pollen concentration steadily decreased during the past 6000 yr BP at GB1 (Fig. 3). Since the sedimentation rate was constant, the total pollen accumulation rate (PAR) paralleled the concentration curve. Maximum concentrations and accumulation rates occurred between 3500 and 3000 yr BP at BN7 (Fig. 4). At EC2, pollen concentration remained relatively high until 3000 yr BP, and subsequently gradually declined, while the PAR decreased abruptly at 3500 yr BP when the sedimentation rate changed (Fig. 5). At both BN7 and EC2, PARs were very low in the late Holocene.

A principal components biplot (TerBraak, 1983) of the three diagrams, along with modern pollen from the region (Gajewski, 1991) illustrates the similarities in the two pollen diagrams of BN7 and GB1 (Fig. 6). The first two components explain 38% and 33% of the variance respectively. The two pollen sequences track each other very closely and interpretation of the biplot indicates a development from *Alnus*-dominated forest-tundra to lichen woodland during the past 6000 years. EC2 followed a different history, however, with the fossil assemblages containing more significant amounts of *Alnus crispa* (4000 yr BP) and NAP (2000 yr BP to the present). The high values of *A. crispa* between 4000 and 5000 yr BP have no analogues in the modern pollen rain.

DISCUSSION

The three diagrams presented here are broadly similar, and share a number of features with other pollen diagrams

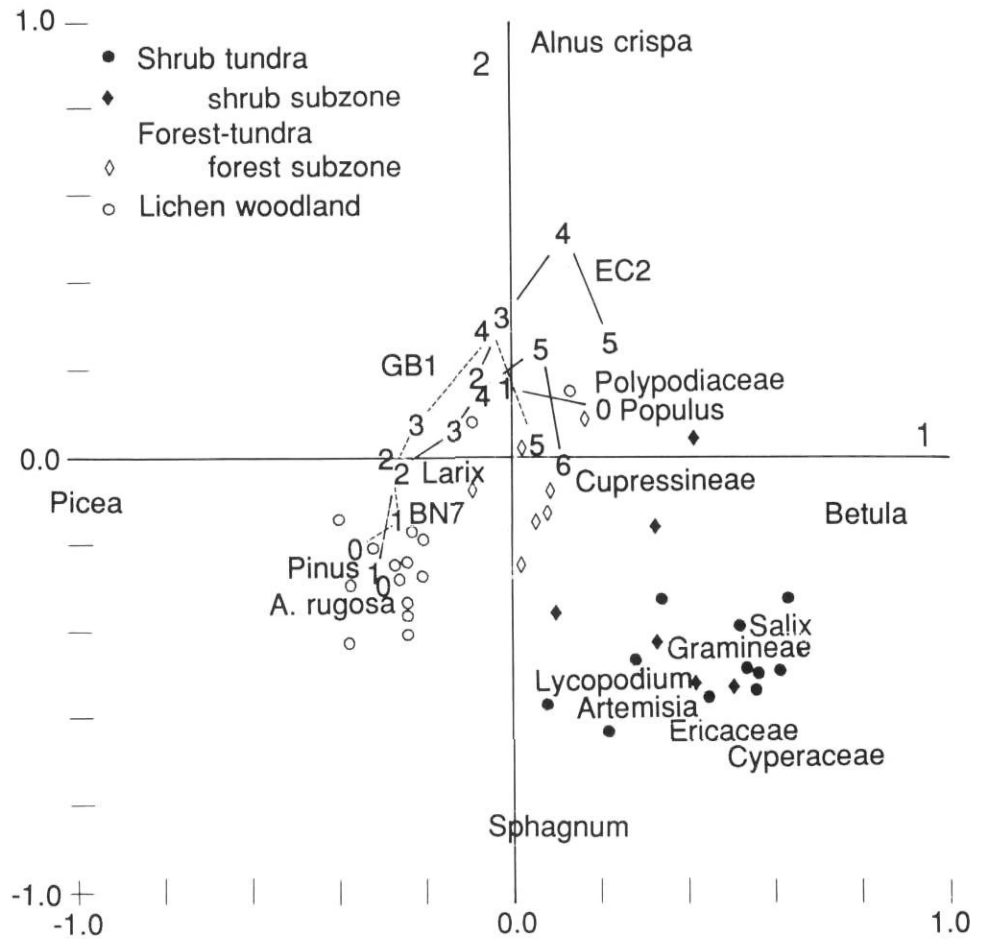
from the north of Québec (Richard, 1979, 1981; Richard *et al.*, 1982). In particular, GB1 and BN7, both from the present-day lichen woodland, had very similar histories after deglaciation. Local differences at the level of the watersheds are not recorded at the resolution of these diagrams.

An initial phase of open vegetation followed deglaciation around 6000 yr BP. This period seems relatively short, but its exact length is difficult to ascertain, because no dates were obtained from the low organic silt-clay at the base of these cores. Relatively high NAP percentages accompanied by high values of *Larix*, *Populus*, and *Cupressineae* pollen characterize these pollen assemblages. The large values of *Larix* and *Populus* pollen percentages are unlike any found today (e.g. Gajewski, 1991; King, 1993). The highest percentages of these pollen types are found in pollen records from areas to the west in northern Québec, with slightly lower values towards the centre of the Québec-Labrador peninsula. These large values suggest that these trees were colonizing the land as the ice melted. Even at this time, *Picea*, *Alnus crispa* and *Betula* were significant components of the pollen rain. *Alnus crispa* and *Betula* (probably *glandulosa*) were present on the landscape, and *Picea* may have also been present in low numbers. Climate simulations suggest conditions warmer than today for the eastern portion of the North American continent (COHMAP members, 1988). Warmer conditions may have permitted the rapid colonization of the region by tree species.

A period dominated by *Alnus crispa* then followed, lasting about 1500 years, between 5500 yr BP and 4000 yr BP. Pollen accumulation rates were high at all sites during this time period. Maxima of *Alnus* pollen are found at other sites in northern Québec (Gajewski *et al.*, 1993) as well as central

FIGURE 6. Principal components biplot (axes 1 and 2) of pollen assemblages from lakes BN7, GB1 and EC2 along with modern samples from northwestern Québec (Gajewski, 1991). The ordination was done using all levels from the cores, but the scores were averaged by 1000 year intervals and connected by lines for the illustration (0 = 0–1000 yr BP; etc).

Ordination en composantes principales (les axes 1 et 2) des spectres polliniques des lacs BN7, GB1 and EC2 et des spectres polliniques actuels du nord-ouest du Québec (Gajewski, 1991).



Canada (Moser and MacDonald, 1990). *Alnus* pollen percentages are greatest in the forest-tundra (Gajewski, 1991), but as the taxon is over-represented (Ritchie, 1984), these high percentages do not necessarily translate into abundant plants in the landscape (Moser and MacDonald, 1991). The values of *Alnus* pollen percentages are greater than modern samples from the forest-tundra of northwestern Québec (Gajewski, 1991). A forest-tundra environment is suggested by these results, but the lack of a modern analogue precludes a more detailed interpretation.

Maximum *Picea* percentages and presumably abundances in the vegetation are found between 3000 yr BP and the present. Although pollen accumulation rates declined at all sites, sedimentation processes in the lake are probably responsible for this decrease. In the past 2000 years BP there was a slight decline in spruce tree abundance at EC2, but not at the other two sites (Fig. 7). This decrease is also registered in other sites in the forest-tundra (EC1, LB1: Gajewski *et al.*, 1993; Delorme, Daumont: Richard *et al.*, 1982; Fig. 1) but not in the lichen woodland (GB2: Gajewski *et al.*, 1993; Bereziuk, Chism-I, Chism-II: Richard, 1979). Although there is a suggestion of a decrease in spruce in northwestern Canada during the past 4000 yr BP (Spear, 1993), there is less change in central Canada (Moser and MacDonald, 1990). The modern climate patterns had set in between 6000 and 3000 yr BP, as the last of the Laurentide ice had melted by this time (COHMAP, 1988). The data presented here indicate

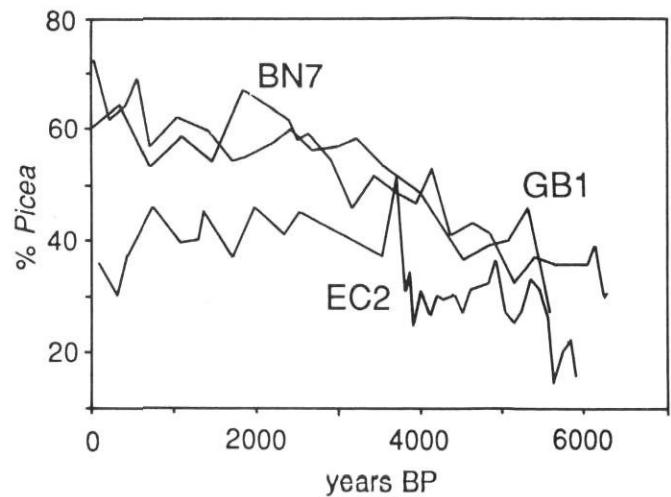


FIGURE 7. *Picea* percentages as a function of time for lakes GB1, BN7 and EC2.

Les pourcentages de Picea en fonction du temps pour les sites GB1, BN7 et EC2.

that a late Holocene cooling which has diminished (at a regional scale) tree cover in the forest-tundra of northwestern Québec has not yet affected the vegetation in the present-day lichen woodland.

These results suggest that either BN7 or GB1 could be used in continental-scale reconstructions of treeline movement, as they record a regional-scale signal of vegetation changes, and the pollen diagrams closely resemble each other. However, the distance between GB1 and BN7 is similar to the distance between GB1 and EC2, and there are significant differences between the pollen diagrams of the latter two sites. In northwestern Québec, the primary climate gradients are north-south, so sites separated by few degrees of latitude can be influenced by different air masses. On the other hand, longitudinal climatic gradients are less pronounced, and the vegetation is more similar. Site selection needs to be carefully determined by the question to be investigated and the resolution needed.

The *Picea* pollen can be mostly attributed to *P. mariana*, and given the margin of error in discrimination (see Appendix 1), this suggests that *P. glauca* never migrated to northwestern Québec. The percentages of black and white spruce at the top and bottom of the sequences are similar. Since there is no white spruce in the region today, this suggests there was none in the past. The amounts of white spruce pollen greater than expected by misclassification could presumably be transported from long-distances. *Picea glauca* is found in Labrador and northeastern Québec and also along a narrow coastal strip along Hudson Bay to the west of the study area (Payette, 1993). The reasons for this lack of white spruce in the study area needs further study.

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APPENDIX 1

The discrimination of *Picea* pollen has been studied by Richard (1970), Birks and Peglar (1980), Hansen and Engstrom (1985) and Brubaker *et al.* (1987), among others. Separation of species has been attempted using both qualitative (based on morphology of the pollen grains) and quantitative (based on measures of some characters of the grains) methods. Qualitative methods rely, in spruce, on differences in some characters that are quite variable within a species. Quantitative methods rely on size measurements of the pollen grain. One problem with empirically-based quantitative methods is that they are usually estimated from a small number of collections from one local area. Given the variability in size statistics, it is necessary to determine if empirical equations derived from one group of samples can be applied elsewhere (Hansen and Engstrom, 1985). We here present results on the separation of spruce pollen from northwestern Québec.

Reference material was available from 12 trees, seven *Picea glauca* and five *Picea mariana* (Table A1). Pollen was treated using the same methods as used for the sediment samples, omitting HF and HCl. Twenty pollen grains in good position were measured for each collection. In some instances, there were insufficient grains in suitable position and in good shape to be measured for the quantitative discrimination, and for these levels, 50 grains (if available) were identified using the qualitative method only.

Two methods were attempted to separate *P. glauca* and *P. mariana*. Firstly, pollen of *P. rubens*, the only other species in eastern North America were identified by the undulating cap margin (Birks and Peglar, 1980). We then applied the method of Hansen and Engstrom (1985) to the remaining grains. A qualitative separation was

based on three of the four characters of Hansen and Engstrom (1985): form of the saccus, saccus reticulum, and the saccus attachment to the body the grain. Their fourth character (saccus area/corpus area) was not useful in our collection. A grain was assigned to the species indicated by a majority of the characters.

Quantitative separation was based on the methods of Hansen and Engstrom (1985) and Birks and Peglar (1980). The length and width of the saccus and the length of the body of the grain were measured using a micrometer in the microscope eyepiece.

Both the qualitative and quantitative measures successfully discriminated the reference material (Table A2). Between 0 and 15% of the grains in any one sample were mis-classified (not shown) comparable to the results presented by Brubaker *et al.* (1987). Although either quantitative or qualitative characters can successfully be used to distinguish spruce species, using qualitative methods is faster. Separation using qualitative characters can also be used when the pollen grains are less well preserved.

Analysis of the spruce pollen from GB1, BN7 and EC2 is discussed in the body of the text. In addition, we reanalyzed the *Picea* pollen from several previously published pollen diagrams from northwestern Québec: GB2, EC1, LB1 and LR1 (Gajewski *et al.*, 1993) and BI7 (Gajewski and Garralla, 1992). Again, the majority of the spruce grains were assigned to *P. mariana* by both methods (Table A3). No distinct trends through time were found, as opposed to the results presented by Hansen and Engstrom (1985) for Labrador. This suggests that *P. glauca* never arrived in northwestern Québec during the Holocene, as suggested by Payette (1993).

TABLE A1

Location of reference material analyzed for *Picea* pollen discrimination

| No. | Species | Latitude | Longitude | Province | Origin |
|-----|-------------------|----------|-----------|----------|----------|
| 1 | <i>P. glauca</i> | 49°03' | 66°51' | Québec | UL102068 |
| 2 | <i>P. glauca</i> | 46°24' | 70°30' | Québec | UL9821 |
| 3 | <i>P. glauca</i> | 46°43' | 71°12' | Québec | UL101336 |
| 4 | <i>P. glauca</i> | 60°04' | 134°50' | Yukon | UL123908 |
| 5 | <i>P. glauca</i> | 49°53' | 97°07' | Manitoba | UL215743 |
| 6 | <i>P. mariana</i> | 47°19' | 71°09' | Québec | UL221183 |
| 7 | <i>P. mariana</i> | 58°59' | 125°47' | Brit Col | UL123527 |
| 8 | <i>P. glauca</i> | 43°36' | 79°40' | Ontario | Gajewski |
| 9 | <i>P. mariana</i> | 46°47' | 71°17' | Québec | Gajewski |
| 10 | <i>P. mariana</i> | 55°37' | 74°25' | Québec | Gajewski |
| 11 | <i>P. mariana</i> | 56°48' | 74°54' | Québec | Gajewski |
| 12 | <i>P. mariana</i> | 55°17' | 77°45' | Québec | Gajewski |

TABLE A2

Success of discrimination of *Picea* reference material using qualitative and quantitative methods

| Method | Discrimination success (%) | | Pollen not discriminated (%) | |
|--------------|----------------------------|-------------------|------------------------------|-------------------|
| | <i>P. glauca</i> | <i>P. mariana</i> | <i>P. glauca</i> | <i>P. mariana</i> |
| Qualitative | 97 | 92 | 0 | 0 |
| Quantitative | 91 | 88 | 1 | 5 |
| | n=140 | n=99 | | |

TABLE A3

Discrimination of Picea pollen from several previously published sites (Gajewski et al., 1993; Gajewski and Garralla, 1992) in northern Québec. Percent of grains from selected levels assigned to P. glauca and P. mariana (depth in cm)

| Lake | Depth | Qualitative | | | | Quantitative | | | |
|------|-------|------------------|-------------------|--------|----|------------------|-------------------|---------|----|
| | | <i>P. glauca</i> | <i>P. mariana</i> | uniden | n | <i>P. glauca</i> | <i>P. mariana</i> | unident | n |
| GB2 | 0 | 28 | 54 | 18 | 74 | – | – | – | – |
| | 40 | 20 | 80 | 0 | 20 | 30 | 55 | 15 | 20 |
| | 80 | 5 | 90 | 5 | 20 | 24 | 57 | 19 | 21 |
| | 120 | 14 | 74 | 12 | 73 | – | – | – | – |
| | 160 | 0 | 100 | 0 | 20 | 15 | 85 | 0 | 20 |
| | 200 | 10 | 90 | 0 | 20 | 10 | 85 | 5 | 20 |
| | 236 | 16 | 76 | 8 | 63 | 15 | 85 | 0 | 20 |
| EC1 | 0 | 10 | 90 | 0 | 20 | 38 | 62 | 0 | 21 |
| | 20 | 6 | 94 | 0 | 17 | 29 | 59 | 12 | 17 |
| | 40 | 11 | 89 | 0 | 18 | 22 | 56 | 22 | 18 |
| | 60 | 34 | 52 | 14 | 56 | – | – | – | – |
| | 80 | 12 | 74 | 14 | 65 | – | – | – | – |
| | 100 | 8 | 78 | 13 | 60 | – | – | – | – |
| LB1 | 0 | 16 | 76 | 8 | 63 | – | – | – | – |
| | 40 | 0 | 100 | 0 | 20 | 35 | 50 | 15 | 20 |
| | 80 | 10 | 90 | 0 | 20 | 24 | 69 | 7 | 29 |
| | 120 | 20 | 80 | 0 | 15 | 13 | 60 | 27 | 15 |
| | 136 | 5 | 95 | 0 | 21 | 24 | 62 | 14 | 21 |
| LR1 | 1 | 23 | 73 | 4 | 26 | – | – | – | – |
| | 26 | 11 | 89 | 0 | 9 | – | – | – | – |
| | 66 | 9 | 91 | 0 | 11 | 18 | 73 | 9 | 11 |
| | 106 | 0 | 100 | 0 | 7 | – | – | – | – |
| | 124 | 8 | 92 | 0 | 12 | 17 | 50 | 33 | 12 |
| BI2 | 2 | 9 | 76 | 15 | 55 | – | – | – | – |
| | 76 | 15 | 74 | 11 | 74 | 25 | 65 | 10 | 20 |
| | 120 | 11 | 89 | 0 | 19 | 11 | 68 | 21 | 19 |
| | 142 | 0 | 100 | 0 | 16 | 15 | 85 | 0 | 20 |