Pergamon

Quaternary Science Reviews, Vol. 12, pp. 613–628, 1993.
1994 Elsevier Science Ltd.
Printed in Great Britain.
0277-3791/93 $26.00

LATE-QUATERNARY CLIMATE IN THE RIDGE AND VALLEY OF VIRGINIA, U.S.A.: CHANGES IN VEGETATION AND DEPOSITIONAL ENVIRONMENT

A Contribution to the 'North Atlantic Seaboard Programme' of IGCP-253, 'Termination of the Pleistocene'

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Browns Pond, Virginia, in the Ridge and Valley physiographic province, contains a record of changing vegetational and depositional environments that dates to 17,130 BP. Six cores were retrieved in a transect of the pond. Pollen and macrofossils were identified from the longest central core and a series of AMS radiocarbon dates obtained from identified macrofossils and sediment. The pollen and macrofossil record combined with laterally consistent changes in lithostratigraphy reveal a changing climate. From 17,300 to 14,100 BP, a closed boreal forest of *Pinus-Picea-Abies* grew at the site. *Pinus* dominates the pollen assemblage while *Picea* and *Abies* dominate the macrofossil assemblage. Subtle increases in more thermophilous and mesophytic taxa indicate gradual climate amelioration after the full-glacial. A marked increase in *Alnus* at 14,100 BP signals an increase in moisture, possibly related to the global evidence for rapid climate change at 14,000 BP. At this central Appalachian site, *Abies* and *Alnus* are found in relatively greater amounts in the late-glacial forest than previous studies indicated. Low organic contents and evidence of gleyed conditions, seen in the core transect from 10,000 to 8000 BP, point towards low-water levels in the early Holocene—approximately coincident with the expansion of *Quercus*.

INTRODUCTION

The east coast of North America which lay south of the Laurentide ice sheet is valuable to Late-Quaternary climate studies precisely because it was ice free. It has the potential to show the range in vegetational response prior to, and during, the deglacial transition. Isotopic studies of the Summit, Greenland, GRIP ice core indicate a gradual warming had commenced by 18,000 BP (Johnsen *et al.*, 1992), corresponding to approximately 21,500 calendar years (based on the U-Th conversion of Bard *et al.*, 1992). However, GISP2 alkaline dust concentrations indicate that the first post-LGM abrupt decrease in dustiness is at 14,700 calendar BP (Taylor *et al.*, 1993), corresponding to approximately 12,500 calendar years (based on the U-Th conversion of Bard *et al.*, 1992). A global synthesis of records from marine sediments, mountain snowlines and glaciers suggests an abrupt change in atmosphere and ocean temperatures at 14,000 BP (Broecker and Denton, 1989). Bulk dates on sediments containing fossil *Coleoptera* from the British Isles indicate that the first rapid warming also occurred at about 13,300 BP (Atkinson *et al.*, 1987). The exact regional or global extent of the warming signal and the forcing mechanisms are the subject of much Late-Quaternary climate research (Watts, 1979; Broecker *et al.*, 1985; Bard *et al.*, 1987; Ammann and Lotter, 1989; Charles and Fairbanks, 1992; Lehman and Keigwin, 1992). In this study, we attempt to define the timing of warming occurring just south of the Laurentide ice sheet and evidence for climate change at 14,000 BP in this region. Recent pollen records from Kentucky (Wilkins *et al.*, 1991) and Florida (Watts *et al.*, 1992) have shown intriguing oscillations during the Late-glacial but have not shown obvious indications of climate amelioration at approximately 14,000 BP.

At the last glacial maximum (LGM), a boreal-type forest lay to the south of the North American Laurentide ice sheet (Whitehead, 1973; Delcourt and Delcourt, 1987; Overpeck *et al.*, 1992). On the east coast of North America, the boreal-type forest was located from approximately 30° to 40° N latitude. From Pennsylvania to northern North Carolina, the interpretation of the jack pine-spruce-herb pollen assemblage ranges from a spruce-dominated boreal forest (Whitehead, 1973) to an open spruce-jack pine forest or spruce parkland (Watts, 1979, 1980a; Webb *et al.*, 1987). Further south, from southern North Carolina to Georgia, the pollen assemblage contains mostly pine with up to 10% herb elements. The assemblage may indicate either a mosaic of jack pine woods and herbaceous communities or an open forest (Watts, 1979, 1980b; Jacobson *et al.*, 1987; Webb *et al.*, 1987). Determining the compositional similarity between the modern and LGM boreal-type forests however, is based on pollen assemblages from few sites (Watts, 1980a; Delcourt and Delcourt, 1987; Webb, 1988). We present here a new pollen and plant macrofossil record, from the Ridge and Valley section of Virginia, that spans 17,300 radiocarbon years (all dates are in radiocarbon years unless otherwise noted). The changing composition of the glacial and late-glacial boreal-type assemblage is examined in light of the changing global climate.

Browns Pond, Virginia is approximately 300 km south of the LGM Laurentide ice sheet margin (Denton and Hughes, 1981), see Fig. 1, Site Location Map, for sites mentioned in the text. A transect of sediment cores was retrieved and pollen and plant macrofossil analyses were conducted in order to depict the forests changing composition beginning from the LGM. In addition, we experimented with AMS radiocarbon dating a variety of fossil samples thereby

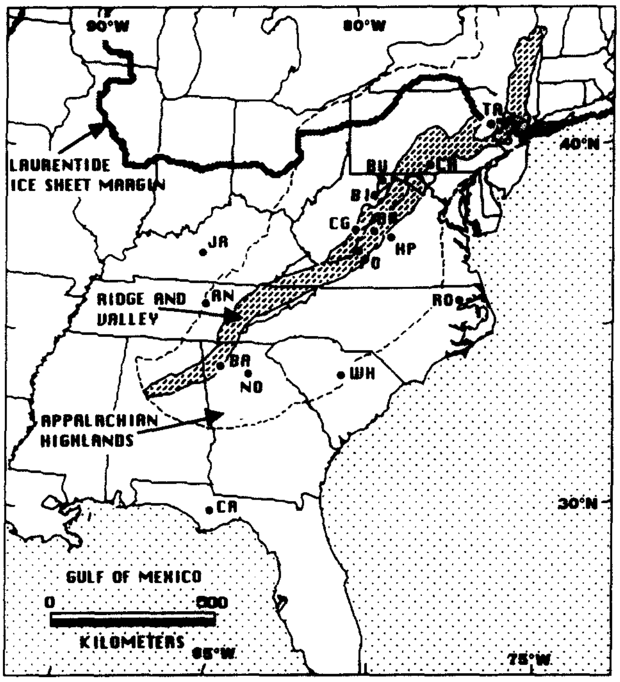

FIG. 1. Map of the eastern United States, showing the location of BR, Browns Pond, Virginia and other sites mentioned in the paper. The sites are: AN, Anderson Pond, Tennessee, (Delcourt, 1979); BA, Bartow County Ponds, Georgia, (Watts, 1970); BI, Big Run Bog, West Virginia, (Larabee, 1986); BU, Buckle's Bog, Maryland, (Maxwell and Davis, 1972); CA, Camel Lake, Florida, (Watts *et al.*, 1992); CG, Cranberry Glades, West Virginia, (Watts, 1979); CR, Crider's Pond, Pennsylvania, (Watts, 1979); HP, Hack Pond in the Shenandoah Valley, Virginia, (Craig, 1970); JA, Jackson Pond, Kentucky, (Wilkins *et al.*, 1991); NO, Nodoroc Site, Georgia, (Jackson and Whitehead, 1993); PO, Potts Mountain Pond, Virginia, (Watts, 1979); RO, Rockyhock Bay, North Carolina, (Whitehead, 1981); TA, Tannersville Bog, Pennsylvania, (Watts, 1979); WH, White Pond, South Carolina, (Watts, 1980b). The Appalachian Highlands geographic province is outlined and the Ridge and Valley section is shaded. The Laurentide ice sheet margin is sketched according to Denton and Hughes (1981).

producing a well-controlled chronology of vegetation and depositional changes within the basin.

The record from Browns Pond will address the following issues: (1) What was the composition of vegetation during the full glacial; and (2) Is there evidence for climate change coincident with the global evidence for warming at 14,000 BP? The answer to the first question is relevant to refining our ecological understanding of the extent and composition of the LGM boreal-type forest (Watts and Stuiver, 1980; Wright, 1981; Delcourt and Delcourt, 1984; Webb *et al.*, 1987). Answering the second question provides additional information on the geographical extent of the abrupt deglacial warming signal and may thereby constrain the climate forcings responsible for the warming.

SETTING

Browns Pond, Virginia is in the Ridge and Valley physiographic province at an elevation of 620 m. It is approximately 50 km west of Staunton, Virginia, at 38°09' N, 79°37' W (Williamsville Quadrangle, Virginia). The basin is small, about 20 by 60 m, situated in an area of moderate to hilly relief. There is no surface inflow and the site of outflow is not perennially active. In two visits to the pond, during summer 1989 and winter 1991, water depth at the center ranged from 17 to 21 cm. Sinkholes in this region generally manifest seasonally fluctuating water levels (District Ranger, Warm Springs, Virginia, *pers. commun.*). The underlying bedrock is upper-Silurian age limestone, sandstone and shale of the Cayuga Group (Bick, 1962). The colluvium surrounding Browns Pond is sandstone-rich (Department of Conservation and Recreation, Virginia, *pers. commun.*).

The pond is covered with *Dulichium arundinaceum* (three-way sedge). *Cephalanthus occidentalis* (buttonbush) grows at the pond's perimeter. *Glyceria* (manna grass), *Osmunda* (flowering fern), *Carex vesicaria* and *Sphagnum* are also found near the water (Department of Conservation and Recreation, Virginia, *pers. commun.*). The surrounding slopes are forest-covered: *Quercus alba* and *Q. rubra* (white and red oak) predominate. Other trees found near the site include *Pinus strobus* (white pine), *Sassafras albidum*, *Acer rubrum* (red maple), *Nyssa sylvatica* (sour-gum), *Carya* (hickory), *Liriodendron tulipifera* (tulip-tree), *Betula lenta* (black birch) and immature *Castanea dentata* (chestnut). Shrubs identified in the understory were *Vaccinium corymbosum*, *V. angustifolium* (highbush and common lowbush blueberry), *Rhododendron*, *Kalmia latifolia* (mountain laurel), *Cornus* (dogwood) and Rosaceae (rose). This forest cover has developed after recent logging.

The site is situated within the Ridge and Valley section of the Oak-Chestnut Forest region described by Braun (1950). The trees and ericaceous undergrowth surrounding Browns Pond are typical of vegetation at moderate elevations on south-facing slopes of the Oak-Chestnut region. Less than 15 km to the west the forest becomes part of Braun's Mixed Mesophytic Forest region. Hence, mesophytic trees such as *Fagus grandifolia* (beech), *Tsuga* (hemlock), *Acer saccharum* (sugar maple) and *Tilia* (basswood) can be found in this region and in more moist pockets of the Oak-Chestnut forest. Coniferous spruce-fir forests typify higher elevations or higher latitudes (Oosting and Billings, 1951). In the central Appalachians, *Picea rubens* (red spruce) begins at 1370 to 1670 m elevation while *Abies fraseri* (Fraser fir), a species endemic to the southern Appalachians, occurs above 1800 m. Northward, *P. rubens*, *Abies balsamea* (balsam fir), *Pinus resinosa* and *P. banksiana* (red and jack pine) become dominant species at higher elevations in the northeast (Braun, 1950).

Mid-elevation Virginia experiences a temperate mid-latitude climate influenced by humid southerly flow patterns in summer and frontal zones in winter. Mean annual precipitation is 100 cm. Average January temperatures range from –6 °C to 6 °C, July averages range from 13 °C to 27 °C (National Oceanic and Atmospheric Administration, 1985).

METHODS

Six sediment cores were collected from Browns Pond using a 5 cm dia. modified Livingston piston corer (Wright *et al.*, 1984). Core lithology was described using the Troels-Smith classification modified by Aaby and Berglund (1986). The Munsell system (Munsell Color Company, 1990) was used for color description of the sediments. Organic content was measured according to Dean (1974). The sampling interval was 5 cm between 0 and 405 cm core depth and approximately 50 cm below 405 cm, with some intermediate sampling. Pollen analysis was conducted on the deepest central core, BR89. Pollen samples were taken at 10 cm intervals, with some intermediate sampling. Pollen processing was conducted according to Faegri and Iverson (1975) as modified by Heusser and Stock (1984). A known concentration of *Lycopodium* spores were added in order to calculate pollen concentration and accumulation rates (Stockmarr, 1971). A minimum of 300 upland tree, shrub or herb pollen grains were counted for those samples between 0 and 405 cm depth except in an interval of very low pollen concentration (140 and 145 cm). Pollen counts were not made below 405 cm depth because the core was inorganic and pollen extremely sparse.

Pollen identification was aided by the reference collections at Lamont–Doherty Earth Observatory, New York and by the keys of McAndrews *et al.* (1988) and Faegri *et al.* (1989). Unidentifiable and indeterminable grains, using the criteria in Cushing (1967), were also tallied. Conifer pollen fragments that were not identifiable by genus were counted and summed into a total number of unidentifiable conifer grains. *Picea mariana* and *P. glauca* pollen types were distinguished using the four morphological characteristics established by Hansen and Engstrom (1985). *Alnus rugosa* and *A. crispa* types were distinguished according to Watts (1979). Nomenclature follows Fernald (1970).

The central core, BR89, was also examined for plant macrofossils in alternate 5 cm long sections. Samples were prepared and then identified according to Watts and Winter (1966) and Peteet (1986). Macrofossils were compared to the seed collection at Lamont-Doherty Earth Observatory and the guides of Martin and Barkley (1961), Fernald (1970), Montgomery (1977) and Lévesque *et al.* (1988). The *Isoetes* macrospores were identified by Carl Taylor of the Milwaukee Public Museum. The number of macrofossils were counted for the core volume examined, usually 50 ml. *Isoetes* macrospores were counted from 2 ml of sediment taken at the pollen sampling intervals. The volume of visible charcoal fragments was estimated.

All radiocarbon dating was conducted on BR89, the central core. No material adequate for radiocarbon dating was found below 406 cm and between 130 to 201 cm. Four samples of several macrofossils each, from terrestrial or emergent plants, were submitted to the NSF-Arizona AMS facility, in order to date lithostratigraphic changes. Up to five seeds and/or needles were grouped, for any one sample, in order to have at least 1 mg of datable material and thereby reduce the statistical error associated with even smaller samples (Peteet *et al.*, 1990; Törnqvist *et al.*, 1992). Five samples were dated by AMS methods at ETH-Zürich, Institut für Mittelenergiephysik. The purpose of these radiocarbon dates was twofold: first, to refine BR89's chronostratigraphy and second, to compare the results of sediment versus macrofossil samples. Approximately 1 ml of sediment and several macrofossils, grouped to weigh more than 3 mg, were dated from two intervals: from 220.0 to 222.5 and from 340.0 to 343.0 cm depth. The depth, weights and types of macrofossils for all dated samples are presented in Table 1.

The five additional cores include three cores in a 22 m long west-trending transect, W1, W2 and W3 (22, 12 and 2 m in distance from BR89, respectively); and two cores in an 8 m long north-trending transect, N1 and N2 (8 and 4 m in distance from BR89). Lithostratigraphy and coarse resolution pollen and LOI sampling were conducted, at about a 50 cm sampling interval, in order to correlate changes amongst the transect cores.

TABLE 1. Core BR89. Radiocarbon Dates

Lab sample number	Sample depth (cm)	Items analyzed	Approximate weight (mg)	Uncorrected radiocarbon age
AA-5578	125.0–130.0	2 *Carex lupulina* seeds; 1 *C.* cf. *lurida* seed	3.02	7730 ± 90*
AA-5760	210.0–215.0	2 *Picea* needle tips; 1 *Picea* seed; 1 *Rubus* seed	1.02	13035 ± 230
ETH-7514	220.0–222.5	1 ml sediment	1650	12940 ± 110*
ETH-7515	220.0–222.5	2 *Picea* seeds; 2 *Picea* sterigmata; 1 *Cyperus* seed; 1 *Scirpus* seed; 1 conifer needle fragment; 3 wood fragments	18.3	12910 ± 100*
AA-5761	300.0–305.0	2 *Picea* needle tips; 3 *Rubus* seeds	2.15	13010 ± 95
ETH-7516	340.0–343.0	1 ml sediment	1620	14310 ± 110*
ETH-7517	340.0–343.0	2 *Sparganium* seeds; 5 *Menyanthes* seeds; 1 needle fragment; 1 *Picea* sterigmata	4.64	14300 ± 110*
ETH-7518	340.0–343.0	needle fragment		13790 ± 130
AA-5762	400.0–401.0	2 *Picea* needles; 1 *Picea* seed	2.41	17130 ± 180*
Beta-32419	401.0–406.0	90 ml sediment		16920 ± 230

*These six dates were used to calculate sediment and pollen accumulation rates.

RESULTS

Radiocarbon Dates, Lithology and Organic Content

Radiocarbon dates from core BR89 are generally in stratigraphic order, see Table 1. Given the overall chronological consistency of the dates, three results emerge: (1) the AMS dates from 1 ml of organic sediment (ETH-7514, 220–222.5 cm; ETH-7516, 340–343 cm) when compared to the large number of grouped plant macrofossils (ETH-7515, 220–222.5 cm; ETH-7517, 340–343 cm) are very consistent; (2) there is no evidence for errors related to contamination due to older carbonates or humic acid infiltration; and (3) accumulation rates fluctuated significantly in this section of the pond. Dates derived from a small number of grouped terrestrial plant macrofossils (AA-5760, 210–215 cm; and AA-5761, 300–305 cm) are offset from the overall age trend. These dates are also within or adjacent to the section of BR89, from 244 to 337 cm, containing frequent sand lenses, which may represent high-energy depositional events. Episodic influx of terrestrial detritus into the pond may partly explain the slight offset of radiocarbon dates from the overall age trend.

Calculation of sediment accumulation rate is based on six of the nine AMS radiocarbon dates, the dates utilized are marked in Table 1. Three of the dates were not utilized in favor of those dates closer to the stratigraphic shifts or obtained from smaller depth intervals. Their inclusion would not significantly change the record's interpretation. As a simplifying assumption, accumulation rates are calculated to be constant with changes at the distinct shifts in the lithostratigraphy. The core top was estimated at 0 BP since there was no indication of surface disturbance. Accumulation rates are presented in Fig. 2.

Five depositional regimes are recorded in core BR89, the sediment description is in Table 2 and organic content in Fig. 3. From 697 to 405 cm, clay, silt and sand accumulated (all measurements are in depth from the sediment-water interface). No depositional features and little organic matter are preserved. At 405 cm, 17,300 BP, organic content of the sediment increased. Between 405 and 337 cm, organic content of the clay ranges between 8 and 16% and the accumulation rate is 21 cm/1000 years. The interval from 337 to 201 cm, 14,090 to 12,720 BP, is characterized by rapid accumulation rates, 99 cm/1000 years; a rate comparable to sites in southern New England (Watts, 1979; Peteet *et al.*, 1990). Organic content fluctuates from 6 to 36% within the sand-silt-clay sediments. In the core section from 401 to 201 cm, well-preserved plant macrofossils and organic detritus are clearly visible. A highly inorganic (<8%) sand–silt–clay interval is found above, from 201 to 130 cm, with a much slower accumulation rate of 15 cm/1000 years. From 130 to 0 cm, 7880 BP to present, organic content rises from 12 to 92% and accumulation rate of the organic clay increases slightly to 16 cm/1000 years.

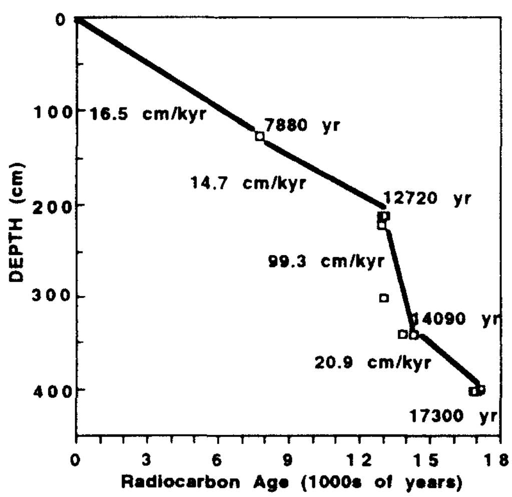

FIG. 2. Accumulation rates calculated for Core BR89, Browns Pond, Virginia. Rates were calculated to change at distinct lithostratigraphic shifts. Acccumulation rates and year of changes are given. Squares denote radiocarbon dated intervals.

The lateral coherency of the stratigraphic units is seen in the lithology and organic content of the transect cores (Figs 3 and 4). The surface has a uniformly high organic content. In all cores, an inorganic layer is encountered which is similar to that seen in BR89 from 130 to 201 cm; depth to this layer varies from 79 to 164 cm. The distinctive upper inorganic layer is characterized by its pale color (10YR 6/4 and 5Y 8/1 in core BR89; 10YR 6/2 in W1; 10YR 6/4 in W2; and, 5YR 5/2 and 5Y 6/1 in W3), low organic content and lack of preserved organic detritus. This upper inorganic layer is from 46 cm (W1) to 62 cm (W2) thick. In cores BR89, W3 and W1, 1 to 1.5 cm diameter woody stem or root fragments occur at the top of this layer. The north transect cores, N1 and N2, terminate in the inorganic layer. The three cores in the westerly transect, W1, W2 and W3, contain the organic-inorganic-organic sequence that is found from 0 to 405 cm in BR89. The bottom of these three cores is organic: a highly organic clayey lignaceous peat is found at the bottom of W1 (incomplete recovery at a depth of 257 cm prevented further coring) while W2 and W3 contain a slightly organic silty clay.

The expression of the transition from the late-glacial organic sediments into the early-Holocene inorganic sediments varies from core to core. In W3 and in BR89, the transition is expressed as many fine to coarse, prominent mottles (mottling described according to Soil Conservation Service, 1981). These mottles, at the base of the overlying inorganic layer, indicate a gleyed interval that was formed by incomplete oxidation–reduction reactions that occurred in periodically saturated sediments (Soil Conservation Service, 1981). Below the mottles, the sediment was usually continuously saturated. In W2, a clear color change, possibly representing a remnant water-level horizon and below which embedded macrofossils are well preserved, marks the transition whereas in W1 it is represented by a sharp change in organic content. Above the inorganic layer are Holocene organic clays and silts which contain many distinct, small to medium size mottles.

The results from radiocarbon dating BR89 and the lithostratigraphy of all transect cores together contain evidence of water levels below the sediment surface and a depositional hiatus. The prominent mottles indicate that the water tables position was beneath the surface (Simonson and Boersma, 1972; Birkeland, 1984). A nearly complete absence of organic material in the upper inorganic layer

TABLE 2. Core BR89. Lithostratigraphy and Organic Content

Depth (cm)	Troels–Smith classification	Sediment description	Munsell color	Depth (cm)
0	Dg2+, As2−	organic clay with rootlets	dusky brown, 5YR 2/2	
48		no rootlets		
90	Dgl, Ag3	organic silt		
			mottles (fine, faint), dusky and lt. brown, 5YR 2/2, 5YR 5/6	96
130	As4, Gmin+	inorganic sandy clay	medium gray and yellow gray, N5, 5Y 8/1	130
176	As2, Ag2, Gmin+	sand-silt-clay		
			mottles (many, medium prominent spots), 5YR 3/4 in 10YR 6/4	180
218	Dl/h+, Ld+, Asl+, Agl+, Gminl−	sand-silt-clay, slightly organic	mod. brown, 5YR 3/4	218
244		frequent sandy lenses		
337	Dl/h+, As3+, Gmin+	clay, slightly organic	grayish brown, 5YR 3/2, few mottles	337
			dusky brown, 5YR 2/2, few mottles	388
405	As4, Ag+	inorganic silty clay	light gray, N7	405
			lt yellow gray, 5Y 7/1	426
457	Asl+, Agl+, Gmin2−	clay-silt-sand, rare charcoal		
555	As3+, Gmin+	sandy clay, rare charcoal		
			lt olive gray, 5Y 6/1	588
608	As3, Ag+, Gmin+	inorganic sand-silt-clay		
697				697

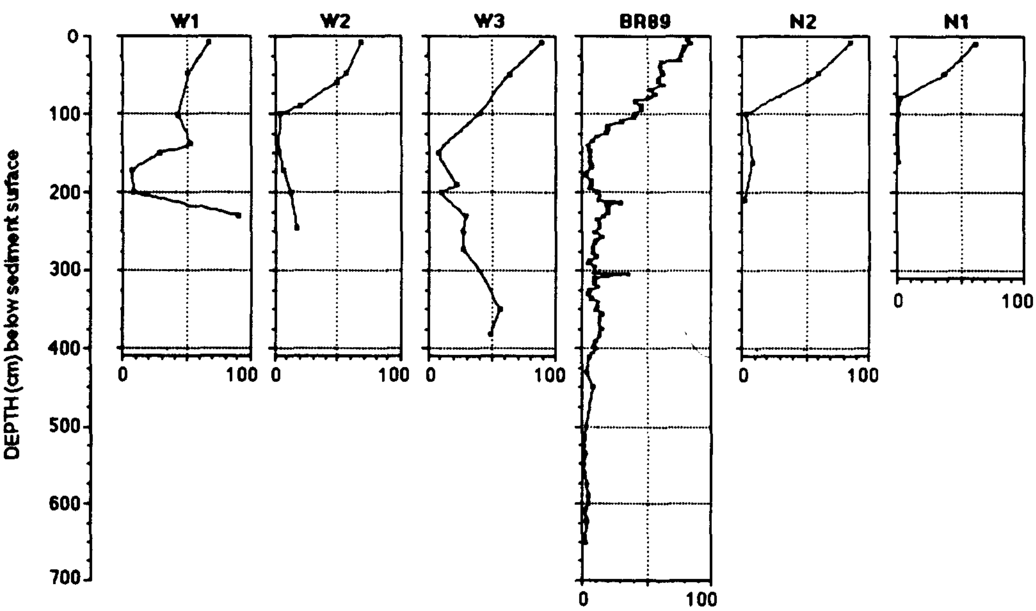

FIG. 3. Percent organic content of cores as determined by loss-on-ignition tests.

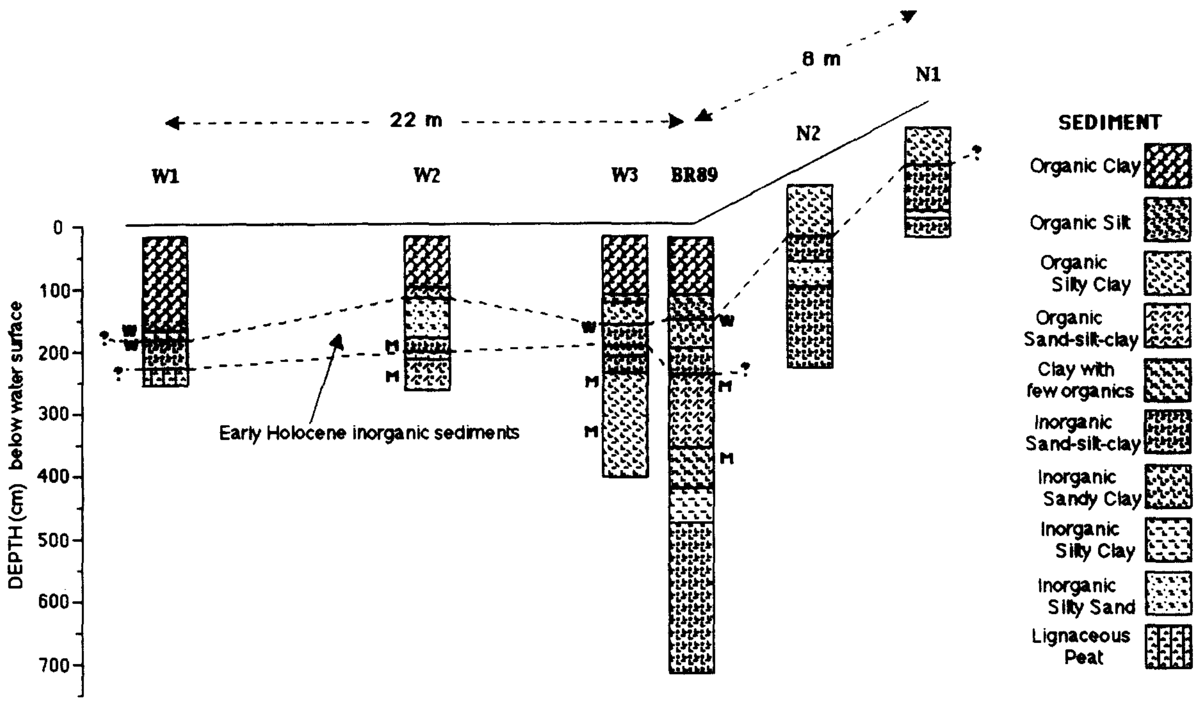

FIG. 4. Stratigraphy of cores in profile. The W symbol denotes 1–1.5 cm diameter wood fragments and the M symbol denotes core sections with significant visible plant macrofossils.

suggests oxidation and degradation due to exposure. In core BR89, the formation of this layer is bracketed between approximately 12,800 and 7900 BP. The small wood fragments found at the top of this layer suggest minor plant colonization during the hiatus. If the sediments were continuously exposed to the atmosphere, significant root growth and bioturbation ought to be evident. This is not the case and therefore the drop in water level was probably episodic, perhaps seasonal or drought related.

Pollen and Plant Macrofossil Assemblages

The complete pollen and plant macrofossil diagrams for core BR89 are presented in Figs 5 and 6. Core BR89 is divided into four pollen and plant macrofossil zones. The age for any specific zone is based on the assumption of a constant accumulation rate that changes only at lithostratigraphic shifts. This assumption must be viewed with caution between 12,800 and 7800 BP and therefore the ages of the zones within this interval are only approximate. Pollen influx values for selected taxa are presented in Fig. 12. The results from these analyses will be first described followed by the results of the coarser resolution pollen diagrams from cores W1, W2, W3 and N1, see Figs 8 through 11.

Zone BR-1: *Pinus-Picea-Abies* zone (17,345 to 14,090 BP; 405 to 337 cm). *Pinus* and *Picea* are the major pollen types. *Pinus* is dominant, with totals from 26% to 52% and both haploxylon and diploxylon types are present. *Picea* pollen ranges from 14% to 32% and is always less than *Pinus*. Both *Picea mariana* and *P. glauca* types are found. Small amounts of *Abies* (<6%), *Quercus* (<5%) and *Betula* (<2%) occur. *Alnus rugosa*-type (speckled alder) is a minor presence except for a single 36% spike at 370 cm. Herbaceous pollen accounts from 11 to 14% of the pollen sum except for a 5% occurrence at 405 cm, the lowest sample. Tubuliflorae, *Sanguisorba canadensis* (American burnet), *Thalictrum* (meadow rue) and Cyperaceae (sedges) are the main taxa present. *Isoetes melanopoda* (quillwort) microspores swamp the pteridophyte taxa. The total pollen accumulation rate (PAR) increases from 950 to 2600 grains cm^{-2} year at the top of the zone. The plant macrofossils include many *Picea* seeds and needles with fewer *Abies* needles and *Alnus* seeds. Only two *Pinus* needle fragments were found, both two-needled. The species to which the needles may belong include *P. banksiana*, *P. resinosa*, *P. pungens*, *P. virginiana* and *P. echinata*, species with modern ranges extending into Virginia and northwards. Herbaceous macrofossils present include *Menyanthes trifoliata* (buckbean), *Viola* cf. *lanceolata* (lance-leaved violet) and *Carex lurida* (a sedge). There is a strong aquatic contingent which includes *Potamogeton spirillus* (pondweed) and Characeae (stoneworts) oogonia. *I. melanopoda* macrospores occur in abundance.

The pollen and macrofossils indicate *Picea* was present although the dominant species cannot be conclusively identified. *Arceuthobium* (mistletoe) pollen co-occurs with *Picea*; this hemi-parasite is most frequently associated with *P. mariana* and less often with *P. glauca* or other conifers (Gleason and Cronquist, 1991). Therefore, at least two of the three eastern *Picea* species might have grown at the site. *Abies*, which may be under-represented (Davis and Goodlett, 1960) or equally represented (Janssen, 1966) in the pollen record, must have been an important presence in the latter part of the interval as shown by both pollen and macrofossils. The pond itself was likely unproductive with seasonally fluctuating water levels: *I. melanopoda* is a pioneer species growing in springtime saturated water conditions and then senescing in the drier summer season (C. Taylor, *pers. commun.*). It is a major but decreasing presence within the

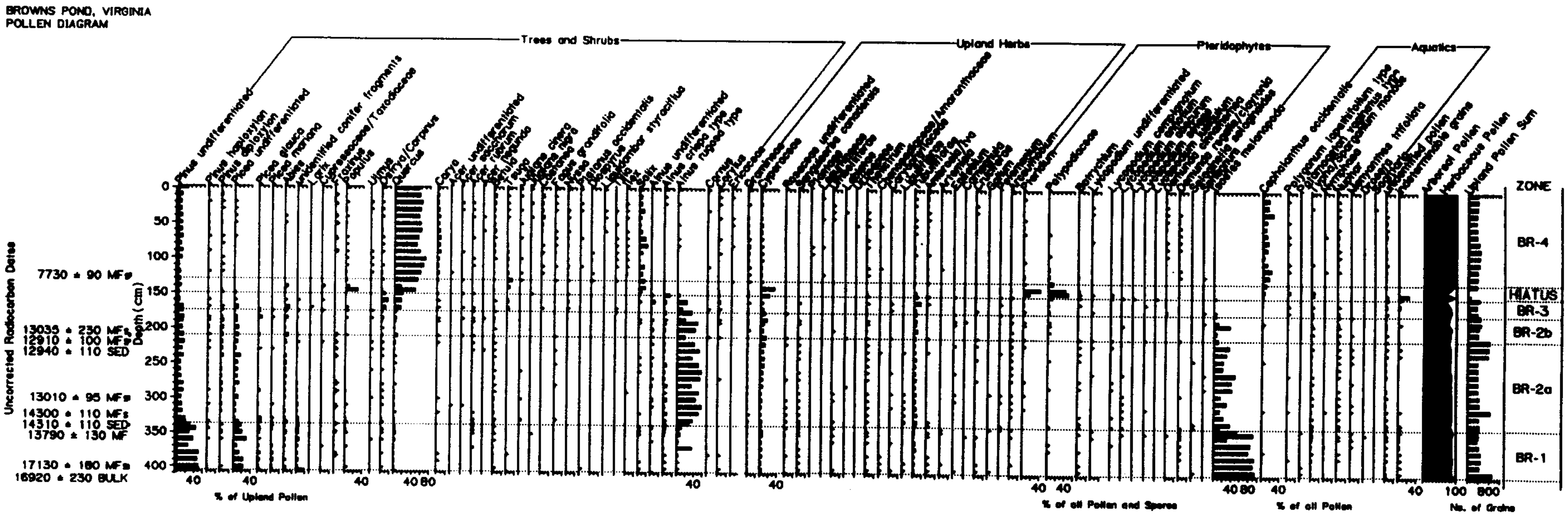

FIG. 5. Pollen percentage diagram from Core BR89, Browns Pond, Virginia. The total of tree, shrub and upland herb pollen is used to calculated their percentages. Aquatics are calculated as a percentage of all pollen, pteridophytes as a percentage of all pollen and spores. Radiocarbon dates on MFs (macrofossils), SED (1 ml of sediment) or BULK (bulk sediment) are listed.

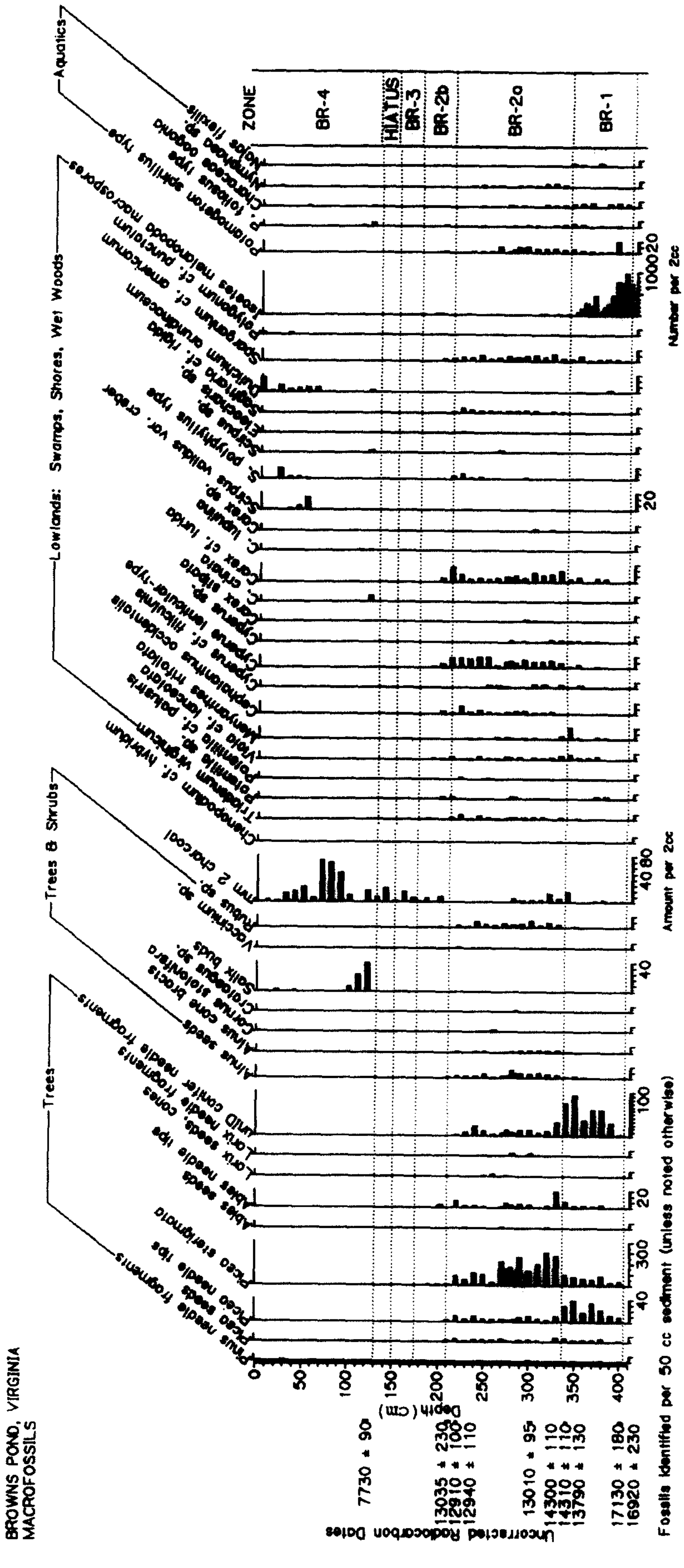

FIG. 6. Plant macrofossil and charcoal diagram from Core BR89, Browns Pond, Virginia. All macrofossils are seeds unless otherwise noted. The number of the fossils identified per 50 cm³ of sediment is plotted (except for *Isoetes* and charcoal which are plotted per 2 cm³ of sediment).

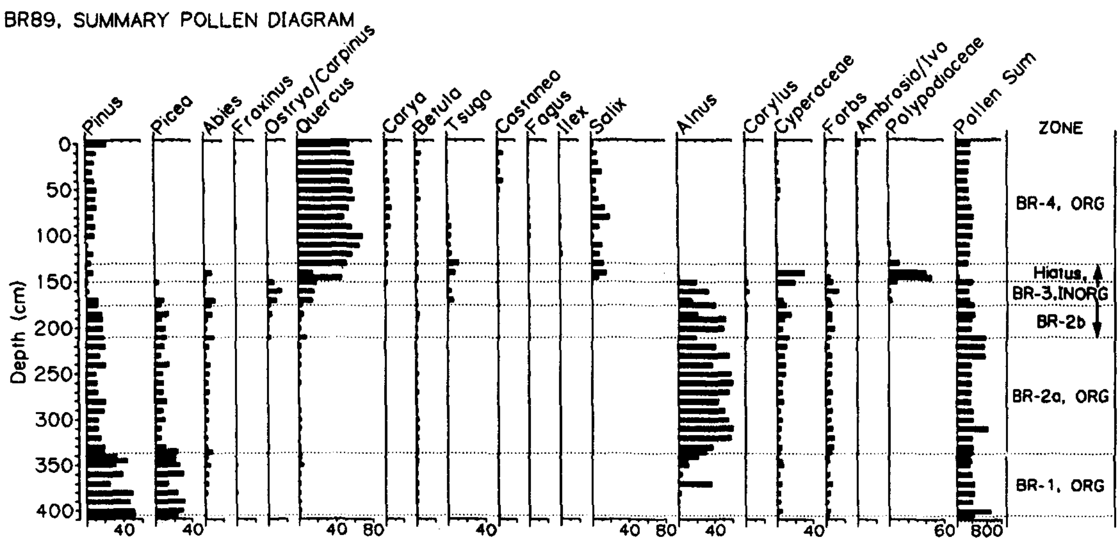

FIG. 7. Summary pollen diagram for core BR89, Browns Pond, Virginia. Forbs comprise Chenopodiaceae/Amaranthaceae, Liguliflorae, Tubuliflorae and Artemisia pollen types.

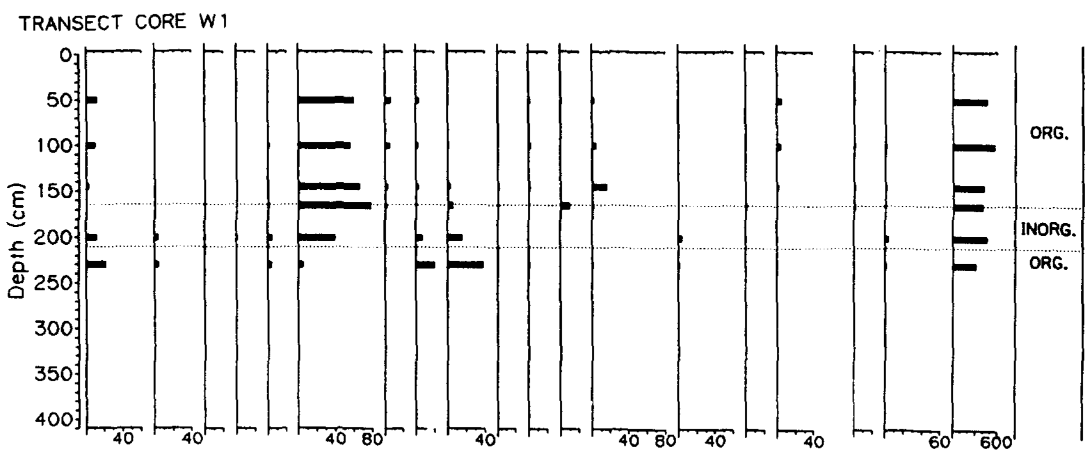

FIG. 8. Summary pollen diagram for transect core W1, located 22 m west of core BR89.

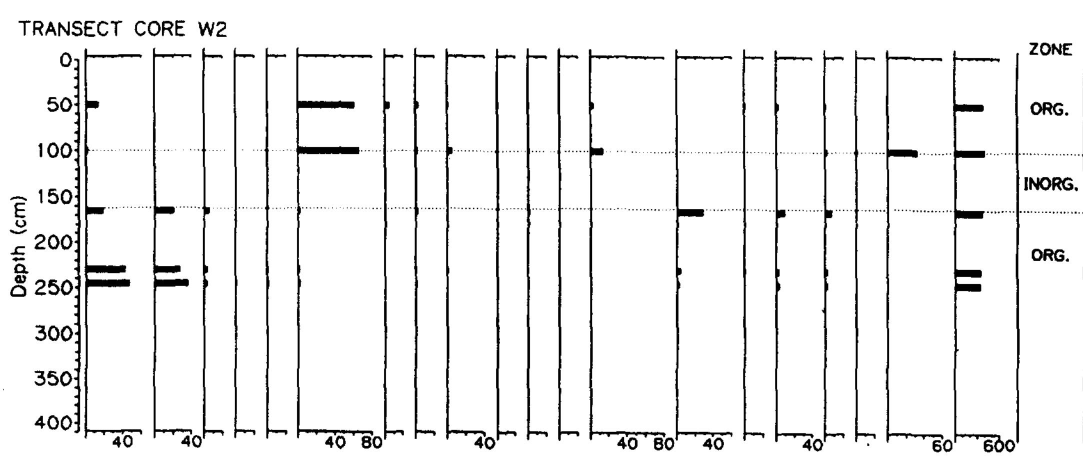

FIG. 9. Summary pollen diagram for transect core W2, located 12 m west of core BR89.

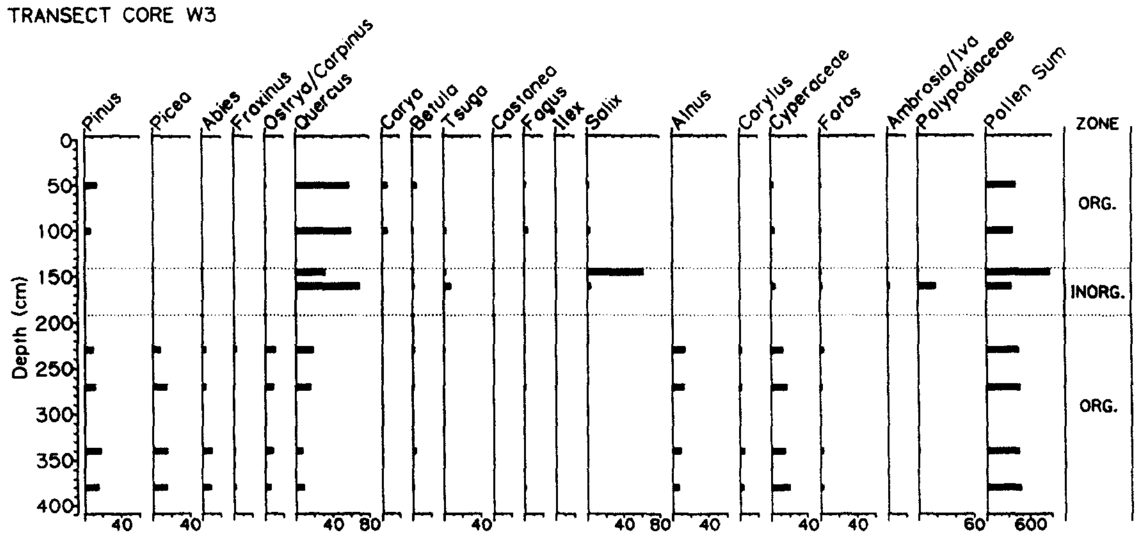

FIG. 10. Summary pollen diagram for transect core W3, located 2 m west of core BR89.

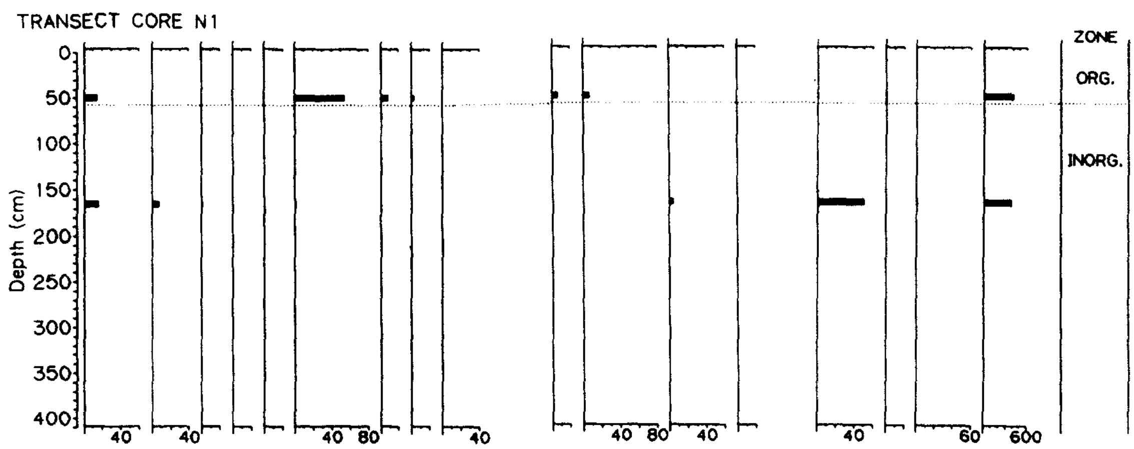

FIG. 11. Summary pollen diagram for transect core N1, located 8 m north of core BR89.

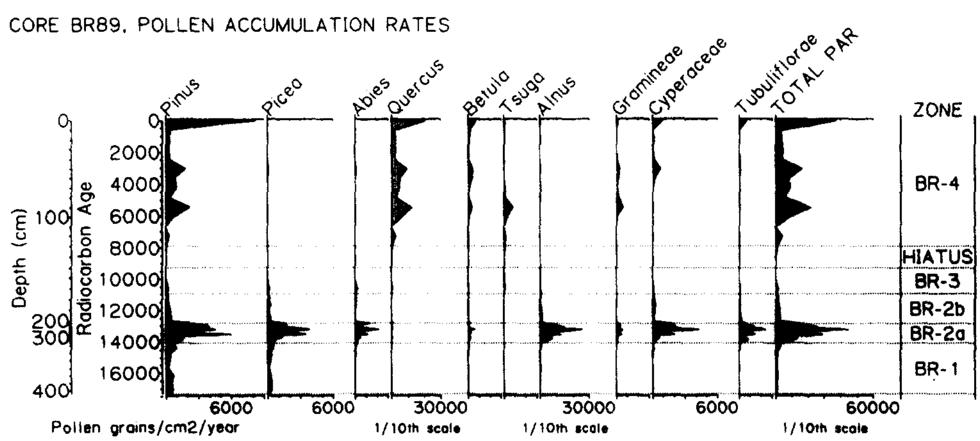

FIG. 12. Pollen accumulation rate diagram for selected taxa at Browns Pond. The age axis is based on the assumption of linear accumulation rates between radiocarbon dates. Units of PAR are in number of pollen grains per square centimeter per year. Note that *Quercus*, *Alnus* and Total pollen are plotted at a different scale.

interval. At least part of the pond may have been perennially water-filled since the aquatic, *P. spirillus*, is present.

Zone BR-2a: *Alnus-Pinus-Picea-Abies* zone (14,090 to 12,810 BP; 337 to 210 cm). *Alnus* pollen dominates this assemblage: it ranges from 30 to 59%, most of which is identified as *A. rugosa*-type, a shrub with a swamp or low-ground habitat. The conifers, *Pinus*, *Picea* and *Abies*, are the next main pollen contributors. As in zone BR-1, *Pinus* always exceeds *Picea* and *Abies* is rarely >5%. This zone is also distinguished by high PARs: they range from 6000 to 45,000 grains cm^{-2} year. While *Alnus* is the major component, the three conifer taxa also manifest their highest influx rates during this zone. *Quercus* and *Betula* provide the only significant hardwood presence although neither exceeds 2%. The percentages and type of upland herbs are similar to that found in zone BR-1. Cyperaceae pollen gradually increases in this zone from 3% near the bottom to 11% at the top. The total herbaceous component varies from 10 to 18%. *I. melanopoda* continues to dominate the pteridophytes. Pollen from *Nuphar* (yellow water lily) is continually recorded in this zone. These last two taxa imply that the pond did contain standing water year-round yet the shallows experienced seasonal fluctuations.

In the macrofossil record, needles and seeds clearly reflect the local presence of *Picea* and *Abies*. Scattered *Larix* seeds, cones and needle fragments indicate its local occurrence. It is possible that the high amounts of *Alnus* pollen may be due to a very local population. A relatively lush growth of *Rubus* shrubs and varied herbs is suggested by the many macrofossils. The herbaceous types include *Triadenum virginicum*, *Viola* cf. *lanceolata* and *Menyanthes trifoliata*—all indicative of damp soil and shore regions. *Carex*, *Cyperus* and *Sparganium* cf. *americanum* (bur-reed) are also abundant and are likely swamp or low-ground species. The basin had some perennially standing water since *Nymphaea* (water-lily) seeds are consistently present. In addition, the herbs and sedges proliferated on the damp margins of the pond.

Zone BR-2b: *Alnus-Pinus-Picea-Abies* zone (12,810 to 10,950 BP; 210 to 175 cm). The percentages of most pollen taxa are comparable to those in zone BR-2a. Only the hardwoods, *Ostrya/Carpinus* and *Quercus*, have increased slightly to about 5% at the top of the interval. This sub-zone is delineated because influx rates diminish significantly. The lower influx rates, decreasing from 14,000 to 2300 grains cm^{-2} year, occur in the interval of slower sediment accumulation rates, from 130 to 201 cm depth. Therefore, as with the accumulation rates, the low PARs may be a partial artifact of post-depositional processes. Similarly, the obvious decrease in numbers of macrofossils may result from a combination of changing pond environment and post-depositional degradation of the record.

Zone BR-3: *Quercus-Ostrya/Carpinus* (10,950 to 9240 BP; 175 to 150 cm). This short zone, encompassing four samples, contains a wide distribution of arboreal taxa. *Pinus-Picea-Abies*, which are about equally represented, decrease from a combined total of 35% at 175 cm to 9% at 150 cm. *Tsuga* ranges up to 4%. *Alnus* fluctuates between 15% and 40%. The hardwoods ≥ 1% are *Quercus*, *Ostrya/Carpinus*, *Corylus* and *Betula*: their maximum occurrences are 20%, 15%, 6% and 1% respectively. Herb pollen varies from 15 to 32% with Cyperaceae and Tubuliflorae being the main components. A few aquatic pollen were counted and the proportion of fern spores increases within the interval. Pollen influx decreases to a low of 90 grains cm^{-2} year at 150 cm—this decrease in influx is seen in all the upland taxa. No plant macrofossils were found in this interval, except for a few *Isoetes* macrospores at 175 cm.

Sub-surface water levels and subsequent desiccation degraded the pollen and macrofossil records hence, the low pollen influx values and lack of preserved macrofossils. This zone contains the transition from a conifer to deciduous hardwood forest.

Hiatus: 9240 to 7880 BP; 150 to 130 cm. The preceding lithostratigraphic data indicate that these 20 cm, at the top of the upper inorganic layer, represent a depositional hiatus. The low pollen counts, extremely low PARs (<40 grains cm^{-2} year) and high number of indeterminable (primarily corroded) grains all imply that a hiatus affected this part of the record. Even the high percentages of Polypodiaceae and *Pteridium* are a counting artifact since their actual concentrations do not increase in this zone.

Zone BR-4: *Quercus-Pinus* (7880 BP to present; 130 to 0 cm). *Quercus* is the predominant upland tree taxon, composing from 50 to 71% of the record. *Pinus* pollen is the next highest taxon, at 3% to a core-top high of 22%, with both haploxylon and diploxylon types present. *Carya* and *Betula* usually maintain levels below 5%. *Tsuga* initially reaches a maximum of 12% at 130 cm, drops to 1% at 70 cm and then occurs rarely. *Castanea* does not exceed 1% until 60 cm. *Salix* (willow), a large genus encompassing many southeast lowland species, reaches up to 20%. Total herbaceous pollen is 9% or less of the pollen sum. Gramineae and Cyperaceae appear while Tubuliflorae pollen has become insignificant. *Cephalanthus*, a shrub growing in semi-submerged environments, is abundant while traces of *Nuphar* are recorded. Total PARs range from 3000 to 10,000 grains cm^{-2} year. A few taxa are well-represented by macrofossils: *Salix* and the swamp plants *Scirpus validus* var. *creber*, *S. polyphyllus* type and *Dulichium*.

The presence of *Quercus* and *Castanea* pollen is in accord with the present-day Oak-Chestnut deciduous forest that surrounds the site. That *Quercus* does not occur in the macrofossil record is consistent with other pollen-macrofossil studies at sites presently dominated by oak (Watts, 1979; Peteet *et al.*, 1990). The *Pinus* pollen most likely comes from regional populations of *P. strobus*. The few diploxylon grains may be derived from high-elevation Southern Appalachian *P. resinosa* or *P. banksiana* populations. *Salix* is not at the site now, however, the significant amounts of pollen and buds found lower in the zone indicate its earlier local presence. *Nuphar* pollen throughout the zone coupled with the finding of a single *Nymphaea* seed at 20 cm implies that Browns Pond had pools of standing water, up to a meter deep, until recent times. Estimates of charcoal content clearly show that the largest amounts of charcoal were found in this mid-Holocene section of the core.

By comparing the complete pollen diagram of BR89 with the pollen counts from W1, W2, W3 and N1, the lateral coherancy of the described pollen zones becomes evident (Davis *et al.*, 1984; Beaudoin and Reasoner, 1992). The results from the transect pollen records are presented by examining each pollen profile with respect to the upper inorganic layer occurring from 201 to 130 cm in BR89. Minor differences in pollen percentage profiles may be due to the hiatus and lateral variations in organic preservation. Summary pollen diagrams are presented for these transect cores in Figs 8 through 11. For ease of comparison, a summary pollen diagram of core BR89 is shown in Fig. 7.

Transect core W1: 22 m west of BR89; inorganic layer from 210 to 164 cm; Fig. 8. The one sample beneath the inorganic layer, at 230 cm, contains significant percentages of *Tsuga* (40%) and *Betula* (20%) along with *Pinus* (22%), which is unlike any BR-89 pollen zone. *Picea*, *Ostrya/Carpinus* and *Quercus* are minor components. *Alnus* is rare and *Abies*, Cyperaceae and Gramineae are absent. The next sample at 200 cm is dominated by *Quercus* however *Tsuga* and *Betula* (16% and 7%) are still found in quantities higher than at any level in BR89.

At 165 cm, *Quercus* constitutes 77% of the upland pollen. *Ilex* (holly) is the next most significant pollen contributor at 9%. *Ilex* encompasses several swamp species and this pollen signal is probably local. The pollen distribution is consistent with other samples from the top of the inorganic/hiatus interval. The upper three samples, from 145 to 50 cm, are dominated by *Quercus*, followed by *Pinus*, *Salix* and *Carya*. These results are consistent with zone BR-4.

Transect core W2: 12 m west of BR89; inorganic layer from 162 to 100 cm; Fig. 9. Below the inorganic layer, from 245 to 165 cm depth, *Pinus* and *Picea* are the dominant arboreal taxa followed by *Abies* at <5% and *Quercus* at <2%. *Alnus* is a minor component until the upper sample at 165 cm where it exceeds 25%. The lower two samples are similar to zone BR-1 while the sample at 165 cm, with more *Alnus* and herbaceous pollen, better fits zone BR-2a. At 100 cm, *Quercus* pollen dominates, followed by *Salix* and then *Pinus*. A spike in Polypodiaceae is also seen at this level. These characteristics match those of the hiatus interval. The uppermost sample, 50 cm, is consistent with the pollen distribution in zone BR-4.

Transect core W3: 2 m west of BR89; inorganic layer from 193 to 142 cm; Fig. 10. All four samples below the inorganic layer (380 to 230 cm) contain similar pollen distributions: *Quercus*, *Pinus*, *Picea*, *Abies*, *Ostrya/Carpinus* and *Alnus rugosa* occur in nearly equal amounts. *Corylus* is present at 2 to 5%. This conifer-hardwood pollen distribution is most similar to the BR-2b zone (210 to 175 cm). The percentages of *Ostrya/Carpinus*, *Quercus* and *Corylus* are more similar to zone BR-3 although BR-3 contains *Tsuga* pollen. The assemblage from within the inorganic layer resembles the hiatus zone in BR89: *Quercus* is dominant and *Pinus* reaches its minimum value. A 60% spike in *Salix*, not evident in BR89, suggests a local source for this tree or shrub. The uppermost samples at 100 and 50 cm have pollen distributions matching those in zone BR-4.

Transect core N1: 8 m north of BR89; inorganic interval from >173 to 58 cm; Fig. 11. The pollen sample at 165 cm contains 50% Tubuliflorae pollen; no other cores showed such high amounts of herbaceous pollen. Arboreal taxa (*Pinus* and *Picea*), a possible aquatic (*Polygonum lapathifolium* type), Gramineae, Ericaceae and Ranunculaceae (buttercup) also occur in amounts exceeding 5%. The lithostratigraphy indicates this section of the basin was not flooded until after 7780 BP and thus the large percentages of herb and shrub pollen may come from a local source. A sample at 75 cm yielded virtually no identifiable pollen. The upper sample from 50 cm contains an assemblage consistent with zone BR-4.

DISCUSSION

Chronology and Lithostratigraphy

The transect of cores from Browns Pond, Virginia reveals that water levels have fluctuated in the basin (Digerfeldt, 1975, 1986). During the duration of this record, the most significant drop in water levels created a hiatus between 150 and 130 cm depth in core BR89. Assuming constant accumulation rates, this interval dates between 7900 and > 9200 BP. Alternatively, one may use the increases of *Betula* and *Tsuga*, seen in West Virginia at 10,760 BP (Larabee, 1986) and in Maryland after 10,530 BP (Maxwell and Davis, 1972), as a local chronozone. At Browns Pond, the *Betula* rise seen in core W1 lies below the inorganic interval and thus the hiatus affects W1's record after approximately 10,500 BP. If organic accumulation recommenced across the basin at approximately the same time, then the hiatus ends at roughly 7900 BP. This simple estimate would confine the period of lowest water levels to the early Holocene, from about 10,000 to 8000 BP.

The results from the transect work and AMS dating are highly applicable to other Late-Quaternary pollen and sediment records from small sinkholes. Watts recognized that several mid-elevation, small lake sites from New Jersey to Georgia, contained early-Holocene sections of oxidation-damaged pollen and coarser sediments, leading him to suggest that summer drying was more extensive at that time (Watts, 1970, 1979). However, the possible hiatus zones are not bracketed by radiocarbon dates. A comparison of conventional bulk and AMS radiocarbon dates at the Nodoroc Site, Georgia, also illustrates the importance of dating hiatuses and fluctuations in accumulation rate for accurate environmental interpretations (Jackson and Whitehead, 1993). Recognizing and AMS dating these hiatuses will produce well-controlled pollen chronologies (Webb and Webb, 1988).

Vegetation

At Browns Pond, several arboreal taxa occur in amounts greater than previous glacial and late-glacial studies have found. *Larix* cones and needles found between about 14,000 and 13,000 BP substantiate the occurrence of these mesophytic trees in the vicinity of Browns Pond, although the pollen is not evident. *Larix* pollen does occur in the LGM and transitional assemblages at Rockyhock Bay, North Carolina (Whitehead, 1981) and Big Run Bog, West Virginia (Larabee, 1986). In earlier studies, *Larix* was not found in unglaciated Appalachia nor the Coastal Plain and therefore, it was hypothesized that *Larix* migrated from the midwest, eastward, during deglaciation (Watts, 1979). However, because of its occurrence now documented in the central Appalachians and even earlier, at 19,000 BP, on the Coastal Plain (Whitehead, 1981), it becomes plausible that *Larix* had a southerly refugium.

At Browns Pond, *Abies* pollen is more abundant from 16,000 to about 9000 BP than at two neighboring sites, Cranberry Glades, West Virginia (Watts, 1979) and Hack Pond in the Shenandoah Valley, Virginia (Craig, 1970). *Alnus* pollen often exceeds 50% from about 14,000 to <12,800 BP. Macrofossils of both *Abies* and *Alnus* confirm their presence. *Alnus* pollen is commonly interpreted as a local rather than regional signal. The high values here are typical of modern Alaskan surface samples taken from alder thickets with scattered or adjacent spruce (Heusser, 1983) or from treeline and muskeg communities (Peteet, 1986). The Browns Pond record indicates that *Abies*, *Larix* and *Alnus* were present, in the late-glacial forest, at levels greater than previously mapped for this region (Delcourt and Delcourt, 1987; Webb, 1988). The fossil evidence from Browns Pond enhances existing reconstructions by revealing spatial heterogeneities in the boreal-type forest, south of the Laurentide ice sheet.

The BR-1 *Pinus-Picea-Abies* pollen assemblage, from 17,345 to 14,090 BP, is similar to the pre-15,120 BP zone at Criders Pond, Pennsylvania (Watts, 1979), the 19,000 to 10,000 BP interval at Rockyhock Bay, North Carolina (Whitehead, 1981) and the 17,040 to 13,870 BP zone at Big Run Bog, West Virginia (Larabee, 1986). However, the West Virginia site contains substantially more sedge pollen than Browns Pond as does the 18,550 to 12,640 BP interval from Buckles Bog, Maryland (Maxwell and Davis, 1972). The BR-1 pollen assemblage of boreal conifers, low amounts of herb pollen and macrofossils and numerous *Picea* and *Abies* macrofossils together suggest a closed boreal-type forest during the LGM. This interpretation is consistent with previous studies which place the boreal forest south of Buckles Bog and below the central Appalachian Mountain peaks (Wright, 1981; Delcourt and Delcourt, 1984).

The pollen and macrofossil assemblages combined with data on the modern range distributions of the plants (Little, 1971; Gleason and Cronquist, 1991), suggests the environment warmed from 17,300 to 14,100 BP. During this interval, *Abies* pollen increases and macrofossils are evident after 16,000 BP, later than *Picea*. This signal indicates that the climate at 17,300 BP was initially too cold or dry for *Abies* growth, but gradually ameliorated. The aquatic, *Nuphar*, enters at the same time that *Abies* pollen begins to increase, followed by *Menyanthes trifoliata*, a shallow water circumboreal/sub-boreal species. *Alnus* seeds are first seen at approximately 15,200 BP. Together, these taxa indicate the local climate became warmer and moister after 17,000 BP. Other key herbaceous species found during the LGM at Browns Pond are: a few rare occurrences of *Selaginella selaginoides*, with a modern range from the boreal region to Michigan; *Sanguisorba canadensis*, a species mostly found in New England and the Great Lakes region, and; *Triadenum virginicum*, now found from Nova Scotia south to Florida. *S. selaginoides* has not been identified in other southeast pollen records. Its presence may be related to increased seasonality. Thus, the period from 17,300 to 14,100 BP contains a mixture of boreal to temperate flora.

An increase in pollen and sediment accumulation rates evident at 14,100 BP at Browns Pond is similarly evident at 13,900 BP at Big Run Bog, West Virginia (Larabee, 1986) and at 12,700 BP at Buckles Bog, Maryland (Maxwell and Davis, 1972). At Big Run Bog (980 m elevation), the vegetation assemblage shows increases in *Abies* pollen and macrofossils and pollen from mesophytic deciduous taxa (*Fraxinus*, *Ulmus*, *Ostrya/Carpinus*, *Quercus* and *Juglans cinera*). At Buckles Bog (800 m elevation), *Abies*, *Fraxinus*, *Ostrya/Carpinus* and *Quercus* increase in the pollen assemblage. A rise in *Alnus* and *Abies* pollen accompanied by an increasingly diverse arboreal and aquatic macrofossil assemblage occurs after 13,300 BP at Criders Pond, Pennsylvania (289 m elevation, Watts, 1979). Taking the radiocarbon dates at face value, a pattern of increasingly diverse and mesic vegetation commences from approximately 14,000 to 12,700 BP.

At Browns Pond, the hardwood trees (*Quercus* and *Ostrya/Carpinus*) and *Tsuga* show small but clear increases at 12,810 BP. This timing corresponds well to the previously described changes beginning at 12,700 BP at Buckles Bog, Maryland except that at Buckles Bog, *Tsuga* does not consistently appear until after 10,500 BP. At Criders Pond, Pennsylvania the increases are seen around 11,600 BP.

The BR89 pollen record is poorly preserved from 10,950 to 7880 BP although high percentages of *Tsuga* and *Betula* do occur just below the inorganic layer in core W1. Watts (1979) believed that *Tsuga*, *Betula*, some *Quercus* species and other deciduous trees (especially *Fagus*, *Castanea* and *Tilia*) formed a mesic forest at Cranberry Glades, WV, from 10,000 to 6000 BP. The nearby Big Run Bog, West Virginia, record may support this interpretation. However, poor chronological control at the sites makes a robust interpretation impossible for this time interval. At more distant sites such as Anderson Pond, Tennessee (Delcourt, 1979) and White Pond, South Carolina (Watts, 1980b), hardwood pollen assemblages dating between approximately 12,500 to 10,000 BP are interpreted to show a more mesic climate. Therefore, the geographical and temporal extent of a late-glacial or early-Holocene mesic forest remains unresolved.

The final vegetation pattern to emerge is the Holocene *Quercus*-dominated assemblage. At Browns Pond, the increase in *Quercus* can only be constrained between 10,900 and 7900 BP, which is consistent with its arrival time at other sites in the central Appalachians (Watts, 1979). Whether or not *Quercus* is a late-successional tree, in the southeast, is controversial (Fowells, 1965; Abrams, 1992). Its continuous dominance throughout the Holocene, combined with the relatively greater abundance of charcoal found here, may be related to fire frequencies of approximately 50 to 100 years (Abrams, 1992).

Paleoclimate

Three paleoclimate signals emerge from the Browns Pond record: (1) a gradual warming and moistening of the environment from approximately 17,000 to 14,100 BP; (2) increased moisture at 14,100 BP; and (3) a drier climate from 10,000 to 8000 BP.

The amelioration of the cold, dry climate after 17,000 BP is evidenced by the shifting composition of arboreal and herbaceous vegetation. Anderson Pond, Tennessee may also show a changed climate at this time. There, the appearance of mesic hardwoods between 16,300 to 12,500 BP has been interpreted as a result of decreasing winter severity and an increasing growing season (Delcourt, 1979). In the central Appalachians, at sites north of Browns Pond and south of the Laurentide ice sheet, Watts concluded that ecosystems and therefore, also climate were stable prior to 14,000 BP (Watts, 1979). However, the sites that Watts addresses are either no older than 15,000 BP or were located in LGM tundra environments. These sites may lie within a distinct local climate created by the Laurentide ice sheet. We hypothesize that mid-latitude vegetation provides subtle indications of increasing warmth and moisture after 17,000 BP. The precise timing of the warming cannot be determined because of low accumulation rates. There are no indications of shifts in North Atlantic ocean circulation prior to 14,500 BP (Charles and Fairbanks, 1992) however Greenland ice cores do show temperature increases commencing after 18,000 BP (Johnsen *et al.*, 1992). Therefore, vegetation may be responding to climate change forced by increasing summer insolation (Berger, 1978).

The existence of any late-glacial climate oscillations, including any changes correlative with the Bølling-Allerød-Younger Dryas chronozones, cannot be ascertained from this record because of the chronological uncertainties between 12,810 and 7880 BP. We are examining core W1, at a finer resolution, to document the timing of increases in individual hardwood taxa, in zones BR-2b and BR-3, that compose the late-glacial interval.

An abrupt increase in *Alnus* pollen and macrofossils may signal a major change in climate at approximately 14,100 BP. Pollen and macrofossils of *Picea* and *Abies*, boreal and sub-boreal trees, are still major components of the assemblage and therefore warming may not have accompanied the increased moisture. The regional extent of this signal must be examined with additional sites. If *Alnus* does indicate a regional change in climate, it would provide additional evidence toward the global nature of a climate reorganization at 14,000 BP (Broecker and Denton, 1989).

A relatively drier climate is inferred from the evidence for a hiatus in the sediment record between approximately 10,000 and 8000 BP. Other small lakes from Connecticut to Georgia also contain sedimentary evidence of Holocene aridity (Watts, 1970, 1979; Thorson and Webb, 1991). A pattern of Holocene low lake levels in eastern North America is apparent in Harrison's compilation (1989). Lakes on the coast of Pennsylvania (Watts, 1979) and in South Carolina (Watts, 1980b) are the nearest records to Browns Pond in this study. In contrast to Harrison's study, in which dry conditions define eastern seaboard lakes from 9000 until 4000 to 3000 BP, maximum aridity is confined to a 2000 year interval in the early Holocene at Browns Pond. The early-Holocene arid period at Browns Pond may indicate that the existing regional pattern needs refinement. Alternatively, the drop in lake level at Browns Pond may be related to shifts in local drainage patterns. The limestone formations underlying parts of central Appalachia are susceptible to periodic dissolution which in turn influences drainage patterns in the sinkholes.

CONCLUSIONS

(1) In the Ridge and Valley of Virginia, a boreal-type forest was established prior to 17,300 BP. The BR-1 pollen zone is dominated by *Pinus*, followed by *Picea* and *Abies*. In contrast, *Picea* and *Abies* dominate the macrofossil assemblage. The sedge and herbaceous taxa are only a minor component of the zone. Their low percentages indicate that a closed boreal-type forest grew in the region in which all three conifers were significant. The increase of more mesophytic and thermophilous taxa, including *Abies*, *Alnus* and *Nuphar*, suggests gradual climate amelioration commencing after 17,000 BP.

(2) At Browns Pond, an increase in moisture at 14,100 BP is indicated by large amounts of *Alnus* pollen and macrofossils and rapid accumulation rates. In U.S. southeast pollen records, the high amounts of *Alnus* are unique. It is possible that the *Alnus* rise is related to the global deglaciation signal commencing at 14,000 BP (Broecker and Denton, 1989). Finding indications of rapid climate change at other sites in the central Appalachians, at approximately 14,000 BP, would be additional evidence of the strength of this signal.

(3) Zone BR-2a, 14,090 to 12,810 BP, at Browns Pond is characterized by a diverse assemblage of trees, shrubs and lowland flora. If the bulk radiocarbon dates from other sites within 300 kms of the southern border of the Laurentide ice sheet are accurate (Maxwell and Davis, 1972; Watts, 1979; Larabee, 1986), then a pattern emerges of vegetation assemblages becoming increasingly diverse and mesic from approximately 14,000 to 12,700 BP. The increases in these taxa are earlier at the lower elevations and more southerly sites. The climatic significance of this assemblage rests on improved resolution of pollen records from this region.

(4) An increase in hardwood pollen percentages is first apparent at the beginning of zone BR-2b, at 12,810 BP. However, the significant increases of *Quercus* and *Ostrya/Carpinus* become evident in subsequent zone BR-3, possibly concurrent with the virtual disappearance of the conifers. Based on calculated accumulation rates, Zone BR-3 may begin at approximately 11,000 BP. However, since accumulation rates are slow in these zones and no material for radiocarbon dating was found, the chronology of events remains equivocal.

(5) During the 17,300 radiocarbon years represented by the Browns Pond record, lake levels were lowest from 10,000 to 8000 BP. No studies have focused on Holocene aridity in the U.S. southeast. Improved chronological control of existing or new records is essential to indicate if early Holocene aridity was a regional event.

(6) Very few natural lakes occur in the U.S. southeast. Slow accumulation rates and hiatuses often affect the records. However, at a small sinkhole such as Browns Pond, the combination of pollen, macrofossil and lithostratigraphic analyses on a transect of cores is a successful method for

compiling a record of environmental change. AMS radiocarbon dating of a variety of materials, macrofossils and small sediment samples, provides accurate chronological control.

ACKNOWLEDGEMENTS

We thank W. Broecker, M. Chandler, R. D'Arrigo, D. Rind, R. Webb, members of the University of Minnesota, Research Training Group in Paleorecords of Global Change and two reviewers for discussions and comments that significantly improved the quality of this paper. We gratefully acknowledge Georges Bonani of the Institut für Mittelenergiephysik, ETH Honggerberg and the NSF-Arizona AMS Facility, for the crucial assistance with AMS analyses. Beta Analytic Inc., Florida provided additional radiocarbon analyses. We appreciate the identification and habitat description of *Isoetes* provided by Carl Taylor of the Milwaukee Public Museum. We are indebted to C. Clampitt and T. Rawinski of the Virginia Department of Conservation and Recreation for site identification and description. M. Chandler, G. Hartke, S. Parke and R. Webb provided invaluable field assistance.

This research was funded by: a NASA Interdisciplinary Grant; the Climate Center of the Lamont-Doherty Geological Observatory, New York; the Barbara J. Harvill Botanical Research Fund, Virginia; with summer field assistance from the Department of Geological Sciences, Columbia University. Lamont-Doherty Earth Observatoy contribution number 5116.

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