

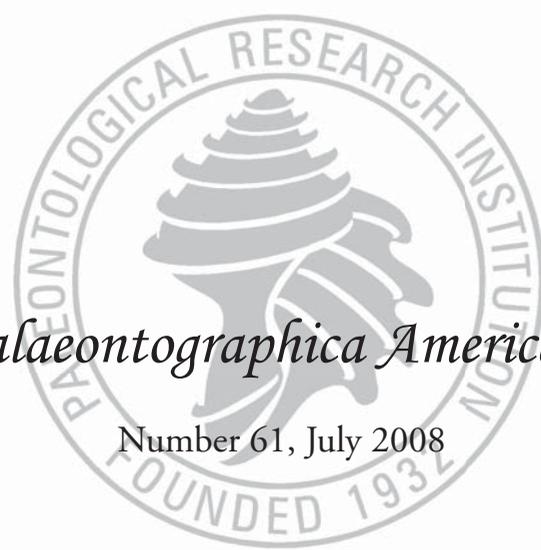
Mastodon Paleobiology,  
Taphonomy, and  
Paleoenvironment in the Late  
Pleistocene of New York State:  
Studies on the Hyde Park,  
Chemung, and North Java Sites



Edited by  
Warren D. Allmon and Peter L. Nester

*Palaeontographica Americana*

Number 61, July 2008



## THE HYDE PARK MASTODON AND PALYNOLOGICAL CLUES TO MEGAFUNA EXTINCTION

GUY S. ROBINSON

Department of Natural Sciences, Fordham College at Lincoln Center, 113 West 60th Street, New York, New York 10023, U. S. A., email grobinson@fordham.edu.

and DAVID A. BURNEY

National Tropical Botanical Garden, Kalaheo, Hawaii 96741, U. S. A.

### ABSTRACT

A late Pleistocene microfossil record for the vicinity of Lozier Pond is drawn from samples taken out of the face of a mastodon excavation pit. The Bölling/Alleröd warming period of the late-glacial forms the upper of two distinct pollen zones, but the sediment record has been truncated shortly before the onset of the Younger Dryas cooling event, apparently by recent backhoe operations. The pollen stratigraphy establishes a relative chronology by which other microfossil data can offer insights into rates and processes of megafaunal extinction. Spore counts of the dung fungus *Sporormiella* serve as a proxy for megafaunal biomass and levels of microscopic charcoal particle concentration are a proxy for fire history and human-induced landscape transformation. These data suggest that during the latter part of this chronology, megafaunal biomass was greatly reduced, followed by a significant rise in fire frequency indicative of human activity. Bone collagen dates from this and other New York sites however, establish that *Mammuth americanum* (Kerr, 1792) persisted for at least a millennium after megafaunal collapse, probably at a low population density, at least until the beginning of the Younger Dryas cooling. In suggesting that human activities rather than environmental factors drove the extirpation of megafauna, the observed pattern resembles other regional records.

### INTRODUCTION

The demise of the American mastodon is one of many losses to the fauna of North and South America at the end of the last ice age. By *ca.* 11,000 <sup>14</sup>C yr BP (radiocarbon years before present), both continents were deprived of at least 75% of their large mammals. Over the last 50,000 yr, all landmasses except Africa and tropical Asia lost most of their large animals (Martin & Steadman, 1999; Burney & Flannery 2005; Martin, 2005; Koch & Barnosky 2006). Compared with other revolutions in the history of life, the events of the late Quaternary are remarkable. Whereas large terrestrial animal communities suffered heavily, along with flightless birds and land snails on oceanic islands, microscopic organisms and marine life have been largely spared. Africa was apparently bypassed. Although Africa underwent an earlier bout of extinction involving pigs, large carnivores, large primates, and elephants in the Lower Pleistocene (Martin, 1984; Klein, 1984, 1999), Africa today retains a diverse large mammal community.

Whether human activity or environmental change was the critical factor in North American extinctions remains controversial. In spite of the proliferation of data over the last two centuries, thus far, neither hypothesis has been soundly refuted (Grayson, 1984, Grayson & Meltzer, 2003). Of all supportable bone collagen or dung dates on the extinct

megafauna, none are significantly younger than 11,000 <sup>14</sup>C yr BP. Thus it appears that this continent was deprived of 34 large mammal genera in only a few hundred years of landscape and climate change (Martin, 1990, Martin & Steadman, 1999). In the meantime, skilled human hunters rapidly colonized the expanding territory south of the ice sheets (Fiedel, 1999, 2002).

The principal hypotheses that have been advanced to explain late Pleistocene extinctions in North America were presented in synoptic form by Burney & Robinson (2008), including the respective rate, pattern, and process of extinction expected for each cause (Burney, 1999).

### SPORES OF THE DUNG FUNGUS, *SPORMIELLA*

Because the remains of large animals are relatively rare in the fossil record, the most recent radiocarbon dates on the bones of extinct Pleistocene megafauna might only be approximate indications of the timing of population collapse and regional extinction. For example, Signor & Lipps (1982) pointed out that in cases of rare taxa, the last occurrence in the record often precedes actual extinction (the "Signor-Lipps effect"). O. K. Davis (1987) has proposed the use of a microfossil proxy that could circumvent this difficulty. Following European settlement and introduction of grazing animals (livestock) to areas of the western United States, spores of dung fungi in the genus *Sporormiella* (Sordariaceae, Ascomycetes) are abundant in associated sediments. Dung deposition accompanying heavy land use generates elevated spore values in local pond

or marsh sediments (O. K. Davis, 1975, 1987). Found in high concentrations in mammoth dung from Bechan Cave, Utah, (Davis *et al.*, 1984), *Sporormiella* values are also high throughout the late glacial sediments of many sites of the western United States, until *ca.* 11,000  $^{14}\text{C}$  yr BP, after which they decline rather abruptly. Spore data from 30 sites were discussed by Davis & Shafer (2006) and provide additional support for the use of *Sporormiella* as a microfossil that can indicate when a high level of herbivory occurred at a local level. A study of *Sporormiella* occurrence in a suite of cores throughout Madagascar (Burney *et al.*, 2003) demonstrates that this dung fungus has global potential as a proxy indicator for both native megafauna and livestock. The microfossil stratigraphy at the Hyde Park mastodon site provides an opportunity to examine this novel aspect of the record for the first time in the Northeast.

#### MICROSCOPIC CHARCOAL AND FIRE HISTORY

To establish whether humans had a role in the extinction of the North American megafauna, we need a way of detecting the time of their arrival regionally. Evidence for Clovis culture is widespread in North America, and Paleoindian sites are scattered around in the lower Hudson Valley region (Funk, 1976; Funk & Steadman, 1994), but well-stratified Clovis sites are scarce in the eastern United States (Haynes, 1984). In the case of paleolithic cultures, absolute dates on projectile points and other worked stone materials can only be obtained from associated sediments. On rare occasions, defensible radiocarbon dates can be obtained from bone tools. Under optimal conditions, growth of founding human populations might take several centuries. Until such time, the conventional archaeological record will be sparse or missing entirely, a situation that is the temporal reverse, as it were, of the "Signor-Lipps effect." In this case, the archaeological record begins centuries after humans have begun to modify the landscape. Analysis of prehistoric landscape fires is a proxy method for detecting human activity in the stratigraphic record. Stratigraphic charcoal analysis has been used to detect prehistoric landscape transformation by humans in the northern Atlantic, northern Europe, Australia, the Americas, Madagascar, and oceanic islands of the Pacific and Caribbean (Singh *et al.*, 1981; Burney, 1987; Burney *et al.*, 1994, 1995; Athens, 1997; and references by Grayson, 2001; Kay, 2002: 234). Not surprisingly, such data tend to place human activity somewhat earlier than the dates derived from artifacts.

Although fire is often started naturally by lightning, deliberate burning has been practised for several hundred thousand years. Pyne (1984) remarked, "everywhere and from the earliest times, humans have altered the natural fire regimes they have entered" (cited by Patterson & Sassaman, 1988: 111). Whereas the low incidence of lightning-caused

fires in the Northeast has been noted, the early European settler reports of deliberate fire setting were not considered by Russell (1983) to be strong evidence that large areas of forest were burned frequently. Nevertheless, people are the primary cause of almost all wildland fires in New England today. Although more study is needed, human-ignited fires probably extensively modified the precolonial landscape as well (Patterson & Sassaman, 1988). With a few exceptions noted by Patterson & Sassaman (1988), and additional recent cases (Maenza-Gmelch, 1997a, b; Peteet *et al.*, 1993), the stratigraphic charcoal studies in the Northeast do not extend as far as the late Pleistocene. Most research on the regional fire history extending beyond ten millennia was designed to address questions of climate change and vegetational succession, and tends to lack the resolution needed to perceive human activity in the record.

Typically, the anthropogenic pattern is observed stratigraphically as a sharp rise in charcoal particle concentrations of at least an order of magnitude above background levels. Although peak levels tend not to persist for long, average concentrations settle down well above the previous background and this high level is sustained for 1-2 millennia before showing a gradual decline (Burney *et al.*, 1994b; Burney, 1997). Such a pattern in the record is understood to reflect rapid human population expansion and consequent regional landscape transformation followed by a change in human land use, and/or an ecological response (Burney, 1997).

The records of microscopic charcoal, *Sporormiella* counts, and pollen stratigraphy of the Hyde Park mastodon site (Lozier Pond) can be integrated and compared with similar records elsewhere in the southeastern New York region (Robinson, *et al.*, 2005). The late glacial pollen spectra are used in conjunction with  $^{14}\text{C}$  dating as a high resolution stratigraphic tool reflecting the chronology and process of large herbivore extinction at the landscape level.

#### METHODS

Following excavation of the mastodon skeleton from below water table (Burney & Robinson, 2008), a vertical face of the "bone pit" was cleaned in preparation for sampling. Inspection of this face (HPM-2) indicated that although twentieth-century excavation of the Lozier Pond might have removed much of the upper sedimentary units, the underlying stratigraphy remained intact and undisturbed. Samples were taken directly from the face, at 5-cm intervals, for palynological analysis, beginning from the bottom and working upward to avoid contamination from above. Sampling from 100 cm below the sediment surface (below floor of excavated pit) was continued at 5-cm intervals using a three-inch diameter bucket auger. Fist-sized cobbles were encountered at 175 cm, requiring the use of a posthole digger to remove material down to 190 cm,

at which point the substratum became too hard packed to penetrate. Bulk samples were also taken from this same face, at 10-cm intervals, for plant macrofossil analysis (see Miller, 2008).

Processing of samples for fossil pollen followed the methods outlined by Faegri *et al.* (1989). To allow calculation of pollen concentrations, the digest from each 0.5-ml sediment subsample was "spiked" with a known quantity of an exotic pollen type (*Eucalyptus* sp.) before suspending in liquid glycerine for permanent mounting on microscope slides. Routine counting of pollen grains and spores was carried out at 400x magnification in traverses evenly dispersed across the slide. At least 400 grains of tree and shrub pollen were counted for each sample; descriptive keys (*e. g.*, Kapp, 1969) and pollen reference slides aided in identifying palynomorphs. Oil immersion (1000x) was used for more critical determinations together with color photography of individual microfossils through a trinocular microscope. Voucher specimens (PRI 55300-55325) are deposited at the Paleontological Research Institution, Ithaca, New York.

Pollen and spore data have been presented graphically as pollen diagrams, using TILIA software (Eric Grimm, Illinois State Museum), ver. 2.0.b.4 (see Results), in which the raw-count data for major taxa present have been converted to a percentage of all upland pollen and spores for that subsample (pollen sum). Pollen and spores of aquatic and bog plants (including Cyperaceae) tend to be over-represented because they often grow on or around the water surface. These counts have been excluded from the upland pollen sums to obtain a regional and local pollen rain.

*Sporormiella* spore counts have been included among the aquatics and so also appear as a percentage of the total pollen sum. Note that the scale of the *Sporormiella* x-axis has been expanded six-fold to highlight the trends in the record.

Among the major species shown, pines are separated into *Pinus strobus* Linnaeus, or white pine, of the subgenus *Haploxylon* Koene, where it was possible to positively identify verrucae on the furrow membrane characteristic of this group (Hansen & Cushing, 1973). When such characters could not be seen, pine pollen was categorized as "*Pinus* undifferentiated." Because in practice, *P. strobus* does not become abundant in the region until the Holocene (M. B. Davis, 1983), it can be assumed that the lower portion of the diagram, the "*Pinus* undifferentiated" category is comprised exclusively of diploxylon pines such as *P. rigida* P. Miller and *P. banksiana* Lindley & Gordon (pitch pine and jack pine).

Pollen zones have been assigned using stratigraphically constrained cluster analysis (CONISS) on the square-root transformed data, using Cavalli-Sforza & Edwards' (1967) Chord Distance for the dissimilarity coefficient (see Text-fig. 1). Only taxa comprising > 5% of the pollen sum in at least

one sample have been included in this analysis. Zones were established without regard to either the values of *Sporormiella* or charcoal concentrations.

Charcoal analysis was carried out on separate subsamples using a modification of the Winkler nitric acid process (Winkler, 1985) to remove pyrites. Resulting digests were washed through 250- $\mu$ m sieves to remove macrofossils and macroscopic charcoal before hydrogen fluoride treatment. Calibrated tablets of *Lycopodium* spores were added before the final residues were suspended in glycerine jelly mounted on microscope slides.

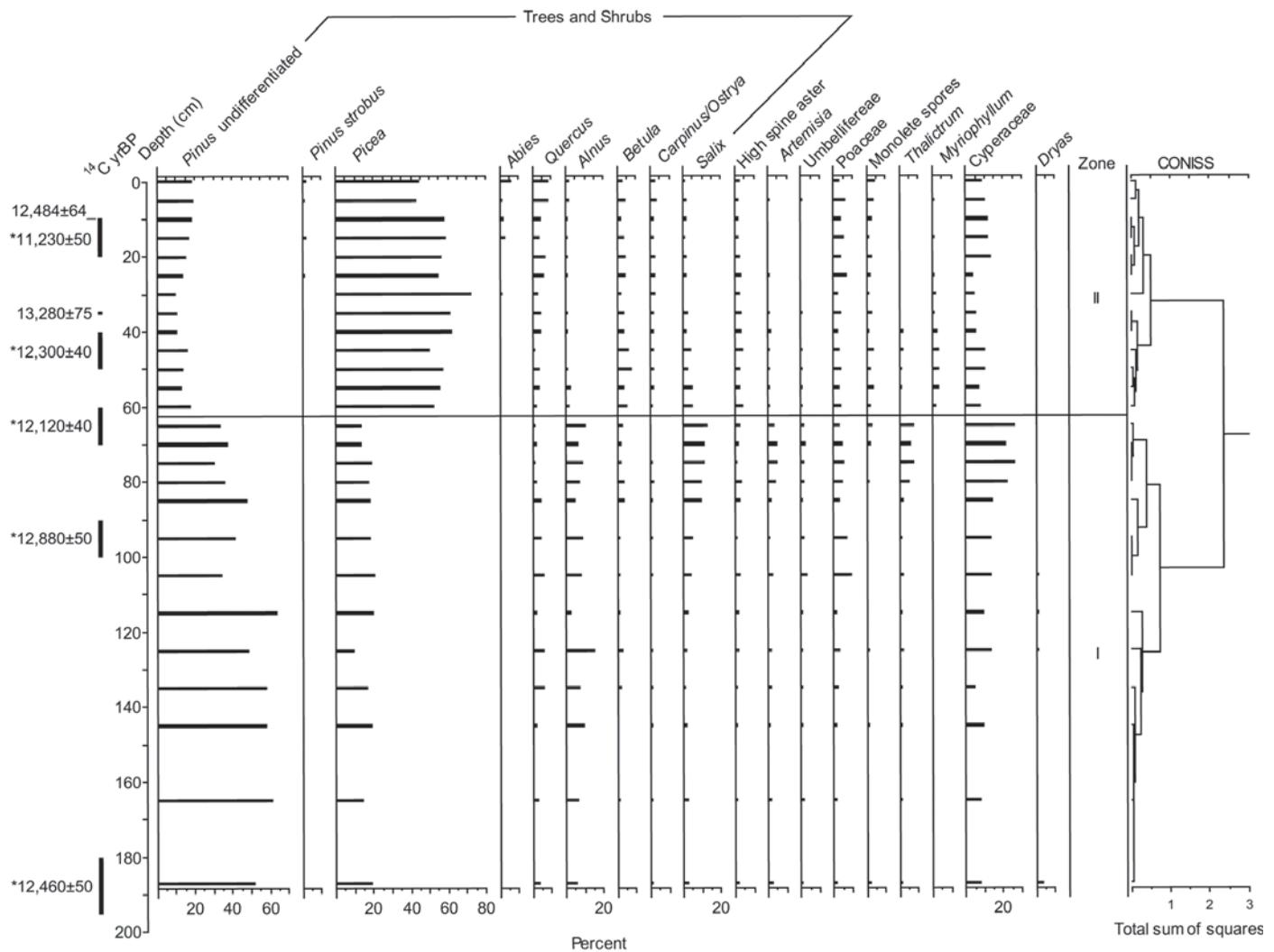
Charcoal residues were counted at 400x magnification using an eyepiece reticule to measure the two-dimensional projected area of individual fragments. The method accordingly allows establishment of the following charcoal particle size classes: 0.5-1  $\mu$ m, 2-4  $\mu$ m, 4-8  $\mu$ m, 8-16  $\mu$ m, 16-32  $\mu$ m, 32-64  $\mu$ m, 64-128  $\mu$ m, and > 128  $\mu$ m. Analysis of the size distributions can distinguish local from more distant fires (Burney, 1987; Patterson *et al.*, 1987; Clark, 1988). Because the *Lycopodium* spores were present in a fixed number per volume of sediment, charcoal values could be expressed as concentrations ( $\mu\text{m}^2 \text{cm}^{-3}$ ). Morphology and texture of charcoal fragments were also classified palynologically (Goldberg, 1986; Burney, 1987; Burney *et al.*, 1994). Two categories of microscopic charcoal were thus recognized: graminoid (derived from cuticles of grasses and sedges) and amorphous (from woody and broadleaf plant types), offering further information on types of vegetation burned (Burney, 1987; Patterson *et al.*, 1987). Particles whose smallest dimension exceeded 250  $\mu$ m were caught in the sieving process described above and were then examined under a dissecting microscope to determine if they were macroscopic charcoal. Counts of these larger charcoal fragments were tallied as particles  $\text{cm}^{-3}$ .

## RESULTS

Major pollen and spore types (those reaching at least 2% of the sum at any point in the sequence) are shown in Text-fig. 1. The dendrogram at the right of Text-fig. 1 shows the results of cluster analysis, showing two clear pollen zones. Absolute dates taken on bone collagen and the sedimentary sequence are reported in Table 1.

### POLLEN STRATIGRAPHY

Zone I: *Pinus* dominates throughout, and makes up as much as 60% of the lower part of this zone, where it is followed by *Picea* (15-20%). *Alnus*, *Quercus*, *Salix*, Gramineae, and *Artemisia* form a minor but significant portion of the spectrum in lower Zone I. With the exception of *Quercus*, these taxa then begin to take a larger share in the upper part of the zone, where *Thalictrum* and Monolete spores also show an increase. Cyperaceae rise steadily from 10 to 25%. Ericaceae and



Text-fig. 1. Pollen and spore stratigraphy. All types comprising 2% of sum at any point in the sequence are shown. Note expanded scale for *Sporormiella*. Zones are established by cluster analysis (see text) and displayed as a dendrogram. Asterisk (\*) indicates  $^{14}\text{C}$  dates from plant macrofossils (see Miller, 2008).

certain hardwood taxa such as *Carya*, *Castanea*, and *Fraxinus* are present below 1% in many samples in Zone I. Pollen of the tundra plant *Dryas* is present, forming as much as 3% of the lowest sample, and it continues to be present in trace amounts in many samples throughout this zone. Compared with Deevey's southern New England stratigraphy, Zone I at Hyde Park corresponds to the pine-spruce or A1 zone (Deevey, 1939, 1943).

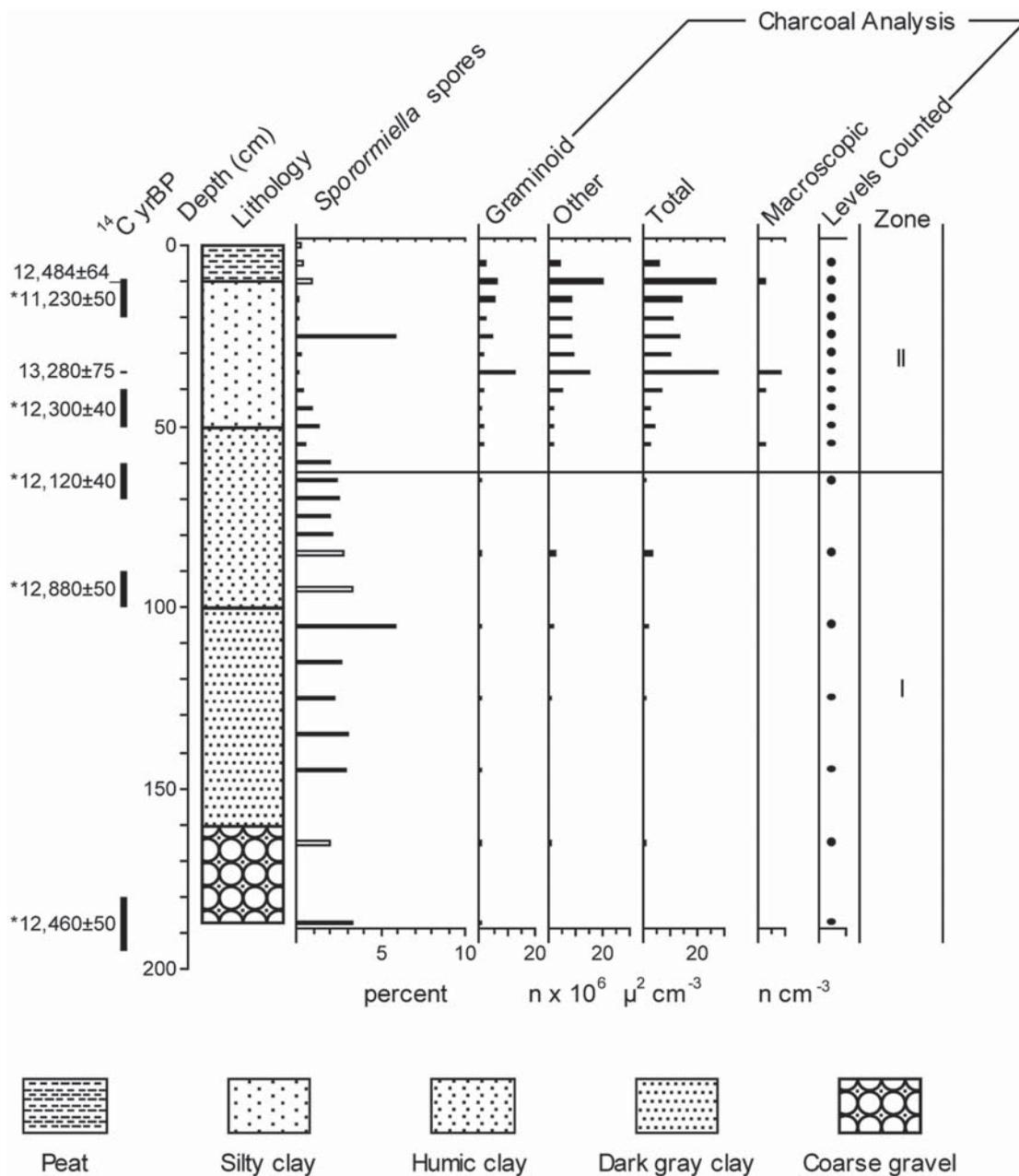
Zone II: *Picea* rises abruptly to 55% and exceeds 70% mid-zone, declining to about 40% at the top. *Pinus* spp. no longer comprise even 20% of the sum; *P. strobus* (haploxylon) appears and although rare is present from the mid-zone on up. *Abies* appears slightly earlier, and increases above 5% at the top. *Quercus* rises steadily to about 18%. *Betula* and *Carpinus/Ostrya* rise and persist at about 5% and 2%, respectively.

*Alnus* and *Salix* decline early on but do not disappear. High-spined asters and Gramineae maintain a steady presence throughout, as they did in Zone I; *Artemisia* declines but persists. Monolete spores are a steady presence sometimes reaching 5%; *Cyperaceae* rises and falls in the lower part of the zone, but exceed 10% in the upper zone. *Myriophyllum* appears abruptly at the bottom and declines steadily, yet is still present at the top, indicating that the basin did not dry up in this period.

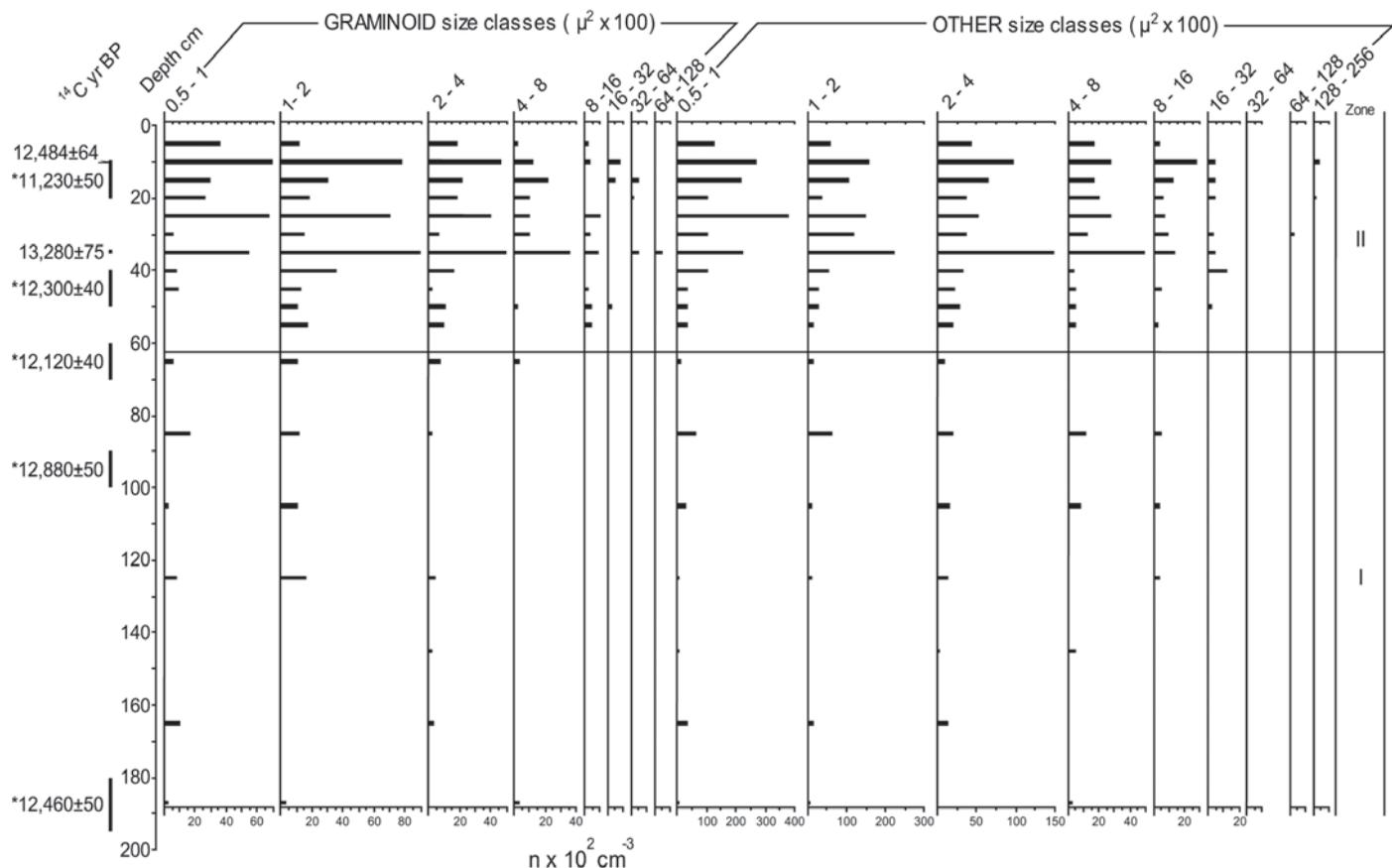
Zone II at Hyde Park correlates with the spruce maximum (Deevey, 1943; Leopold, 1956) or the A2, A3 Zones of the regional pollen stratigraphy (Petet *et al.*, 1993; M.B. Davis, 1969; Maenza-Gmelch, 1997a, b). This part of the sequence also resembles the late-glacial profile of northern New Jersey (Petet *et al.*, 1990). The pollen assemblage shows a rise in

Table 1. Radiocarbon dates.

Lab #	<sup>14</sup> C yr BP ± 1σ	Calibrated calendar age (BP) at 2σ	Material	Pretreatments	Method	δ <sup>13</sup> C	Stratigraphic provenance (cm below surface)
β 135234	11,480 ± 60	13,805-13,165	Tooth enamel (tusk)	Collagen extraction with alkali	AMS	-22.7	unknown
AA46612	12,484 ± 64	15,490-14,150	Sediment	Acid/alkali	AMS	-26.6	9.5-10.5
AA46613	13,280 ± 75	16,430-15,540	Sediment	Acid/alkali	AMS	-26.5	34.5-35.5



Text-fig. 2. *Sporormiella* and charcoal for the Hyde Park site. Spores are expressed as percentage of pollen sum (upland plus aquatic). Microscopic charcoal as projected area on slide per volume of sediment. Macroscopic charcoal (> 250 μm) expressed as number of particles per volume of sediment. Spores drop below 1% at 55 cm depth and microscopic charcoal initially peaks above this, at 35cm. Asterisk (\*) indicates <sup>14</sup>C dates from plant macrofossils (see Miller, 2008).



Text-fig. 3. Microscopic charcoal particle size analysis. Values are in hundreds of particles per volume of sediment. Small size classes dominate the spectrum through Zone I. Larger size classes appear in Zone II and are an important component of the initial charcoal rise at 35 cm. Asterisk (\*) indicates  $^{14}\text{C}$  dates from plant macrofossils (see Miller, 2008).

more thermophilous species, understood by Peteet (1992) to be a regional response to the Bölling/Alleröd warming, long recognized in the late-glacial stratigraphic record of western Europe. The sediment date of  $13,280 \pm 75$   $^{14}\text{C}$  yr BP was taken at 35 cm depth, in the lower half of this zone, but an accelerator mass spectrometry (AMS) age of *Picea* needles located *ca.* 10 cm below this was  $12,300 \pm 40$   $^{14}\text{C}$  yr BP (Miller, 2008). The following observations suggest that Zone III is missing, along with some of the top of Zone II and much of the peat member of the sedimentary strata. Although *Picea* declines slightly near the top the Zone II, *Quercus* has risen to 18% and as yet shows no sign of decline; *Tsuga* remains absent. There is no pronounced rise in *Betula*. Perhaps most significantly, *Alnus*, which has fallen from its strong presence in Zone I, shows no recovery by the top of the sequence, indicating that the Younger Dryas as interpreted by Mayle *et al.*, 1993, is not represented here. The pollen stratigraphy is in close agreement with the record of plant macrofossils, which are abundant throughout the same sample sequence (see Miller, 2008).

#### SPORORMIELLA

The dung fungal spores display a strong presence throughout Zone I, reaching as high as *ca.* 6%. From the bottom of Zone II, the spore values go into a steady decline, and although never quite falling to zero, values are very low by the top of the zone. At 25 cm depth, in the middle of Zone II, spores briefly return to 6% and abruptly fall again to low values (see following discussion).

#### CHARCOAL STRATIGRAPHY

Throughout Zone I, all charcoal is scarce, often below  $1 \times 10^6 \mu\text{m}^2 \text{cm}^{-3}$ , and graminoid charcoal is almost absent. In the lower part of Zone II, an order of magnitude rise occurs. Total microscopic charcoal concentration at 45 cm is  $2.6 \times 10^6 \mu\text{m}^2 \text{cm}^{-3}$ , then jumps to  $28 \times 10^6 \mu\text{m}^2 \text{cm}^{-3}$  at 35 cm, with graminoid and amorphous types making roughly equal contribution. Concentrations fall somewhat above this, yet remain at five to ten times the average seen through Zone I. Macroscopic charcoal, which first appears at the bottom of Zone II, also rises at 35 cm.

Analysis of the charcoal particle sizes, summarized in Text-fig. 3, shows that throughout Zone I, the low concentrations of stratigraphic charcoal characteristic at this time are made up of small size classes. This pattern continues through lower Zone II, suggesting that this was a period of infrequent fire, but also that the source of charcoal was from distant fires (Clark, 1988). Larger size classes as well as macroscopic charcoal of at least 250  $\mu\text{m}$  (Text-fig. 3) take a larger share at 50 cm depth, a pattern indicative of local fires (Clark, 1988). Concentrations remain low overall, however, so by this time fire has not yet become a frequent occurrence. At 35 cm, sediment dated at  $13,280 \pm 75$   $^{14}\text{C}$  yr BP (but see Text-fig. 2 and Miller, 2008), fire abruptly becomes not only frequent, but the distribution of size classes suggest that both local and regional fire are contributing to the rise in charcoal concentration. It is also worth noting that at this time, graminoid (grass and sedge) charcoal accounts for most of the largest size classes. Fire became more frequent in the vicinity of Hyde Park during the same phase of the pollen stratigraphy correlating with the early to middle Bölling/Alleröd warming.

## DISCUSSION

The anomalous spike in the *Sporormiella* stratigraphy at 20 cm, following the initial decline, has no parallel in sites studied elsewhere in the region (Robinson, 2003). It is possible that a large influx of *Sporormiella* could have emanated from the gut contents of the decaying mastodon carcass that sank into the sediments only about 1 m away. A high density of spore can have had little opportunity to disperse in such a small sedimentary basin. The spore spike is stratigraphically flanked by AMS sediment dates of  $12,484 \pm 64$   $^{14}\text{C}$  yr BP and  $13,280 \pm 75$   $^{14}\text{C}$  yr BP, which at  $2\sigma$  do not overlap with the bone collagen date for mastodon of  $11,480 \pm 60$   $^{14}\text{C}$  yr BP (see Table 1 for calibrations). Taken on their own, these dates appear to preclude the possibility that the dated tusk belonged to a mastodon whose gut contents account for the anomalous spike in *Sporormiella* values. However, an *Abies* cone scale AMS-dated to  $11,230 \pm 50$   $^{14}\text{C}$  yr BP was recovered between 10 and 20cm (Miller, 2008), stratigraphically only a few centimeters above the fungal spore spike. Organic sediments from recently deglaciated terrain tend to incorporate infinite age carbon and so make radiocarbon ages too old (Sutherland 1980; Mandryk, 1990). This plant macrofossil date would bring the Lozier Pond pollen record more in line with the dated pollen stratigraphies of the region (Maenza-Gmelch, 1997a, b; Peteet *et al.*, 1990, 1993). In fact, all of the dated plant macrofossils taken from a parallel sample series (Text-fig. 1 and Miller, 2008) from the mastodon excavation pit are generally more in accord with the pollen stratigraphy than the two sediment dates given here (Text-fig. 1 and Table 1). If this later chronology is accepted, then the 10-20 cm sediments

were indeed laid down after the mastodon had collapsed and died, apparently leaving its signature fungal spore contribution in the microfossil spectrum. Furthermore, the bone collagen date and that of the cone scale have significant overlap when calibrated to calendar years (Table 1 and Miller, 2008) so that the possibility remains that the cone scale came from the mastodon digestive tract.

The charcoal stratigraphy suggests that fire is becoming more frequent at a time when the pollen spectra are dominated by *Picea*, the latter agreeing with the macrofossil record (Miller, 2008). Although a similar conjunction occurs in some other pollen and charcoal records in the region (Robinson *et al.*, 2005), the *Picea* signal at the Hyde Park site is most pronounced. Considering that *Picea* does not tolerate frequent fire (Romme & Knight, 1981), it could be that the pollen was contributed mainly by *P. mariana* Britton, Stearns, & Poggenburg, or black spruce, a wetland species that could have been locally abundant but relatively protected.

In its general outlines, the late-glacial microfossil stratigraphy of Lozier Pond displays two key features that have been observed elsewhere in southern New York (Robinson *et al.*, 2005). Spores of the dung fungus *Sporormiella* sp. begin a steady decline that is interpreted as a collapse of the local megaherbivory regime. The spore decline is almost complete before concentrations of microscopic charcoal begin a marked rise, understood to mark an increase in the frequency and/or severity of landscape-level fire.

Deflection of the *Sporormiella* curve begins just above the boundary of Zones II and I, correlating with the beginning of the late glacial spruce maximum (Deevey, 1939; Leopold, 1956). Below the middle of Zone II, at the stratum sediment dated to  $13,280 \pm 75$   $^{14}\text{C}$  yr BP, but which could in fact be later than  $12,300 \pm 40$   $^{14}\text{C}$  yr BP (see Text-fig. 2 and discussion below), *Sporormiella* spores have reached a minimum value, and microscopic charcoal has climbed to a maximum. In the light of a similar order of events observed at other sites in the region, it is tempting to conclude that this conjunction was brought about by the removal of megafauna as a primary consumer of vegetation and their replacement by fire (Schüle, 1990). It appears that megafaunal biomass dropped to very low levels during a warming trend in the late glacial, and in advance of the climatic changes attributed to the Younger Dryas and the Pleistocene-Holocene transition.

Analysis of the *Sporormiella* spores was initially expected to reveal a "Signor-Lipps effect" and pinpoint a possibly later extinction of the local megafauna than that suggested by the bone dates. In contrast, an unexpected result duplicated elsewhere in New York and in a suite of late Holocene records from Madagascar (Burney *et al.*, 2003; Robinson *et al.*, 2005) is that spore decline precedes last occurrences of megafauna.

The significantly later date of  $11,480 \pm 60$   $^{14}\text{C}$  yr BP for the

mastodon tusk at Hyde Park suggests that if a megaherbivory regime was functionally replaced by fire, total extinction of megaherbivores was not the immediate result. Other recently obtained dates from New York on mastodon and mammoth point to survival of these animals at least until the opening of the Younger Dryas at ca. 11,000 <sup>14</sup>C yr BP. It is proposed here that human activities severely reduced the density of large herbivores such as mastodon. Straggler populations might then have persisted for another millennium before they finally succumbed to successive rounds of human exploitation, possibly aggravated by environmental factors.

### LITERATURE CITED

- Burney, D. A. 1987. Late Quaternary stratigraphic charcoal records from Madagascar. *Quaternary Research*, 28: 274-280.
- Burney, D. A. 1997. Tropical islands as paleoecological laboratories: gauging the consequences of human arrival. *Human Ecology*, 25: 437-457.
- Burney, D. A. 1999. Rates, patterns and processes of landscape transformation and extinction in Madagascar. Pp 145-164, in: *Extinctions in Near Time*, R. D. E. MacPhee (ed.), Plenum Publishers, New York.
- Burney, D. A., L. P. Burney, & R. D. E. MacPhee. 1994. Holocene charcoal stratigraphy from Laguna Tortuguera, Puerto Rico and the timing of human arrival. *Journal of Archaeological Science*, 21: 273-281.
- Burney, D. A., & T. F. Flannery. 2005. Fifty millennia of catastrophic extinctions after human contact. *Trends in Ecology and Evolution*, 20: 395-401.
- Burney, D. A., & G. Robinson, G. 2008. Excavating and interpreting flooded megafaunal sites. Pp 43-48, in: *Mastodon Paleobiology, Taphonomy, and Paleo-environment in the Late Pleistocene of New York State: Studies on the Hyde Park, Chemung, and North Java Sites*, W. D. Allmon & P. L. Nester (eds), *Palaentographica Americana* 61.
- Burney, D. A., G. S. Robinson, & L. P. Burney. 2003. *Sporormiella* and the late Holocene extinctions in Madagascar. *Proceedings of the National Academy of Sciences*, 100: 10800-10805.
- Cavalli-Sforza, L. L., & A. W. F. Edwards. 1967. Phylogenetic analysis: models and estimation procedures. *American Journal of Human Genetics*, 19: 233-257.
- Clark, J. S. 1988. Particle motion and the theory of charcoal analysis: source area, transport, deposition, and sampling. *Quaternary Research*, 30: 67-80.
- Davis, M. B. 1983. Holocene vegetational history of the east-tern United States. Pp 166-181, in: *Late Quaternary Environments of the United States, Vol. 2*, S. C. Porter (ed.), University of Minnesota Press, Minneapolis, Minnesota.
- Davis, M. B. 1969. Climatic changes in southern Connecticut recorded by pollen deposition at Rogers Lake. *Ecology*, 50: 409-422.
- Davis, O. K. 1975. *Pollen Analysis of Wildcat Lake, Whitman County, Washington: the Introduction of Grazing*. Masters thesis, Washington State University, Pullman, Washington, 43 pp.
- Davis, O. K. 1987. Spores of the dung fungus *Sporormiella*: increased abundance in historic sediments and before Pleistocene megafaunal extinction. *Quaternary Research*, 28: 290-294.
- Davis, O. K., L. Agenbroad, P. S. Martin, & J. I. Mead. 1984. The Pleistocene dung blanket of Bechan Cave, Utah. *Special Publications of the Carnegie Museum of Natural History*, 8: 267-282.
- Davis, O. K., & D. S. Shafer. 2006. *Sporormiella* fungal spores, a palynological means of detecting herbivore density. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 237: 40-50.
- Deevey, E. S., Jr. 1939. Studies on Connecticut lake sediments, I. a postglacial climate chronology for southern New England. *American Journal of Science*, 237: 691-724.
- Faegri, K., P. E. Kaland, & K. Krzywinski. 1989. *Textbook of Pollen Analysis*. John Wiley & Sons, New York, 328 pp.
- Fiedel, S. J. 1999. Older than we thought: implications of corrected dates for Paleoindians. *American Antiquity*, 64: 95-115.
- Fiedel, S. J. 2002. The "Big Chill" or "The Killing Fields"? The Younger Dryas, Clovis and the demise of the megafauna (abstract). *Society for American Archaeology, Abstracts of the 67th Annual Meeting, Denver, Colorado*, p. 104.
- Funk, R. E. 1976. Recent contributions to Hudson Valley prehistory. *New York State Museum Memoir* 22, 325 pp.
- Funk, R. E., & D. W. Steadman. 1994. *Archaeological and Paleoenvironmental Investigations in the Dutchess Quarry Caves, Orange County, New York*. Persimmon Press, Buffalo, New York, 128 pp.
- Goldberg, E. D. 1986. *Black Carbon in the Environment: Properties and Distribution*. Wiley, New York, 216 pp.
- Grayson, D. K. 1984. Explaining Pleistocene extinctions: thoughts on the structure of a debate. Pp 807-823, in: *Quaternary Extinctions: a Prehistoric Revolution*, P. S. Martin & R. G. Klein (eds), University of Arizona Press, Tucson, Arizona.
- Grayson, D. K. 2001. The archaeological record of human impacts on animal populations. *Journal of World Prehistory*, 15: 2-68.
- Grayson, D. K., & D. J. Meltzer. 2003. A requiem for North American overkill. *Journal of Archaeological Science*, 30: 585-593.
- Hansen, B., & E. J. Cushing. 1973. Identification of pine pollen of Late Quaternary age from the Chuska Mountains, New Mexico. *Geological Society of America Bulletin*, 84: 1181-1200.
- Haynes, C. V., Jr. 1984. Stratigraphy and late Pleistocene extinction in the United States. Pp 807-823, in: *Quaternary Extinctions: a Prehistoric Revolution*, P. S. Martin & R. G. Klein (eds), University of Arizona Press, Tucson, Arizona.
- Kapp, R. O. 1969. *How to Know Pollen and Spores*. William C. Brown Company, Dubuque, Iowa, 249 pp.
- Kay, C. E. 2002. Are ecosystems structured from the top-down or bottom-up? Pp 215-237, in: *Wilderness and Political Ecology*, C. E. Kay & R. T. Simmons (eds), University of Utah Press, Salt Lake City, Utah.
- Klein, R. G. 1984. Mammalian extinctions and stone age people in Africa. Pp 553-573, in: *Quaternary Extinctions: a Prehistoric Revolution*, P. S. Martin & R. G. Klein (eds), University of Arizona Press, Tucson, Arizona.
- Klein, R. G. 1999. *The Human Career: Human Ecological and Cultural Origins*. University of Chicago Press, Chicago, 840 pp.
- Koch, P. L., & A. D. Barnosky. 2006. Late Quaternary extinctions: the state of the debate. *Annual Review of Ecology, Evolution and*

- Systematics*, 37: 215-250.
- Leopold, E. B. 1956. Two late-glacial deposits in southern Connecticut. *Proceedings of the National Academy of Sciences*, 42: 863-867.
- Maenza-Gmelch, T. E. 1997a. Late glacial- early Holocene vegetation, climate, and fire at Sutherland Pond, Hudson Highlands, New York, USA. *Canadian Journal of Botany*, 75: 431-439.
- Maenza-Gmelch, T. E. 1997b. Vegetation, climate, and fire during the late glacial-Holocene transition at Spruce Pond, Hudson Highlands, southeastern New York, USA. *Journal of Quaternary Science*, 12: 15-24.
- Martin, P. S. 1966. Africa and Pleistocene overkill. *Nature*, 212: 339-342.
- Martin, P. S. 1967. Overkill at Olduvai Gorge. *Nature*, 215: 212-213.
- Martin, P. S. 1990. 40,000 Years of extinction on the "planet of doom." *Palaeogeography, Palaeoclimatology, Palaeoecology (Global and Planetary Change Section)*, 82: 187-201.
- Martin, P. S. 1995. *Twilight of the Mammoths*. University of California Press, Berkeley, California, 240 pp.
- Martin, P. S., & D. W. Steadman. 1999. Prehistoric extinctions on islands and continents. Pp 17-55, in: *Extinctions in Near Time*, R. D. E. MacPhee (ed.), Plenum Publishers, New York.
- Mayle, F. E., A. J. Levesque, and L. C. Cwynar. 1993. *Alnus* as an indicator taxon of the Younger Dryas cooling in eastern North America. *Quaternary Science Reviews*, 12: 295-305.
- Miller, N. 2008. Contemporary and prior environments of the Hyde Park, New York, mastodon on the basis of associated plant macrofossils. Pp 151-181, in: *Mastodon Paleobiology, Taphonomy, and Paleoenvironment in the Late Pleistocene of New York State: Studies on the Hyde Park, Chemung, and North Java Sites*, W. D. Allmon & P. L. Nester (eds), *Palaeontographica Americana* 61.
- Patterson, W. A., III, K. J. Edwards, & D. J. Maguire. 1987. Microscopic charcoal as a fossil indicator of fire. *Quaternary Science Reviews*, 6: 3-23.
- Patterson, W. A., & K. E. Sassaman. 1988. Indian fires in the prehistory of New England. Pp 107-135, in: *Holocene Human Ecology in Northeastern North America*, G. P. Nicholas (ed.), Plenum Press, New York.
- Peteet, D. M. 1992. Major contributions of radiocarbon dating to palynology: past and future. Pp 454-472, in: *Radiocarbon After Four Decades*, R. E. Taylor, A. Long, and R. S. Kra (eds), Springer-Verlag, New York.
- Peteet, D. M., J. S. Vogel, D. E. Nelson, J. R. Southon, R. J. Nickmann, & L. E. Heusser. 1990. Younger Dryas climatic reversal in northeastern USA? AMS ages for an old problem. *Quaternary Research*, 33: 219-230.
- Peteet, D. M., R. A. Daniels, L. E. Heusser, J. S. Vogel, J. R. Southon, & D. E. Nelson. 1993. Late-glacial pollen, macrofossils and fish remains in northeastern USA - the Younger Dryas oscillation. *Quaternary Science Reviews*, 12: 597-612.
- Pyne, S. J. 1984. *Introduction to Wildland Fire*. Wiley, New York, 769 pp.
- Robinson, G. S., L. P. Burney, & D. A. Burney. 2005. Landscape paleoecology and megafaunal extinction in southeastern New York State. *Ecological Monographs*, 75: 295-315.
- Romme, W. H., & D. H. Knight. 1981. Fire frequency and subalpine forest succession along a topographical gradient in Wyoming. *Ecology*, 62: 319-326.
- Russell, E. B. W. 1983. Indian-set fires in the forests of the northeastern United States. *Ecology*, 64: 78-88.
- Schüle, W. 1990. Landscapes and climate in prehistory: interactions of wildlife, man and fire. Pp 273-318, in: *Fire in the Tropical Biota*, J. G. Goldammer (ed.), Springer-Verlag, Berlin, Germany.
- Signor, P. W., & J. H. Lipps. 1982. Sampling bias, gradual extinction and catastrophes in the fossil record. *Geological Society of America Special Paper* 190: 190-296.
- Singh, G., A. P. Kershaw, and R. Clark. 1981. Quaternary vegetation and fire history in Australia. Pp 23-54, in: *Fire and the Australian Biota*, A. M. Gill, R. A. Groves, & I. R. Noble (eds), Australian Academy of Sciences, Canberra.
- Winkler, M. G. 1985. Charcoal analysis for paleoenvironmental interpretation: a chemical assay. *Quaternary Research*, 23: 313-326.