Palynology of Three Bog Cores Shows Complex European Impact on the Forests of Central Maine

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Abstract - Short peat cores from three sphagnum bogs in central Maine were analyzed palynologically to determine whether recent reforestation approximates forest composition immediately prior to European colonization and deforestation. Radiocarbon dating and palynology show that the cores extend to 600–2000 years b.p., beginning well before 18th-century colonial forest disturbance. Cores from Round Pond bog (Franklin County) and Kanokolus Bog (Waldo County) show that *Tsuga canadensis* (Eastern Hemlock) was much more abundant on the local landscape at the time of European settlement than it is today; a core from Hamilton Pond bog (Kennebec County) records an abrupt local Eastern Hemlock decline, and accompanying *Acer* spp. (maple) rise, that preceded European contact by several centuries. All three bogs show increased heath (Ericales) abundance with deforestation, presumably a result of augmented nutrient flux into the bog basins due to increased erosion on surrounding slopes.

Modern forest composition around all three sites is quite different from the forests immediately preceding European colonization and clearing. Pollen types indicative of agricultural activities (*Ambrosia*, other Asteraceae, Poaceae, Brassicaceae) that mark European deforestation and the onset of farming, have faded or disappeared as many farms have been allowed to revert to forest in the past half-century. Pine (mostly *Pinus strobus* [White Pine]) is more abundant in the modern pollen record than in subhistoric time, as are *Abies* spp. (fir) and *Picea* spp. (spruce); dominant hardwood taxa have responded differently to reforestation of the areas surrounding the study sites, in part determined by local edaphic conditions.

Introduction

The nature of pre-European North American environments is becoming a question of significance as we attempt to evaluate the impacts of global climate change and as attempts are made to re-establish "natural" ecological habitats or restore aquatic ecosystems (e.g., Cantor et al. 2007, Carroll 1973, Clark et al. 2007, Fuller et al. 1998, Lorimer 1977, Myrbo 2005, Pederson et al. 2005, Russell and Davis 2001, Russell et al. 1993, Sanderson and Brown 2007). The full impacts of European colonization are only becoming readily apparent in Maine as we carefully re-examine data at hand and undertake new studies.

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Much of central Maine, heavily agricultural prior to World War II, has been allowed to return to forest as large-scale agriculture has become non-competitive with areas with warmer and longer growing seasons, and a common popular assumption is that this reforestation represents a return to natural—i.e., "normal"—conditions. This study was undertaken to compare the modern post-agricultural forest composition of central Maine with that which existed at the onset of European settlement, to determine whether this assumption is warranted, and was based on study of the pollen content from sphagnum bog cores, as a proxy for vegetation change on land.

Russell et al. (1993) and Russell and Davis (2001) have already studied pollen from lacustrine cores across the northeastern United States, and documented the regional impacts of European settlement, noting that modern forests represent a product of complex interactions between natural conditions and human disturbance. However, humans often interact with their environments on a more local scale, and data at this level are not readily available. The second contribution of this study is thus to document local-scale modern conditions in central Maine as they compare to those of two to three centuries ago. A third contribution is to determine what local changes might be masked in large-scale studies, and particularly to determine whether bog pollen records may show details hidden or absent in lacustrine vegetational histories.

Study Sites

Three sphagnum bogs were chosen for coring (Table 1, Fig. 1), aligned roughly in an east–west transect across three formerly predominantly agricultural counties in central Maine. Kanokolus Bog lies atop a bedrock-based drainage divide with outlet streams to the north and south; Hamilton Pond bog and Round Pond bog lie on the outlet ends of kettle pond basins in glacial esker/outwash complexes, from which either first-order streams originate (Round Pondbog) or subsurface flow (Hamilton Pond bog) drains excess waters. Hamilton Pond undoubtedly drains through adjacent esker sediments into the adjoining (and much smaller) Stuart Pond, from which a first-order stream originates.

Kanokolus Bog is surrounded by soils of the Monarda series (Hedstrom and Popp 1984), characterized by poor drainage and natural vegetation that tolerates or prefers wetter sites, including *Fraxinus* spp. (ash), *Acer rubrum* L. (Red Maple), *Betula populifolia* Marsh. (Gray Birch), *Tsuga canadensis* (L.) Carrière (Eastern Hemlock), *Thuja occidentalis* L. (Northern White Cedar), *Larix laricina* (Du Roi) K. Koch (Tamarack), and *Picea mariana* (Mill.) Britton, Sterns and Poggenb. (Black Spruce).

Table 1. Specific locality information for each of the sites reported in this study.

Study Site	County	Town	Core geographic coordinates
Round Pond bog	Franklin	Chesterville	44°31'14"N, 70°05'22"W
Hamilton Pond bog	Kennebec	Belgrade	44°27'58"N, 69°50'15"W
Kanokolus Bog	Waldo	Unity	44°33'28"N, 69°22'22"W

Both Round Pond bog and Hamilton Pond bog occur in complex esker-outwash glacial systems and are underlain by much-better-drained substrates. Upland soils near Round Pond bog are predominantly Adams loamy sand and Colton gravelly fine sandy loam (Hedstrom 2003); Hamilton Pond bog is surrounded by Hinckley gravelly sandy loam (Faust and LaFlamme 1978). Adams, Colton, and Hinckley soils are all considered excessively well-drained, and forested sites underlain by these soils today commonly support communities dominated by *Pinus strobus* L. (White Pine), *Quercus rubra* L. (Northern Red Oak), *Fagus grandifolia* Ehrh. (American Beech), *Betula alleghaniensis* Britton (Yellow Birch), and *Acer saccharum* Marsh. (Sugar Maple).

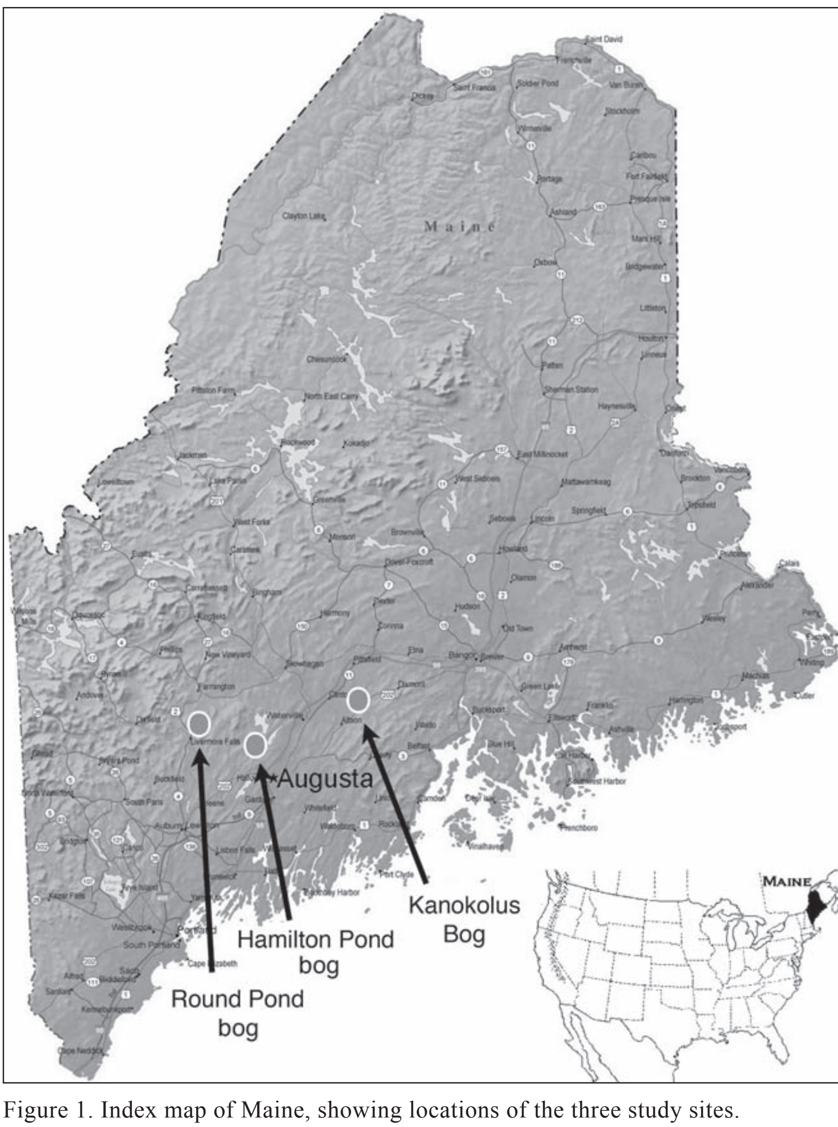

Figure 1. Index map of Maine, showing locations of the three study sites.

Historical Records

Earliest probes into the central Maine area were by fur trappers and explorers, followed shortly by loggers, perhaps as early as 1650. Unfortunately, early historical records by European explorers are unreliable as regards species composition of the forests, inasmuch as all conifers were generally called pines (Carroll 1973). However, Carroll (1973:24) presented a generalized map indicating that the area under study lay near the northern margin of a hemlock-White Pine-hardwood forest in presettlement times.

The earliest documented European settlers in the area of interest were apparently in the Unity area, where they were driven out by the onset of the French and Indian War in 1754 (Taber 1916). Settlers returned following the close of the war, and the first frame house was erected in 1782, and the censused population had grown to 264 people by 1799 (Taber 1916).

The earliest forest clearing in the Belgrade area apparently occurred in 1774, and the population had grown to 159 by 1790 (Guptill et al. 1976). Logging had begun in Chesterville by 1780, and the first clearing for a farm took place in 1782 (York 1976). Thus, it appears that the onset of widespread forest clearing across the area of study occurred in the latter half of the 18th century.

Field and Laboratory Methods

Coring sites at Round Pond bog and Hamilton Pond bog were selected in open areas away from trees and shrubby vegetation; difficulty in reaching such a site at Kanokolus Bog resulted in coring being done in a small sphagnum-bearing swale in a wooded portion of the bog, surrounded by Black Spruce and Tamarack.

Cores from 0.8–1.8 m in length were extracted from each of the bog sites using a modified Livingstone piston corer (Livingstone, 1955). The coring device was constructed with 5-cm-diameter stainless steel coring tubes and T6 aluminum extension rods; the principal modification of Livingstone's original design was the use of a coring tube with sharpened, serrated teeth for cutting through the sphagnum mat (and any roots encountered) with a minimum of compaction.

Coring success was outstanding, with no loss noted from any core segments obtained. Peats recovered from Hamilton Pond bog and Round Pond bog consisted of fibrous sphagnum peat, while that from Kanokolus Bog was less fibrous and more humified, but nonetheless sufficiently coherent to yield continuous core when extruded.

Hamilton Pond bog and Round Pond bog were cored from the open sphagnum mats surrounded by heath thickets and occasional Black Spruce and Tamarack; Kanokolus Bog was cored from within a Black Spruce stand adjacent to the main sphagnum mat. Core segments were extruded and wrapped in plastic film and aluminum foil in the field, and refrigerated until sampled in the laboratory.

In the lab, cores were split lengthwise in January–February, 2007; winter sampling minimized potential for airborne pollen contamination. Samples were taken from the interiors of the cores at 5-cm intervals, beginning with the core top. Pollen samples were immediately placed in 15-ml polypropylene centrifuge tubes, covered with glacial acetic acid, and sealed. Samples from approximately mid-depth and at the base of each core were oven-dried in glass beakers at ≈50 °C, and submitted for commercial AMS radiocarbon dating. The sample from 33 cm deep in the core from Kanokolus Bog consisted of a piece of wood; other radiocarbon samples were 5-mm-thick slices of sphagnum peat from the indicated depths.

Pollen samples were processed using standard techniques (Faegri and Iversen 1989), including 5% KOH, coarse sieving (0.250 mm), HF digestion, acetylation, dewatering using 95% ethanol and tert-butyl alcohol, and mounting of residues in silicone oil (2000 cs. viscosity).

Pollen counts were performed at 400x magnification, with at least 300 identifiable pollen grains being counted at each level. Counting was continued downwards in the cores until the bottom of the core was reached (Hamilton Pond bog, Kanokolus Bog) or it was clear that pre-European sediments had been reached (Round Pond bog). Pollen percentages were calculated from the basic pollen sum (**Σ** on diagrams) including all identifiable pollen grains, including potentially identifiable but unknown pollen grains, but excluding moss, fern, and fungal spores. Monolete and trilete fern spores were also counted.

Results

Radiocarbon ages for samples from these cores are shown in Table 2. Results of pollen analysis for Hamilton Pond bog, Round Pond bog, and Kanokolus bog are shown in Figures 2–4, respectively.

Radiocarbon dating shows clearly that all core bases date to well before the initial European contact period. Although some modern carbon may have been introduced via root contamination, this would have yielded apparent

Table 2. Radiocarbon dates for samples from each of the cores utilized in this study. All dates are AMS radiocarbon determinations on 5-mm-thick peat slices from the indicated core depths, except that from 33 cm at Kanokolus Bog, which consisted of a piece of wood ≈15 mm in diameter. Avg. sed. rate = average sedimentation rate.

Core Site	Depth (cm)	^{14}C age*	Calendar age**	Lab number	Avg. sed. rate (mm/yr)
Round Pond bog	88	480 ± 40	1400–1460 A.D.	Beta 228432	1.83
Round Pond bog	175	2120 ± 40	350–300 B.C.E.	Beta 228433	0.83
Hamilton Pond bog	50	1090 ± 40	880–1020 A.D.	Beta 228434	0.46
Hamilton Pond bog	90	1770 ± 40	140–380 A.D.	Beta 228435	0.51
Kanokolus Bog	33	330 ± 40	1450–1650 A.D.	Beta 228436	1.00
Kanokolus Bog	86	1950 ± 40	40 B.C.E.–130 A.D.	Beta 228437	0.44

*Conventional radiocarbon age.
**2-sigma confidence interval.

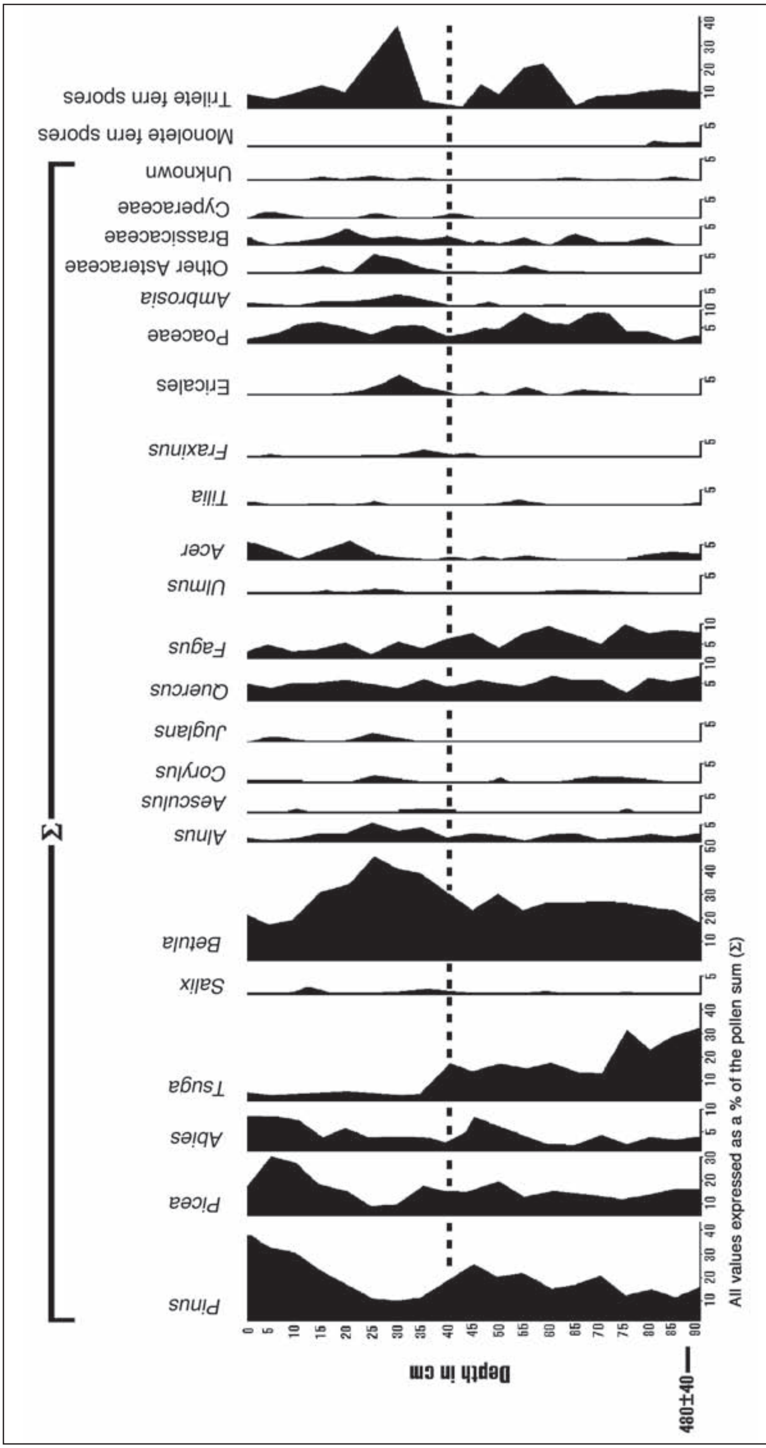

Figure 2. Percentage pollen diagram for Round Pond bog, including position of applicable radiocarbon date; all percentages based on the basic pollen sum (**Σ**). Dashed line represents approximate level of European impact. Analysis by E.F. Littlefield.

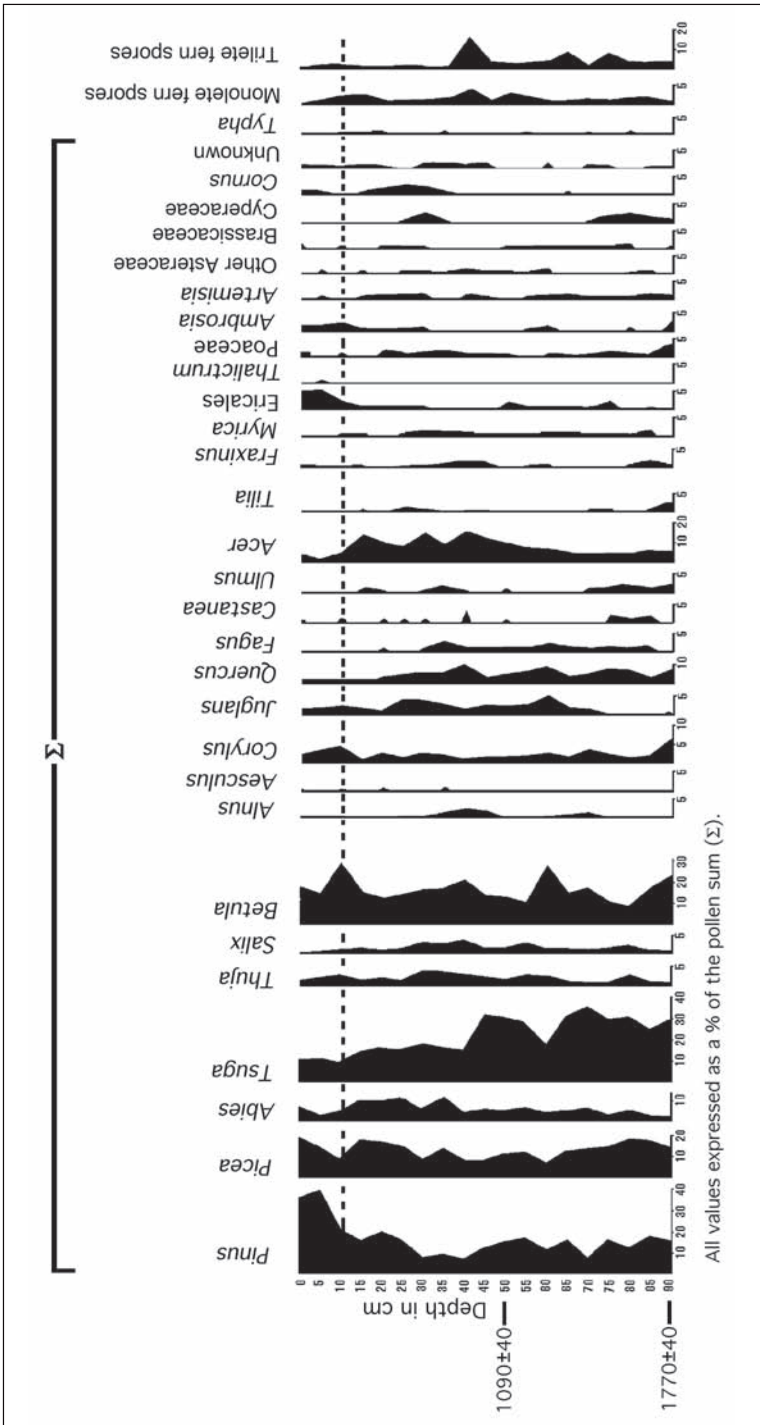

Figure 3. Percentage pollen diagram for Hamilton Pond bog, including position of applicable radiocarbon dates; all percentages based on the basic pollen sum (**Σ**). Dashed line represents approximate level of European impact. Analysis by C.K. Clark.

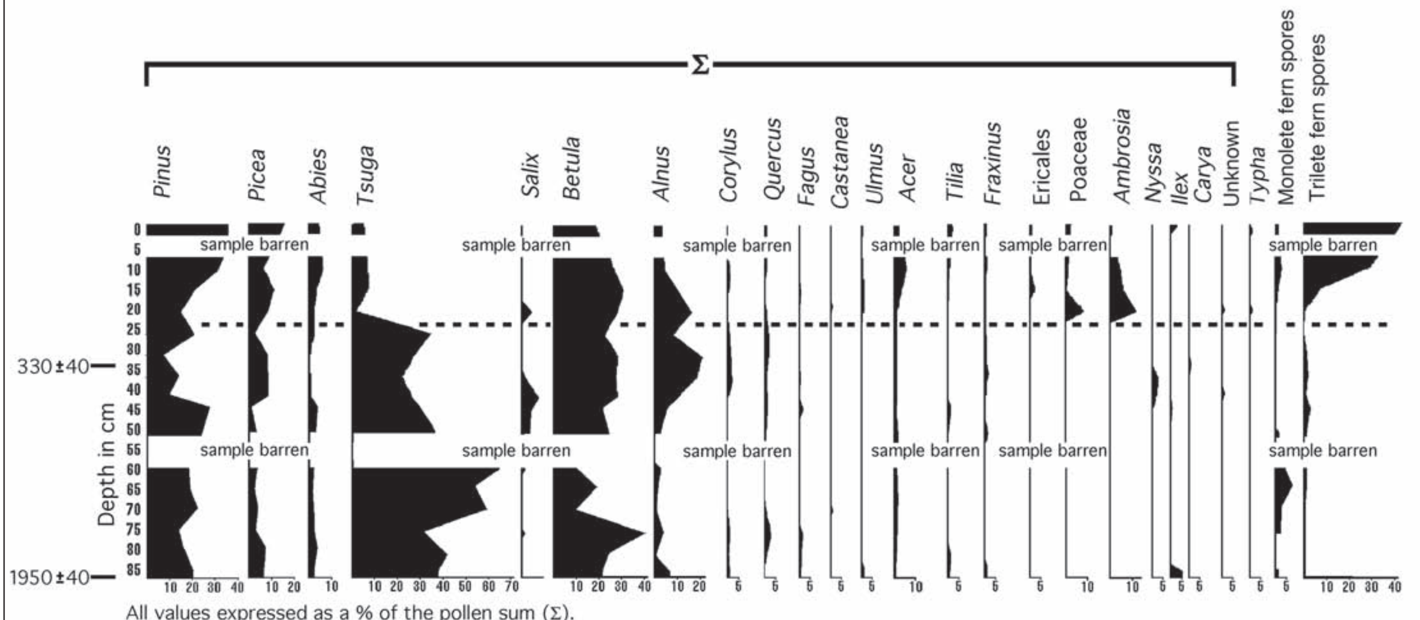

Figure 4. Percentage pollen diagram for Kanokolus Bog, including position of applicable radiocarbon dates; all percentages based on the basic pollen sum (**Σ**). Dashed line represents approximate level of European impact. Analysis by N.W. Krumdieck.

ages younger than the true age. Pre-European contact ages for core bases are, however, confirmed by the palynology: increases in *Ambrosia* L. (ragweed), grass and other agricultural weed pollen, commonly associated with forest clearing, occur well above the core bases. Average sedimentation rates vary among basins, with Round Pond bog showing the greatest resolution with 2 mm/yr accumulation; Kanokolus Bog sediments accumulated at ≈1 mm/yr, and Hamilton Pond bog's average sedimentation rate was ≈0.5 mm/yr.

All three sites show a significant increase in ragweed pollen about 200 calendar years b.p., which is accompanied by a sharp and significant decline in hemlock at both Round Pond bog and Kanokolus Bog. At Hamilton Pond bog, Eastern Hemlock declined abruptly some 600–800 years earlier (800–1000 b.p.), for unknown reasons, and was accompanied by a rise in *Acer* (maple) pollen; lesser but significant local declines in pre-European Eastern Hemlock pollen percentages were also seen at Round Pond bog at about 380 b.p. and at Kanokolus Bog about 500–800 years ago. At all three sites, a rise in pollen of heaths also accompanies the spike in ragweed. Significant (30–50%) increases in birch pollen percentages occur immediately above the spike in ragweed in each core.

At Round Pond Bog, both pine and spruce declined significantly with European settlement, though both taxa were relatively unaffected by forest clearance around both Kanokolus Bog and Hamilton Pond Bog. All three sites, however, show modern pine pollen percentages far in excess of those that characterized pre-European landscapes.

Maple increased in post-European time at Round Pond bog and Kanokolus Bog, but decreased at Hamilton Pond bog. Oak is constant across the European contact at Round Pond bog and Kanokolus Bog, but declined at Hamilton Pond bog. Beech was not abundant at any site prior to European contact, but nonetheless declined at both Round Pond bog (from 10% to 3.5% of total pollen) and Hamilton Pond bog (from 2–3% to all but absent). Fir and spruce have both increased in recent years at Round Pond bog and Kanokolus Bog, but remain essentially unchanged at Hamilton Pond bog.

Discussion

Based on this study and those of previous workers (e.g., Carroll 1973, Russell and Davis 2001, Russell et al. 1993), the virgin forests at the time of European arrival in central Maine had more Eastern Hemlock, birch, and beech, and less pine, fir, and spruce than those of today. Eastern Hemlock and Northern White Cedar were particularly abundant on wetter sites, such as the riverbanks along which early exploration proceeded, including the lower Kennebec Valley (Pierce 1775, reported in Roberts 1942). Small, local clearings for Native American cultivation of *Zea mays* L. (Corn; reported by Smith 1616) apparently were insufficient in size and impact to show in the pollen record.

Forest clearing at the time of European colonization in Maine was mainly for the purpose of opening farmland and followed closely on the heels of commercial logging. The tall, straight conifers were highly prized for shipbuilding timbers and masts; those greater than 24" in diameter one foot above the ground were claimed as "King's Timber" in the Massachusetts Charter of 1691, and officially protected for exclusive use by the English Crown (Kawashima and Tone 1983). Hemlocks were particularly prized for the density and durability of their wood, and were also harvested for use of the bark by the leather-tanning industry (Russell et al. 1993).

The deforestation with European colonization resulted in different major impacts on species composition and relative abundances in the remaining forests, and in land that was cut over and then allowed to regenerate naturally. At Round Pond bog, the hemlock decline was accompanied by an abrupt rise in birch and *Alnus* (alder) and a minor increase in ash, and followed shortly by a rise in maple and walnut (probably *Juglans cinerea* L. [Butternut]), The cooling climatic signal of the past two centuries, the rise in spruce and fir (Russell and Davis 2001), is accompanied by a rise in pine and, to a lesser extent, birch, that is probably in part successional and in part anthropogenic, as pines are being widely planted for timber and pulpwood production. Multi-crowned "pasture pines" (due to leader-killing by *Pissodes strobi* Peck [White Pine Weevil]) in old pasturelands have also regenerated areas of pine-dominated forest as abandoned pastures have reverted to forest stands. Current birch pollen percentage, however, remains below where it was in even late pre-European time.

Round Pond also showed significant grass pollen percentages (up to nearly 10% of the total) prior to European forest clearing, probably in part derived from marsh grasses at the outlet stream, though Hamilton Pond also showed 2–5% grass pollen prior to disturbance. Both sites are situated in geologic settings surrounded by exceptionally well-drained sandy soils that may also have supported grasses in small open areas in addition to those in the bog margins.

At Hamilton Pond bog, the European impact on Eastern Hemlock appears to have been negligible, though maple, and to a lesser extent, fir, both declined. *Corylus* (hazel) pollen percentages rise at the same time as Ericales and ragweed, perhaps in response to greater light availability in forest margins. The pre-European drop in hemlock, too abrupt to likely be just a product of a climatic cooling (Russell et al. 1993), was followed by a gradual decrease in oak and beech abundances, and an increase in maple (probably mostly Sugar Maple) and subtle increases in both birch and spruce, which may have been driven by gradual drying, or climatic cooling as suggested by Russell et al. (1993). The pollen record culminates with a dramatic rise in pine, particularly in the post-European time frame, where modern relative abundance is twice what it was in the pre-European period. Only at the very top of the core does maple drop dramatically. There is no discernible increase in the abundance of either spruce or fir pollen at Hamilton Pond bog from the time of first forest clearing, though the exceptionally well-drained substrates in this area are not particularly hospitable to either fir or spruce.

Birch pollen, though variable, shows no clear trend over the entire Hamilton Pond bog record.

At Kanokolus Bog, perhaps the least disturbed of the three sites, grass was essentially absent from the record prior to the rapid rise in Ragweed pollen that marked European agricultural clearing. Grass has dropped to lower abundances than pre-European values at both Hamilton Pond bog and Round Pond bog in modern samples, but remains detectable at modest levels (3–5%) at Kanokolus Bog. This last site is also the only one of the three still surrounded by significant active agricultural activity, predominantly hayfields supporting a local dairy industry.

The climatically controlled modern rise in spruce and fir pollen (Russell et al. 1993) is probably most dramatic at Kanokolus Bog, though overall percentages remain low (<15% spruce, ≈5% fir); like the other two sites, pine pollen here has increased dramatically—to almost 40% of the total pollen content, or about four times what it was at the time of European forest clearing. Birch pollen at Kanokolus Bog, however, is also less important today than it was earlier in the record, just as at Round Pond bog.

A new finding from the study of all three of these cores, however, is an increase in the pollen percentages of heath pollen at each of the sites—something that has not been detected, and would not be expected, in studies of lacustrine cores. Heaths are insect-pollinated and are represented by a number of taxa in Maine's sphagnum bogs, including *Chamaedaphne calyculata* (L.) Moench (Leatherleaf), *Rhododendron canadense* (L.) Torr. (Canadian Rhododendron or Rhodora), *Vaccinium oxycoccos* L. (Dwarf Bog Cranberry), *Kalmia angustifolia* L. (Sheep Laurel), *K. polifolia* Wangenh. (Bog Laurel) and *Ledum groenlandicum* Oeder (Labrador Tea). Pollen of these plants would enter a depositional basin primarily by gravity fall of dead flowers directly below the plants, rather than widespread dissemination in the wind. Thus, the rise in this pollen type in all three sites indicates significant local floral change at or proximal to the actual core sites.

Maine's sphagnum bogs, including those in this study, are generally ombrotrophic, and receive all nutritional input directly from the atmosphere (Davis and Anderson 1991), either in dust or as nucleation centers in precipitation (raindrops or snowflakes). *Sphagnum* moss is able to survive and develop extensive mats in wet lowland settings under these conditions, but does not do well where greater nutrient availability allows competition. The abrupt rise in Ericales pollen in each of these basins, coincident with the rise in ragweed and agricultural weeds, strongly suggests that deforestation resulted in increased nutrient flux, either by windblown dust or in surface or subsurface water flow, into the waters of the respective bogs. At both Kanokolus Bog and particularly at Hamilton Pond bog, pollen abundance of heaths remains higher today than at any time in the late prehistoric record; only at Round Pond bog has the level of heath pollen dropped back to pre-European levels.

Hamilton Pond is ringed by multiple homes with septic systems for waste-water discharge, and the bog coring site is situated at the outflow end, adjacent to a state highway that runs on an esker crest. Thus, it may be receiving enhanced nutrient flux at a rate higher than the other sites, neither of which has any human dwellings nearby, from both road runoff and subsurface water flow into the basin.

Kanokolus Bog also shows a sharp increase in pollen of *Ilex* (holly) at the very top; *I. verticillata* (L.) A. Gray (Winterberry) grows extensively around the perimeter of Kanokolus Bog today and is likely the species represented in the pollen record. This wetland shrub has also apparently benefited from increased nutrient flux into this particular basin, although it was also quite abundant in the earliest sample studied, which dates from nearly 2000 years ago.

Conclusions

Study of these three sites in Maine have shown that European impacts on local forest composition, and its response, has varied significantly by site. Eastern Hemlock, however, was much more important in the Maine forest prior to European colonization than it is today. Maples have benefited from the loss of Hemlock in the mature forest, though this has likely been Red Maple at Kanokolus Bog and similarly wet sites and Sugar Maple on drier substrates such as that surrounding Round Pond and Hamilton Pond. Reforestation remains a dynamic process, influenced by both climate and human impacts, as recorded regionally by Russell et al. (1993) and Russell and Davis (2001) and in central New England by Fuller et al. (1998). Bog-dwelling ericaceous shrubs, however, likely benefited from increased nutrient flux into the bogs, particularly at Hamilton Pond bog. Pine, likely predominantly White Pine, is clearly a much more important element in the modern Maine forests than it was at any time in the late prehistoric period. This enhanced importance of pine is likely a product of both intentional plantation management and natural reforestation of abandoned agricultural lands.

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