

Human disturbance of North American forests and grasslands: The fossil pollen record

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Introduction

The population of North America, now about 360 million, has grown from 30 million in the 15th century immediately prior to European contact (Driver, 1969). During this population expansion, much of the natural vegetation was destroyed or modified. Mature forests were logged and replaced by early-successional species, farmland and settlements. Grasslands were destroyed by plowing or modified by cattle grazing (Curtis, 1956). Weeds, both native and exotic, flourished. Cultivated plants, both native and introduced, became increasingly important as food, fiber and timber and for their aesthetic value. Introduced pathogenic fungi also decimated native *Castanea* and *Ulmus* populations.

Prehistoric Indians destroyed or modified the natural vegetation but on a smaller scale than European activities. Most Indians at the time of European contact practiced *Zea mays* agriculture. The common farming technique was swidden (slash and burn), but more intensive methods such as irrigation were used in some areas (Meggars, 1979). This prehistoric human impact, however, was more local than the later European disturbance because Indian populations were smaller and lacked domestic grazing animals.

This chapter reviews some of the fossil pollen evidence for human disturbance and provides illustrations of this evidence from the sediment records of ten lake sites. These studies emphasize the close-interval analysis that is necessary to resolve the often brief episodes of prehistoric and historic disturbance (Birks and Birks, 1980; Oldfield, 1978). I will focus on the evidence for disturbance linked with agriculture, first in mesoamerica, where plant domestication and village life began, then northward into the U.S. to southern Canada. I also review the pollen evidence for European disturbance in North America.

For a review of the specialized methods needed for sediment collection,

sediment dating, and pollen analysis see chapters by Jacobson (this volume), Saarnisto (this volume), and Grimm (this volume). Delcourt (1987) has recently compared the impact of prehistoric agriculture between eastern North America and Europe.

Prehistoric disturbance

The intensity of disturbance wrought by a prehistoric people depended upon their type of subsistence and population size. Small, dispersed populations of hunter-gatherers moved from site to site throughout the year, although some fishing peoples congregated in villages, particularly along the Pacific coast (Jennings, 1974). On the other hand, farming peoples had larger populations, mostly congregated in villages, towns and cities. Driver (1969) estimates that at the time of contact 75% of the food of native peoples was from cultivated plants. He lists 155 plant species that were grown in mesoamerica for food but others were cultivated for stimulants, condiments, fibers etc.

Zea, the chief food crop, was widespread in North America south of 46° latitude, except for south Florida, western U.S. and the Chihuahuan Desert (Fig. 1). Within the area of *Zea* cultivation, population densities were highest in mesoamerica, the Southwest, the southeastern and middle Atlantic states and around Lakes Erie and Ontario. In these areas fossil pollen assemblages display human impact on vegetation, although the record is sometimes ambiguous because of the concurrent role of climatic change in modifying vegetation.

Mexico

Southern Mexico yields the first evidence of plant domestication and subsequent village life supported by agriculture. Remains from definitely domesticated *Zea*, *Phaseolus* and *Cucurbita* date from 8,000 B.P. However, displacement of hunting and gathering economies was slow, and it was not until 4,000 B.P. that farming villages appeared. Population growth was most pronounced in highland valleys, where by AD 700 cities had developed that were supported by irrigation agriculture. In the 15th century the Valley of Mexico supported about a million people (Fagan, 1984).

A pollen diagram from Lake Patzcuaro (2044 m elevation) on the west-central Mexican Plateau shows a 44,000 year record dominated by *Pinus* and *Quercus* (Watts and Bradbury, 1982). Figure 2 shows the last 10,000 years divided into two zones. Human disturbance due to agriculture becomes evident about 1700 BC (ca. 3700 B.P.) with the appearance of



Figure 1. Map of North America showing Indian population densities at the time of European contact (15th-18th centuries) and the area of prehistoric Indian *Zea* cultivation. The shaded area had an estimated population of over 0.60 persons km⁻² (from Driver, 1969). The dotted line indicates the northern limit of *Zea* cultivation (northeastern Mexico lacked *Zea*). Selected sites of pollen stratigraphic studies are shown.

Zea together with increases of weedy plant pollen such as *Chenopodium*-type, Compositae subfamily Tubuliflorae and Cyperaceae. This disturbance does not appear to affect the upland forest pollen assemblage but does correspond with a decline of *Alnus* pollen attributable either to the "drying of stream beds and loss in habitat following reduction in precipitation", or to its destruction by native farmers. The pollen diagram from the Madero core in the Valley of Mexico of Clisby and Sears (1955) as

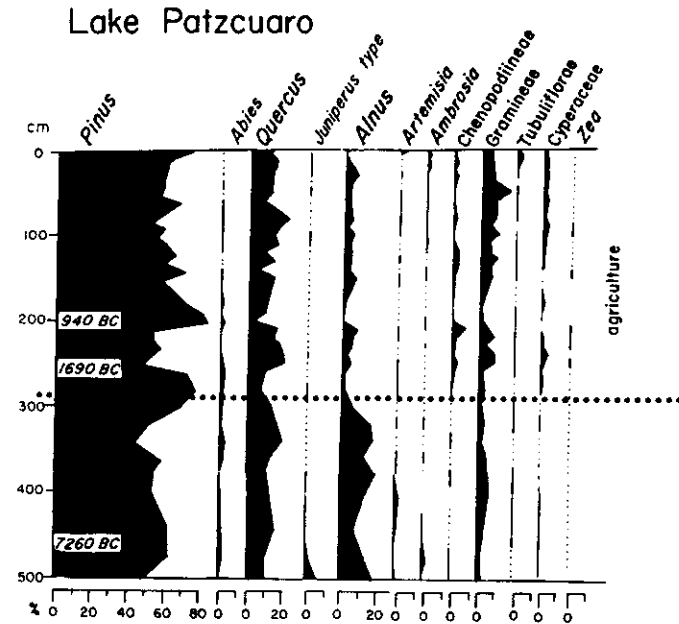


Figure 2. Pollen diagram from Lake Patzcuaro, Mexico, showing main pollen types. Modified from Watts and Bradbury (1982).

redrawn in Bradbury (1971) shows a similar record in the upper 6 m, except that *Pinus* and *Quercus* decline suggesting destruction of upland forest. For other studies in Mexico see Brown (1985).

Guatemala

The lowland Maya of Honduras, Guatemala, Belize and adjacent Mexico were one of the high civilizations of pre-European North America, with an estimated population of two to five million in 100 BC (Blanton *et al.*, 1981). In the Peten district of Guatemala a dense rural farming population surrounded the Classic Period city of Tikal and other centers. The Peten is well-suited to pollen analytical studies because of numerous lakes. These lakes lie in karst depressions in a landscape that historically supported tropical forest, except for local savanna and grassland.

As elsewhere in North America the important crop plants were *Zea*, *Phaseolus* and *Cucurbita*, but the Maya also grew tropical roots or tubers including *Ipomoea batatas*, *Manihot esculenta*, *M. dulcis*, *Xanthosoma violaceum*, and *Pachyrhizus erosus* (Turner and Harrison, 1978). Among the important food-producing trees were *Brosimum alicastrum*, a forest dominant that today grows on Maya ruins. Puleston (1978) argued from

circumstantial rather than fossil evidence that *Brosimum* nuts rivalled *Zea* as human food for the Late Classic Period at Tikal.

Based on modern Maya practices and inferences from man-made terraces and raised fields, Wiseman (1978) proposed that several agricultural systems were practiced by the ancient Maya. These include swidden where *Zea* and perhaps *Phaseolus* and *Cucurbita* were interplanted for one, two or three years on land where forest had been cut and burned. After 3 to 5 or more years of fallowing, the cycle was repeated, but as the need for food expanded along with the population the fallowing period might have been reduced or eliminated. Terraced fields on slopes may have retained and accumulated soils that would have preserved fertility for intensive cropping. Raised fields on seasonally-inundated lowlands probably were also cropped intensively (Turner and Harrison, 1983). This intensive cropping would provide more habitat for weedy annuals of such families as Gramineae, Compositae, Chenopodiaceae and Amaranthaceae than the less-intensive short-term, episodic swidden.

Several lakes in the Peten have been cored and studied by pollen analysis. Lake Salpeten and Lake Quexil sediment shows that before 11,000 B.P. the vegetation was arid savanna with *Juniperus*; this was followed by one or two millenia of temperate *Pinus-Quercus* forest that succeeded to mesic tropical forest with *Brosimum* (zone 1) (Leyden, 1984). Lake Quexil (Fig. 3) shows that during zone 2 (8,000 to 6,000 B.P.) low percentages of savanna trees (*Byrsonima*, *Quercus*) and shrubs (Melastomataceae) appeared, indicating replacement of some mesic forest with more xeric savanna (Vaughn *et al.*, 1985). This succession parallels a contemporary trend toward aridity in tropical Africa and presumably tropical North America (Kutzbach and Street-Perrot, 1985). However, increasingly abundant microscopic charcoal fragments together with *Zea* pollen near the top of the zone suggests that the practice of swidden may have contributed to the decline of forest. Zone 2 is in organic mud, but the overlying zones 3, 4 and 5 are all contained in the so-called Maya clay, which is soil eroded lakeward after land clearance. The uppermost post-Maya zone 6 is in organic mud, indicating that stable soils accompanied the return of forest following the Maya population collapse.

The Maya zones, 3, 4 and 5, have less than 30% tree pollen. Variations in the non-tree pollen sequence are inferred to be the Late Preclassic (zone 3), Early Classic (4) and Late Classic plus Postclassic (5). In zone 3 savanna trees and shrubs form a peak, in 4 grassland pollen expands, and in 5 the percentages of *Ambrosia* pollen reaches one or two maxima. *Zea* is the only pollen from a crop plant, and it is found as occasional pollen grains in zones 3 through 6, as well as near the top of zone 2. The ages of the Mayan zones are inferences from archeological data because radio-

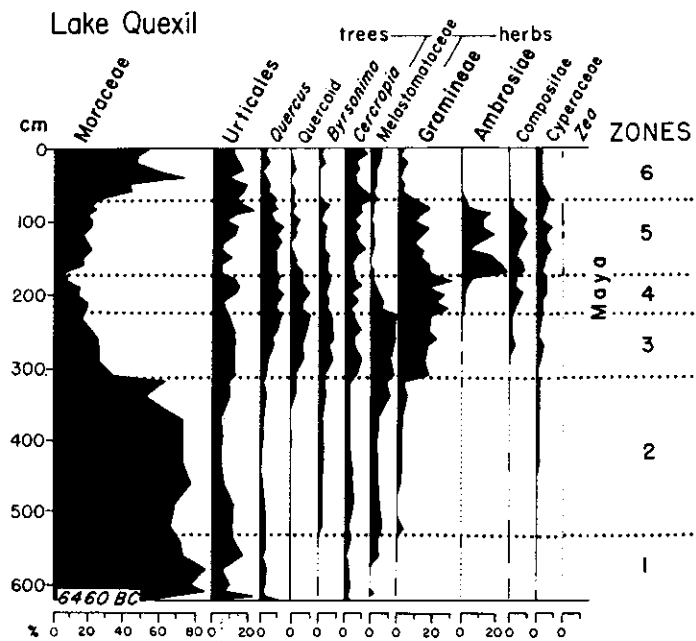


Figure 3. Pollen diagram from Lake Quexil, Guatemala, showing main pollen types. Modified from Vaughn *et al.* (1985). The radiocarbon-dated material was wood.

carbon dating of Peten lake sediment has produced poor results. Dating errors were produced by the hardwater effect (Saarnisto, this volume) and by colluvial deposition of upland soils containing non-contemporaneous C-isotope ratios. Consequently, Deevey *et al.* (1979) rejected the 29 radiocarbon dates on cores from Lakes Yaxha and Sacnab and regarded the eight dates from Lake Petenxil (Tsukada, 1966) as being systematically too old.

A pollen diagram from Laguna de Cocos, Belize, (Hansen, 1986) displays many of the features of the Peten record. Here a 5 m-long core of marl overlies clay. At 475 cm a radiocarbon date of 4820 B.P. indicates the sedimentation rate to be about 1 mm per year. The date is on the earliest pollen zone that is dominated by tree pollen. Above this forest zone, tree pollen is replaced by pollen of savanna plants together with weed species that flourished because of fluctuating water levels and/or human disturbance. *Zea* pollen appears ca. 2800 B.P. (800 BC), accompanied by Gramineae and Compositae Subfamily Tubuliflorae. An *Ambrosia* peak at 190–110 cm corresponds to Late Classic time ca. AD 600 to 850. The percentage of forest pollen increases during Postclassic time AD 850 to 1550 but does not become as high as in pre-Maya time.

In western Honduras, radiocarbon-dated pollen diagrams from Lake Yajoa and Petapilla Swamp show evidence for *Zea* agriculture from 4800 B.P. to 800 B.P. (i.e. 2800 BC to AD 1200) (Rue, 1987).

Southwestern United States

Zea was introduced northward into the arid southwestern U.S. about 1,000 BC, but it was not until about AD 1 that *Zea*, *Phaseolus* and *Cucurbita* were grown with irrigation. Village size increased and agriculture spread northward into the highlands of the Colorado Plateau by AD 500 where agriculture was at first based on flood plains and adjacent slopes but later shifted to uplands where small dams and terraces were used to conserve rainfall. Human populations shifted and fluctuated but generally increased until AD 1100 (Dean *et al.*, 1985) when there was a decline accompanied by migration to large river valleys.

On the Colorado Plateau, habitation was primarily in *Pinus edulis-Juniperus* woodland and the woodland ecotone with low elevation grassland and high elevation *Pinus ponderosa* forest (Euler *et al.*, 1979). Pollen analysis in the Plateau area is largely confined to deposits above house floors and to alluvial and colluvial deposits. Despite the fact that prehistoric people harvested trees for house construction and fuel, this effect on vegetation is usually not recognized in fossil pollen diagrams. Variations in the ratios of *Pinus-Juniperus* pollen probably reflect differential pollen production linked to effective moisture changes (Euler *et al.*, 1979).

An example is the pollen diagram from the colluvial trash slope at Mug House Pueblo (Fig. 4). Artifacts in the 130 cm thick section indicate soil accumulation since before AD 1100 through abandonment at AD 1300. The occupation deposit of the Pueblo people has relatively abundant herb pollen, notably Chenopodiaceae, that probably reflects weedy species. The high values of *Cleome* pollen could represent local growth of this food plant on the slope, but more likely the pollen became artificially concentrated due to the discarding of uneaten flower heads. The only other indications of agriculture are a few pollen grains of *Zea*, one of which is in the post-occupation zone. The three pollen spectra from this zone show a rise in the percentages of *Pinus* and *Juniperus* and a decline in herb values. These changes indicate secondary succession from fields to woodland.

Southeastern United States

In eastern North America, *Cucurbita pepo* is the first introduced cultivated plant to appear in the archeological record, possibly as early as 7,000 B.P.

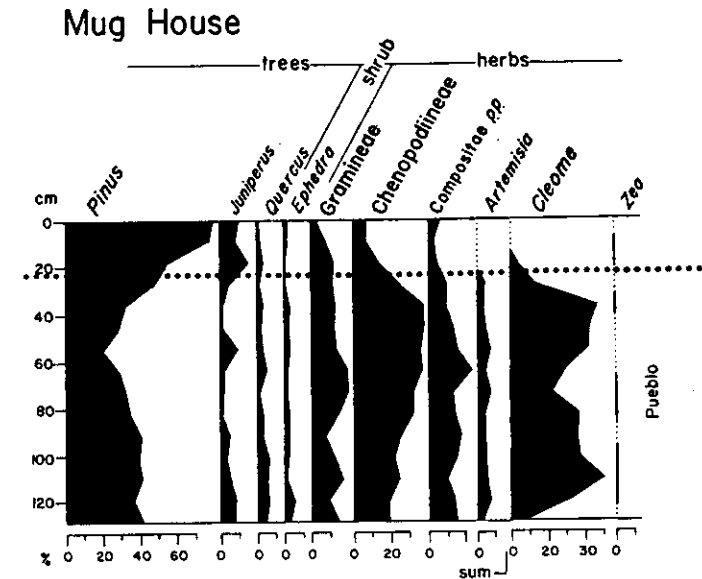


Figure 4. Pollen diagram from Colorado Plateau. The section is profile 3 from a trash slope at Mug House Pueblo. Modified from Martin and Byers (1965).

but certainly by 4,300 B.P. (Ford, 1985). During the second millennium BC several native species were probably domesticated in the river valleys of the central Mississippi River drainage, including *Helianthus annuus*, *Iva annua* and *Chenopodium berlandieri*. *Zea* was introduced in the late first millennium BC, but it did not become important until after AD 800. With the introduction of *Phaseolus* about AD 1000, a nutritional balance was achieved and village populations expanded, particularly away from large river valleys.

Whitehead (1965) reported five *Zea* pollen grains in organic sediment from Dismal Swamp in southeastern Virginia and estimated the age to be 200 BC. The *Zea* pollen are accompanied by slight maxima in the percentages for Gramineae, *Corylus*, *Myrica* and *Ilex* pollen. These maxima suggest shrub succession following field abandonment, but there was no change in the regional *Taxodium-Nyssa* pollen assemblage.

Another site where *Zea* pollen has been reported is B.L. Bigbee Swamp in eastern Mississippi (Whitehead and Sheehan, 1985). The site is in the Tombigbee River valley where *Zea* agriculture was practiced by Indians during the 16th and 17th centuries (Rostlund, 1957). *Zea* pollen dated at about 400 BC occur at a pollen zone boundary where *Pinus* replaces *Quercus*; Whitehead and Sheehan (1985) suggest that the implied

upland forest succession was due to changing Indian land-use practices that were linked with agriculture and increased fire-frequency. A similar forest succession elsewhere in the Southeast about 5,000 B.P. is attributed to climatic change (Watts 1980).

In the Little Tennessee River Valley, Delcourt *et al.* (1986) reconstruct human disturbance of vegetation over the past 9,500 years using charred plant materials from stratified archeological sites together with pollen diagrams from two ponds. Six cultural periods were studied: early archaic (7500–6000 BC), middle archaic (6000–4000 BC), late archaic (4000–1000 BC), woodland (1000 BC–AD 900), Mississippian (AD 900–1700) and historic (AD 1700–present). The wood charcoal record shows that beginning in the late archaic the disturbance-favoured *Pinus* and *Arundinaria* nearly replace bottomland taxa; with this shift there appear the charred seeds of the native cultigens *Phalaris caroliniana*, *Helianthus annuus* and *Iva annua* together with the introduced *Cucurbita pepo* and *Lagenaria siceraria*. *Zea* appears in the woodland period, but most charred remains are from the Mississippian and historic periods; *Phaseolus vulgaris* is Mississippian and historic.

Black Pond on the upland and Tuskegee Pond on the alluvial bottomland of the Little Tennessee River yielded cores of sediment back to 1000 BC and AD 500, respectively. Their five radiocarbon dates are stratigraphically consistent and indicate that historic sedimentation rates are 10 to 20 times the prehistoric rate. At Black Pond, *Zea* pollen and abundant *Ambrosia* pollen appear first in the latest Mississippian, whereas at Tuskegee Pond *Zea* and abundant *Ambrosia* pollen trace back into the woodland period. This pattern is consistent with the archeological data that indicate the bottomland was farmed earlier than the upland.

Southern Canada

In southern Ontario, archeological evidence for *Zea* agriculture appears first at about AD 600. From AD 600–1600, agricultural villages increased in number and size (Fecteau, 1985), implying an increasing population. This trend culminated at the time of contact in the early 17th century with an estimated human population of 50,000 (Krober, 1939). Villages tended to be clustered within a few kilometres of one another. Near Crawford Lake, one such cluster has been the subject of intensive study because the precisely-dated sediment can be linked to a village at the lake.

Crawford Lake is located 60 km west of Toronto. Its small surface area of 1.5 ha and maximum depth of 24 m has induced permanent meromixis and the preservation of annual couplets of sediment or varves (Boyko-

Diakonow, 1979). Varve counts produced an absolute chronology from AD 1970, when the sediment was collected, back to AD 1000.

Pollen analysis was done at mostly contiguous 5- or 10-year intervals (McAndrews and Boyko-Diakonow, 1987) (Fig. 5). The pollen diagram shows that prior to AD 1360 the lake was surrounded by deciduous forest dominated by *Fagus*, *Acer saccharum*, *Ulmus* and *Tilia* together with *Betula*, *Ostrya/Carpinus*, *Fraxinus*, *Carya*, *Juglans cinerea* and *Populus*. The conifers *Pinus strobus*, *Tsuga* and *Thuja* were present in small quantities. *Fagus* pollen shows a long-term decline in abundance and replacement by *Betula* and *Thuja*. This change may be due to climatic cooling.

Evidence for *Zea* cultivation consists of *Zea* pollen together with pollen of weedy Gramineae and *Portulaca* (Byrne and McAndrews, 1975), but unlike sites along the Little Tennessee River *Ambrosia* pollen was rare. The archeological age of the Indian village adjacent to Crawford Lake is consistent with the first appearance of *Zea* pollen in AD 1360. This village coincides with a 50-year minimum in the abundance of *Thuja* pollen, perhaps due to the harvest of *Thuja* for poles and bark for use in village construction. The Crawford Lake village was probably occupied for 10 to 20 years but there were contemporary and later villages within 5 km.

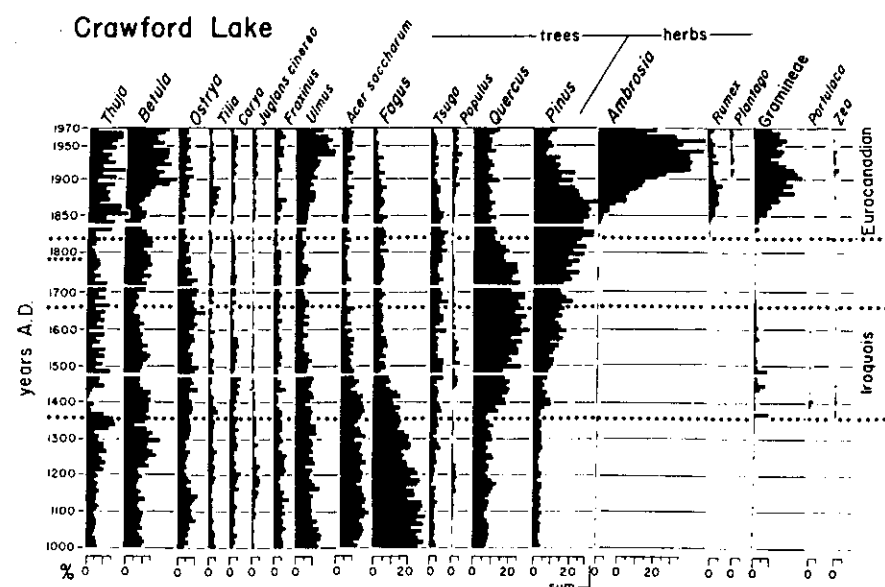


Figure 5. Pollen diagram from Crawford Lake, Ontario, showing main pollen types. The chronology is derived from organic varves. Analyses span ten-year intervals before AD 1790 and five-year intervals after AD 1790. Modified from McAndrews and Boyko-Diakonow (1987).

The long-term influence of *Zea* agriculture on the forest is problematical. Beginning in AD 1370 the abundance of *Quercus* pollen, probably *Q. rubra*, increased to a peak about AD 1650. This change is followed by an increase in pollen percentages of *Pinus strobus*, which begins a slower rise in AD 1390 and peaks about 1860. Today both tree species invade old fields: the sequential pollen peaks may represent tree longevity and the age at which the species produce abundant pollen. On the other hand, *P. strobus* is a northern tree that is near its southern Ontario range limit at Crawford Lake, and thus it may have expanded due to the cooler climate of the Little Ice Age. Support for a climatic cause lies in the parallel curve of *Tsuga* which, like *P. strobus*, is a northern species but, unlike *P. strobus*, is a terminal member of the forest succession in southern Ontario. Nevertheless, Indian farmers probably contributed to the succession by providing *Q. rubra* and *P. strobus* with disturbed habitat necessary for seedling establishment. Less equivocal is the peak in *Populus* values from AD 1440 to 1570, which indicates disturbance, although this early-successional species also had a short-lived peak in pre-agricultural time from AD 1150 to 1230. A similar pollen succession from Awenda Park lakes, Ontario, is described by Burden *et al.* (1985).

Historic disturbance

Forest destruction and farming by Europeans began along the Atlantic coast in the 17th century and proceeded westward. Penetration westward from the Appalachian Mountains to the prairie grassland spanned AD 1800–1860. The grasslands were grazed by cattle and sheep beginning in AD 1860, but with the expansion of the railway during the period AD 1880 to 1910 much of the grassland was plowed and replaced by grain fields. Because of poor climate and soils, much of northern New England, Ontario, Michigan and Minnesota were sparsely settled by farmers, but the forest was logged for *Pinus strobus* from east to west during the late 19th and early 20th centuries. Settlement along the Pacific coast began in the 1840's.

Ambrosia-type pollen is a common component of the modern pollen rain south of 49° latitude and east of 100° longitude. This type also contains *Iva* and *Xanthium* which are morphologically distinct but whose fossils are rare (McAndrews *et al.*, 1973). Most of the *Ambrosia*-type pollen is from *A. artemisiifolia*, a widespread, aggressive, native annual (Wodehouse, 1971). The uppermost part of almost all pollen diagrams from this area contains a distinct rise (settlement horizon) in the percentages of *Ambrosia*-type pollen. Above the rise is a European zone

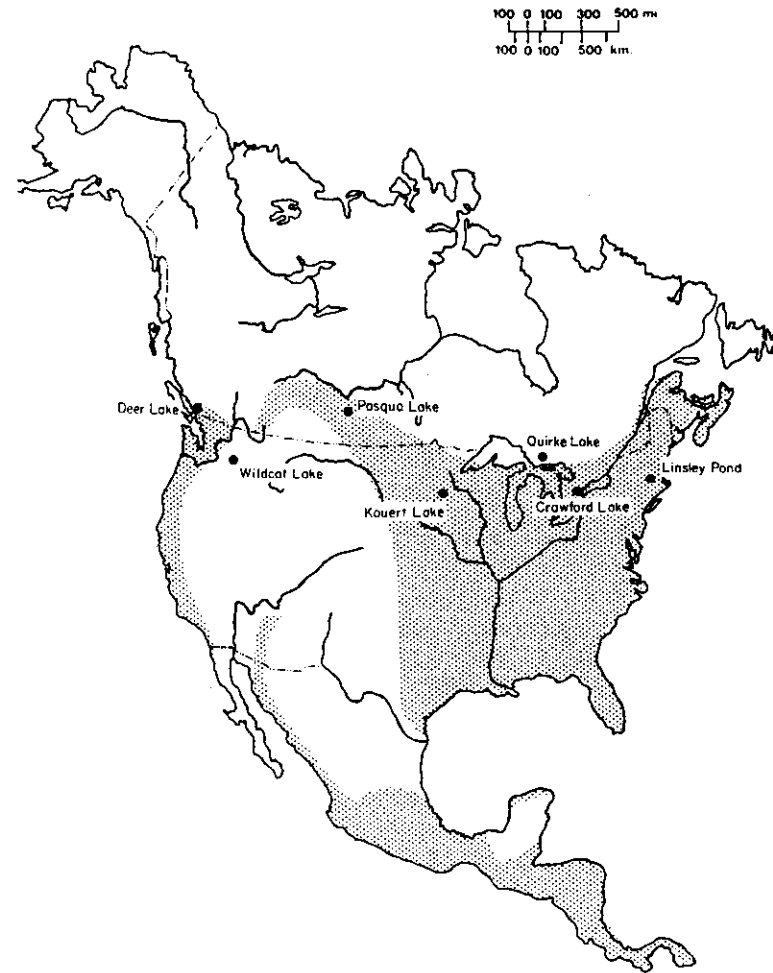


Figure 6. Map of North America showing population densities in the late 20th century. The shaded areas have a population of over 2.00 persons km^{-2} (Times Atlas, 1981). Pollen stratigraphic sites figured in the text are labelled.

characterized by this easily-recognizable pollen in sediments that have preserved pollen from the last one to several centuries (Fig. 7). This zone usually contains pollen of other weeds such as introduced *Rumex* and *Plantago* as well as Gramineae, both weed and cereal types, and locally *Cannabis* (van Zant *et al.*, 1979) and Chenopodiaceae (a suborder combining Chenopodiaceae and Amaranthaceae). It also contains altered proportions of tree pollen reflecting forest disturbance.

In addition to the position of the *Ambrosia* zone at the top of the accumulating sediment, its chronology indicates that it accumulated be-

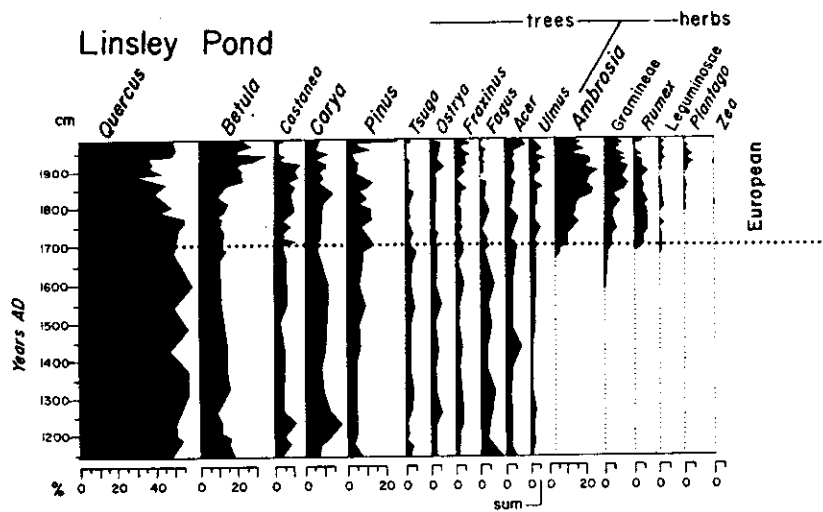


Figure 7. Pollen diagram from Linsley Pond, Connecticut, showing main pollen types. Modified from Brugum (1978).

ginning with European settlement. In midwestern lakes, counts of annual pairs of sediment layers or varves date the beginning of the zone to the 19th century (Swain, 1973; McAndrews and Diakonow, 1987) whilst ^{210}Pb isotopic-dating date its beginning to the 18th century in the Northeast (Brugum, 1978; Brush *et al.*, 1982). However, radiocarbon dates on sediment at the *Ambrosia* rise range from AD 1500 (McAndrews, 1969) to AD 1 (Jones and Kapp, 1972). These dates are in error probably due to dilution of contemporary carbon by "dead" carbon.

Evidence for European environmental impact in the *Ambrosia* zone includes smoke particles from forest fires (Gajewski *et al.*, 1985), industrial sources (Griffin and Goldberg, 1981; Clark and Patterson, 1984; Clark *et al.*, 1986), increased mineral-sedimentation from soil erosion (Brugum, 1978), deposition of mine tailings (Bradbury and Waddington, 1973; Maher, 1977), pollution from heavy metals (Matthewes and D'Aura, 1982) and lake eutrophication due to increased nutrient-input (Birks *et al.*, 1976).

Seven pollen diagrams from lakes aligned from east to west across the midcontinent were chosen to illustrate the pollen stratigraphic record of European impact (Fig. 6).

Northeast

In Connecticut, Brugum (1978) used ^{210}Pb and radiocarbon dating to

determine sedimentation rates at Linsley Pond. European farming, which began in 1700, was signalled by the appearance of *Ambrosia* and *Rumex* pollen (Fig. 7). Chestnut blight, which began in 1913, caused a decline of *Castanea* pollen and secondary succession is shown by a rise in *Betula* and *Quercus*. The steep rise in *Pinus* near the top of the core reflects planting in the last 50 years.

Davis (1985) compared tree-pollen percentages in surface sediment with percentages just below the *Ambrosia* zone in the sediment of 13 New Hampshire lakes whose elevations range from near sea level to about 1500 m. The percentages of *Betula* pollen increased most over time together with smaller but less consistent increases in *Abies*, *Ostrya* and *Acer rubrum* pollen; corresponding declines in abundance were shown by *Acer saccharum*, *Picea*, *Tsuga* and *Fagus* pollen. These trends are more pronounced below 750 m elevation where agriculture is practiced but less pronounced at higher elevations where the disturbance is from logging. Forest communities at lower elevations require more time than high-elevation forests to complete the cycle of secondary succession after disturbance.

Midwest

At Crawford Lake, in southern Ontario, the varve-dated pollen diagram (Fig. 5) reflects European land-clearance for roads and fields with the appearance of pollen of the introduced *Rumex acetosella* in the 1820's. Land within 2 km of the lake was settled during the period 1822–1864. Other disturbance indicators are the rise in Gramineae in the 1830's followed by *Ambrosia* a decade later. Trends in the pollen diagram reflect logging and forest succession. Beginning in the 1870's the percentages of *Pinus* and *Tsuga* pollen decline, and these taxa are partly replaced by *Thuja*, *Betula*, *Juglans cinerea*, *Ulmus* and *Populus*. *Ulmus* pollen percentages have declined slightly since the 1950's due to the death of trees by disease. Today, local cultivated fields have abundant weedy Gramineae and *Ambrosia* while *Rumex acetosella* grows mostly in pastures and fallow fields. Relict woodlots around the lake are dominated by *Acer saccharum*, but numerous rotted, cut stumps of *Tsuga* and especially *Pinus* indicate former conifer-dominance.

Because *Ambrosia* pollen is produced in large quantities and distributed widely by the wind, a rise in *Ambrosia* may not indicate its local occurrence but rather a more distant disturbance and pollen source. An example is Quirke Lake near the town of Elliott Lake in central Ontario. The pollen diagram (Fig. 8) shows that *Pinus* pollen is dominant throughout but that there is virtually no herbaceous-weed pollen below 12 cm.

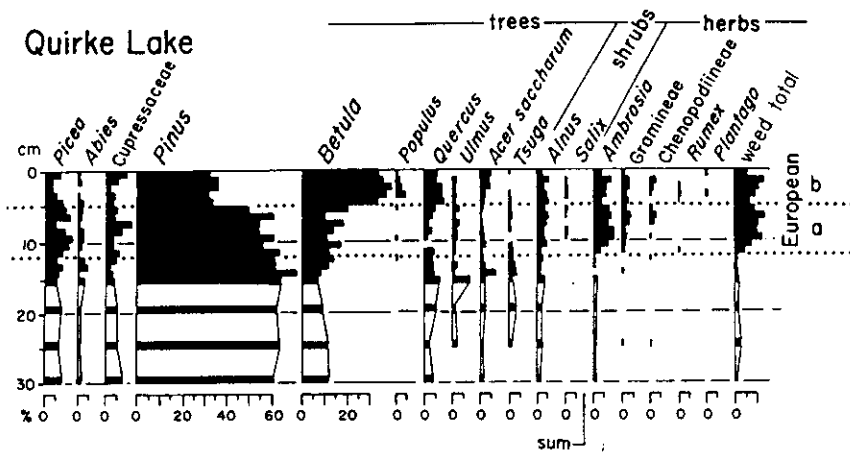


Figure 8. Pollen diagram from Quirke Lake, Ontario, showing main pollen types. Modified from McKee *et al.* (1987).

The European zone is signalled by increased percentage of *Ambrosia*, Gramineae and Chenopodiaceae together with the presence of *Rumex acetosella* and *Plantago* pollen. Although *Ambrosia* plants have been collected in central Ontario they are rare compared with their abundance southward. Thus the fossil *Ambrosia* pollen was probably wind-blown from the south beginning in the early 1800's. The other weed pollen may have either also come from a distance or else may be derived from local plants.

Two subzones are distinguished based on tree pollen (Fig. 8). In subzone a, the tree pollen is similar to pre-European levels except for a slight increase of *Betula* pollen percentages. In subzone b, from 5 cm to the sediment surface, *Betula* pollen doubles in percentage and *Populus* pollen appears. The European zone b reflects the *Betula papyrifera*-*Populus tremuloides* forest now growing around the lake. Forest-inventories indicate that the trees are 50 to 75 years old and if 15 years is allowed for the *Betula* and *Populus* to mature to pollen-bearing age, then the pollen boundary must date to 1925 and the forest destruction, probably by logging and fire, to 1910.

Westward in lower Michigan, U.S.A., Webb (1973) compared the differences in percentage tree pollen in lake sediment below the European zone with the surface pollen. A series of pollen difference maps from 23 cores show that the abundance of *Betula*, *Ulmus* and *Salix* had increased, whereas the abundance of *Fagus*, *Acer* and *Tsuga* had decreased. In the predominantly-forested northern area, the abundance of *Pinus strobus* decreased but *P. banksiana/resinosa* type increased. *Quercus* percentages

decreased in the south and generally increased northward. These changes are compatible with the historic record: *Pinus strobus* was extensively logged and replaced by the successional growth of *Betula*, *Quercus* and *Pinus banksiana*. The rise in *Ulmus* and *Salix* is attributed to their low commercial value, to planting, and to the fact that they are components of forested lowlands that have low agricultural value.

The prairie-forest transition of Iowa, Wisconsin and Minnesota was settled by European farmers in the mid-19th century. Immediately before this settlement, land surveyors recorded the natural vegetation. Comparison of the survey record with the composition of relict forest stands shows a trend of mesic succession. Former prairie has been invaded by *Quercus* and *Ulmus*, open *Quercus* savanna has become *Quercus* forest, *Quercus*-forest stands have succeeded to *Ulmus-Tilia* forest and presettlement *Ulmus-Tilia* forests have become dominated by *Acer saccharum*. Fossil pollen diagrams such as Kouert Lake (Fig. 9) indicate that these successions began in the 16th and 17th centuries (McAndrews, 1968; Waddington, 1969; Grimm, 1983). The immediate cause of these successions was decreased fire frequency mediated by topography. McAndrews (1968) attributed this reduction in fires to either a decline in Indian populations, due to the introduction of European diseases, or else a trend toward a cooler, moister climate. Stratigraphic evidence of increased runoff supports climatic change as the cause of the succession (Grimm, 1983). This shift in forest composition was enhanced by European settlers through the construction of fields and roads that acted as firebreaks.

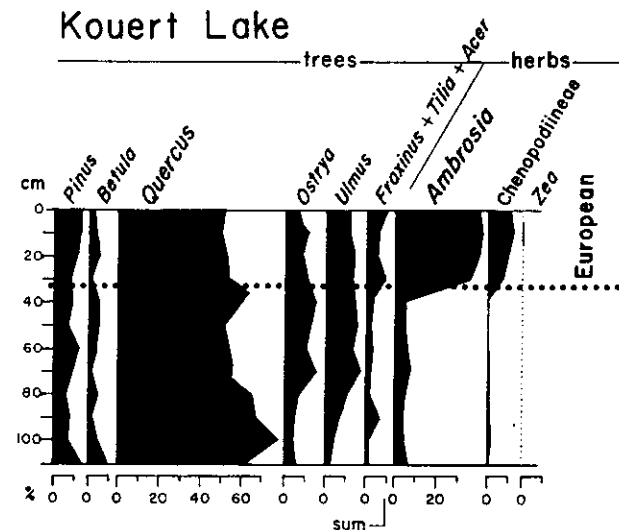


Figure 9. Pollen diagram from Kouert Lake, Minnesota, showing main pollen types. Modified from McAndrews (1968).

Fossil evidence of tree planting in the Midwest is meager. An example is the pollen diagram from Lake Harriet in Minneapolis, Minnesota, where the planting of *Ulmus americana* throughout the city in the early 20th century is reflected by the doubling of *Ulmus* pollen percentages beginning in 1925 (Brugam and Speziale, 1983).

Forest invasion of grassland is shown in a pollen diagram from Pasqua Lake, Saskatchewan. The lake is in the aspen parkland where groves of *Populus tremuloides* and *P. balsamifera* grew in a matrix of grassland. Stands of *Populus*, *Acer negundo*, *Fraxinus pennsylvanica* and *Ulmus americana* grow in ravines and on slopes between the upland and the lake. According to the presettlement land survey in the 1880's, the upland around the lake was about 85% grassland and less than 10% woodland, but in the valley woodland and grassland contributed equally to the vegetation (Archibold and Wilson, 1980). Before European settlement, forest invasion of the grassland was inhibited by fire, drought and browsing and trampling by bison and elk, factors ameliorated by the slopes. Today, most of the upland is devoted to small grain-farming enterprises with some cattle grazing. Among the weeds, the native *Selaginella densa* has increased with intensive cattle grazing. Common weeds of cultivated fields include genera of the suborder Chenopodiineae (especially the introduced *Salsola kali*), *Iva xanthifolia* and Cruciferae (particularly *Brassica*).

The pollen diagram of 75 contiguous 1 cm thick samples (Fig. 10)

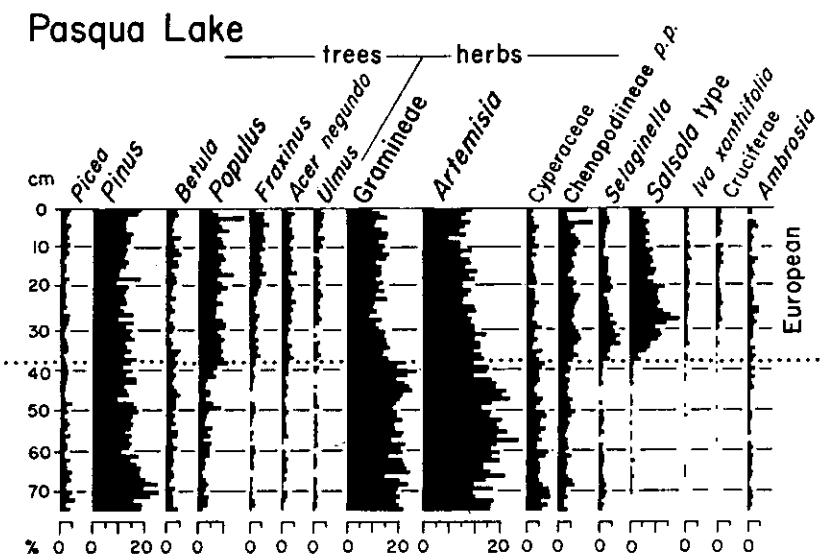


Figure 10. Pollen diagram from Pasqua Lake, Saskatchewan, showing main pollen types. The percentage sum is 300 pollen and spores of upland plants. Pollen analysis is by J. McAndrews. By permission of W. Warwick and The National Hydrology Institute, Saskatoon, Canada.

shows only the main pollen types. *Picea* and *Pinus* pollen are derived from trees growing over 150 km to the north or west (Zoltai, 1975) and therefore are not considered in the interpretation of the regional vegetation. *Populus* pollen is derived either from upland groves or the slope forest around the lake or both, while *Fraxinus*, *Acer* and *Ulmus* pollen are from the slope forest; Gramineae, *Artemisia* and Cyperaceae pollen are derived mainly from the regional grassland. The remaining grains of herb pollen are probably from weedy plants. *Salsola*-type, which was separated from other Chenopodiineae using the criteria of O'Rourke (1983), includes the introduced weed *Salsola kali* as well as the native (Betancourt *et al.*, 1984) but rare *Corispermum*. *Ambrosia* plants are rare and local this far north, and most of the pollen is probably derived from plants several hundred kilometres distant.

The base of the European pollen zone is placed at 38 cm where the amount of *Salsola*-type increases together with the percentages of *Iva*, *Selaginella* and Chenopodiineae pollen. This boundary dates to about 1900 when *Salsola*, introduced to North America in 1873 (Dewey, 1894), occupied fields in newly-plowed grassland. Thus the average sedimentation rate for the European zone is about 4.8 mm yr⁻¹. Due to compaction of sediment, however, the lower levels represent relatively more time than upper levels.

With the onset of European settlement, grassland pollen types such as Gramineae, *Artemisia* and Cyperaceae decreased to be replaced not only by weed pollen but also by tree pollen. These trees, *Populus*, *Fraxinus*, *Acer* and *Ulmus* expanded from ravines to adjacent slopes with the reduction of grassland fires. Among the trends within the European zone is the peak in percentages of *Selaginella* in the early 1900's that preceded the *Salsola* peak. This may reflect overgrazing by cattle and horses followed by plowing of this pasture and the spread of *Salsola* populations during the dry 1930's.

Westward in Alberta, Strong (1977) cored the upper sediment of nine lakes. Pollen analysis was done from the sediment surface down to depths ranging from 11 to 21 cm. Using a statistical technique, he placed the base of the European zone at depths ranging from 7 to 16 cm. However, the Chenopodiineae pollen curves show that only Gooseberry Lake and Keiver Lake have stratigraphic differences that clearly indicate the boundary with the pre-European zone. This otherwise promising study should be done with longer cores and more detailed palynology.

In the *Agropyron-Festuca* grassland of southeastern Washington a detailed study of land use is compared with a pollen diagram from Wildcat Lake (Davis *et al.*, 1977). Replacement of native large herbivores by cattle, sheep and horses began in 1860. Horse populations peaked in

1900 but declined to insignificance by the 1940's. Sheep were most numerous in the 1930's but have mostly been replaced by cattle since the 1950's. Grazing animals became largely restricted to shallow soils when extensive wheat farming began in the 1880's.

Wildcat Lake is surrounded by grazed grassland. The pollen diagram (Fig. 11) shows dominance by *Pinus* pollen derived from distant mountain forests as well as pollen of *Artemisia*, Gramineae and other grassland herbs. The European zone begins at 50 to 45 cm with the rise of Compositae Subfamily Tubuliflorae percentages followed by *Ambrosia* type, Chenopodiaceae, Umbelliferae, Caryophyllaceae, *Eriogonum*, Cruciferae and *Erodium* pollen. In the European zone, the clastic mineral component of the sediment increases by about a factor of three compared with the pre-European zone, indicating increased erosion in the watershed due to intensive grazing. Spores of *Sporomiella*, a horse-dung inhabiting fungus, are most abundant at 35 to 17 cm and probably reflect the peak horse population centering on the 1890's.

Northwest

The vegetation of the Pacific Northwest appears not to be extensively modified by the relatively large population of Indians that lived by fishing.

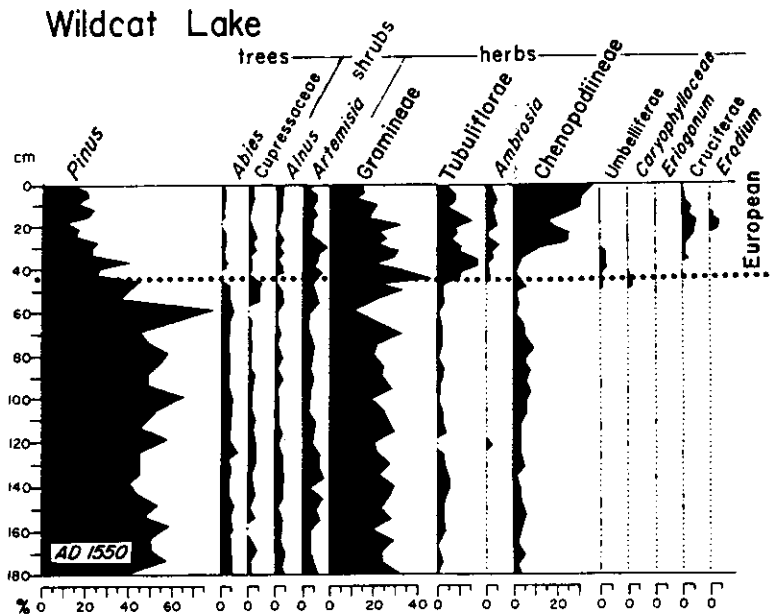


Figure 11. Pollen diagram from Wildcat Lake, Washington, showing main pollen types. Modified from Davis *et al.* (1977).

However, beginning in the 19th century Europeans have extensively logged this forest dominated by *Thuja plicata* and *Tsuga heterophylla* with lesser amounts of *Picea*, *Abies* and *Pinus*. Much of this land has developed secondary mixed-forest dominated by *Alnus rubra* together with *Populus*, *Prunus* and *Acer*. This forest destruction and succession, together with farming and urbanization, are recorded in pollen diagrams from Lake Washington near Seattle, Washington (Davis, 1973) and Deer Lake near Vancouver, British Columbia (Mathewes and D'Auria, 1982) (Fig. 12).

At Deer Lake logging began in 1892 followed by farming and pasturing until the 1970's when the area became devoted to residential and commercial activities. Remnant forest stands are dominated by *Alnus rubra* with a few conifers; the understorey includes the ferns *Blechnum spicant*, *Polystichum muticum* and *Dryopteris* spp. *Nymphaea alba* was introduced to the lake and *Impatiens glandulifera* has become locally naturalized.

In addition to the pollen evidence for the beginning of logging in 1892, other dates in the sediment core were established by geochemical methods. The beginning of a lead rise at 22 cm is correlated with a rise in the consumption of leaded gasoline as measured by local vehicle registration. A copper peak at 19 cm reflects the use of CuSO_2 pesticide in the lake in 1957 and a ^{137}Cs peak at 17 cm is attributed to 1963 fallout from nuclear-bomb testing. Unfortunately the relatively rare pollen of weedy

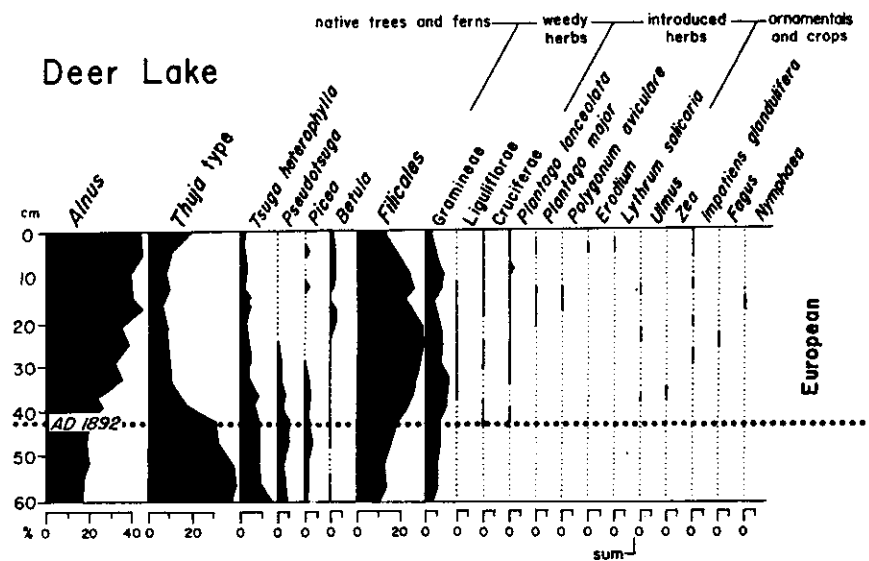


Figure 12. Pollen diagram from Deer Lake, British Columbia, showing main pollen types. Modified from Mathewes and D'Auria (1982).

and introduced herbs, introduced ornamentals and crops do not provide insight into detailed episodes of floristic change.

The stratigraphic order of the fossil pollen can be linked to historic introductions. Mudie and Byrne (1980) in their study of California saltmarsh sediment found that *Rumex acetosella* pollen appeared earliest in the European zone, and based on the plant's abundance in pastures in 1864 was probably introduced 1820–1840. *Plantago lanceolata* was a rare plant in 1860 and was probably introduced in the 1850's. Pollen of introduced ornamental trees appear later; *Eucalyptus* spp. was locally planted beginning in the 1850's, *Acacia* spp. in 1910 and *Pinus thunbergii* in 1945. Mudie and Byrne (1980) suggest a range of error for the plant introductions to be ± 20 years, except for ± 10 years for *Pinus thunbergii*.

Conclusions

Of the over 300 published pollen diagrams spanning the 12,000 years of human occupation, most of them, except in the far north, show modification of the vegetation by Europeans. Much of this is expressed in the proliferation of weeds, both native and introduced, owing to plow agriculture, cattle grazing and industrialization. Forest modification is less obvious but some pollen diagrams reflect, for example, logging of *Pinus* and replacement by early successional species such as *Betula* and *Populus*.

In contrast, the impact of the smaller and more localized populations of prehistoric agriculturists is reflected in fewer than 20 pollen diagrams, mostly from mesoamerica. Weed and the rare *Zea* pollen are the chief indicators. Concurrent variations in tree pollen are few and small, and these may reflect climatic fluctuations such as the Neoglacial cooling culminating in the Little Ice Age. The elucidation of the impact of prehistoric humans on native vegetation requires collaboration between the archeologist and palynologist at sites suitable for detailed pollen analysis.

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