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AN ECOLOGICAL HISTORY OF THE GREAT LAKES FOREST OF MICHIGAN

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SUMMARY

(1) The historical development, i.e. changing species composition and the areal extent, of the vegetation of the High Plains region of Michigan is traced with the use of printed and manuscript materials and contemporary forest survey records.

(2) The classic pre-settlement Great Lakes pine forest occupied the rolling upland areas and was conditioned to fires at 130–260 year intervals. Fires were much more frequent on the drier outwash sands of the jack pine plains and openings and almost non-existent on the moist hemlock–white pine–northern hardwoods forests of the uplands and the swamp conifer forests of the lowlands.

(3) Selective logging of the white pine and later the hemlock and the better hardwoods converted the hemlock–white pine–northern hardwoods type to sugar maple. Waves of fires, following the logging in rapid succession, upset the natural equilibrium of the Great Lakes forest. The ignition of the remaining debris or the slash destroyed the remaining seed trees and the seedling pine in the mixed pine type. The result was a poorly stocked forest of oak sprouts and aspen suckers. Oak and aspen had formerly played a relatively subordinate role in the pre-settlement forest.

(4) The cessation of fires in 1920–40 allowed the maturation of the oak, the aspen, and the jack pine and set the stage for the new pulp-oriented industrial forest of the 1950s.

INTRODUCTION

In Europe, the transition from the natural woodlands of the past to the semi-natural woodlands of today is obscured by an extended period of human occupancy. Millenia of gradual forest clearance, exploitation, and management have altered the face of the land to the point where, except for palynological evidence, it is almost impossible to reconstruct the original character of the vegetation (Rackham 1976; Peterken 1981; Ellenberg 1987).

North America presents a strikingly different picture. Like the analogous pinewoods of Scotland (Steven & Carlisle 1959), the commercial assault on North America's forests was much more instantaneous and dramatic. The full weight of a technologically advanced culture was thrown against the pine forests of the interior of the continent. Arthur Lower's statement that 'the sack of the largest and wealthiest of medieval cities could have been but a bagatelle compared with the sack of the North American forest' (Lower, Carrothers & Saunders 1938) may be only hyperbole. It certainly, however, represented a dominant theme among historians and ecologists early in the twentieth century. By the 1920s the axe, the circular saw, and the railroad had destroyed most of the primeval old-growth pine and hardwood forests of Michigan (Gleason 1923). Weaver & Clements (1929) noted that the 'climax' pine–hemlock or lake forest of the Great Lakes region had been reduced to such small fragments that there were doubts as to its former existence and status.

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Paradoxically, much of the recent work on the disturbance history of the Great Lakes region suggests pines are fire-dependent species which owe their existence to natural catastrophies (Heinselman 1973). Given the high level of disturbance in the pre-settlement forests, it is not surprising that many forest ecosystems have a high degree of resilience and an ability to return to pre-disturbance conditions (Raup 1967; Marks 1974). Alternatively, other investigators (Tansley 1935; Botkin 1979) have suggested ecosystems may have multiple stable equilibrium states. The disturbances accompanying European settlement may have significantly altered the nature of the forest ecosystem, creating radically new but stable plant communities (Bormann & Likens 1979).

Fortunately, we do have methods of analysing the nature and magnitude of the change induced by human activities. The federal government under the auspices of the General Land Office (GLO) survey programme systematically recorded the nature of the vegetation in the nineteenth century prior to settlement. A detailed picture of the pre-settlement vegetation can be constructed relatively easily from the GLO records (Barber 1976). The upper Great Lakes states of Michigan and Wisconsin also possess an abundant store of documentary materials on the post-logging forests of the region. Interest in the fledgling field of forestry and the country's resources early in the twentieth century lead to a number of reports, like Michigan's Land Economic Surveys, which detailed the status of the Great Lakes forest resources on a county by county basis.

The purpose of the present paper is:

(a) to compare the pre- and post-settlement species composition of a small segment, i.e. Crawford and Roscommon Counties, Michigan, of the Great Lakes forest;

(b) to consider the impact of past forest harvesting and management practices on the composition, structure and areal extent of the forest; and

(c) to contrast the natural disturbance regime of the pre-settlement period with the selective logging of the late nineteenth century and the more intensive wood utilization practices of the twentieth century.

DESCRIPTION OF STUDY SITE

Nineteenth-century Michigan, particularly the northern half of the Lower Peninsula, possessed some of the finest pinelands in the world (Maxwell 1912) and was the leading state in the production of lumber from 1870 to 1890 (Benson 1976). Extracting pines and later hardwoods from the forest was the dominant economic activity of Michigan throughout the later half of the nineteenth century (Benson 1976).

Crawford and Roscommon Counties (44°30′N, 84°30′E) comprise an area of 2800 km^2 situated in the centre of the pinelands and the High Plains region of northern lower Michigan (Fig. 1). The region was part of a prominent interlobate area between the Michigan and Saginaw lobes (13800 B.P.) and later the Michigan and Huron lobes (12500 B.P.) of the late Wisconsin Laurentide ice sheet. A number of poorly sorted ice-contact features (large plateau-like moraines and kamic ridges and masses) rise 15–75 m above the flat outwash plains and mark splits between the lobes and successive positions of the ice front. The major lakes in the region, Higgins and Houghton Lakes, are kettleholes formed in the outwash plain (Burgis 1977; Farrand 1982). The climate is of the humid continental type with an average annual precipitation of 760 mm fairly evenly distributed throughout the year. Much of the precipitation during the winter months occurs as snow. The mean annual temperature is 5·5 °C with a January mean of −8·5 °C and a July mean of 19·6 °C (Veatch *et al.* 1931). The slightly elevated nature of the terrain (300–450 m) and its

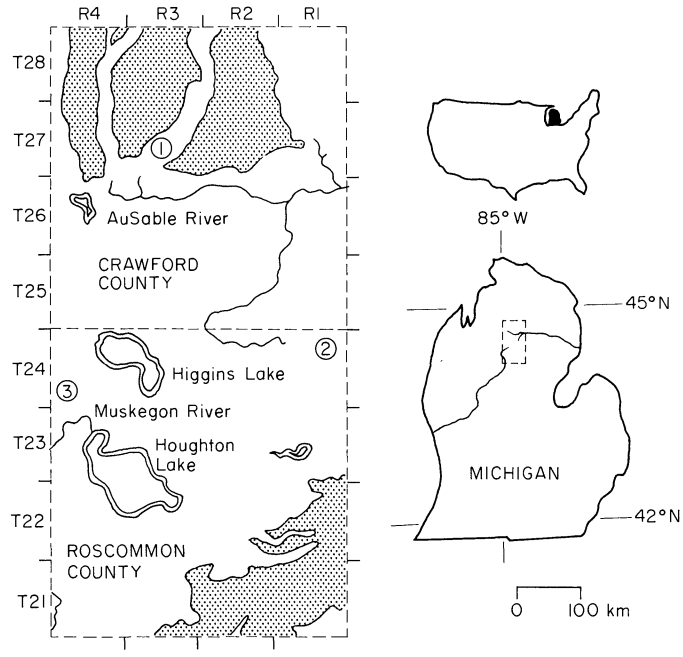

FIG. 1. Map of study site showing location of upland moranic areas (shaded), Hartwick Pines (1), Roscommon Red Pines Study Area (2), and Dead Stream Swamp (3).

location in the interior of Michigan's Lower Peninsula results in a short frost-free growing season of 70–100 days (Van Den Brink, Strommen & Kenworthy 1971).

The area, as one of the early land surveyors noted, 'embraces a variety of soils'. Differences in the source of the parent material, topographic position, drainage and vegetation have combined to create a mosaic of soil types. Acidic, frequently-leached soils, i.e. haplorthods (Soil Survey Staff 1975), derived from coarse-textured parent materials, dominate most of the region. The driest soils are the excessively drained coarse-textured sands, i.e. the udisamments, of old outwash channels. Local accumulations of peat in varying degrees of decomposition, i.e. hemists and saprists, characterize the lower lying areas. The eutroboralfs or colder, moderately base-rich soils of the moraines of the north-western corner of Crawford County were derived from moderately alkaline silty clay-loams and are among the few agriculturally productive soils of the region.

Braun (1950) placed the forests of northern lower Michigan in the Great Lake Section of the hemlock–white pine–northern hardwood region while Küchler (1975) mapped most of the area as part of the Great Lakes pine forest. Although pine is synonymous with the Great Lakes forest and some of the best white and red pine (*Pinus strobus* and *P. resinosa*) in the upper Midwest were extracted from the area (Hudgins 1961), Crawford and Roscommon Counties also contained a number of other forest types. Roth (1905a) identified three other forest types as characteristic of the region at the turn of the century. Broken and open stands of jack pine (*Pinus banksiana*) occupied the outwash plains. The hemlock–white pine–northern hardwoods (*Tsuga canadensis–P. strobus–Acer saccharum–Fagus grandifolia–Betula alleghaniensis*) type characterized the uplands while swamp forests of cedar–tamarack and spruce (*Thuja occidentalis–Larix laricina–Picea*

mariana) dominated the low-lying depressions. Crawford and Roscommon Counties in many ways represented a microcosm of the Great Lakes forest.

SOURCES OF DATA

Crawford and Roscommon Counties possess a wide chronological range of source materials on the forest history of the Great Lakes region. Material was obtained as follows.

GLO survey plat maps and field notes

All of the thirty-two townships of the study area were surveyed by the federal government prior to settlement and exploitation of the area's forest resources. The surveys of the 6 mile square (9·6 km square) township lines were initiated in 1836 while the subdivision of the interior of the townships into thirty-six 1 mile square (1·6 km square) sections was completed in 1859. Section and quarter-section posts were established at mile (1·6 km) and half-mile (0·8 km) intervals on the north–south, east–west section lines. Their position was permanently marked by recording the species, the estimated diameter, the compass bearing and the distance to two or more adjacent 'bearing' trees. Surveyors were also required to take notes describing the face of the country, the character of the soil, 'the several kinds of timber and undergrowth, naming each kind of timber in the order in which it is most prevalent,' and the occurrence of windfalls and swamps on each of their mile (1·6 km) long section lines (White 1984). The surveyors also noted the occurrence of burnt land along the section lines. Most investigators feel the GLO records provide a relatively reliable method of reconstructing the pre-settlement vegetation of the Midwest (Bourdo 1956; Curtis 1959). Whitney (1986) concluded that the GLO records of Crawford and Roscommon Counties were relatively free of the major problems cited by Bourdo (1956): fictitious data and surveyor bias in the selection of bearing trees. Copies of the field notes and the surveyed township or plat maps were obtained from the Lands Division of Michigan's Department of Natural Resources in Lansing.

Michigan Forestry Commission reports

In 1903 the state of Michigan set aside 35 000 acres of cut-over land (land from which saleable timber has been removed) and land reverting to the State in default of tax payments in Crawford and Roscommon Counties as the first of the State's forest reserves. The Forestry Commission, established to administer the reserve, issued a number of informative reports on the forest resources of the reserve from 1903 to 1906.

Land Economic Surveys

The State of Michigan inherited a large portion of the cut-over pinelands of the northern counties through the non-payment of taxes early in the twentieth century. Interest in the economic potential of the state's public domain eventually lead to the creation of the Land Economic Survey programme of the State Department of Conservation. The 1:63 360 scale farm and forest maps and surveys of Roscommon County (1924) and Crawford County (1927) were part of a larger attempt to assess systematically the forest resources and the agricultural potential of Michigan's northern counties.

TABLE 1. Species composition by percentages of the pre-settlement forest types. Percentages are based on bearing tree counts of the loamy uplands of townships 28N,R3W and 28N,R4W (hemlock–white pine–northern hardwoods type), the rolling uplands and ridges of townships 25N,R3W and 28N,R2W (mixed pine and pine and oak types), the flat plains of townships 25N,R1W (jack pine plains type), and all of the jack pine openings and the swamp conifer forests of Crawford and Roscommon Counties (Whitney 1986). Nomenclature follows Fernald (1970).

	Forest type				
Species	Hemlock–white pine–northern hardwoods	Mixed pine or pine and oak	Jack pine plains	Jack pine openings	Swamp conifers
Abies balsamea					1·7
Larix laricina					29·7
Picea sp. predominantly *mariana*	0·3				10·6
Pinus sp.*	0·6	2·1	2·6	16·6	1·5
Pinus strobus	3·5	19·3	0·5	2·4	7·6
P. banksiana		18·0	90·2	43·8	1·7
P. resinosa	0·6	41·2	3·6	34·6	1·1
Tsuga canadensis	20·3	0·4		0·3	3·2
Thuja occidentalis					25·2
Populus sp., predominantly *tremuloides* and *grandidentata*	1·0	4·7	2·6		3·8
Acer saccharum	16·9				0·1
A. rubrum	1·2	0·4			1·6
Betula sp.	3·8		0·5	0·3	2·5
B. alleghaniensis					0·5
B. papyrifera					2·9
Ostrya virginiana	0·6				
Ulmus sp., predominantly *americana*	0·6				1·0
Fagus grandifolia	50·6	1·3			0·2
Quercus alba		8·6		0·6	
Q. coccinea–rubra–velutina complex		3·9		1·5	
Fraxinus americana					0·7
F. nigra					3·6
Miscellaneous spp.					0·5
Total no. trees counted	344	233	194	338	1380

* Not all of the bearing trees were identified to species. The small size and the location of most of the pine on outwash plains suggests a majority of the pine was *P. banksiana*.

Michigan's Fourth Forest Inventory

The current composition of the forests of Crawford and Roscommon Counties was taken from the U.S. Forest Service's unpublished 1980–81 fourth forest inventory programme of Michigan. Estimates of the numbers of live trees by species and size-class were based on a series of 1 acre (0·405 ha) ground plots sampled by means of the variable-radius plot technique (Jakes 1982). The intensity of the sampling was approximately one plot for every 2000 acres (809 ha) of land (Mark Hansen, personal communication). The Renewable Resources Evaluation Project of the North Central Forest Experiment Station in St. Paul, Minnesota supplied the data for the two-county study area.

Michigan Forest Resource Inventory Programme

Detailed forest inventories based on the photo-interpretation and field checking of colour-infrared aerial photographs have recently been completed for a number of Michigan's counties as part of the Michigan Resource Inventory System (MIRIS)

programme. Cover type maps at a scale of 1 : 24 000 and a forest inventory report showing stocking by species and size class for Crawford County were obtained from the MIRIS programme in Michigan's Department of Natural Resources in Lansing.

ORIGINAL OR PRIMARY FOREST

The GLO survey records and the early Forestry Commission reports allow a fairly detailed reconstruction of the pre-settlement forests of the area. Mixed forests of red, white and jack pine and an occasional oak occupied approximately 45% of the study area and were centred on the coarser-textured, more heterogeneous deposits of the uplands and ridges (Whitney 1986). Red pine was the dominant element of the mixed pine forest, equalling the combined representation of white and jack pine (Table 1). The size of the pine was often impressive as evidenced by the surveyors' accounts and early reports on the cut-over stumplands of the forest reserve. Good pinery land carried 100 stumps to the acre (0·4 ha) (Roth 1905b). The timber on the better sites was mostly 2–4 ft (0·6–1·2 m) diameter (at 1·3 m) white pine (Skeels 1903) with a height of up to 140 ft (43 m) (Higgins 1945). Red pine was somewhat smaller, reaching 'a diameter of 2–3 ft (0·6–0·9 m) and a height of over 100 ft (30 m)' (Roth 1905b).

Oaks, here largely *Quercus alba* and the *Q. coccinea–rubra–velutina* complex (Voss 1985), were poorly represented in the canopy, and pure stands of oak were even more infrequent in the pre-settlement forest (Michigan Land Economic Survey 1927). Much of the early literature (Beal 1901; Kittredge & Chittenden 1929; Davis 1935) and the surveyors' comments suggest oaks of moderate size occasionally mixed with the pine in the pine–oak type or forming a permanently suppressed understorey in many of the mixed pine stands. Oak was the most frequently mentioned understorey species in the surveyors' early section-line descriptions, occurring in over 70% of those for the overstorey mixed pine (Whitney 1986). Beal (1888) also noted that seedling sprouts of oak, or oak grubs (enlarged root stumps persisting after fire) up to 60–100 years of age occurred sporadically throughout many of Michigan's pine stands.

Pine's predominance in the pre-settlement forest was largely a substratum dependent phenomenon. The drought-prone coarse-textured soils promoted a forest type which was extremely flammable and liable to natural stand initiating fires at 130–260 year intervals (Table 2). Fire eliminated many of the competing hardwoods. It created the mineral seedbed required by the pine and it allowed the few remaining trees which escaped the fire to restock the land (Van Wagner 1970). As in the case of the few existing remnants, e.g. Hartwick Pines State Park, the virgin pine stands were composed of several distinct age-classes (Whitney 1986). Trees like the large 1·2 m diameter 'monarch' pine at Hartwick Pines supplied the seed for the re-establishment of the stand.

Jack pine was an even more fire-dependent type (Table 2). Natural stand initiating fires swept through the dry jack pine plains on approximately an 80-year cycle (Whitney 1986). The serotinous nature of the cones of many of the trees and jack pine's ability to bear seed at an early age (as early as the seventh year) enabled it, however, to reseed rapidly the burned area (Cayford 1970). The jack pine type covered approximately 15% of the study area.

The surveyors' comments suggest the structure and configuration of the jack pine forest varied considerably from one site to the next. Some areas were described as dense 'spruce pine thickets', spruce pine being the nineteenth century name for jack pine. Other areas, characterized by open drifting sand, were referred to as 'burnt openings' or 'barrens'.

TABLE 2. Fire regime of the pre- and post-settlement forests of Crawford and Roscommon Counties, Michigan. Values given are fire rotation periods or return times in years. Return time is the length of time required on a percentage basis to burn an area equal to the forest type under consideration. It is determined by dividing 100 by the average area (in percentages) burned annually.

	Forest type						
	Jack pine	Mixed pine	Pine–oak*	Hemlock–white pine–n. hardwoods†	Aspen–birch‡	Swamp conifers	Method of determining return time
Pre-settlement period 1810–60	83–167	129–258	172–342	1389–2778		2959–5917	Analysis of surveyors' section lines (Whitney 1986). See Lorimer (1980) for technique.
Logging era 1870–1920			9				Fire scar analyses (Kittredge & Chittenden 1929).
Fire protection era 1965–1985	392		313	276	568	2034	Fire statistics obtained from Michigan DNR for 1965–1985. See Fahey & Reiners (1981) for technique.

* Pine with an occasional oak converted to oak after 1920.
† Forest type converted to northern hardwoods after 1920.
‡ Forest type developed after 1870.

High temperatures and dry seasons frequently killed the first wave of seedlings established on the more drought-prone sites (Benzie 1977) and produced the relatively open conditions of the barrens (Abrams 1984). The open nature of the vegetation, in turn, probably minimized the incidence of crown fires and crown scorch and favoured a high frequency of red pine in the barrens (Table 1). Although red pine's thick bark makes it relatively resistant to surface fires, it is still very sensitive to crown scorch (Van Wagner 1970; Vogl 1970).

Fires were much more infrequent in the moist hemlock–white pine–northern hardwood forests of the uplands and the conifer swamp forests of the lowlands (Table 2). Beech, sugar maple and hemlock dominated the richer, loamier soils of the morainic uplands (Table 1), while a variant of the hemlock–white pine–northern hardwoods type, lacking the sugar maple, occasionally occurred on the moister depressions of the lowlands. Both types together covered approximately 20% of the two-county study area. Many of the largest white pines, trees up to 50 inches (1·27 m) in diameter, were scattered sporadically throughout the hemlock–white pine–northern hardwoods type. Roth (1905b) noted the hemlock and the hardwoods typically rose to a height of 80–110 ft (24–33 m), while diameters of 24–30 inches (0·6–0·75 m) were common. Cedar, tamarack and spruce, predominantly black spruce, formed the mass of the swamp conifer forest type (Table 1) and covered the remaining 20% of the study area.

HISTORICAL DEVELOPMENT OF THE GREAT LAKES FOREST

Wood and its by-products have always been the central focus of the Great Lakes forest. Consequently, any history of the forest is largely a history of the increasingly intensive commercial utilization of the forest's resources.

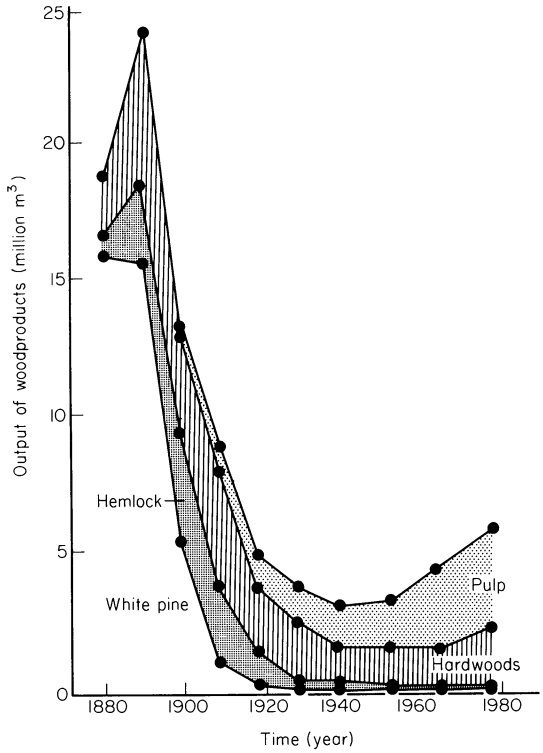

FIG. 2. Output of wood products (saw and veneer logs and pulpwood) in Michigan from 1879 to 1978. Data compiled from Steer (1948), Findell *et al.* (1960), Chase, Pfeifer & Spencer (1970) and Raile & Smith (1983). Maple has generally accounted for at least 50% of the hardwood category. Aspen and jack pine are the major pulpwood species.

Pre-settlement and early settlement period

Archeological evidence suggests the population density of the prehistoric Indians in the High Plains region was very low (Hinsdale 1932; Sommers 1977). None of the early surveyors mentioned the abandoned Indian clearings or 'Indian gardens' so characteristic of the more densely populated lakeshore sections of Michigan's Lower Peninsula (Voss 1956).

Unlike the more agriculturally orientated landscape to the south, logging actually preceded settlement in north-central Michigan. Logging and settlement spread over the two-county area in the 1870s and the 1880s (Michigan Land Economic Survey 1924, 1927). Due to its relatively inaccessible location, the High Plains was one of the last regions in the Lower Peninsula of Michigan to experience commercial logging (Benson 1976).

The pine era, 1870–90

White pine, and to a lesser extent red pine, was synonymous with lumber in the earlier, more selective days of the lumber industry from 1870 to 1890 (Fig. 2). It was compact, lightweight, and easily worked: ideal for interior and exterior house finish. Due to the difficulty of transporting bulky commodities overland, however, the harvest was limited

to areas adjacent to rivers (Benson 1976). Most of the pine was driven down the Muskegon River to the Muskegon mills on Lake Michigan or down the AuSable River to the Oscoda mills on Lake Huron (Michigan Land Economic Survey 1927). Sargent's (1884) map of the forests of Michigan in 1881 indicates that the merchantable white and red pines within 1–5 miles (1·6–8·0 km) of the AuSable, the Muskegon, and the Manistee Rivers had already been cut off by 1881. The advent of extensive logging railways in the 1880s provided entry to the more inaccessible stands of pine on the uplands and permitted the profitable extraction of the poorer grades of logs (Maybee 1976).

The hemlock–hardwood era, 1890–1920

With the exhaustion of the pine in the 1890s, loggers shifted their emphasis to hemlock and later hardwoods (Fig. 2) (Michigan Land Economic Survey 1927). The bark of hemlock was a major source of tannin for the leather industry, while the lumber served as a substitute for the depleted pine. Michigan's abundant forests of hemlock made it a leader in the tanbark industry for the first two decades of the twentieth century (Fulling 1956). New technology (the advent of drying kilns and stronger saws) and railroads made the full utilization of the dense, unfloatable hardwoods possible (Worth 1981; Sandberg 1983). Large quantities of durable hardwoods were increasingly funnelled into the hardwood flooring industry. By 1912 sugar maple had replaced pine as Michigan's most important lumber species (Maxwell 1912).

The high cost of the logging railway also placed a premium on exploiting the woods to their fullest (Marquis 1983). Before the rise of the petrochemical industry in the 1920s, wood was the major source of organic chemicals (Baker 1983). The local tanbark and chemical wood industries provided a market for almost every size-class of hemlock and hardwoods growing in the High Plains region.

Agriculture

Agriculture both accompanied and followed the earliest phases of the logging frontier. Often the cut-over land was converted to cropland or stump pastures. Farmers found a ready market and a high price for their crops and forage in the local lumber mills (Davis 1935). Unfortunately crops, pastures and farms were rather transitory affairs on the poorer soils (Skeels 1903). The combined area under cultivation or in pasture or fallow never exceeded 3% of the land (U.S. Bureau of the Census 1922) and even that area steadily decreased after the disappearance of the lumber industry (Davis 1935).

The post-logging landscape

By 1920, forty years of lumbering and cordwood cutting had removed most of the merchantable pine, the hemlock and even the smaller hardwoods. The few remaining mature pines were limited to the 30 ha Hartwick Pines tract and the 15 ha Roscommon red pine area (Fig. 1). Both of the sites had been by-passed during the earlier pine era due to the relatively small size of the trees (Wackerman 1924).

Cutting permanently altered the species composition of the hemlock–white pine–northern hardwoods type. Exposure and the drying of the soil eliminated the seedlings and the saplings of the more sensitive species like hemlock (Buttrick 1921; Michigan Land Economic Survey 1927). Widespread disturbance also favoured the more aggressive, sprouting and wind-dispersed sugar maple as opposed to the less mobile, animal-dispersed beech (Table 3) (Buttrick 1923; Forcier 1975). The old-growth forests of

TABLE 3. Percentage composition of the pre- and post-settlement forests of Crawford and Roscommon Counties.

	Crawford County						Roscommon County					
	Small trees 6–27 cm dia.		Medium trees 28–53 cm dia.		Large trees 54+ cm dia.		Small trees 6–27 cm dia.		Medium Trees 28–53 cm dia.		Large trees 54+ cm dia.	
Species	1836–59	1980	1836–59	1980	1836–59	1980	1836–59	1980	1836–59	1980	1836–59	1980
Abies balsamea	0·3	1·6	0·2	0·2	—	—	1·3	5·4	0·2	0·5	—	—
Acer rubrum	2·1	12·3	0·7	1·8	—	0·5	4·2	18·4	2·1	6·8	—	3·7
A. saccharum	1·4	6·2	3·4	3·0	2·5	—	0·5	0·4	0·4	—	—	—
Betula sp.	1·7		1·6		0·6		1·4		0·4		—	
B. alleghaniensis	—	—	0·2	—	—	—	0·3	0·1	0·2	—	—	3·8
B. papyrifera	0·6	2·2	0·1	0·7	—	—	3·0	4·8	0·6	1·6	—	—
Fagus grandifolia	10·1	1·6	8·7	1·9	—	—	5·4	0·2	4·0	—	—	—
Fraxinus sp.	0·1	0·1	—	0·4	0·6	—	2·3	3·8	1·7	2·3	—	—
Larix laricina	4·0	0·2	2·1	0·3	—	—	14·7	0·3	4·1	—	—	—
Pinus sp.	17·0		11·3		4·4		0·2		0·1		—	
P. banksiana	36·6	28·4	13·9	13·8	—	—	19·9	7·0	3·7	6·2	—	—
P. resinosa	4·9	6·2	35·0	11·8	60·0	43·5	5·4	5·8	41·7	10·3	23·6	10·6
P. strobus	4·8	1·4	9·2	2·5	28·8	20·3	7·9	0·5	18·0	3·0	63·6	48·0
Picea sp. largely *mariana*	2·5	1·8	0·6	—	—	—	5·2	2·0	0·3	—	—	—
Populus sp. largely *tremuloides* and *grandidentata*	2·6	11·7	1·1	12·5	—	0·7	5·1	10·9	1·9	23·8	—	—
Prunus sp.	—	0·7	—	0·4	—	—	—	0·3	—	—	—	—
Quercus alba.	3·3	4·5	2·2	6·0	—	—	2·8	5·5	1·6	5·9	1·0	3·6
Q. coccinea-rubra-velutina complex	2·0	14·9	1·4	38·1	—	23·9	2·0	12·4	0·9	31·7	4·1	26·9
Tsuga canadensis	2·9	—	5·5	1·0	2·5	—	5·9	0·5	11·8	0·2	6·7	—
Thuja occidentalis	2·6	5·4	2·3	0·2	—	—	11·7	21·4	4·8	6·3	—	3·6
Tilia americana	0·1	0·3	—	4·9	—	—	0·3	0·1	0·2	1·3	—	—
Ulmus americana	—	0·5	0·2	—	0·6	—	0·4	—	1·0	—	1·0	—
Miscellaneous	0·3	0·2	0·1	0·1	—	10·9	0·1	—	—	—	—	—
Total no. trees counted (thousands) (GLO survey or estimated 1980 survey)	2·1	72200	1·2	3270	0·16	40·2	1·95	67500	1·16	5270	0·2	92·2

hemlock–beech and sugar maple were converted to second-growth forests of sugar maple (Fig. 3a) (Woollett & Sigler 1928).

The change in the mixed pine type was more dramatic. All the authorities agreed that the fires which followed the logging in quick succession and not the logging itself were the major instruments of change (Beal 1901; Roth 1905b; Kittredge & Chittenden 1929). The slash left after the logging provided the fine fuel while the fires set by vandals, berry pickers, farm-clearing operations and sparks from railways supplied the ignition (Skeels 1903; Davis 1935). The earlier phases of the lumbering operation left a number of cull seed trees which eventually stocked the more disturbed and scarified sites with seedling pine (Beal 1903; Kittredge & Chittenden 1929). Unfortunately, most of the seedlings and eventually the seed trees were eliminated by successive waves of fires. Since few of the conifers bear cones until they are 20–50 yrs old, frequent fires favoured the sprouters—oak and maple—over the seed producers (Heinselman 1973). Kittredge and Chittenden's (1929) analysis of the scrub oak forests of northern lower Michigan showed most of the oak forests had been burned two or more times with an average interval of nine years between fires (Table 2). Fires also promoted the spread of aspen and maintained the more fire-dependent jack pine. It created the bare mineral soil required for aspen's (largely *Populus tremuloides* and *P. grandidentata*) seedling establishment and it stimulated root suckering by the aspen (Graham, Harrison & Westell 1963). Outside the selective harvesting of red pine in the openings and potentially a decrease in the age and size of the remaining jack pine due to more frequent fires, there is little evidence that human activities altered the jack pine plains or barrens (Roth 1905b).

Fires were not as common in the moist cut-over hardwood forests or the swamp conifer type (Roth 1905b; Beal 1888). Where they occasionally burned down to the mineral soil, they converted the maple forests and the swamp conifers into sprout forests of aspen and paper birch (*Betula papyrifera*) and fire or pin cherry (*Prunus pensylvanica*) (Fig. 3a) and dense stands of alder (*Alnus rugosa*) and willow (*Salix* sp.) respectively (Davis 1935; Michigan Land Economic Survey 1924).

The cumulative impact of the fires was profound. In 1905 Livingston described Crawford and Roscommon Counties as 'regions of dwarfed *Quercus alba*, *Quercus rubra*, *Acer rubrum*, and a number of shrubs. The oaks and maples are rarely more than twice as high as a man, are burned down every few years, and exist here only because of the fact that they sprout from the roots which are not always killed by the fire. Over vast stretches originally covered with white pine there are now no trees at all.' The Land Economic Survey reports of the 1920s (Michigan Land Economic Survey 1924, 1927) likewise emphasized the conversion of the pinelands to large expanses of sweet fern (*Comptonia peregrina*) and open stands of aspen suckers, scrubby oak and red maple (Fig. 3b; Table 4). The only species which increased on the former pinelands were the aspens and they were of little economic value (Maxwell 1912).

Forest protection period, 1920–50

The protection of the forests was a major concern of Michigan's early Forestry Commission, the Public Domain Commission, and later the more inclusive Department of Conservation. A more aggressive state fire-fighting policy, increasing state appropriations, and modern equipment and techniques eventually brought the fire problem under control. The incidence of fires and the total acreage burned dropped dramatically during the period from 1920 to 1940 (Table 2) (Mitchell & Robson 1950).

Reafforestation was really impossible until the forest fire issue had been resolved. The

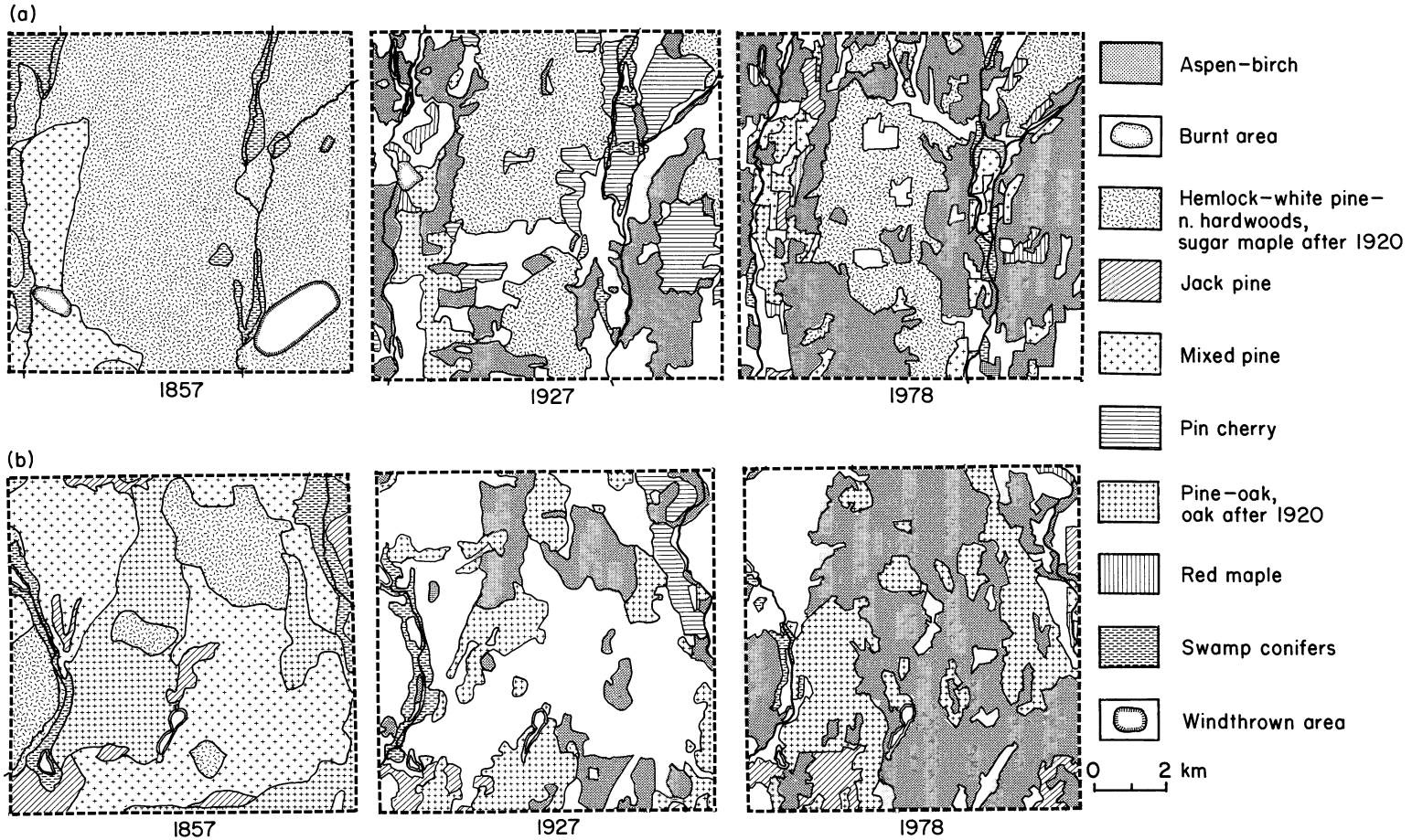

FIG. 3. Changes in areal extent of forest cover types of (a) Township 28N, Range 4W (originally a hemlock–white pine–northern hardwoods area) and (b) T28N,R2W (originally a representative mixed pine area), Crawford County. Unshaded areas are largely grasslands and open shrublands. Information based on GLO field survey notes and 1857 township plat maps, 1927 Michigan Land Economic Survey map for Crawford County and 1978 MIRIS township maps for Crawford County.

TABLE 4. Pre- and post-settlement extent of various forest types in Crawford County, Michigan. Values are percentages of total land area, i.e. of 145630 ha.

	1836–59 GLO Survey*	1927 Land Economic Survey	1979 Michigan Forest Resource Inventory
Hemlock–white pine–northern hardwoods†	16·4	3·7	4·5
Aspen–birch	0·0	12·0	18·9
Pin cherry	0·0	2·2	0·0
Mixed pine	27·4	0·3	7·8
Pine–oak	22·3	0·0	0·0
Oak	0·0	24·2	19·5
Jack pine	24·4	23·7	28·2
Jack pine openings‡	0·5	—	—
Lowland conifers and alder swamps	8·2	6·2	6·1
Grassland and upland shrubs (i.e. *Comptonia peregrina*, etc.)	< 1·0	20·6	8·0

* Percentages from GLO records based on percentage coverage of section lines by various vegetation types.

† Predominantly sugar maple after 1920.

‡ Probably included under category of poorly stocked jack pine forests after 1920.

TABLE 5. Summary of major forest types in Crawford County, Michigan by size-class and stocking of stands. Values are percentages of the total area for each forest type. Data from Michigan Land Economic Survey (1927) and unpublished forest inventory report on Crawford County, Michigan Forest Resource Inventory Programme.

Diameter class	Size-class 1927	Size-class 1979	Stocking*	Stocking* 1927	Stocking* 1979
Oak (35444 ha in 1927, 25749 ha in 1979)					
0–14 cm	92·5	7·2	poorly	25·1	13·7
> 14–24 cm	7·1	81·6	medium	57·6	25·1
> 24 cm	0·4	11·1	well	17·3	61·1
Aspen–birch (17530 ha in 1927, 24762 ha in 1979)					
0–14 cm	98·3	34·9	poorly	26·5	5·7
> 14–24 cm	1·2	60·4	medium	42·8	19·0
> 24 cm	0·5	4·7	well	30·7	75·2
Jack pine (34699 ha in 1927, 40918 ha in 1979)					
0–14 cm	77·9	33·2	poorly	30·6	10·3
> 14–24 cm	21·6	65·4	medium	48·8	28·7
> 24 cm	0·4	1·4	well	20·6	61·0

* Stocking refers to the relative number of trees ha^{-1}. In a *poorly* stocked stand the trees are few and scattered, crown cover is less than 40%. The canopy is still relatively open (40–69% crown cover) in a *medium* stocked stand. Trees are numerous in a *well* stocked stand canopy cover exceeds 69%.

lack of a seed source, the result of years of fires and cutting, inhibited the natural regeneration of white and red pine. Reafforestation started on a very small scale at the turn of the century and then expanded dramatically with the depression-born federal and state work programmes of the 1930s (Stone 1958a). Michigan has long been the centre of

reafforestation efforts in the Lake States. By 1956 approximately 20000 ha or 7% of the two-county area had been planted predominantly to red, jack and white pine (Stone 1958b). Artificial regeneration accounts for most of the recent increase in the areal extent of the mixed (now predominantly red) pine type (Table 4).

Pulpwood era, 1950–present

The decreasing incidence of fire in the 1920s and the 1930s allowed the regrowth of the forests. Both the density or stocking of the forests and the size of the trees has increased dramatically in the last 50–60 years (Table 5). A large share of the stands are in the 40–60 year age class and date to the effective implementation of a fire-control programme (Spencer 1983). The short-lived stands of pin cherry have disappeared (Table 4; Fig. 3a).

Since the 1950s the formerly worthless stands of aspen and to a lesser extent the jack pine have assumed a new, more economically vital role as sources of pulpwood, used in the production of paper, fiberboard and waferboard (Graham, Harrison & Westell 1963). Pulpwood has replaced lumber as Michigan's major forest resource (Fig. 2). Most of the aspen and jack pine forests are managed or clear-cut on a rotation cycle of 30–60 years (Chase, Pfeifer & Spencer 1970). Site-preparation of the area for regeneration often includes prescribed burning (Ron Wilson, personal communication). The low incidence of fire in recent years in the jack pine and aspen forest types (Table 2) has prompted concern about the difficulty of maintaining the short-lived, shade-intolerant aspen and jack pine indefinitely (Graham, Harrison & Westell 1963; Heinselman 1973; Abrams 1984). Unless cutting or fires intervene, most of the aspen stands start to deteriorate in 35–60 years (Graham, Harrison & Westell 1963). Jack pine stands, as in the case of the 'old-growth' jack pine tract at Hartwick Pines State Park, are considered mature at 90 years and generally begin to break up shortly thereafter (Benzie 1977).

DISCUSSION

The nineteenth and twentieth centuries are but brief intervals in the longer term Holocene history of forest change and development. Human activities during this period, however, have significantly altered the face of the Great Lakes forest. The post-settlement decline of beech, hemlock and white pine and the rise of the oaks in northern lower Michigan are all events which have been documented in the pollen record (Webb 1973). The historical record, however, provides a much more detailed picture of the scale of the change. It is difficult from the pollen record, for instance, to separate red pine pollen from jack pine pollen (Webb 1973) or to pick up the rise of the aspens, species which are poorly preserved in lake sediments (Cushing 1967).

Years of cutting and burning have created a new set of equilibrium conditions. Where the human-imposed disturbance regimes approximated pre-settlement conditions, i.e. in the fire-adapted jack pine type and in the swamp conifers, the change has been minimal. The pure jack pine type is still the dominant community on the drier, outwash sands of the study area, although it has had little success invading the former mixed pine sites (Livingston 1903) and concern has been expressed about its regeneration in the post-fire era (Heinselman 1973). Tamarack's representation in the swamp conifer type has declined (Table 3) due to perhaps natural outbreaks of the larch sawfly (*Pristiphora erichsonii* (Hartig)) (Graham 1956). Otherwise large natural areas like the Dead Stream Swamp in Roscommon County (Fig. 1) still preserve the pre-settlement character of the swamp conifer forest.

In other cases, the disparity between the primeval and the secondary forests is much more obvious. As in a variety of other studies in the upper Great Lakes region (Stearns 1949; Ward 1956; Mladenoff & Howell 1980), beech, hemlock and white pine were considerably more important in the pre-settlement hemlock–white pine–northern hardwoods type (Table 3). They are only slowly, if at all, regaining their former position.

The transition from the mixed pine type to the aspen and oak types (Table 4, Fig. 3b) reflects the human imposition of a new disturbance regime to which many of the larger pines were not adapted. As long as fires were infrequent, the few remaining mature pines following a fire rapidly saturated the burned site with light, wind-dispersed seed. White and red pine seeded in under the occasional oak sprout, completely dominated the open sites, and soon (in 20–40 years) surpassed the more widely spaced oak in growth rate (Kittredge & Chittenden 1929). Newly established oaks were subsequently relegated to a subordinate position as slow-growing seedlings or seedling-sprouts under the pine canopy. White and red pines' eventual dominance, consequently, was tied to the existence of a few mature pine which survived the fire, and to their prolific seeding habit. Cutting and repeated fires following the logging eliminated both the seed trees and the seedling pine. The oaks simply resprouted following the fires. When released from competition with the pine, the oaks seeded in the more open areas, eventually converting much of the mixed pine and pine and oak types to pure oak. As Maissurow (1935) noted, the disappearance of the pine 'was brought about by a disturbed balance between the seed-bearing capacity of the forest and frequency or destructiveness of forest fires'. The build up of a dense network of competing aspen roots and the advent of the white pine blister rust (*Cronartium ribicola* Fisch) have compounded the problems of regenerating pine. Some investigators (Ahlgren & Ahlgren 1984) have argued that it will be impossible to restore white and red pine to their pre-settlement status. Human exploitation also altered the configuration of the vegetation by creating a new, even more disturbance-mediated type of plant community. Due to its relatively shade-intolerant nature, aspen was a minor and temporary constituent of windthrows and other disturbed sites in the pre-settlement forest (Graham, Harrison & Westell 1963). It represented 2% of the bearing trees (Table 3) and was the first cited or most common species on only 1% of the surveyors' early section line descriptions of the two-county study area. Like the phoenix, however, aspen grew out of the ashes of the Great Lakes pine forest (Graham, Harrison & Westell 1963). It, and to a lesser degree jack pine, laid the foundations of the new industrial pulpwood forests of the Great Lakes region in the twentieth century. Historically it is a symbol of the exploitation of the region and at the same time a mark of the permanence, albeit in altered form, of the forests of the Great Lakes region.

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