Chapter 22
The Fire Research Program at the Silas Little Experimental Forest, New Lisbon, New Jersey

Kenneth L. Clark, Nicholas Skowronski and Michael Gallagher

Abstract In this chapter, we document the development and current research efforts of the fire research program at the Silas Little Experimental Forest of the Northern Research Station, USDA Forest Service, in the Pinelands of southern New Jersey. The 450,000-ha (1.1 million-acre) Pinelands National Reserve contains some of the most challenging fuel types for wildland fire managers in the eastern USA. These highly flammable forests occur adjacent to extensive wildland–urban interface and major transportation corridors. We first briefly discuss the ecological setting of upland forests in the Pinelands, highlighting how fire, past industrialization, and other disturbances have shaped the composition and structure of these forests. We then document the establishment of the Experimental Forest and the fire research program. We focus on the career of Dr. Silas Little, a silviculturist with the Northeastern Forest Experiment Station, Upper Darby, PA. Beginning in the late 1930s, his research on prescribed burning practices and silviculture in the Pinelands resulted in cost-effective methods to reduce wildfire risk while promoting the regeneration of commercially important timber species. We discuss how many of the prescribed burning practices developed during these research efforts are now used operationally by the New Jersey Forest Fire Service (NJFFS) and

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Silas Little, Jr., received a B.S. degree from Massachusetts State College, and M.F. and Ph.D. degrees from Yale University. In 1937, Dr. Little was assigned to the Forest and worked there until his retirement in 1979, much of that time serving as the research project leader. He was instrumental in conducting early research on forest regeneration and silviculture following intense land-use change (charcoaling for iron forges, mills, glassworks, and towns); thus, the use of prescribed fire to reduce wildfire hazard was designed simultaneously to promote tree growth in the New Jersey Pinelands. Dr. Little also conducted primarily silvicultural, fire, and forestry-related research in Maryland and Pennsylvania. He produced more than 100 publications, many of which focused on the Pinelands of New Jersey.

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federal wildland fire managers in the Pinelands. Finally, we highlight current and future research efforts at the Experimental Forest.

Keywords Prescribed fire · Wildfire · Forest management · Pinelands National Reserve · LiDAR · Hazardous fuels management

22.1 Forests of the New Jersey Pinelands

The potential for destructive wildfires in the pine-dominated forests of southern New Jersey has been dramatically illustrated numerous times. On average, 10% or more (>40,000 ha) of the predominantly pine- and oak-dominated forests could burn in a single year, and did at approximately 20-year intervals before the adoption of modern fire-suppression activities. The most notable recent major event occurred on the weekend of April 20–21, 1963, when wildfires burned 74,000 ha of forest, destroyed or damaged 186 homes and 197 buildings, and were responsible for seven deaths. More recently, a wildfire burned 7,786 ha in Ocean County in 1995, and during the late spring of 2007, 6,298 ha were burned near Warren Grove and the Garden State Parkway (Fig. 22.1, Table 22.1).

It is believed that park-like stands of pines with an open understory prevailed in the original upland forests as a result of frequent fires set by Native Americans, mostly during the fall and winter (Wacker 1979). The present-day forests have been shaped by previous land uses and extensive fire history, especially the occurrence of large, hot wildfires (Forman and Boerner 1981; Little 1979b). Most of the upland forest stands in the Pinelands have regenerated naturally following the cessation of logging and charcoaling activities in the late 1800s. As in the past, fire continues to be the major factor affecting stand age, species composition, and biomass and structure of these forests.

Wildfires burn primarily in upland forests in the Pinelands. Dominant tree species include pitch pine (*Pinus rigida*), shortleaf pine (*P. echinata*), and mixed oaks, primarily black (*Quercus velutina*), white (*Q. alba*), and chestnut (*Q. prinus*) oak. Understory vegetation is dominated by shrubs, including huckleberries (*Gaylussacia baccata*), blueberries (*Vaccinium* spp.), and scrub oaks (*Q. ilicifolia*, *Q. marilandica*). Pine canopies are burned far more frequently than oaks because most fires in the Pinelands occur during the spring when oaks are leafless (Fig. 22.1). During wildfires, pines may have only their foliage killed, or with greater fire intensity, apical buds and branches, yet individuals can survive and resprout new canopies from "epicormic buds" that occur in cambial tissue on stems and branches (Little and Somes 1951, 1956). This capacity to resprout from stems and branches following fire is retained into maturity in pitch and shortleaf pines, and contrasts with many other pine species. Following the most intense wildfires, regrowth of shoots from stump sprouts frequently occurs, but growth is retarded by the age of the stumps from which they originate, and by competition among large numbers of sprouts (Little and Somes 1951, 1964). Most of the fire damage to oaks occurs near the base, damaging or kill-

Fig. 22.1 A wildfire burns pitch pine (*Pinus rigida* Mill.) and scrub oaks in the Pine Plains in March 2006. (Photo credit Dr. Nicholas Skowronski)

Table 22.1 Recent major wildfires in the New Jersey Pine Barrens. (Data are from the New Jersey Forest Fire Service)

Date	Ha	County	Township
August 3, 2007	983	Burlington	Washington
May 15–19, 2007	6,300	Burlington, Ocean	Stafford, Bass River
August 15, 2002	1,100	Ocean	Plumstead
June 2, 2002	517	Ocean	Berkeley
June 10, 2001	600	Ocean	Little Egg Harbor
April 30, 1999	4,773	Burlington	Bass River
July 29, 1997	800	Atlantic	Hammonton
April 4, 1995	7,786	Burlington	Woodland
June 13, 1992	2,140	Ocean	Lacey
May 23, 1992	400	Burlington	Woodland
May 3, 1992	3,131	Ocean, Burlington	Lacy, Woodland

ing the cambium. When all of the cambium is killed and the aboveground portion of the stem dies, sprouts may initiate from buds located just belowground. Following severe wildfires, a dense understory of oaks can form from sprouts, along with scattered pine sprouts and seedlings.

Four major upland forest types can be recognized: Pine Plains, pine–scrub oak, pine–oak, and oak–pine (Forman 1979; Lathrop and Kaplan 2004; McCormick and Jones 1973; Skowronski et al. 2007). In the Pine Plains, the low stature of pitch pine and scrub oaks is a result of repeated severe wildfires (Little 1945, 1946, 1973, 1979b; Lutz 1934; Fig. 22.1). Severe fires at fairly frequent intervals (<20 years) have eliminated species that do not bear seed at an early age, such as shortleaf pine and canopy oaks (Little 1946, 1979b). Frequent wildfires have also favored a race of pitch pines that is relatively slow growing, develops a mature, often crooked form relatively early, and has serotinous cones. Nearly all individuals have crooked stems in "mature" stands because they have originated from stump sprouts following the last severe wildfire.

Pitch pine–scrub oak stands, which are similar in composition to those in the Pine Plains, arise from slightly less frequent and/or less intense wildfires. Pines are typically slow growing because many stems likely started as sprouts following a severe wildfire, and many individuals have lived through one or more large fires that damaged their crowns. Pine–oak stands are dominated by a mix of oaks and pines. In contrast to Pine Plains and pitch pine–scrub oak stands, the frequency and intensity of wildfires are lower, and the importance of oaks in the canopy is greater. Oak–pine stands are dominated by oaks with scattered pitch and shortleaf pines that survived the last and, often, earlier fires. This composition apparently results from severe fires at intervals of approximately 30–65 years, and certainly at longer intervals than in the Pine Plains and pitch pine–scrub oak stands.

Among mature upland stands of approximately the same age, canopy stature and biomass are typically greatest in oak–pine stands and least in pine–scrub oak stands (Forest Inventory and Analysis data at www.FIA.gov; Skowronski et al. 2007). In contrast, these forest types can be equally productive in terms of net CO_2 exchange in the absence of disturbance or drought (Clark et al. 2010b), and pine-dominated stands typically have higher gross primary productivity on an annual basis because pine foliage is displayed year-round. For example, Clark et al. (2010b) reported that net CO_2 uptake occurred in a pine–scrub oak stand throughout the winter months when air temperature during the previous night did not drop below 0 °C. Because foliage is displayed year-round, annual ecosystem respiration also can be higher in pine-dominated stands than in oak-dominated stands.

If fires are excluded and no other disturbances such as harvesting or insect infestations occur, hardwoods will gradually replace pitch and shortleaf pines and eventually dominate the stand. The succession from pines to hardwoods is due to two main factors: Hardwood seeds, being larger, can become established in the relatively thick litter and organic matter layers that accumulate in unburned stands, and hardwoods can survive and grow under lower light conditions than pines (Little 1973, 1979a). Fire history also affects the structure and composition of the understory (Buell and Cantlon 1953). For example, frequent light fires tend to reduce the shrub cover and favor herbaceous plants, especially along roads or under open stands.

22.2 Historic Use of Forest Resources in the Pinelands

Industrial development beginning in the late 1600s had a major impact on upland forests in the Pinelands (Pearce 2000; Wacker 1979). Harvesting of forest for timber, pitch, and charcoal to operate bog iron furnaces, forges, and glassworks occurred until the mid-1800s. In addition, a number of pulp and paper mills existed in the Pinelands until the late 1800s. These industries produced numerous goods for the large markets in Philadelphia and New York City. Following extensive harvesting for high-quality timber, second-growth and third-growth stands were harvested by axe for charcoal and pulpwood on an approximately 30-year rotation (Mounier

1997; Pearce 2000). "Colliers" or charcoal tenders would stack logs and then bury them with sand and humus for charring using oxygen-depleted fires. Covered log stacks typically measured 4–11 m in diameter, and were 2–3 m tall. The center was formed into a chimney or archway to ignite the logs and to control combustion. Separate holes in the charcoal "pits" were used to control the oxygen supply to the charring wood. Logs were charred for several days, depending on the size of the pile, the initial moisture content and condition of the wood, and weather conditions. Many of these charcoal "pits" are still visible throughout the Pinelands today.

Two industrial developments in the vicinity of the Experimental Forest are notable: the Mount Misery mill and the Lebanon glass works (Beck 1961). Mount Misery, located ca. 10 km from the forest, was one of the centers of the timber and charcoaling industries in the northern portion of the Pinelands in the 1800s. First settled in the early 1700s, Mount Misery once contained more than 100 homes, a store, and a hotel. It is also notable because it was the location of one of the early prescribed fire trials described below. The Lebanon glass works, located ca. 5 km from the Experimental Forest, employed more than 200 people and had 20 homes on-site at its peak. Sand in the vicinity contained few impurities, and the glassworks produced artistic as well as production pieces from 1851 to 1867, when it was finally abandoned because of local charcoal depletion (Beck 1961).

The Pinelands' population peaked around 1859 (Pearce 2000; Wacker 1979). The discovery of new sources of iron ore in Pennsylvania and the depletion of bog iron beds in the Pinelands led to the decline of the iron industry in the mid-1800s. By this time, industrial-scale charcoaling was also waning. Transportation of coal from Pennsylvania to the major urban centers by rail and local exhaustion of forest resources were major factors in the demise of the charcoal industry in the Pinelands. After the iron, charcoal, and glass industries collapsed, people gradually moved to other areas.

22.3 A Degraded Forest and the Beginnings of Silas Little Experimental Forest

Following the abandonment of industrial uses of forests in the Pinelands, most stands had been harvested repeatedly for timber and charcoal. Wildfires were apparently unchecked through the late 1800s and early 1900s. For example, one wildfire burned 50,600 ha in 1894, approximately 41,000 ha were burned in 1915, approximately 400,000 ha were burned in 1923, and eight wildfires burned 70,000 ha in May 1930. As an example closer to the site of the Experimental Forest, one scarlet oak (*Q. coccinea*) that was harvested to create a fire break in the late 1930s showed wildfire damage in 1878, 1884, 1889, 1900, and 1902. The essentially unregulated harvesting activities since the 1700s and repeated wildfires had resulted in poorly stocked stands of pitch and shortleaf pine with a dense understory of oaks that had originated from burned stumps. Many upland stands had entered into essentially a positive feedback loop, producing stands of wildfire-damaged pines and oaks that had little to no commercial value, and were prone to repeated wildfires. In a report to the State Geologist of New Jersey in 1899, Gifford Pinchot noted that wildfires in southern New Jersey needed to be controlled, and that without forest fire protection, forests could not be managed successfully for public benefit. As these forests regenerated and burned, a new interest in fire management and silviculture arose in the Pinelands.

By the late 1920s, state foresters considered the large contiguous stands of oak- and pine-dominated forests in the Pinelands to be highly degraded and in need of rehabilitation. State policy at the time was to remove the hardwoods in favor of planted conifers. It was also concluded that any rehabilitation of oak–pine stands that had originated from sprouts following wildfire had to be based on intensified fire protection and aggressive stand improvement techniques, including thinning and restocking by seed and/or seedlings.

It is within this context that the Silas Little Experimental Forest began (Adams et al. 2004). The fire research program dates back to 1927, when forest yield plots were established and weather measurements recorded at Camp Ockanickon. In 1933, the Northeastern Experiment Station and the Board of Conservation and Development, State of New Jersey, signed a cooperative agreement for a new location in Burlington County in response to increased recreation pressures at Camp Ockanickon. The State placed at the disposal of the Station 239 ha (591 acres) "for the purpose of conducting studies, experiments, and demonstrations in silvics and silviculture… to solve forest problems of the region typified by conditions in southern New Jersey. These may include experiments in obtaining natural reproduction of the forest after cutting, in thinning to stimulate growth, and in artificial reforestation; also, more fundamental studies of the factors which affect tree growth" (http://www.nrs.fs.fed.us/locations/nj/silas-little). Over the next few years, the USDA Forest Service (USDA FS) constructed an office, part of the current garage and a fire tower, and moved a bunkhouse to the site from Medford Lakes as part of a Works Progress Administration project. The Experimental Forest was initially known as the Lebanon Experimental Forest because of its location in the Lebanon State Forest.

In 1937, Dr. Silas Little, Jr., was assigned to the Forest. In addition to research on prescribed fire to reduce wildfire risk and silviculture of tree species in the Pinelands, major themes of his research were the ecology and silviculture of Atlantic white cedar (Little 1950, 1959; Little and Somes 1965) and tree improvement and the production of a pitch/loblolly hybrid (Garrett 1981).

22.4 Prescribed Fire in the Pinelands

When the fire research program got under way, limited use of prescribed fire was already in place in the Pinelands. The Lenni-Lenape Indians were the first to introduce prescribed burning to New Jersey's forests, using fire to facilitate travel, improve hunting, drive away insects, and also increase the availability of browse, acorns, and berries (Wacker 1979). Starting in the late 1600s, settlers in the

Pinelands cleared and burned forest and agricultural residue, two centuries before industrial forest clearing and burning (Pearce 2000; Wacker 1979). Beginning in the early 1900s, cranberry and blueberry growers protected their property by using prescribed fire to remove heavy accumulations of forest fuels from around their fields and buildings.

The New Jersey Forest Fire Service (NJFFS) first used prescribed burning practices in 1928 to protect state forestlands by burning along roadside safety strips (Little 1979b; Section Forest Fire Wardens of Division B 2006). Prescription burning along roads involved using low-intensity fires, mostly in the winter and early spring. Protection strips along roads were normally between 10 and 70 m wide. Following the large and destructive wildfires in 1930, state agencies expanded this practice to include larger blocks of woodland. There was also a precedent for silvicultural management of upland forests in the Pinelands, following ideas regarding regeneration of sprout oak stands. For example, the Civilian Conservation Corps undertook numerous projects in the state forests between 1933 and 1940. One of the most common treatments was thinning in predominantly oak stands on upland sites. Thinnings varied from very light, involving only the removal of trees that would die soon, to very heavy. Thinning treatments were usually justified on the assumption that growth of the residual stems would be stimulated. Thus, when the fire research program began at the Experimental Forest, the use of prescribed fire and silvicultural management techniques were accepted in the Pinelands, and it is likely that little public sentiment existed against these management practices. In fact, because of the long history of destructive wildfires, burning of hazardous fuels was viewed as an essential survival strategy for residents of the Pinelands (McPhee 1968).

22.4.1 Early Research Efforts on the Use of Prescribed Fire

In 1935, the State Forester of New Jersey proposed a large study of the effects of fire and the Experiment Station agreed to cooperate. A 30-year effort of active fire suppression by the State had not solved the problem of protecting the oak–pine lands against destructive wildfires. Two objectives of the 1935 agreement were to evaluate damage from wildfires and to compare losses from wildfires with the much lighter losses expected to occur from prescribed fires set under favorable conditions. The scope of this research included measurements of biomass and productivity of the sites, measuring changes in water-holding capacity of litter and soil and monitoring effects on wildlife.

Out of this agreement, the first studies of prescribed burning were initiated in 1936. An experimental area consisting of 16.2-ha blocks, each bounded by disked firebreaks, was installed at the Experimental Forest. Prescribed burns were to be conducted at intervals of 1, 2, 3, 4, 5, 10, and 15 years, with an unburned control. All blocks except the control were first burned in March 1937 (Little and Moore 1945; Fig. 22.2). All trees and tree reproduction in transects through the center of each block were recorded. Shrubs and litter were also sampled in subplots in each block. The New Jersey Agricultural Experiment Station investigated the effects of

Fig. 22.2 Prescribed burning near the Lebanon Experimental Forest (now the Silas Little Experimental Forest) in 1937. Note the leafless deciduous trees, indicating that this burn was conducted in late winter or early spring. (Photo credit Dr. Silas Little)

prescribed burning on soils, and soil samples were collected from preburning and postburning blocks and analyzed over the years. A second 14-block experimental area was installed and monitored near Mount Misery in 1940 (Little and Moore 1945).

Prescribed burning of large plots and blocks in interior forest in the Pinelands was more involved than burning plots along roads and required knowledge of forest fuels, fire behavior, suppression techniques, and local weather conditions. An orderly progression of sections in each block was burned sequentially to reduce the accumulation of fine and 10-h fuels on the forest floor and to reduce ladder fuels consisting of shrubs, saplings, and lower branches. Prescribed fires were typically conducted during the winter and early spring (note leafless canopies in Fig. 22.2). Horrace Somes, Jr., a recently retired Fire Warden for Division B of NJFFS, recalls that when he was a child, his father (Horrace Somes, Sr.) and Silas Little would conduct some prescribed fires at night to better control fire behavior.

Although prescribed burns were conducted primarily to reduce the wildfire hazard, prescribed burning also tended to create stands of seedling or seedling sprout origin, which permitted trees to develop without the deformities created by severe wildfires. Thus, these research efforts served a dual purpose. In oak–pine stands, use of prescribed fires favored the regeneration of pines, which had a higher commercial value than oaks at that time. One of the early papers published by Silas Little concludes that prescribed burning in the form of low-intensity winter fires in the oak–pine stands of New Jersey's pine region lessens the danger of severe spring fires and may also be used advantageously for preparing the seedbed for pine reproduction and the control of hardwoods (Little 1946). Further research indicated that frequent light fires under an overstory of pines or oaks cause significant mortality of acorns and seedlings and provide seedbeds unfavorable for most hardwood seedlings. Frequent prescribed fires did not damage the current stand appreciably

Table 22.2 Years and total area burned using prescribed fire in Lebanon State Forest (now Brendan Byrne State Forest) over a 9-year period from 1949 to 1957

Year	Area burned, ha	% Reburns
1949–1950	1,305	0
1950–1951	1,137	36
1951–1952	686	39
1952–1953	611	67
1953–1954	709	75
1954–1955	1,128	100
1955–1956	926	86
1956–1957	997	97

Percentages denote percentage of burns that were conducted in areas that had been previously treated with prescribed fire

but did provide conditions that favor pine seedlings to become established (Little and Moore 1949; Little et al. 1948).

By around 1940, active wildfire suppression by the NJFFS with better equipment had considerably reduced the average size of wildfires in oak–pine forests in the Pinelands (Forman and Boerner 1981; Section Forest Fire Wardens Division B 2006). Analyses by Forman and Boerner (1981) indicated that the average area burned annually dropped sharply from about 20,000 ha (50,000 acres) during 1906–1939 to 8,000 ha after 1940. Similarly, the frequency of severe wildfires decreased, and after 1940, oak- and pine-dominated stands burned at an average of 65-year intervals, compared with 20-year intervals earlier in the nineteenth and twentieth centuries.

However, large wildfires still occurred, especially during the late spring. One of the most interesting early accounts of the effectiveness of prescribed burning in reducing wildfire risk occurred on April 26, 1946. A wildfire had ignited to the north of the Experimental Forest near the railroad tracks in New Lisbon and burned towards the south. Firefighters from NJFFS attempted numerous times to backfire along roads moving from north to south to suppress the crown fire but failed because it was a class-five fire day, and weather conditions were causing erratic fire behavior and spotting from wind-driven embers. By 5:00 to 5:15 pm, a large head fire approached and then burned into a prescribed fire block just to the north of the Experimental Forest (similar to the treatment block in Fig. 22.2). Reduced fuel loading in the treatment block caused the head fire to lose intensity, and crews were able to suppress the spot fires that burned into the block.

In 1948, the practice of prescribed burning as a management tool for silvicultural purposes and fuels reductions on state and private lands was introduced to the public. Prescribed fires were used operationally in large forest blocks starting in 1949, and hectares burned per year in Lebanon State Forest are shown in Table 22.2. An attempt to conduct prescribed fires at various intervals is apparent, as indicated by the increasing number of burns conducted in previously burned areas. These areas are consistent with current burning practices in Brendan Byrne State Forest (previously Lebanon State Forest). For example, the NJFFS burned 501 ha (1,236 acres) in this state forest in 2007–2008.

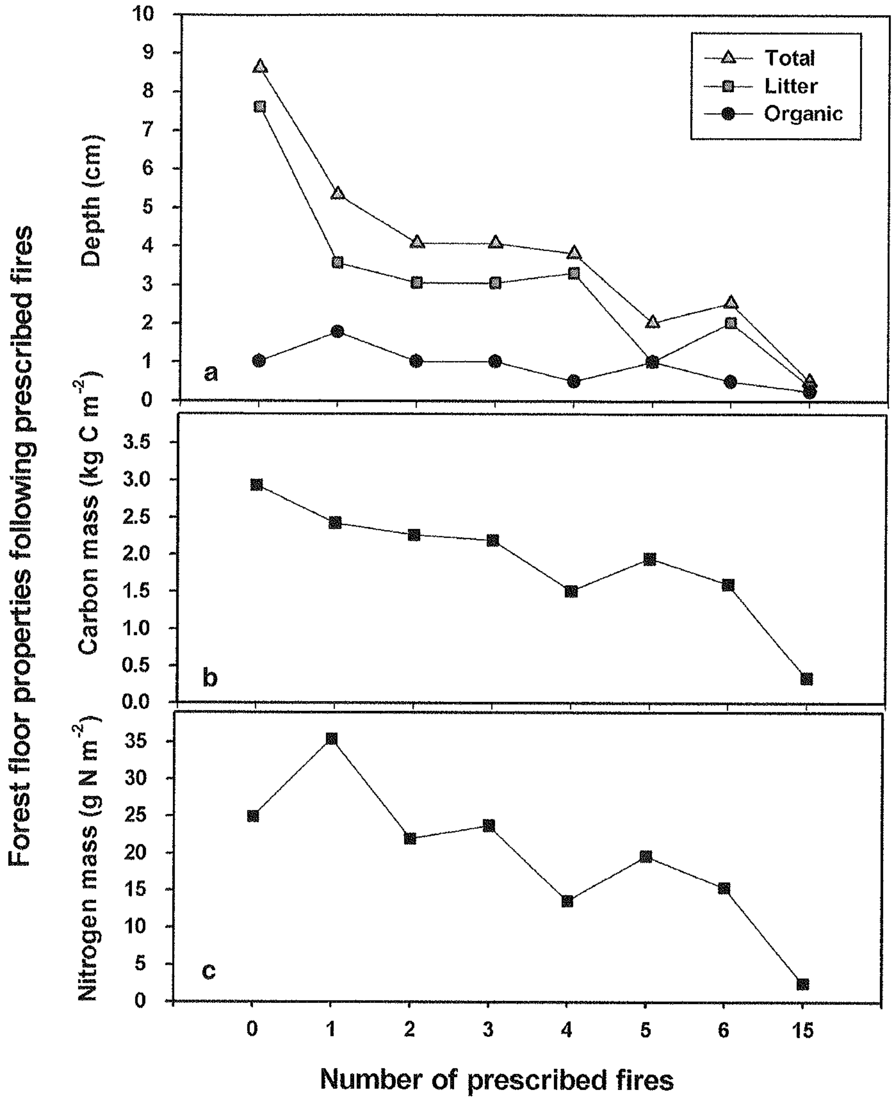

Fig. 22.3 Forest floor properties as a function of the number of prescribed fires conducted starting in 1937 at the Lebanon Experimental Forest. Variables are (**a**) litter layer (L horizon) depth, organic matter layer (O horizon) depth, and total depth; (**b**) total carbon content of the forest floor; and (**c**) total nitrogen content of the forest floor. (Data are plotted from tables in Burns 1952)

Further results of the study initiated in 1937 were published in the 1940s and 1950s. Repeated prescribed fires reduced the depth, mass, and nitrogen (N) content of the litter layer (L horizon) but had relatively little effect on the depth of the humus layer (O horizon; Burns 1952; Fig. 22.3). In terms of soil chemistry, repeated, low-intensity winter burns increased exchangeable calcium and pH but had only

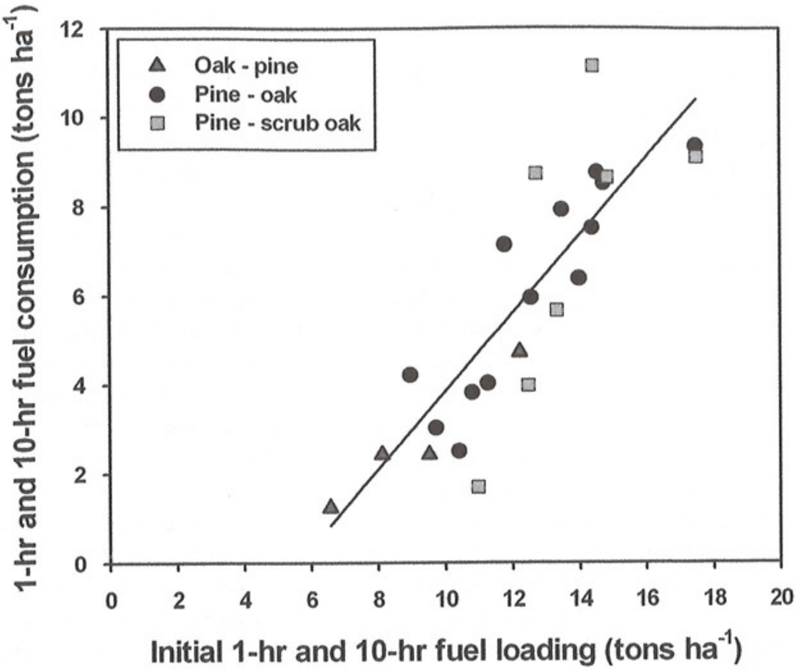

Fig. 22.4 The relationship between initial 1-h + 10-h fuel loading and amount of fuel consumed by forest type during 24 prescribed fires conducted in the Pinelands National Reserve in 2004–2009. Prescribed fires conducted in the Pine Plains were included in the pine–scrub oak category. Consumption = 0.898 (fuel loading)—5.319, r^2=0.722, P<0.001. (Redrawn from Clark et al. 2010b)

minor effects on nitrogen and phosphorus (P) contents, which overall were very low in the sandy soils at the Experimental Forest. Thus, low-intensity prescribed burning conducted in the late winter and early fall was effective at reducing 1- and 10-h fuels in the litter layer but had only limited impact on the organic horizon and surface soil layers. These results are consistent with current research results, which also indicate minimal effects of prescribed burning on organic matter layers, soil, and soil nutrients in Pineland ecosystems (Clark et al. 2009; Neill et al. 2007; Fig. 22.4).

Further research efforts addressed the effects of a series of prescribed fires and then the suspension of fire management activities on hardwood regeneration (Little 1973). Low-intensity winter fires used for a short period from 1954 to 1962 had relatively little effect in checking the development of hardwood understory after 18 years (1953 to 1971). In fact, the increase in the number of stems of primarily black and scarlet oak, but also white, post, and chestnut oaks, was greater in plots burned between 1954 and 1962 than in unburned plots. Results suggested that if succession were to be checked by fire alone, periodic winter burns should be followed by one or more summer burns, which are more effective at killing hardwood rootstocks. It was also concluded that periodic winter fires would be far more effective in reducing fuel loading and oak sprouts than a short period of use of prescribed burns followed by fire exclusion.

Dr. Little's research results and field observations were condensed into several "rules of thumb" for conducting prescribed fires in the Pinelands. In interior forest blocks that were used for firebreaks, prescribed burns were conducted at 4–6-year intervals. Less strategic blocks were burned at longer intervals, and roadside safety strips were burned at 1–2-year intervals. Two aspects of the research conducted by Dr. Little were unique. First, responses of different ecosystem components to varying frequencies of prescribed fire, as described above, had rarely been studied until then. Second, the arrangement of burn block locations and return intervals was designed to form a landscape-scale pattern of firebreaks. The early burn maps indicate a strategic orientation of the burn blocks, and in the earliest published results it is clear that Dr. Little had taken a landscape-scale perspective on the use of prescribed fires to protect against severe wildfires in the Pinelands. These landscape-scale firebreaks were oriented in a north–south axis because many of the severe wildfires burned from west to east on strong westerly winds in spring (Fig. 22.5).

Dr. Little first considered a checkerboard pattern of prescribed burns at the landscape scale but apparently realized early on that this was impractical to accomplish with 15–20 "safe" burning days occurring per year across more than 450,000 ha of forest. However, the landscape-scale distribution of rivers, wetland forest, and cranberry bogs provided an excellent opportunity to break up the largest extents of upland forest. For example, obvious fuel breaks occur in what is now Wharton State Forest between the Batsto and Mullica rivers and in two other north–south-oriented wildfire protection areas shown in Fig. 22.5. This effort was likely assisted by aerial reconnaissance; one of the first complete set of aerial photographs of the Pinelands was taken in 1937. Many of these original images and maps are available in the library at the Silas Little Experimental Forest today.

22.4.2 Prescribed Burning in the Pinelands today

Today, most of the practices initiated in the 1930s are still in use. The NJFFS is authorized to conduct prescribed burning by the authority of New Jersey Statutes, Title 13:9-2, General powers of department, and as specified in the NJ Air Pollution Control Code (Title 7, Subchapter 27). The prescribed burning season is limited to the period between October 1 and March 31, and the NJFFS burns an average of 4,000–6,000 ha of public lands and 2,000 ha of private lands annually. In addition to reducing hazardous fuel accumulations, prescribed burns provide a foundation for safer, more effective fire suppression and protection operations during wildfires. The second goal of Dr. Little's research, to provide commercially important timber, was never fully realized. The creation of the Pinelands National Reserve by the US Congress in 1978, expanded tourism on the coast, and the demise of local timber and pulp mills and the rising cost of hauling logs from the Pinelands essentially eliminated the timber industry from southern New Jersey.

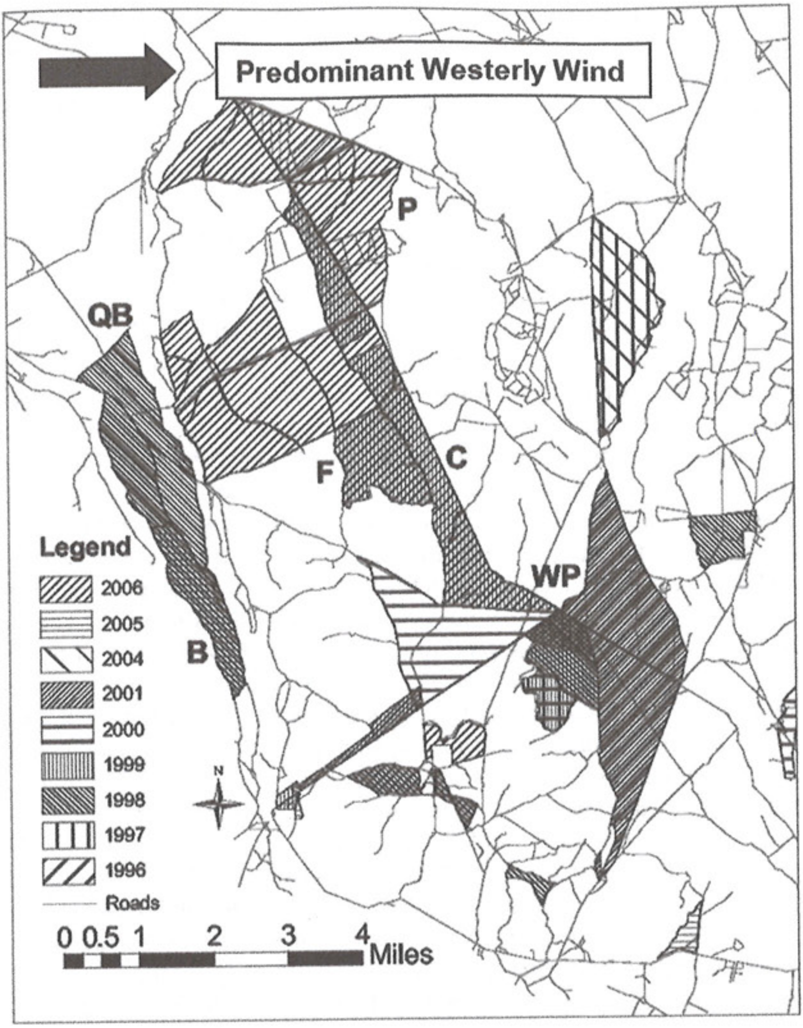

Fig. 22.5 Landscape-scale pattern of prescribed burn blocks in Wharton State Forest in the New Jersey Pine Barrens. Prescribed fires have been conducted in these blocks since the early 1950s, and prescribed burns conducted from 1996 to 2006 by the New Jersey Forest Fire Service are shown. Three large "firebreaks" consisting of multiple prescribed fires are visible: Quaker Bridge (*QB*) to Batsto (*B*) between the Mullica and Batsto rivers, Block *P* to the Washington Pike (*WP*) complex, and north of Washington Pike. These firebreaks are intended to limit the spread of wildfires from west to east with the predominant westerly spring winds. (From Clark et al. 2009)

Burn blocks in the Pinelands are arranged as they have been since the 1940s and 1950s. For example, three large fuel breaks are indicated on the map of prescribed burn blocks in Wharton State Forest (Fig. 22.5). Prescribed burning today follows many of the traditional practices, with some mechanized improvements. A written plan is first developed detailing the proposed burn, and once the plan is approved by the New Jersey Department of Environmental Protection, perimeter and internal firing lines are located and cleared using a tractor and fire plow unit, or occasionally a gyrotrack. The fire plow cuts a path through the forest floor down to the sand and gravel, usually between 30 and 60 cm deep. The lines are plowed in the fall after leaf senescence but before the ground freezes. As in the past, only about 15–20 optimum burning days occur during the burning season. These sometimes require coordination with the National Weather Service for prescribed fire "spot forecasts." Fire managers in the Pinelands also can now utilize real-time fire weather data provided by the USDA FS and the State Climatologist of New Jersey (available at http://climate.rutgers.edu/usfs/monitoring.php). On the correct day, burning crews first gather for a coordination meeting to summarize the burning plans. Crews then ignite the control and interior lines in a systematic and progressive manner to assure that the entire area is burned, utilizing drip torches to ignite the lines. All communications are by portable radio and cell phones, and aircraft or helicopter observations are used for the more difficult burns with heavy fuels. The NJFFS has recently acquired an aerial ignition device, which was first used successfully in spring 2009 to burn large prescribed burn blocks in the Pine Plains that had limited road access.

Prescribed burning in a given area is normally repeated on an interval of 4–8 years. Hazard reduction blocks and safety strips require burning at annual or biennial intervals. Other less strategic blocks are burned at longer intervals. The reduction of 1- and 10-h fuels during prescribed fires is largely a function of the initial fuel loading, with loading explaining 72 % of the variability in consumption when forest types are considered together (Fig. 22.4). Typically, only a portion of the litter layer is burned during prescribed fires, leaving the humus layer intact, consistent with results from the original study initiated in 1937 (e.g., Burns 1952; Fig. 22.3). The reduction of ladder fuels from 1- to 4-m height due to repeated prescribed fires over a 15-year period is shown in Fig. 22.6 (see Skowronski et al. 2007, 2011 for a description of Light Detection and Ranging, LiDAR, sampling in the Pinelands; Clark et al. 2009). These data generated from light detection and ranging (LiDAR) indicate that the 5–8-year burn interval is effective at reducing ladder fuels to below 20 % cover, while the landscape-level mean is ca. 39 % (Fig. 22.6).

Most wildfires continue to occur in Pine Plains and pitch pine–scrub oak forest types, as in the past. These stands are concentrated towards the eastern margin of the Pinelands, where, unfortunately, land-use pressures have resulted in a proliferation of residential subdivision and developments adjacent to these forests with heavy fuel loads. The "wildland–urban interface" or "WUI" is the term used to describe the placement of residential communities within forested areas. Forest fires burning into unprotected developments can take a large toll on lives and property. Prescribed burning to reduce forest fuels, coupled with other fire protection measures, can help provide an effective level of fire protection for homes and businesses in the WUI today.

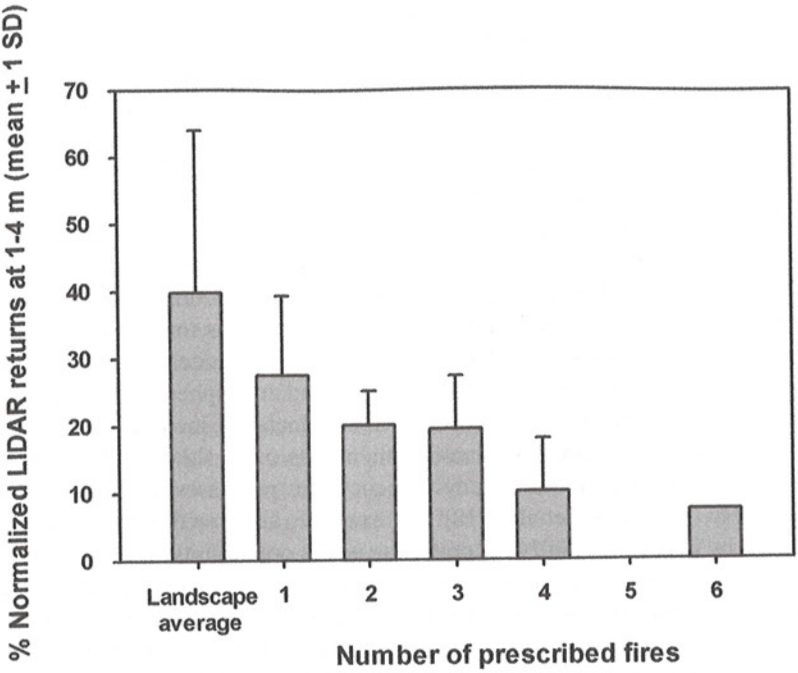

Fig. 22.6 Density of "ladder fuels" from 1- to 4-m height as a function of the number of prescribed fires conducted over a 15-year period (1991–2006) in Wharton State Forest. (Data are derived from profiling LiDAR, and were analyzed to estimate cover in 1-m height classes and then averaged from 1 to 4 m. From Clark et al. 2009)

22.5 Current and Future Research Efforts at Silas Little Experimental Forest

Following the retirement of Silas Little in 1979, the Experimental Forest was leased to Rutgers University. The Silas Little Experimental Forest was then reinstated with National Fire Plan Funding in 2003 to conduct research on fire weather and fire danger models specific to the Pinelands. Since then, substantial progress has been made in monitoring and delivering fire weather information to wildland fire managers (real-time fire weather data for the Pinelands available at http://climate.rutgers.edu-usfs-monitoring.php), measuring hazardous fuel loads (Clark et al. 2009; Skowronski et al. 2007, 2011; Wright et al. 2007), and assessing fire danger in the Pinelands. Current and future research efforts directed specifically towards the prescribed burning program encompass three major topics: (1) quantification and management of smoke from prescribed fires (Clark et al. 2010a), (2) quantifying trade-offs between hazardous fuels management and carbon (C) sequestration by forests in the Pinelands (Clark et al. 2009, 2010b), and (3) determining trade-offs between WUI protection and land-use change. These efforts are summarized in the following paragraphs.

In addition to the fire research program, scientists at the Silas Little Experimental Forest are also active in a number of the problem areas assigned to Northern Research Station Group 6, specifically an understanding of carbon and water exchanges between the land and atmosphere, and development of quantitative methods for ecosystem science. We have operated a number of eddy covariance towers in the dominant upland forest types since 2005 to quantify carbon and energy exchanges between these forests and the atmosphere (Clark et al. 2010b). Tower research sites are included in the USDA FS climate tower network and the Ameriflux network (http://public.ornl.gov/ameriflux/), and research efforts are consistent with efforts of the North American Carbon Program. In conjunction with forest inventory plots nested at 0.1, 1, and 9 km^2 scales around each flux tower, this monitoring network is capable of closing the landscape-scale carbon budget, i.e., accounting for all major exchanges of carbon between the land and atmosphere. The combination of disturbances that have recently occurred in the Pinelands, including fire, repeated invasive insect defoliation, and severe drought, has made the Silas Little Experimental Forest an ideal site for studying ecosystem processes during disturbance and recovery (e.g., Amiro et al. 2010). For example, all three flux tower sites were defoliated by gypsy moth in 2007, providing us the opportunity to quantify the impacts of invasive insects on disturbance and subsequent recovery of carbon, water, and nutrient cycling (Clark et al. 2010b; Schafer et al. 2010). Research efforts are consistent with Northern Research Station science themes—Managing with Disturbance, Sustaining Forests, and Providing Clean Air and Water.

Researchers at the Experimental Forest also have pioneered the use of LiDAR technology, which uses laser measurements to accurately quantify canopy and understory structure. We have utilized this technology to map hazardous fuels and evaluate the effectiveness of fuel reduction treatments conducted by the NJFFS and federal fire managers (Skowronski et al. 2007, 2011; Clark et al. 2009; Fig. 22.6). LiDAR technology can also be used to accurately project plot-based biometric measurements across the landscape for forest carbon inventories. Current research in this area at the Silas Little Experimental Forest is focused on improving the estimation of leaf area at the ecosystem and landscape scales for physiological studies and modeling purposes, and to estimate variations in canopy structure and fuel loading due to management and disturbance regimes. These efforts have been recently funded by the Joint Fire Sciences Program.

Management of smoke from prescribed burning is now a critical issue. Prescribed fires are subject to federal and state air pollution laws, and can affect air quality, highway traffic, and properties adjacent to urban areas that sometimes exceed state and federal standards for criterion air pollutants. Recent changes in the federal air pollution standards require reduced emissions of particulate matter, PM 2.5, to conform to hourly ambient air concentrations of 35 $\mu g\ m^{-3}$ rather than 65 $\mu g\ m^{-3}$, as well as reduced gaseous emissions. All adjacent smoke-sensitive areas must now be identified in the burning plan. Wind direction, wind speed, and smoke dispersal are some of the atmospheric characteristics that must be considered before conducting a burn. Firing techniques also affect smoke emissions, with backfires producing considerably lower emissions than other firing techniques.

We are currently using E-BAM Beta particle attenuators (Met One Instruments, Grants Pass, OR) to measure ambient PM 2.5 concentrations in the air at Silas Little Experimental Forest (Clark et al. 2010a). Mean seasonal ambient air concentration of PM 2.5 are highest in the summer, averaging 8.5 ± 8.0 μg m^{-3}, whereas burning season (January–May) PM 2.5 concentrations averaged 4.0 ± 5.0 μg m^{-3} in 2008. Seasonal patterns are consistent with previously measured PM 2.5 concentrations in ambient air at the margins of the Pinelands. E-BAM collectors were also used to measure ambient air concentrations of PM 2.5 during a series of prescribed fires near the Cedar Bridge Fire Tower in March 2008. Highest concentrations were measured in and near prescribed fires at the end of March 2008, peaking at 4,155 μg PM 2.5 m^{-3}. Following this peak, which was associated with flaming combustion within 1 m of the instrument, PM 2.5 concentrations dropped to below 35 μg m^{-3} within 12 h.

Using the combustion data presented in Fig. 22.4, published emission factors for particulate emissions during prescribed fires from the Environmental Protection Agency (WebFIRE at http://www.epa.gov/ttn/chief/efpac/index.html, Battye and Battye 2002) and a database of prescribed fire locations and sizes, we calculated emissions from prescribed fires conducted by the NJFFS from 2002 to 2009. Average fuel consumption for 24 prescribed fires conducted from 2004 to 2008 was 606 ± 319 g m^{-2}, and average emission of PM 2.5 was estimated at 8.2 ± 3.8 g m^{-2} during prescribed fires. Annual emissions from prescribed fires conducted by the NJFFS for 2002–2008 averaged 365 t PM 2.5 $year^{-1}$ and ranged from 256 to 611 t $year^{-1}$. For comparison, PM 2.5 emission estimated to have occurred during the Warren Grove wildfire (6,280 ha or 15,500 acres) on May 15–19, 2007, was 727 t (range of 535–913 t), approximately twice the annual emissions from prescribed fires. When considered in the context of overall total metric tons PM 2.5 emitted annually in New Jersey in 2002 (29,103 t $year^{-1}$), prescribed fire in New Jersey added an estimated 1.3 %, with a range of 0.9–2.1 % of total PM 2.5 emitted to the atmosphere across the state (Clark et al. 2010a).

Current research efforts involve conducting "fireflux" experiments by monitoring prescribed burns using an array of flux towers to measure turbulence and meteorological variables at multiple heights through the canopy in and around the burn block. These data will be used to estimate parameters for predictive smoke dispersion models, specifically CalPUFF, BLUESKY, and others used by the Eastern Area Modeling Consortium (http://www.ncrs.fs.fed.us/eamc/). This effort is part of a Joint Fire Science Program project to better understand and predict smoke dispersion from low-intensity fires. We also are continuing our research efforts with the USDA FS Fire and Environmental Research Applications Team, which is using consumption data from prescribed fires in the Pinelands to further develop models of forest floor and shrub consumption during prescribed fires (CONSUME 3.0).

A second set of currently unresolved questions involves the trade-offs between prescribed fires and wildfires in the context of carbon dioxide (CO_2) release to the atmosphere, and how both of these disturbances impact long-term rates of carbon sequestration by upland forests in the Pinelands. Our current research indicates that 24 prescribed fires conducted by the NJFFS from 2004 to 2009, where we collected preburn and postburn fuel loading data, released an average of 312 ± 138 g C m^{-2} to the atmosphere (Fig. 22.4). In contrast to these relatively minor losses due to prescribed fires, we estimated that the Warren Grove wildfire in May 2007 released approximately 874 ± 370 g C m^{-2} (Clark et al. 2010a). Following the initial combustion losses during prescribed burns, further CO_2 emissions from the forest floor were not enhanced appreciably over preburn levels during "fireflux" experiments conducted in 2006 and 2008. For example, the prescribed fire conducted at the Cedar Bridge flux tower in March 2008 resulted in an average combustion loss of 447 g C m^{-2} and killed aboveground stems of nearly all understory shrubs and scrub oaks. Following the prescribed fire, resprouting of pines and understory vegetation resulted in the rapid recovery of leaf area (Clark et al. 2010b, 2012). Excluding combustion losses, net CO_2 exchange for 2008 at the Cedar Bridge stand totaled 48 g C m^{-2} $year^{-1}$, a small net uptake of carbon. In 2009, leaf area had nearly recovered to pre-prescribed burn values, and daytime net CO_2 exchange rates are very similar to preburn levels, resulting in an annual uptake of 169 g C m^{-2} $year^{-1}$. Net CO_2 exchange had completely recovered by 2010, and averaged 194 g C m^{-2} $year^{-1}$ from 2010 to 2012. For comparison, mature undisturbed stands sequester 100–200 g C m^{-2} $year^{-1}$ (Amiro et al. 2010; Clark et al. 2010b; Pan et al. 2006), suggesting that burned stands begin to sequester C rapidly following prescribed fires.

The protection of homes and property in and around the margins of the Pinelands is an ongoing problem. Early on, Silas Little advocated 60-m-wide protection strips around structures and housing developments in the Pinelands. Currently, the NJFFS suggests using 30-m protection areas ("Do you have what it takes? 100 ft of defensible space!"; http://www.state.nj.us/dep/parksandforests/fire/aboutus.html) and has devoted considerable effort to educate homeowners as to proper fuel management techniques. However, the amount of impervious surfaces and lawns or other landscaping around homes impacts peak flows in streams during storms, and where these plantings require N and P fertilizers, they potentially degrade water quality (e.g., Dow 2007). One of us (NS) is working with the Center for Remote Sensing and Spatial Analysis at Rutgers University to quantify trade-offs between fuel reduction in the WUI and impacts on surface waters.

Future research efforts using the tools and monitoring network developed at the Silas Little Experimental Forest will involve the interactions of invasive insects, fire, and climate change. Although timber harvesting now occurs only on a very limited basis in the Pinelands National Reserve, disturbances from insect infestations, intense storms, and wildfire may increase with climate change. One new threat that will likely have a large impact on pine-dominated stands in the Pinelands is the northern migration of southern pine beetle, recently detected in southern New Jersey (http://www.state.nj.us/dep/parksandforests/forest/njfs_spb.html). Gypsy moth defoliation has already resulted in substantial oak mortality and an increase in coarse fuels on the forest floor. Mortality due to other insects has the potential to increase wildfire intensity, which may be further accelerated by a changing climate.

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