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Northeast Region
Boston, Massachusetts



Strategies for Managing the Forest at Morristown National Historical Park

Technical Report NPS/NER/NRTR--2006/040



ON THE COVER

Successional forest at Morristown National Historical Park
Photograph by: Robert Masson

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Introduction

Morristown National Historical Park is located in New Jersey's Morris and Somerset Counties, in the townships of Morris, Mendham, Bernards, and Harding. It was established in 1933 for the purpose of preserving the lands and features associated with the winter encampments of General George Washington's Continental Army during the winter of 1779-80.

The forest management strategies are intended to evaluate options for restoring and maintaining the MNHP vegetation to its condition at the time of arrival of George Washington's army and to articulate the need for goals and objectives of sustainable forest management in the context of historic preservation and rehabilitation.

While it is impossible to reverse the effects of 225 years of land use on the forest, any attempt at rehabilitation benefits from understanding the effects of past natural and anthropogenic disturbances on the land. The historic vegetation at the time of the encampment in 1779/80 has been pieced together from anecdotal accounts and inference. Although we have no quantitative data from which to determine presettlement forest condition, historical accounts and ecological research (Thayer 1975, Ehrenfeld 1982, et al.) are more extensive for MNHP than for many other areas. These indicate that the MNHP forest at the time of Washington's arrival was mature hardwood dominated by oak species (*Quercus* spp.), American chestnut (*Castanea dentata*), and hickory (*Carya* spp.). Prior Native American influence on the forest, though not well understood, is assumed from historical evidence of established Native American communities in the area. However, it is impossible to ascertain the age-class structure of the late eighteenth century forest without dendrochronological analysis (of timbers in colonial period houses if they exist), which is beyond the scope of this work.

Ehrenfeld's (1977 and 1982) research from early colonists' records and land deeds identified the species of boundary trees that characterized forest stands within the park at the time of colonization. These varied between an oak-hickory association on the higher slopes and an oak-chestnut association on the lower slopes around Primrose Brook. This analysis agrees with Braun (1950) and Raup (1938) on the historical distribution of these types of associations in the region. Seventeenth and 18th century travelers cited in Ehrenfeld (1982) described a dominance of oak and chestnut, along with yellow poplar, black walnut, and sassafras. Others mentioned the presence of poplar, beech, ash, linden (basswood), gum trees, hickory, hazel, mulberries, fruit trees, and blackberry bushes. Locust, maple, pine, and cedar were also noted, as well as an abundance of wild grapevine in the forests. A farm approximately 5 km south of Jockey Hollow, settled in 1730, was described as having abundant oak forest free from underbrush but with abundant grapevines.

Ehrenfeld's (1982) thorough witness (boundary) tree research for Jockey Hollow and Russell's (1981) study of pre-settlement vegetation in northern New Jersey confirm the anecdotal evidence given above. The dominant species of the area were oaks, hickory, and chestnut. Frequent mention of chestnut and white oak saplings implies that at the time of settlement the dominant species of the forests were reproducing (Ehrenfeld 1982). This is consistent with little mention of shade-tolerant witness trees like sugar maple and beech.

Important goals of modern park management are to preserve existing mature forests with the character of forests present at the time Washington's army arrived at the site and to restore "successional" stands to a mature forest condition (2004 General Management Plan for the Park). Perceived impediments to maintenance and restoration of modern hardwood stands are, among other influences, overbrowsing of young stems by the large resident deer population and competition from a variety of woody and non-woody invasive species. Concern by park personnel that they may not be able to prevent stands from becoming dominated by exotic species has spurred the need to develop forest management strategies which will identify options for management and evaluate their usefulness with respect to vegetation management objectives.

Compliance with NPS Policy and Relation to Other Plans

Establishment of Morristown National Historical Park

The park is comprised of four separate units totaling 687 ha (1,698 acres):

- A) Washington's Headquarters (approximately 4 ha or 10 acres), located in the town of Morristown, contains the Ford Mansion, which served as General Washington's headquarters during the winter of 1779-80.
- B) Fort Nonsense (approximately 14 ha or 35 acres) encompasses a prominent hill approximately 1.6 km (1 mi) west of Washington's Headquarters overlooking the town of Morristown. To fortify the hilltop, soldiers dug trenches and raised embankments in 1777 on the orders of General Washington.
- B) Jockey Hollow (approximately 538 ha or 1,330 acres), lying approximately 4.8 km (3 mi) southwest of Fort Nonsense, is the site of the "log-house city" constructed by about 10,000 troops during the winter of 1779-80.
- C) New Jersey Brigade (approximately 129 ha or 321 acres), located about 1.6 km (1 mi) southwest of the main encampment area at Jockey Hollow, preserves the site of the encampment of 1,000 troops from the New Jersey Brigade in 1779-80.

The townships surrounding the park—Mendham, Harding, and Chatham—were first settled in the 1730's. It is assumed (Thayer 1975) that the land was not extensively cleared until the arrival of Washington's army. While this is unlikely to have been the first anthropogenic disturbance, given the presence of resident native populations, it is likely to have been the most extensive, barring a stand-replacing natural event, including windstorm or fire (for neither of which have we any evidence). Upon their arrival in 1779, soldiers felled much of the Jockey Hollow forest for building log huts and procuring fuel for cooking and warmth. The construction of huts required abundant trees of a certain bole diameter, and these were apparently plentiful. A letter of Thomas Paschall dated 1683 mentioned that the woods were full of large oaks, "many of them about two foot through, and some bigger, but very many less." (in Myers 1940, cited in Ehrenfeld 1982). Peter Kalm (1770), riding the old road between Trenton and New York, stated that few trees were more than 200 years old, despite the evident absence of cutting by humans, and that the woods were open and easy to ride through (cited in Ehrenfeld 1982). This suggests a multi-aged, old growth forest which, having experienced natural disturbances and possibly Native American-ignited fire, contained an abundance of smaller age-classes.

After the war, much of the park area cleared by troops was converted into farm land through the expansion and subdivision of the existing farms as children married and moved into homes of their own. For example, the Pennsylvania Line across from the Grand Parade was developed into a farm after the war and was occupied from 1820 until around 1930 or so. Other farms were located near the New Jersey Brigade and along Jockey Hollow Road between the visitor's center and the maintenance building, where dairy cattle and sheep were grazed, and a portable saw mill was operated. The Guerins farmed land near the superintendent's house. The Kemble farm is still largely open pastureland from the northeast foot of Mt. Kemble, across its summit, and part way down the south side, as well as the lower southeast slopes of Mt. Kemble down to Route 202. An aqueduct built in the 1880's-90's disturbed the land across from the Primrose Brook Trail Center and along Primrose Brook. A water company ditch

was dug northeast of the Grand Parade near the huts and east of and perpendicular to Sugarloaf Road through which water was routed to Morristown (E. Olsen, NPS, personal communication). Much of the park area continued to be used as cropland or wooded pasture through the mid-19th century, when a regional decline in agriculture following the Civil War initiated the abandonment of fields and pastures. Some agricultural activity persisted on lands now within park boundaries, but most of these had ended by the early 20th century.

Decline of the American chestnut due to blight in the first two decades of the 20th century prompted salvage cuts that probably included at least some stems of associated species. Today, most of the park landscape is dominated by maturing stands of hardwoods. Areas held in fields until the late 19th and early 20th centuries are occupied by “successional” stands dominated by tulip poplar and other shade intolerant hardwoods. Understories of most stands have little regeneration, and many are dominated by exotic species. White-tailed deer, once rare enough to be protected in NJ, are now abundant in the park, and their impact on forest regeneration has become a prominent concern.

The cultural history of the area – both before and after the arrival of European’s in the late 17th and early 18th centuries – is summarized by Thayer (1975). Historic and modern vegetation have been described and sampled by Ehrenfeld (1975, 1982, 1999) and Southgate (Russell) (2002) (see several papers listed in “Literature Cited”).

President Herbert Hoover signed a bill establishing MNHP on March 4, 1933. Subsequently, the Town of Morristown donated Fort Nonsense. Lloyd Smith donated 404.7 ha (1000 acres) in Jockey Hollow. Washington Association stockholders approved the transfer of Washington's Headquarters to the park; and Charles McAlpin, owner of the former Kemble property, donated 50.2 ha (124 acres), which contained the Connecticut Brigade camps. The park was dedicated on July 4, 1933, with the 114-ha (281-acre) Stark Brigade site added later in 1937. The New Jersey Brigade area was not added until 1969. Other land acquisitions have occurred since then to round out park boundaries or protect historic resources.

A brief history of the establishment of Morristown National Historical Park follows, based primarily on the historical summary in the Morristown National Park General Management Plan and EIS. For additional detail, we refer the reader to these documents, and also to Cultural Landscape Inventories and Cultural Landscape Reports (not consulted in the preparation of this report) available from the Park Service.

Washington's HQ

Washington's Headquarters at the Ford Mansion was the first protected area or zone in the MNHP. Its protection came about partly through heightened interest in historic preservation surrounding the country's centennial by four citizens, one a former NJ governor, who formed the Washington Association of New Jersey on March 20, 1874. The Washington Association administered the site from 1874 to 1933 when the site was included in Morristown National Historical Park, the first national historic park in the nation (Morristown National Park General Management Plan and EIS; also see other park landscape studies including cultural landscape reports and cultural landscape inventories).

Fort Nonsense

The Washington Association commissioned a survey of Fort Nonsense in 1886 and placed a memorial boulder on the site in 1888. The property was bequeathed to the town in 1914 by Francis E. Woodruff. It was developed as a municipal park and a road was built to the summit. The Town of Morristown donated Fort Nonsense after President Hoover established the park. In the mid-1930's, CCC workers reconstructed the earthen parapets of Fort Nonsense and created a new entrance. In the 1960's, the earthwork was leveled by a contractor hired to remove dilapidated structures. In the late 1980's, some rehabilitation of the Fort Nonsense site occurred.

Jockey Hollow

Preservation of encampment remains dates to the efforts of Rev. Joseph Tuttle, c. 1871, who visited the encampment and mentioned seeing hut remains. Rev. Tuttle was among the first researchers to write about the encampment. In 1895, a proposal for the establishment of a 121.7-ha (300-acre) park, including Washington's Headquarters, the Morristown Green, the Morris Aqueduct land in Jockey Hollow, and Fort Nonsense, was presented to the Morristown Association for Public Improvement by George W. Howell. The proposal was not pursued at the time, but an expanded form of the concept re-emerged in the 1920's when large portions of Jockey Hollow were privately purchased in order to preserve them for the public. The earliest hut replica was built in Jockey Hollow in the 1930's.

In 1929, Morristown mayor Clyde Potts formed a historical commission to investigate the possibilities of preserving 404.7 ha (1000 acres) in Jockey Hollow. The chairman of the commission and a member of the Washington Association (Lloyd W. Smith) purchased the land using his own money "for the sole purpose of preserving this land for future generations by the creation of a park which would have national importance". An additional 121 ha (300 acres) in Jockey Hollow were owned by the town of Morristown for water supply. After President Hoover signed the bill establishing MNHP in 1933, Lloyd Smith donated his land in Jockey Hollow, and Charles McAlpin, owner of the former Kemble property, donated 50.3 ha (124 acres) that contained the Connecticut Brigade camps.

A Civilian Conservation Corps (CCC) camp established in Jockey Hollow in the summer of 1933 began a program of restoration and reconstruction, road building, and woodland maintenance. Guided by the 1934 General Management Plan, Jockey Hollow managers sought to "restore the area to that of the period when the cabins were just being completed and before too great a devastation had been effected on the woodland". Thus, the Wick House and farm were restored in the 1930's to illustrate the social life at the time of Washington's arrival. A few representative huts were reconstructed at key locations rather than attempting to build all of the huts and related structures that housed even one brigade. These huts were replaced in the 1960's using more recent historical evidence, while a hospital building was removed after it was concluded that such a building had not existed at the encampment.

Tempe Wick Road bypass, a loop road, and a new visitor center were completed in the 1970's in advance of the bicentennial, while the discontinued portion of Tempe Wick Road was interpreted as an historic trace. The new road configuration reduced through traffic in the park.

New Jersey Brigade

The New Jersey Brigade encampment site was acquired in 1969. Subsequently, NPS acquired large tracts of land to link the New Jersey Brigade site with the related encampments in Jockey Hollow. The Cross estate at the New Jersey Brigade site includes a complex of buildings unrelated to park themes.

NPS Management Policies

NPS Management Policies (2001) that guide and limit forest management activities at MNHP, as outlined in the General Management Plan, are as follows:

Boundaries: As part of the (GMP) planning process, the NPS will identify and evaluate boundary adjustments that may be necessary or desirable in order to carry out the purposes of the park. Boundary adjustments may be recommended to:

- (1) protect significant resources and values or to enhance opportunities for public enjoyment related to park purposes;
- (2) address operational and management issues, such as the need for access or the need for boundaries to correspond to logical boundary delineations such as topographic or other natural features or roads; or
- (3) otherwise protect park resources that are critical to fulfilling park purposes.

Natural Resources: The NPS will preserve the natural resources, processes, systems, and values of units of the National Park system in an unimpaired condition to perpetuate their inherent integrity and to provide present and future generations with the opportunity to enjoy them.

Cultural Resources: The NPS will preserve and foster appreciation of the cultural resources in its custody, and will demonstrate its respect for the peoples traditionally associated with those resources, through appropriate programs of research, planning and stewardship.

Interpretation and Education: Through interpretive and educational programs, the NPS will instill in park visitors an understanding, appreciation, and enjoyment of the significance of parks and their resources. Interpretive and educational programs will encourage the development of a personal stewardship ethic and broaden public support for preserving park resources.

These guidelines are broadly stated and may require further definition as specific management alternatives are discussed later in the report, as all management alternatives with the exception of a "hands off" or passive approach have the potential to create temporary disturbance in order to restore ecological integrity and a more natural condition. The tension between forest resources (vegetation) and wildlife (deer) will also raise issues that we will attempt to weigh in later sections. Boundary issues may arise through access needs and protection of sensitive

areas/resources from impacts of adjacent development. Cultural resources in any area of management concern must of course be identified and evaluated before any activity ensues.

Interpretive and educational opportunities abound with and without management of forest resources. For example, management of such factors as non-native, invasive species and deer may provide an opportunity to educate the public about sustainable forest management, functional forest ecosystems, threats to biodiversity, and future forest composition and structure.

Mission and goals for Morristown NHP

Based on the NPS service-wide goals and the MNHP authorizing legislation, the MNHP mission is to "conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations."

The park's goals, expressed in terms of desired resource conditions and appropriate visitor experiences, are in many cases prescribed by federal laws, regulations, and NPS policies. The mission goals stated in the 2004 General Management Plan and Environmental Impact Statement (2004 GMP) update the 1976 master plan and interim 1996 management objectives for the park. Those that pertain to forest management activities are as follows:

Goal Ia: The significant landscapes, structures, features, archeological resources, and collections of Morristown NHP are protected, preserved and maintained in good condition. They are managed within their broad cultural and ecological contexts.

Goal Ib: Morristown NHP contributes to knowledge about cultural and natural resources and associated values. Management decisions about park resources and visitor use are based on adequate scholarly information.

Goal IIa: Visitors safely enjoy and are satisfied with the availability, accessibility, diversity, and quality of park facilities, services, and recreational opportunities compatible with the park's mission.

Goal IIb: The public understands and appreciates the national significance of Morristown NHP, its regional context, and appreciates the preservation of park resources for this and future generations.

Goal IIIb: Through partnerships with other federal, state and local agencies and nonprofit organizations, a nationwide system of parks, open space, rivers and trails provides educational, recreational, and conservation benefits for the American people.

Goal IIIc: Assisted through federal funds and programs, the protection of recreational opportunities is achieved through formal mechanisms to ensure continued access for public recreational use.

Goal IVa: Morristown NHP uses effective management practices, systems, and technologies to accomplish its mission.

MNHP General Management Plan and EIS

A general management plan adopted in 1934 guided early development of MNHP. The MNHP General Management Plan and Environmental Impact Statement (2004 GMP) that replaces this plan was approved in April 2004, and Alternative C, the chosen alternative, provides the objectives on which we base our recommendations for forest management. The philosophy behind Alternative C is described as follows in the 2004 GMP:

Alternative C would emphasize the encampment period; however, it would also recognize the efforts of successive generations (1873-1942) to protect, interpret, and commemorate the encampments. The park would employ interpretive methods, such as programs, exhibits and other media, and focused rehabilitation of the landscape to present to visitors a scene evocative of the encampment period. This alternative would also preserve selected 19th and 20th century conditions and features added to the historic scene, and might draw on them to illustrate the important and complex history of park resources.

Land resources would be managed as follows:

Beyond established interpretive areas, such as the Wick Farm and Pennsylvania Line, lands would be managed to sustain a mixed hardwood forest as a cultural and natural resource. Management would employ expanded scientific inventory and monitoring to provide information on biological diversity, sustainability, and potentially adverse changes.

To the fullest extent possible, park management would try to identify and prevent undesirable intrusions on lands surrounding the park. This could be accomplished through a range of conservation methods and authorization to acquire up to 202.8 ha (500 acres) on a willing-seller basis.

An issue highlighted in the early pages of the 2004 GMP provides one focus of our study:

An initial assumption that natural succession would result in reforestation similar to that of pre-encampment times has proved inaccurate. Invasive nonnative species have become prevalent. Changes to the character of the historic landscape have compelled a reexamination of management policies and called into question the policy of passive forest management (Morristown National Park General Management Plan and EIS, 2003).

We have attempted to clarify how knowledge of the park forest's disturbance history, current condition and ongoing dynamics (in the context of Egler's [1958] initial floristics theory and Gleason's [1926] individualistic response theory) could affect (complicate) current and future management decisions, and the tradeoffs of "passive" vs. more active forest management.

In the 2004 GMP, the alternatives were evaluated across five management zones and by five attributes: desired resource conditions, desired visitor experience, management activities/treatment, kinds and levels of visitor use, and kinds and levels of new development. For the Sustainable Forest Zone, Alternative C proposes the following:

Desired Resource Conditions: Mixed hardwood forest is sustained, naturally regenerating, reflecting historic character, biodiversity and natural processes; woodlands, buffer zones, fields, interpretive exhibits, trails and scientific devices.

Desired Visitor Experience: Reflective, tranquil, solace; little interpretation.

Management Activities/Treatment: Predominantly moderate level of management, with limited areas of intensive management, directed by the results of ecological research. Treatment is rehabilitation.

Kinds and Levels of Visitor Use: Low levels of hiking, horseback riding, and other non-motorized recreational uses as appropriate.

Kinds and Levels of New Development: Scientific devices and new small-scale interpretive wayside exhibits.

For the water quality protection zone, which could potentially be affected by forest management activities, the alternative C prescription is:

Desired Resource Conditions: No degradation of water quality as measured by biota and chemical parameters.

Desired Visitor Experience: Reflective, tranquil; very low interpretation.

Management Activities/Treatment: Moderate levels of resource and visitor management including water quality monitoring and maintenance of narrow trails, bridges, and limited stream access points. Treatment is rehabilitation.

Kinds and Levels of Visitor Use: Low levels of hiking; fishing in accord with state regulations.

Kinds and Levels of New Development: Minimal

Relation to Previous Studies, Other Plans and Projects

Natural Resource Challenge: NPS instituted the Natural Resource Challenge Program in 1999 to address a lack of scientific information about the complex ecosystems and natural resources in parks. The program aims to apply good science to park management. According to the 2004 GMP, ten strategies have been identified to sustain natural resources. They include protecting native and endangered species and their habitats, aggressively controlling nonnative species, enhancing the use of parks for scientific research, and enhancing environmental stewardship. As part of the program, MNHP is monitoring key environmental variables that indicate ecosystem health, including reptiles, amphibians and fish, and vegetation (through mapping).

These forest management strategies follow on the heels of Ehrenfeld's and Russell's combined 25 years of study and recommendations for the park's forest land. We review and re-evaluate their findings, relying on their research to provide historical context and baseline data.

Key studies also include Cultural Landscape Reports and Cultural Landscape Inventories for each site. Although these were not reviewed in the preparation of this report, they should be consulted before management alternatives are implemented to ensure protection of cultural resources.

Description of Morristown National Historical Park

Location, Area and Boundaries

The park is located in north central New Jersey, near the border between the Highlands and the Piedmont physiographic regions. The Highlands encompasses over 8094 km² (two million acres) from western Connecticut, across the Lower Hudson River Valley and into east central Pennsylvania. Within New Jersey, the Highlands are a special resource area. Within the Highlands, the park lies about 48.3 km (30 miles) west of New York City, comprises nearly 687 ha (1698 acres), and includes the four geographically distinct units described above. The largest areas, Jockey Hollow and the adjacent New Jersey Brigade, encompass two northeast/southwest-running ridges of hills, with Primrose Brook and the Passaic River bisecting the two areas, respectively. Bordered by forested open space or sparsely settled residential land, their topography, landscape context, and land use history provide for a diversity of forest types and habitat characteristics. Fort Nonsense and Washington's Headquarters are smaller units located within the city limits of Morristown. Having limited forest resources and a more degraded landscape context, their forest resources have not been independently evaluated here. The Fort Nonsense forest was sampled (1 plot) and data included with the discussion for Jockey Hollow. Many of the forest management guidelines we identify for Jockey Hollow will apply to Fort Nonsense and the New Jersey Brigade as well, as the forests have related land use histories.

Cultural Resources

Cultural resources dating to the period of the encampment of George Washington's army abound at MNHP. In particular, the Wick House and surrounding cultural landscape, remnants of reconstructed log huts, stone structures, and other archeological traces on the land left by Washington's army are all features that are to be preserved for public enjoyment and education under the NPS Management Policies (2001). These resources must figure into any plan for forest management to avoid unwanted impacts.

Climate

The climate of north-central New Jersey is essentially continental due to a prevailing westerly airstream bringing extreme temperatures not moderated by the State's extensive coastline. The park's average temperatures are -3° to -2°C (26° to 28°F) in January and 22° to 23°C (72 to 74°F) in July. Nearly all of New Jersey experiences over 100 cm (40 in) of annual precipitation, with the highest amounts in the north-central area. Morristown NHP averages 117-122 cm (46-48 in) annually (2004 GMP).

Topography/Geology

The topographic description below is from an ecological perspective. Analysis of how the landforms influenced the movement of Washington's troops may be found in a Cultural Landscape Report or Cultural Landscape Inventory for the properties.

Lying northeast of the Ramapo Fault, which marks the border between the Highlands and the Piedmont physiographic regions and runs parallel to Route 202, the park is bordered by the Trowbridge range to the west and the Piedmont to the east. It consists of hilly terrain with ridges trending northeast-southwest, giving most slopes an eastern or western exposure (Ehrenfeld 1982). The hills are underlain by hard crystalline rock, mostly gneiss, containing deposits of iron, graphite and mica. Ehrenfeld (1977) reports that the Jockey Hollow area was covered by the ice sheets of the Jerseyan and Illinoian glaciations during the Pleistocene, but lies south of the Wisconsin glacier's terminus. This would place it in the Parker-Edneyville Highlands Land Type Association (US Forest Service classification), with the parks soils being largely derived from the bedrock, not glacial till (Ehrenfeld 1977).

Topography is well-described in the 2004 GMP Natural Environment section, from which we provide the following synopsis:

New Jersey Brigade: comprised of two hills separated by the Passaic River. In the southwestern portion, an unnamed hill is bounded by Indian Grove Brook, and the northeastern portion includes the southwestern slope of Blachley's Hill. Elevations range from lows of 110 and 116 m (360-380 ft) along Indian Grove Brook and the Passaic River, to heights of 182 m (600 ft) on Blachley's Hill and 195 m (640 ft) on the unnamed hill.

Jockey Hollow: consists of a small Y-shaped valley formed by two branches of Primrose Brook, surrounded by a series of low hills. At the northern edge of the unit Sugarloaf Hill reaches 230 m (756 ft). The other hills in the unit have peaks between 189 and 230 m (620-700 ft) and include Tea Hill (195 m) and Mount Kemble (213 m). Low terraces between 165-177 m (540-580 ft) occur along the gently descending Primrose Brook, which begins at 115 m (380 ft) at the northern edge of the unit and drops to 112 m (370 ft) at the southern edge.

Fort Nonsense: lies on top of a long escarpment that extends northeast from Mt. Kemble. It reaches 177 m (580 ft) at its height in the center of the unit and a low point of 122 m (400 ft) at its northeastern edge. Fort Nonsense affords panoramic views to the east.

Washington's Headquarters: lies on a low terrace overlooking the Whippany River to the north, but separated from it by I-287 and Lafayette Avenue. The unit ranges in elevation from 104 m (340 ft) near the mansion to 91 m (300 ft) near the visitor parking area.

Soils and Parent Material

Five soil series are present in the Jockey Hollow and New Jersey Brigade Units: Edneyville, Parker, Califon, Meckesville and Cokesbury (Ehrenfeld 1982, 1992). The areas of the park used for the encampment of General Washington's soldiers, Jockey Hollow and New Jersey Brigade, are on the Byram and Losee gneisses of the Highland Province. The soils are developed from granitic gneiss parent material. The upland soils include both well-drained gravelly loams in the

Edneyville series and excessively drained extremely stony sandy loams of the Parker series. The Edneyville soils are well-suited for agriculture and are more common on the gentler slopes and level areas in the western half of the park. Substantial weathering of the generally mineral-rich gneiss rock moderates what would otherwise be generally poor acidic mountain soil (Cleland et al. 1997). The stonier Parker soils, not suited to agriculture, are largely situated in the NJ Brigade west of the Passaic River as well as the forested area southwest of the open fields of the Jarvis estate and the steeper southern and eastern slopes of the Cross estate. Parker soils are also characteristic of Mt. Kemble on the eastern side of the Jockey Hollow. The slopes and valley bottoms of both areas include the moderately well drained to poorly drained, very stony loam of the Cokesbury series along the brooks (Primrose and Indian Grove Brook) and the poorly drained loams of the Califon series (characterized by restricted drainage due to a fragipan), are found on gently sloping land and in stream valleys, and east of the Passaic River. River and stream banks are subject to periodic flooding, and alluvial sediments are found in a broad band along the margins of the Passaic River (Ehrenfeld 1982, 2004 GMP). Washington's Headquarters unit and the eastern portion of Fort Nonsense are on Riverhead-Urban soils, gravelly sandy loams formed on outwash plains and terraces, ranging from well drained to somewhat poorly drained.

Land Type Association (LTA) and Ecoregional Cover Types

USDA Forest Service's National Hierarchical Framework of Ecological Units provides a land classification system that integrates forest cover types, soil types, and natural vegetation types into a hierarchical classification from areas of coarser scale to progressively finer scale ecological similarity. Landscape type associations or LTAs are landscape-scale units of similar ecological potential and response to disturbance and human activity. LTAs reflect land formations, soil processes, major forest types, successional trends, and forest productivity. They may also incorporate differences in stream characteristics, wetlands, and features such as disturbance patterns. They correspond to groupings of natural communities that tend to reoccur together (Cleland et al. 1997). Use of this classification system aids comparison to other forests in the same region, so that differences in condition or composition due to land use history, disturbance factors, etc. may be more easily assessed and a broader scale landscape perspective provided.

The MNHP lies on the southeastern border of the NY-NJ Highlands region, near the border between the Rockaway Highlands and the Parker-Edneyville Highlands LTAs. Soils within both LTAs are as described above for MNHP, with the Rockaway Highlands being glaciated in the Wisconsin period and the Parker-Edneyville LTA being south of the Wisconsin terminal moraine. Common tree species include white oak (*Quercus alba*), black oak (*Quercus velutina*), red oak (*Quercus rubra*), sugar maple (*Acer saccharum*), American beech (*Fagus grandifolia*), black birch (*Betula lenta*), red maple (*Acer rubrum*), white ash (*Fraxinus americana*), sassafras (*Sassafras albidum*), and yellow poplar (*Liriodendron tulipifera*). Yellow poplar is the most abundant species in many areas, probably because of the abundance of deep, well-drained mountain soils found throughout the LTA. Chestnut oak (*Quercus prinus*) and scarlet oak (*Quercus coccinea*) are sometimes common on hilltops and rocky plateaus, and red maple and white ash are most common on wet, rocky flats (Cleland et al. 1997).

Vegetation

Existing Condition: Age-class and Composition, Results of Coring Analysis

Twelve permanent vegetation plots at Jockey Hollow established by Ehrenfeld and Russell (Southgate) in 1995 were relocated, and one plot was established by Patterson and Shaw in 2003. In these plots, all live trees and saplings were sampled for diameter at breast height (1.37 m or 4.5 ft), canopy strata, and status (live or dead). Relevé data (Mueller-Dombois and Ellenberg 1974) were recorded for nine plots. In most plots, trees down to about 10 cm dbh were cored with an increment corer (in plots with plentiful saplings, some saplings less than 10 cm dbh were cored). Core samples were taken to the lab, sanded or sliced longitudinally, and growth rings counted and measured using a De Rouen dendrochronometer with accuracy to 0.01 cm. Mean Annual Increment (MAI) was calculated, and for some trees the periodic annual increment. One hundred and forty-six cores yielded complete growth data. Some trees were found to be rotten at the core, and some (in plot BE) were measured, but not cored. The sampling data and cores yield the following composition and age-class profile.

Overall Composition

Species constancy, or the number of plots (out of a total of 12) in which a species was found, provides a sample of the distribution of species throughout the forest. Percent constancy and the canopy strata each species is found in are given in Table 1.

Forest stands represented by the permanent plots are divided into two groups based on successional status. A vegetation map illustrating forest cover types was developed by Ehrenfeld (1978) and forms the basis for the distinct zones. To confirm this delineation, determination of successional status for each plot was based on a cluster analysis of vegetation data for nine of the 12 plots for which we had relevé data. The cluster analysis follows as Figure 1.

Cluster analysis is a method of vegetation classification that includes various polythetic agglomerative or divisive hierarchical techniques. Using species abundance information in this case (percent cover, estimated visually), each sample is assigned to a cluster and grouped into a hierarchy of larger clusters until a final cluster contains all samples. Cluster analysis computes a dissimilarity matrix using a chosen distance measure. The distances between samples in dissimilarity space then define the axis of the space, and a linkage method is employed successively to build a hierarchy of clusters (Gauch 1982).

The cluster analysis shows how the vegetation of 9 plots for which relevé data was recorded groups in an agglomerative method. All plots with -E in their plot name (E designates the presence of exotics at the time the plot was first established) grouped together, along with plot FN1S from Fort Nonsense. These are the "successional" plots, thought to be situated on land that was cleared and kept open for agriculture following the revolutionary encampment. Plot CE2 grouped with successional plots. However, it contains one cohort of the oldest trees (142-175 years) in Jockey Hollow, with no younger cohorts. While it is even-aged and probably open-grown, and has an understory dominated by invasive species, we consider it a mature forest plot due to its advanced age.

Table 1. Species percent constancy.

Species	# Plots Found in	% Constancy*	Canopy Layers**
<i>Acer rubrum</i>	9	75%	3C,5I,19S,
<i>Quercus spp.</i>	9	75%	1D,28C,3I
<i>Fraxinus americana</i>	6	50%	7C,2I,5S
<i>Betula lenta</i>	5	42%	3C,6I,14S
<i>Carya glabra</i>	5	42%	4C,3I,6S
<i>Liriodendron tulipifera</i>	5	42%	1D,6C,2I,3S
<i>Fagus grandifolia</i>	4	33%	4C,7I,9S
<i>Cornus florida</i>	4	33%	S
<i>Acer saccharum</i>	2	17%	C,S
<i>Hamamelis virginiana</i>	2	17%	S
<i>Acer platanoides</i>	1	8%	I,S
<i>Ailanthus altissima</i>	1	8%	S
<i>Prunus avium</i>	1	8%	S
<i>Prunus serotina</i>	1	8%	I
<i>Ulmus rubra</i>	1	8%	S
<i>Amelanchier sp.</i>	1	8%	S
<i>Betula alleghaniensis</i>	1	8%	S
<i>Carpinus caroliniana</i>	1	8%	S
<i>Celtis occidentalis</i>	1	8%	S
<i>Juglans nigra</i>	1	8%	I
<i>Ostrya virginiana</i>	1	8%	S
<i>Robinia pseudoacacia</i>	1	8%	1C,2I,1S
<i>Sassafras albidum</i>	1	8%	S

*Constancy is the number of plots (out of a total of 12) on which each species occurs.

Percent constancy is the number of plots divided by 12 x 100.

**Canopy layers are D=dominant, C=codominant, I=intermediate, S=suppressed.

Numbers before canopy layers are the total number of trees of each species found in each layer.

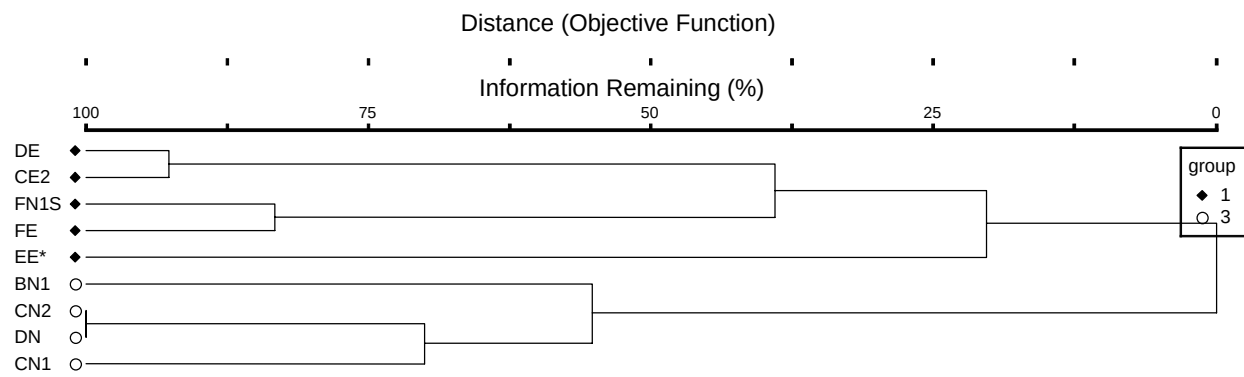


Figure 1. Cluster analysis of vegetation based on relevé data.

Plots for which we lacked relevé data, AN, AE and FN, are included in groups according to designation -N or -E in their plot name or where they appear on the GPS'd version of the forest zone map. (The designation -E in a plot name refers to the presence of non-native species, -N indicates that only native species were present in the plot at the time it was established.)

Table 2 compares age, size, and growth indices for mature and successional stands. Because data on dbh/age ratios of smaller and larger trees were needed in order to determine whether age can be estimated based on diameter for all or some species, where saplings were present, some stems <10cm dbh were measured and cored. In the following table, only tree species are included. The range of dbh's and ages are given, along with the count of trees used in calculation of basal area (BA) for the plot. It is apparent that although the difference between the average dbh and basal areas of mature vs. successional plots is not large, the average ages of trees in mature vs. successional stands differs by more than 20 years.

Species frequencies varied among the stands sampled. Comparing mature to successional plots, the most frequent tree species (number of each species recorded in plot divided by total number of trees sampled [200]) are depicted in Table 3.

While frequency of sampled trees provides information about composition of the permanent plots, the percentages are not a reliable indicator of the composition of the forest as a whole as they are dependent on the number of trees sampled. Constancy (Table 1) gives a better estimate of species distribution in the larger forest. For example, the distribution of beech (*Fagus grandifolia*) in mature stands overall is exaggerated here as it only occurred in 3 of the 7 mature plots sampled, and 23 out of 30 beech trees sampled in those 3 plots occurred in just one plot with many root suckers (plot CN1).

Forest Types Compared

Plots in the "mature" zones of the forest had species frequencies (frequency = number of trees of that species sampled in mature plots divided by total number of trees sampled in mature plots) that differed from plots in the "successional" zones. Mature plots tended to be roughly two-aged, with an even-aged cohort of old trees over 100 years and a cohort of younger trees that originated across a range of years (15 - 90) at roughly 10-yr intervals. Successional plots (including EE, FE, AE, DE, and FN1S) generally had younger trees and a relatively even distribution of cohorts in roughly 10-20-year groupings. Plot FN1S is an exception, as it had a few very old trees remaining. However, in other ways it was typical of successional stands. Two plots, one successional (DE) and one mature (CE2), were even-aged. The average basal area in successional plots was sometimes lower than in the mature plots, but not always due to the presence of relict large, old trees as at FN1S. The differences in diameter at breast height and basal area, averaged by plot between the two types of stands, are not large (see Table 2).

Table 2. Comparison of mature vs. successional stand characteristics.

MATURE

Plot ID	Average dbh	dbh Range	Average Age	Age Range	Mean Plot BA (m ² /ha)	# Trees
DN	31.6	5.5-68.5	88	34-152	39.4	12
FN	28.3	3.5-63.1	83	15-117	34.8	15
CN2	27.8	5.0-54.3	83	37-120	34.5	17
BN1	28.2	5.6-55.0	83	37-126	37.9	14
CN1	23.2	4.7-60.7	77	30-119	31.4	15
AN	22.9	7.7-63.6	66	39-126	20.1	9
CE2	46.2	21.1-72.5	145	89-175	32.7	7
Average	29.7		89		33.0	

SUCCESSIONAL

Plot ID	Average dbh	dbh Range	Average Age	Age Range	Mean Plot BA (m ² /ha)	# Trees
EE	27.4	13.1-56.3	83	34-137	23.4	12
FE	35.7	12.4-76.1	54	35-76	36.7	9
AE	26.6	8.2-57.1	67	44-90	25.2	11
DE	35.5	16.0-72.4	58	54-65	21.2	7
FN1S	26.0	4.4-104.8	67	5-215	41.4	15
Average	30.2		66		29.6	

Table 3: Tree species frequencies in permanent plots.

Mature Plots	% Frequency	Successional Plots	% Frequency
<i>Fagus grandifolia</i>	22%	<i>Acer rubrum</i>	20%
<i>Betula lenta</i>	17%	<i>Fraxinus americana</i>	15%
<i>Acer rubrum</i>	14%	<i>Liriodendron tulipifera</i>	8%
<i>Quercus rubra</i>	13%	<i>Robinia pseudoacacia</i>	7%
<i>Carya glabra</i>	7%	<i>Carya glabra</i>	7%
<i>Cornus florida</i>	5%	* <i>Acer platanoides</i>	5%
<i>Quercus prinus</i>	4%	* <i>Ailanthus altissima</i>	10%
<i>Fraxinus americana</i>	4%	Other oaks (<i>Q. alba</i> , <i>Q. prinus</i>)	4%
Other oaks (<i>Q. alba</i> , <i>velutina</i>)	4%	<i>Ulmus rubra</i>	3%
		<i>Quercus rubra</i>	3%

*Norway maple (*Acer platanoides*) and tree of heaven (*Ailanthus altissima*) were found in just one plot at Fort Nonsense so are not representative of the park vegetation as a whole. Both species, introduced by horticulturists, are capable of becoming invasive and out-competing native species at Fort Nonsense. The species are reportedly also present at Washington's Headquarters (MNHP Invasives Management Plan). If not introduced as part of a commemorative layer or a significant design, they should be removed.

Oaks and flowering dogwood (*Cornus florida*) have a notably reduced importance in successional forest stands; white ash and introduced species such as black locust (*Robinia pseudoacacia*), Norway maple, and tree of heaven are more important in successional forests, although the latter two were only observed at Fort Nonsense. Red maple is prevalent in both forest types, largely in the younger age classes. Black birch, a tolerant species that is a successful colonizer of small gaps, is more frequent and abundant in mature stands. While yellow poplar appeared in both mature (2% frequency) and successional plots (7% frequency), it is among the oldest trees in the successional plots and is among a younger cohort in the mature plots. In successional plots, most yellow poplar individuals >10 cm dbh were approximately 58-81 years of age, establishing between 1922-1945 (yellow poplar grows rapidly from seed and may reach breast height in 3-5 years in good light, thus 3-5 years were added to age determined by increment cores which were sampled at breast height (1.37 m or 4.5 ft).

Mean annual increment (MAI) is the amount a tree grows in diameter per year, averaged over its lifespan, measured at breast height. It is calculated as dbh/years. Yellow poplar cored in successional plots showed a rapid growth rate with an MAI averaging 1.1cm/yr, suggesting they were open-grown. It is a slightly more recent arrival in the mature plots, ranging from 39-64 years, having established between 1939 and 1964. In these plots, yellow poplars grew more slowly, with a MAI averaging 0.5 cm/yr. Although no yellow poplars older than 100 yrs were identified, historical sources imply that it was a component of the colonial forest in the area, and it is currently a dominant component of the NJ highlands forest (Cleland et al. 1997). One 104 cm dbh yellow poplar at Fort Nonsense was not cored as it was too large. Given the average growth rate, it may have been more than 100 years old. Other tree species did not show as distinct differences in MAI between successional and mature stands (Table 4), with the exception of black birch, which was found in nearly all mature plots, but only one individual was cored in a successional plot.

With the exception of yellow poplar, growth rates were essentially the same within species whether grown in mature or successional stands.

Age-class Distribution

Cored trees (146 successfully aged) ranged in age from 215 years (one white oak at Fort Nonsense) to 5 years (tree-of-heaven at Fort Nonsense). At Jockey Hollow, the age range was 175 years (chestnut oak in plot CE2) to 15 years (a 3.5 cm dbh black birch). The age-class distribution (Fig. 2) shows a sharp increase in oak and black birch and some beech recruitment around 1890, and a smaller but longer period of increased establishment of a variety of species of trees between 1940 and 1980. The decline and cessation of oak establishment between 1910 and 1935 coincided with an increase in red maple and black birch establishment.

On a species-by-species basis, it is apparent that the codominant canopy oaks established in earlier times (mostly 1840's, with another peak in the early 1880's), and recruitment of oaks ceased around 1921-26. (Estimate is based on rings counted at breast height minus 4 years for establishment date. Oaks may take 3-6 years to grow to 4.5 ft. from seed.) No younger oaks were observed in any of the randomly located plots, or elsewhere in the forest, except for one white oak sapling about 12cm dbh along Primrose Brook.

Table 4: Mean Annual Increment: Growth rates by species and successional status.

Tree Species	MAI (cm/yr)	MAI (cm/yr)
	Mature	Successional
<i>Acer rubrum</i>	0.22 (8)	0.28 (10)
<i>Betula lenta</i>	0.26 (19)	0.49 (1)
<i>Liriodendron tulipifera</i>	0.50 (3)	1.10 (4)
<i>Carya glabra</i>	0.23 (9)	0.27 (4)
<i>Fraxinus americana</i>	0.46 (4)	0.46 (9)
<i>Quercus rubra</i>	0.50 (14)	0.49 (2)

Numbers in parentheses are numbers of trees measured in each category.

Red maple, white ash and black birch have a more recent history of establishment, generally beginning around 1900 until 1970 (red maple and ash) or 1985 (black birch), although there are rare older specimens of each throughout the forest. In the absence of substantial disturbances that have opened the canopy and reduced understory competition, these species, along with hickories, have been continuously recruited since the late 19th or early 20th century and will likely share codominance in the canopy if they are released from competition by senescing oaks. However, given the relative life spans of the oaks vs. red maple and black birch, (300-600 years for oak spp, approximately 150 years for red maple and black birch) existing subcanopy trees will likely be outlived by the oaks in the canopy. The oldest canopy oaks could conceivably live until 2180 or beyond; the youngest oaks established in the 1920's could live until the 2220's or beyond, depending on the species. The existing red maples, white ash and black birch are likely to be gone by 2120-2135. Without new recruitment, the forest canopy will dramatically change in the coming 100-150 years, gradually becoming more open as canopy and subcanopy trees senesce. Natural disturbances such as wind, fire, pest outbreak, or disease will likely alter this scenario, probably favoring the more opportunistic pioneer species like yellow poplar, red maple and black birch, although oaks may establish as well--all dependent upon the level of deer browsing and competition from exotic species.

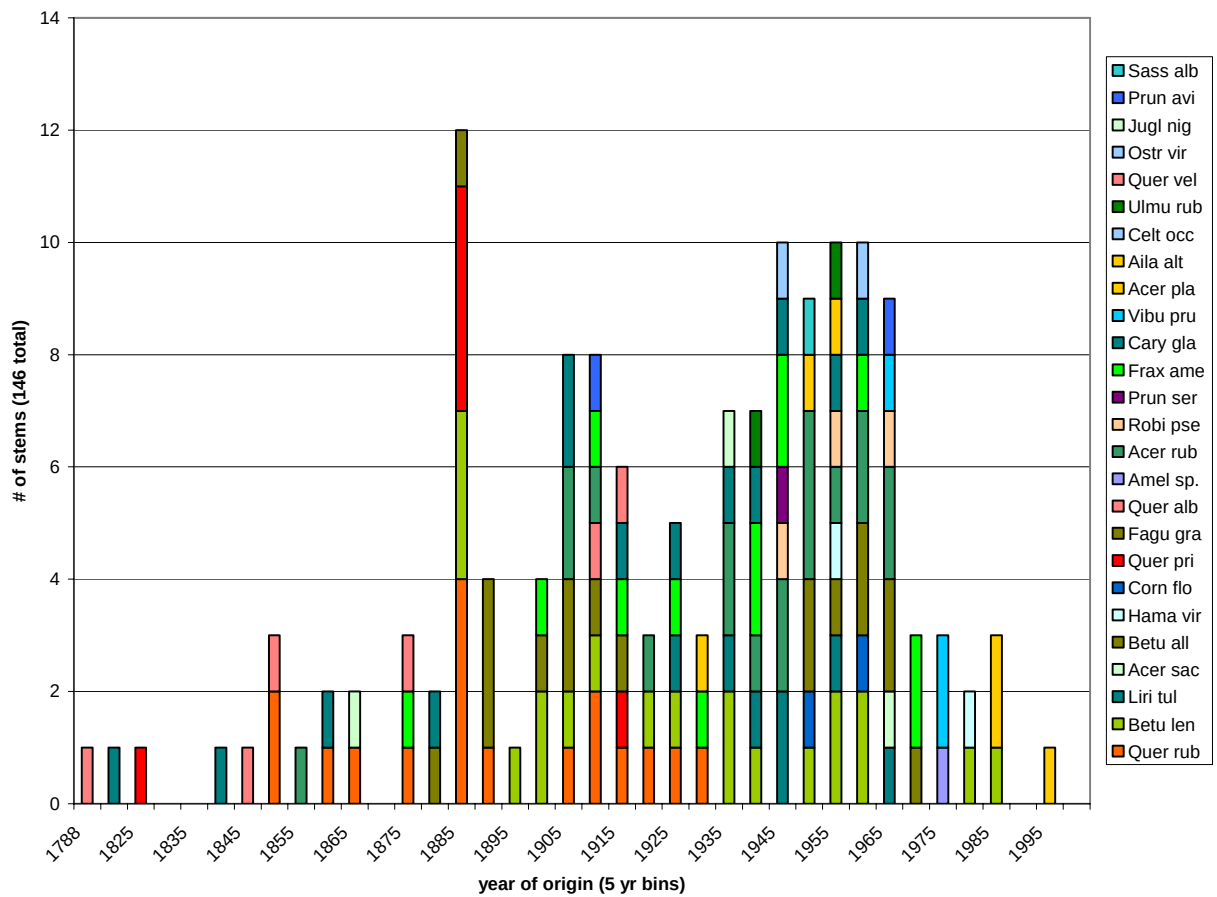


Figure 2. Age-class structure of MNHP forest. Oaks are colored various shades of red, other canopy species green, sub-canopy species shades of blue, and non-native species yellow-orange.

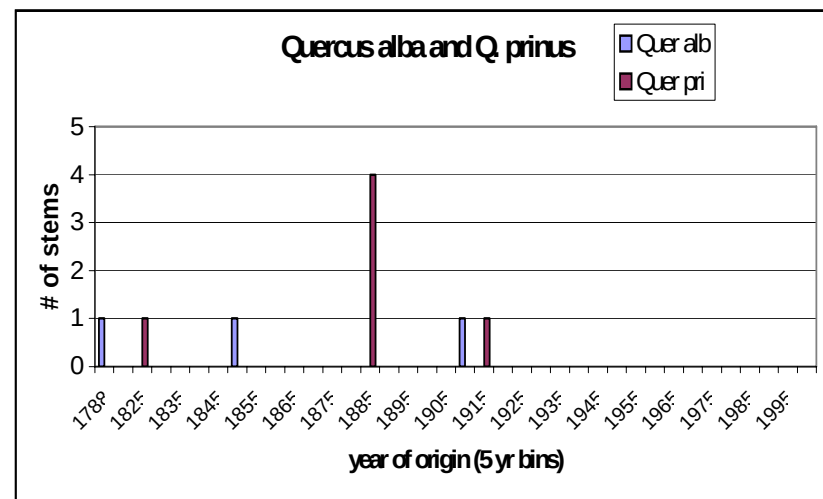
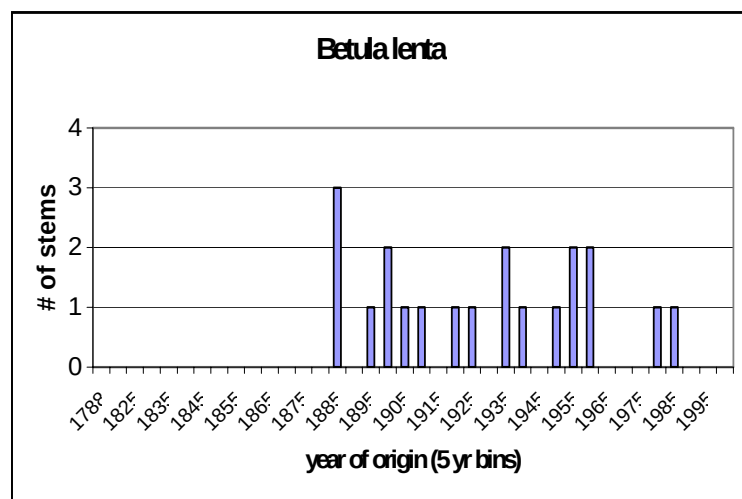
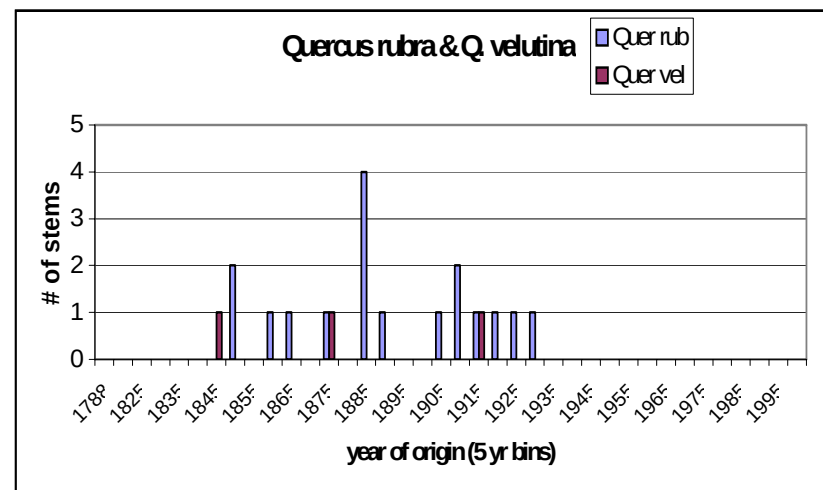
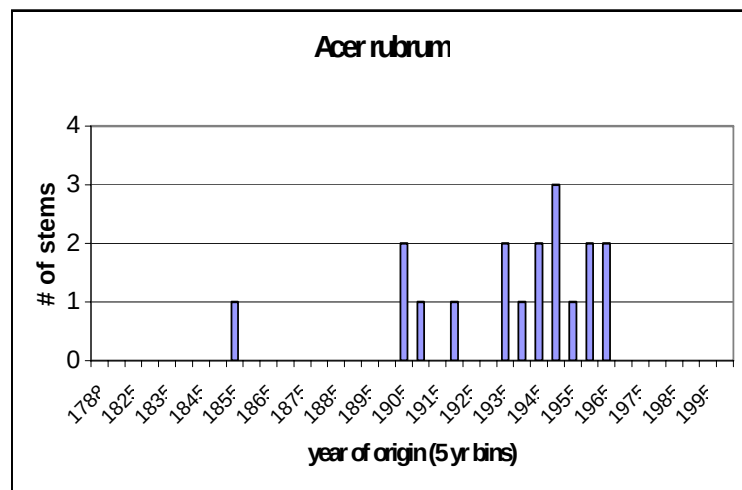


Figure 3. Year of origin of selected species.

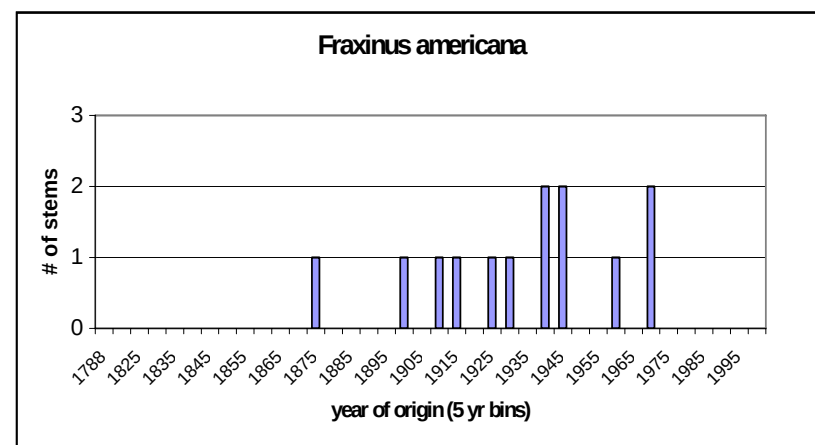
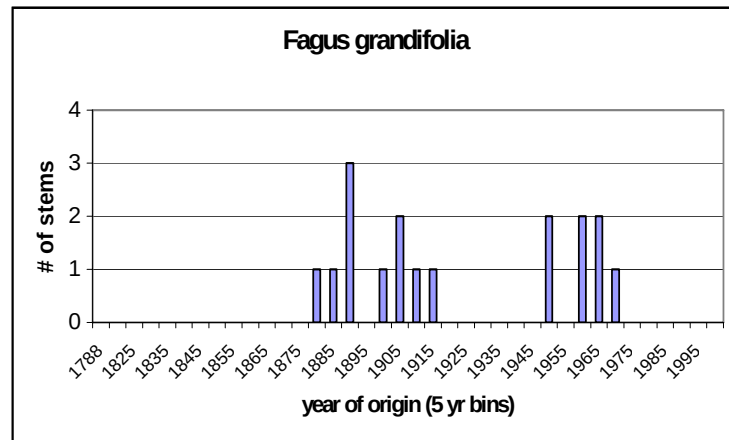
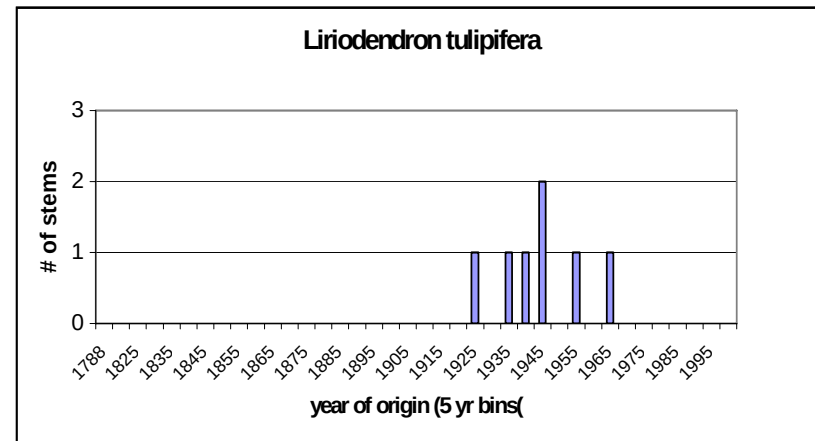
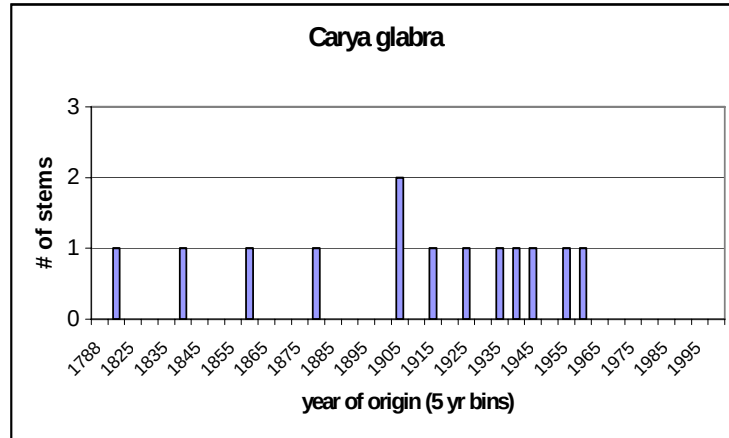


Figure 3. Year of origin of selected species (continued).

Stand Development

Ecosystem recovery of hardwood forests following stand-replacing disturbance (fire, timber-cutting, catastrophic wind, etc.) potentially follows four stages: stand initiation, stem exclusion, understory re-initiation, and old-growth (Oliver and Larson 1990).

Stand initiation is a period in which a site is reoccupied by early successional species combined with re-establishment of a diverse mix of late successional species. During stem exclusion, competition induces self-thinning of weaker plants leading to a decline in species richness and structural diversity. Forest canopies close leaving understory species with inadequate light. Understory re-initiation begins once larger trees die, leaving holes in the canopy large enough for light to reach the forest floor where stems of late-successional, shade-tolerant species can continue to establish and survive. Theoretically, over time and in the absence of new disturbances, an old growth forest develops with characteristic multiple age classes of trees and multiple canopy layers. Plant species richness peaks during the stand initiation stage, declines during stem exclusion, and then slowly increases as growing space is provided by individual tree mortality and the reestablishment of an understory (Schoonmaker and McKee 1988; Stuart et al. 1993, cited in Stuart 1988). In contrast, structural diversity peaks during old-growth, allowing for a greater richness of epiphytes and invertebrates (Schowalter 1989, cited in John D. Stuart 1988).

In multi-species stands, development patterns result from competitive interactions and differences in competitive advantages with respect to scarce resources. Slower growing species may eventually break through to the upper canopy if they can tolerate lower levels of light and nutrients and live long enough. The subcanopy may also differentiate into crown classes. This vertical stratification sorts species or groups of species (sometimes termed species guilds) into horizontal layers. Stratification results from differential height growth patterns over time and under differing light environments.

Stratification patterns can change as stands age. If the overstory is made up of a species that is short-lived (like birch), a longer-lived shade-tolerant understory species (like sugar maple) can eventually replace it. Species that are able to move from lower to upper strata (e.g. hickory species in many eastern forests) generally have strong apical control and /or heavy branches that give them a competitive advantage over weaker understory trees, as canopy crowding causes a great deal of abrasion of growing branches.

Development of mixed oak-hardwood forests generally follows the pattern described above. Initial succession from old field, cleared, or burned sites involves many mineral-soil-propagating species such as birch, maple and oak. Although their seedling densities are lower, oaks grow at the same rate as black birch and red maple for the first 20 years and then begin to exert dominance and overtop maple and birch, which are then relegated to subcanopy positions where they may remain as intermediate and suppressed stems.

Silviculture in mixed-species stands requires a thorough understanding of how (or if) species will stratify when grown together at different spacing and on different sites. Shade tolerant species

such as red maple, sugar maple and American beech can persist in the understory for long periods of time, whereas paper birch and white ash must quickly join oak as codominants in the canopy or they die for lack of light. Hickories start more slowly and can persist in the subcanopy for a long time. Their heavy branches allow them to withstand crowding and abrasion until they can reach the overstory.

Several factors influence the course of development in mixed-species, single-cohort stands. Whether a species height growth is early and rapid or delayed and slow determines its place in the forest canopy strata. Its longevity, ability to exert apical dominance, and the strength of its branches may determine how long it maintains canopy dominance (Agee 2003). In MNHP forests, several examples illustrate this. Yellow poplar and black birch experience rapid early growth, while red maple and hickories grow more slowly and steadily. Other factors related to spatial positioning or stocking density may play a role in stratification patterns. For example, overstory trees with heavy branches can keep understory trees in a subordinate position by damaging leaders. Likewise, understory trees with heavy branches can exert dominance in the subcanopy by abrading neighboring tree's branches.

Even slight differences in age or spatial arrangement can be important in the development of mixed species stands. Adding a species increases complexity of dynamic relationships between growth rates, apical dominance, shade tolerance, and spatial patterns. Removing species has an equally complex effect.

Development of oak forests is a special case. Paleoecologists have established that oak-hickory forests have been a major forest type over much of eastern North America for most (6000-9000 years) of the post-glacial period (Watts 1979). Historical research shows that presettlement oak forests remained in oak whether or not logged by early settlers (Lorimer et al. 1994), and that oak forests were considered climax forests, meaning stable in species dominance. Seedling studies (Lorimer et al. 1994) have shown that oak can regenerate under a mature forest canopy if released from tall understory shade. Historical studies have documented mature oak stands with uneven-aged structure in which the age range is 100-200 years (Lorimer et al. 1994). Evidence cited by Lorimer (1994) and historical and age-class data from MNHP show that uneven-aged oak forests were maintained for extended periods in the 18th and 19th centuries. Abrams and Nowacki (1992) attribute the prevalence of oak dominated forests in central Pennsylvania to repeated disturbance by logging and fire (since presettlement) and successional progression in oak forests primarily to a drastic reduction of these disturbances in the 20th century. Studies of age structures of old stands suggest that continuous overstory disturbance combined with understory fire were integral components of the historic disturbance regimes of oak forests and key to the establishment and survival of a competitive oak understory (Orwig and Abrams 1995).

However, in recent decades the ability of oak to retain its dominance in forest canopies has been questioned, and much research has been devoted to the oak regeneration problem. Oak-dominated canopies are often replaced by species in the understory that are more tolerant of shade, particularly on mesic and dry-mesic sites. Accelerated succession to mesophytic, shade tolerant species in northeastern forests has been documented by Rentch et al. (2003), Abrams and Nowacki (1992), and others. These researchers suspect that 20th century logging, without understory clearing by fire, has accelerated the change to shade tolerant species dominance.

The major species of oaks in North America apparently have limited success in colonizing treefall gaps, raising implications for natural area management. Ehrenfeld's (1980) examination of understory response to canopy gaps of varying size at MNHP found that most canopy species did not colonize dead tree gaps during the 7 years following a gypsy moth outbreak. McCune and Cottam (1985) studied the concept of succession in a white oak-black oak forest in the Noe Woods in southern Wisconsin using 27 years of data. At the time of European settlement, the forest was an oak savannah (25 trees/ha) adapted to frequent disturbance. By the 1840's, it was a pure black oak-white oak forest. The forest is essentially free of invasive species due to honeysuckle eradication efforts in the 1950's. It experienced limited disturbance in the early 1900's and more recently, disease (oak wilt, [*Ceratocystis fagacearum*]). Overall basal area has been decreasing since 1968. They found none of the canopy species in their study area adept at self-replacement and the lack of an obvious trend toward a stable climax community. Tree replacement in the canopy appeared to be due to disease factors (primarily oak wilt) rather than resource competition as a primary causal factor. Tree reproduction—primarily by species that are infrequent, in suboptimal habitat, or are of small stature and unlikely to be able to assert canopy dominance (black cherry, box elder, butternut, hackberry, elm and shrubs)—led them to conclude that a "climax" forest canopy will not be established until after a long period of broken oak canopy with a dense understory of small trees and shrubs. McCune and Cottam conclude that no model based on the ecological characteristics of the tree species would have accurately predicted the changes that have occurred. The destiny of Noe Woods appears to be determined by chance events: disease, windthrow and the introduction of exotics, and the individualistic response of species to these events.

Despite regional and ecological differences, McCune and Cottam's (1985) results have some applicability to the MNHP forest by showing that where natural disturbance, such as disease forces tree replacement, the result can be unpredictable. Similarly, where succession is arrested by suppression of tree reproduction and regeneration (by deer or invasive species competition or both), the character of the future forest cannot be predicted by successional models alone. Without management intervention or catastrophic disturbance, such as windthrow, certainly one scenario for the MNHP forest could be similar to McCune and Cottam's prediction for the Noe Woods: once the 150-year-old cohort of oak trees and the subcanopy of shorter-lived red maples and black birch senesce, there could be a long period of broken oak (plus hickory, yellow poplar and beech) canopy with a dense understory of species that are mostly invasive and unpalatable to deer.

Several studies suggest that shade cast by the understory rather than the main canopy hinders survival and growth of oak seedlings (Lorimer et al. 1994, Orwig and Abrams 1995, Kelty et al. 2003). Because proven guidelines for maintaining oak forests by fire or other means are not yet available, Lorimer (1994) suggests further long-term studies of understory dynamics to determine if oak forests can be perpetuated under a mature forest canopy if understory density is periodically reduced. (At MNHP, reduction of understory density to encourage oak reproduction would have to go hand in hand with protection from deer.) Development of competitive natural oak seedlings is a process that may take decades (Lorimer et al. 1994). However, oak seedlings have been shown to be able to overcome an initial height disadvantage and outgrow their competitors under certain conditions, eventually dominating the stand (Lorimer 1983).

Regeneration mechanisms are important in conferring early height growth. Advance regeneration (new stem growth originating from stump or root sprouts) generally grows faster than seedlings, and oak resprouts vigorously when topkilled by fire. Stump and root sprouts have extensive root systems that confer a competitive advantage by storing carbon and harvesting nutrients and moisture.

Gap-phase Regeneration Dynamics and Silvicultural Methods

Opening size greatly influences understory development, species composition, and growth of reproduction. Generally, large gaps favor shade-intolerant species, and small gaps favor shade-tolerant species. As gap size decreases, shade cast by adjacent trees increasingly limits the development of reproduction within the gap and selects for shade-tolerant species. On the other hand, advance reproduction in place before the gap occurs influences the species composition of reproduction after the gap has been created.

The important effect of opening size on species composition and growth regeneration has been documented. Kelty et al. (2003) cite several examples from the central, transition, and northern hardwood regions which confirm that the survival, height, and growth rates of intolerant species increase with increasing patch clearcut or shelterwood cut sizes over 0.3 acre, with understory removal (all trees cut to a minimum of 3-5" dbh, and smaller vegetation cut or herbicided). In one study (Dale et al. 1995, cited in Kelty 2003), shade tolerant species dominated smaller patches (<0.3 acre), and the edge effect favoring shade tolerants counted for nearly the entire area of patches. Plots in centers of 0.3-acre patches (and larger) had equal densities of shade tolerant and intolerant species.

Studies in New England transition hardwood forests confirm these studies (Kelty et al. 2003). They indicate the importance of combining overstory removal in sufficiently large patch sizes with removal of small trees and understory shrubs in order to obtain high seedling densities that can develop rapidly in height. They found the greatest overall stem density and density of oak stems in shelterwood plots of one acre in size in which the understory had been removed. The situation becomes more complicated where gaps are irregular in shape and where terrain is hilly. The less direct the exposure to sunlight and the less circular the gap, the greater the influence of adjacent vegetation within the gap (Baker et al. 1996).

In light of what is known about the colonization of small forest gaps, the absence of shade tolerants in the canopies of old stands, including that of Jockey Hollow is a matter of some interest. At MNHP today, shade tolerant species exist in greater numbers in the subcanopy, but are rarely found in the canopy. In old stands they studied with a similar structure, Rentch et al. (1994) attribute this phenomenon to two causes: shorter life spans (in the case of red maple and black birch) and susceptibility as seedlings and saplings to low intensity surface fires (for sugar maple and beech, which are long-lived).

The late-successional MNHP forest provides a good example of this pattern, as can be seen from the age-class diagram (Figure 3). Aside from a small resurgence of oak following the demise of chestnut around 1920, oak recruitment had tapered off by the end of the 19th century. The earliest establishment of shade tolerant species was concurrent with the cessation of oak

establishment in the late 19th and early 20th century. Fire chronologies for old, mixed-oak forests support the hypothesis that this is due to the cessation of fire as a persistent and repeated disturbance regime (Rentch et al. 2003, Abrams 1992). Study of the fire chronology of the Jockey Hollow forest would be a valuable contribution to the literature on this subject.

Seedling Survival and Sapling Mortality

Russell (2002) concluded that almost all tree species present in the forest produce propagules that are able to germinate and establish seedlings, many abundantly in some years, but that seedling survival beyond 2-3 years is rare. In addition to insect damage and deer browsing, understory shade is the most likely factor inhibiting seedling survival. In both mature and successional stands, canopy cover was generally over 90%, and successional stands often had heavy low shade as well, due to dense cover of invasive species such as Japanese wiregrass, barberry, or wineberry, with scattered garlic mustard, European bittercress (*Cardamine impatiens*), multiflora rose, or vines including bittersweet, black swallowwort and kiwi (*Actinidia arguta*). In mature stands without extensive invasive cover, the lack of native herbaceous and low shrub diversity and abundance as well as lack of successful tree regeneration is likely primarily due to browsing and antler rubbing by deer.

The establishment of trees from seed is dependent on a number of stochastic and environmental chance events, and tree seed production and germination are usually excessive and sporadic in order for some seedlings to survive. Given the longevity of forest species in general, even with poor seeding establishment for a decade, eventually individuals will reproduce successfully or be replaced by advance generation whether in a disturbed or undisturbed forest. Sapling and tree populations provide a more valid estimate of equilibrium between recruitment and mortality over a significant time period (McCormick and Platt 1980). If a species is well-represented in all size classes and well-distributed throughout the community, that indicates it may continue to hold its place in the community (Keever 1953). According to our age-class reconstruction, this has not been the case for oak, since the early 20th century. Lorimer et al. (1994) concluded that it may be understory shade rather than the main canopy itself that inhibits the survival and growth of oak seedlings, and that even one understory treatment may aid in oak regeneration.

Rentch (2003) concluded that in managed, second growth stands, shelterwood-burn techniques provide the most effective combination of overstory and understory disturbance that facilitates oak success. Kelty et al. (2003) reviewed the literature and found that a combination of overstory clearing combined with complete understory removal (by cutting and or herbicides) was essential to providing conditions for oak regeneration, and could be done in large patches within stands in order to convert even-aged stands to uneven-aged structure.

A number of studies of the oak regeneration problem have found that understory competition may be as large a factor as canopy shade in the success of oak seedlings. Lorimer (1994) studied both natural and planted oak seedlings under a variety of competitive conditions and found that complete removal of tall understory vegetation at the beginning of the experiment following a good seed year resulted in a major and sustained increase in the survival of natural oak seedlings, 10 to 140 times the survival in untreated plots, depending on the site (soil moisture) characteristics. He also concluded that the number of surviving seedlings (some of whom may

experience accelerated height growth up to 55 cm in 5 yrs as in his study) may be more important than the mean size of seedlings. Nevertheless, as Russell (2002) found, the growth of most natural seedlings under tall shade is very slow.

Russell (2002) also observed that saplings are less diverse than forest canopy species even where saplings are abundant. This is also to be expected under a mostly closed canopy, as only shade tolerant or mid-tolerant species are likely to survive. The dominance of oak species throughout much of the forest canopy suggests a more open forest 100-150 years ago when many of the oaks germinated, perhaps due to grazing and/or an increased fire incidence.

Diversity of species and complex structure in the canopy and understory layers both reduces damage in the event of natural disturbance and increases rate of recovery of a fully functioning forest canopy and root system (O'Conner et al. 1995; Barken et al. 1998, cited in de la Cretaz and Kelty 2002). Where invasive ferns or grasses exclude tree regeneration, this could create arrested development, or an "alternate stable state". The concept of alternate stable states is fundamental to restoration ecology (Hobbs and Norton 1996, cited in de la Cretaz and Kelty 2002). In a situation in which natural succession is disturbed (by heavy invasive species competition, heavy deer browse, or both), abundance and diversity of regenerating woody species are reduced and understory species cannot develop. In this case, stem density, tree height and species composition in a forest stand may change with time, but there are substantial differences in the resulting composition and structure compared with the original pattern expected for the site. The general question is will the removal of the causal factor of ecosystem degradation allow the system to return to its original composition and structure or have changes within the ecosystem been so substantial that it will remain stable in an altered state even after that factor has been removed? The examination of the natural recovery process can aid in the design of treatments to promote woody plant species. Ehrenfeld and Russell's research on invasives, deer exclusion and seedling persistence can provide some hypotheses in this regard.

Exclosure Studies

In her exclosure studies, Russell (2002) observed that complete removal of deer has both positive and negative impacts on understory vegetation. Although excluding deer gives native woody and herbaceous plants a chance to survive, reproduce, and increase cover, and (enigmatically) appears to result in a marked reduction of Japanese wiregrass (*Microstegium*) cover in some areas, Russell also observed luxuriant growth of invasive shrubs and lianas (vines) such as barberry, multiflora rose, wineberry, Japanese honeysuckle (*Lonicera japonica*) and bittersweet (*Celastrus orbiculata*) and a decrease in some native forbs unpalatable to deer such as white snakeroot (*Eupatorium rugosum*) in other exclosures. In still other areas, little change was observed between the interior of the exclosure and outside. The 25 m² exclosures may be too small for realistic appraisals of ecological processes in the absence of deer at an appropriate scale (400 m² is a more standard size for sampling within forested communities), but they do provide an indication of relative competitive success of species in the absence of browsing pressure.

The complete lack of tree and native shrub regeneration in some successional stands is likely due to the interaction of three primary factors: 1) heavy deer browsing of seedlings and browsing or rubbing on any advance regeneration (and advance regeneration is limited as many successional

stands have not been disturbed since they colonized abandoned agricultural fields, therefore sprouting has not been triggered), 2) heavy invasive species cover in the understory limiting light and nutrients, and 3) a closed canopy limiting light. Management of such stands to encourage regeneration is problematic under these conditions (de la Cretaz and Kelty 2002, Kelty et al. 2003). While regeneration of native understory shrubs and small trees such as *Vaccinium* spp., *Viburnum acerifolium* and *Cornus florida* would compete with canopy tree seedlings, they create much less dense early shade than exotics and may allow more tolerant tree seedlings to grow up through the shrub layer. They also generally leaf out later than exotic species, which can suppress the early spring height growth of tree species by their early leaf development (de la Cretaz and Kelty 2002).

Some Hypotheses

1. There is an important interaction between deer and invasives. If you remove deer, but not invasives, invasives will burgeon. If you remove invasives, but not deer, native species in interior forest further from open land edges will experience even more browsing pressure, while forests closer to open field edges may continue to show somewhat less browsing, (as, for example, plot DN, which was not sampled in 2001 but appears to have greater species diversity and sapling success than the other plots we sampled in 2003-4).
2. Removal of deer may contribute to
 - a) regeneration of woody forest understory that will affect light levels at the forest floor, which in turn may inhibit the spread and perhaps even reduce the area invaded by Japanese wiregrass (as in the exclosure near plot CE2), but increased understory shade will also limit regeneration of oak and other native tree species that leaf out later and require understory light for rapid early growth.
 - b) release from browsing pressure of woody species like barberry, multi flora rose and other woody shrubs such as pale blueberry (*Vaccinium pallidum*) and maple leaf viburnum (*Viburnum acerifolium*). They may increase, along with advance regeneration and shade tolerant tree seedlings that are able quickly to grow in height above competing invasives.
3. Recovery from the two sources of stress (deer and invasive species competition) will be slow due to a mature, closed canopy that limits light to the forest floor.

It is likely that forest stands that have originated from abandoned agricultural fields will always have different patterns of species assemblages than stands that have been cut but never cleared and plowed. A number of studies have showed that some native species tend not to readily recolonize soils that have been cultivated, while others preferentially do so (Motzkin et al. 1996, 1999), and that patterns of species assemblages and some individual species distributions continue to be influenced by historical land use activity even a century or more after abandonment of agricultural sites and intervening disturbances. Such evidence suggests that species distribution patterns indicate highly individualistic responses to complex physical and historical factors (Motzkin et al. 1999, McCune and Cottam 1985, Gleason 1926). Russell's

observation that witch hazel (*Hamamelis virginiana*) was only present in uninvaded plots, while spicebush (*Lindera benzoin*) and black haw (*Viburnum prunifolium*) were only present in invaded plots may be an example of this, or may be due to differences in site quality. Ehrenfeld's (1980) observation that colonization of single and multiple-tree canopy gaps depends more on existing understory composition and relative density than on gap size provides another example. Excessive deer browse and antler rubbing on saplings and invasive species competition may exert an overriding influence over all other factors at the stand scale and may result in "arrested development" of the stand (de la Cretaz and Kelty 2002).

Effect of Weeds on Competition, Composition

Dense understory stands of invasive species have been referred to as an "ecological filter" (Bazzaz 1999, in de la Cretaz and Kelty 2002). It may be that Japanese wiregrass, which forms dense monocultures differentially suppresses the growth of certain seedlings. Dense stands of barberry could act similarly. Kolb et al. (1990) found that hay scented fern reduced the height growth of red oak by 55% and white ash by 77%. If slowed by invasives, oak and ash are unlikely to persist long enough to overtop their competitors in the understory. Silvicultural studies show that these species do not grow to sapling size in low light conditions beneath closed overstory canopies. A dense *Rubus* canopy is a normal stage in the growth of young stands in northern forests and tree seedlings are able to grow through the canopy and *Rubus* becomes suppressed by the canopy in 5-10 years after establishment. This does not appear to be the case with wineberry (*Rubus phoenicolasius*) which seems to thrive under >90% canopy shade.

Many invasive native and non-native species successful in northern latitudes experience early leaf development that limits light availability at the forest floor and suppresses growth and survival of native seedlings that leaf out later. Since seedlings are the main source of regeneration in an un-cut successional stand, any management effort to encourage regeneration in successional stands with invasive species present would require management to include all of the following: control of all invasives, reduction of deer browse, and possibly planting of desirable species in gaps of sufficient size to succeed, with understory treatment.

If ash, oak, and other species with delayed foliage development are desired, more complete removal of understory competition may be required, along with planting of seedlings in tree shelters (Kelty and Nyland 1981, Kelty and Kittredge 1986). Understory vegetation management may include mowing, cutting, uprooting, prescribed fire or herbicides, depending on the autecology of the species being treated and other constraints.

For MNHP, the mixed species forest composition and structure must be interpreted in the light of the above considerations and two other complicating factors. Further interpretation follows below under the heading species autecology and stand development. The age-class structure of the forest (Figure 3) and the discussion below reveal forest development patterns considered on a species by species basis. Table 5 provides median age by species for the trees cored and estimated longevity of each species.

Table 5. Median age of trees cored by species.

Tree Species	MNHP Median Age (at breast height)	Longevity
<i>Acer rubrum</i>	56	100-150
<i>Betula lenta</i>	71	150+?*
<i>Carya glabra</i>	85	200-300
<i>Fagus grandifolia</i>	89	300-400
<i>Fraxinus americana</i>	64	150
<i>Liriodendron tulipifera</i>	58	300
<i>Robinia pseudoacacia</i>	46	<100
<i>Quercus spp.</i>	116	200-600

*Longevity estimate for *B. lenta* not found. It is genetically closely related to yellow birch (*Betula alleghaniensis*), which has a longevity of 150-300 years, but is more susceptible to a host of pathogens, so is probably generally shorter-lived (approximately 200 year-old black birch has been observed in old growth hemlock-birch-beech stands in the northeast (W. A. Patterson, personal communication).

Regression analysis of diameter at breast height and age by species provides a guide for estimating stand (or tree) age where strong correlation exists. This was done for a number of important species in the MNHP forest. Figure 5 presents the results of our analysis.

Regression analysis of age vs. dbh can be used to approximate a tree's age. Comparing the age of several trees with their corresponding diameters allows us to predict the age of trees for which we know only the diameter—a variable that is much easier to determine than age. The relationship between age and diameter is species-specific, and is often stronger for intolerant (early-successional) species than the tolerant species of MNHP's mature forest. A slope significantly different from 0, a y intercept value close to 0, and an R^2 value greater than about 0.5 indicate that a reasonable correlation exists between age and size. For most species at MNHP, especially those which occur in both mature and successional stands, this estimate is rough at best because diameter growth varies greatly depending on sunlight availability during a tree's early growth stages and whether or not it reaches the canopy. For example, a growth rate (mean annual increment--MAI) for codominant white ash trees is higher (0.53 cm/yr to 0.73 cm/yr) than for intermediate or suppressed ash (0.14 cm/yr to 0.24 cm/yr). Thus we see a split pattern of growth for white ash.

The regressions for black birch, hickory, red maple and black locust provide some guidance, while those for red oak, chestnut oak, white ash, and beech yield poor guides to determine age. This is partly due to the lack of younger specimens among oak species, the peculiar nature of beech sprouts, which may be nearly as old as larger trees when still very small, and the above-mentioned split distribution in ash due to its presence in both successional and mature forests with their contrasting conditions for early growth. For yellow poplar, open grown trees (now codominant) had an MAI of .9 cm/yr to 1.25 cm/yr, whereas the one intermediate and one suppressed tree had MAIs of 0.38 and 0.26 respectively. If we remove the two subcanopy trees (the two datapoints below the regression line on the graph), the resulting regression would provide a good estimate of age for open-grown, codominant yellow poplar, which grows in diameter at a rate of approximately 1cm /yr.

Mature Forest

Portions of the Jockey Hollow forest researched and mapped as "mature forest" zones include either mature second growth stands, originating from areas cleared in 1788-89 by General Washington's forces, but never plowed or cultivated and returning directly to forest after the end of the encampment, or areas never cleared, but repeatedly selectively logged (Ehrenfeld 1982). These areas, in which plots FN, AN, EE, BE, BN1, BN2, CN1, CN2, CE2, CN3 and possibly DN are all mapped (some GPSed, some added by hand to the GIS map provided by R. Masson), have theoretically been in a wooded condition for the longest period, and should therefore have a somewhat similar character with differences based on ecological differences, individualistic species responses, the patchy nature of natural disturbances such as fire and insect damage, and logging rotation, but not due to major differences in the degree of soil disturbance or extent of pasturage. However, some variability noted in these plots suggests more recent disturbance that has favored invasion by non-native species, as reflected in their plot names (CE2 and EE indicate the presence of exotic species).

Figure 4. Tree diameter by age for important species (regression lines shown where relationship exists).

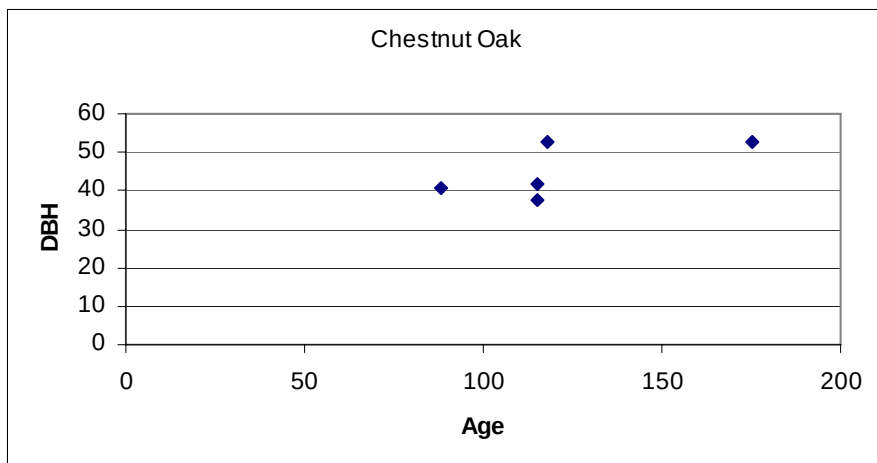
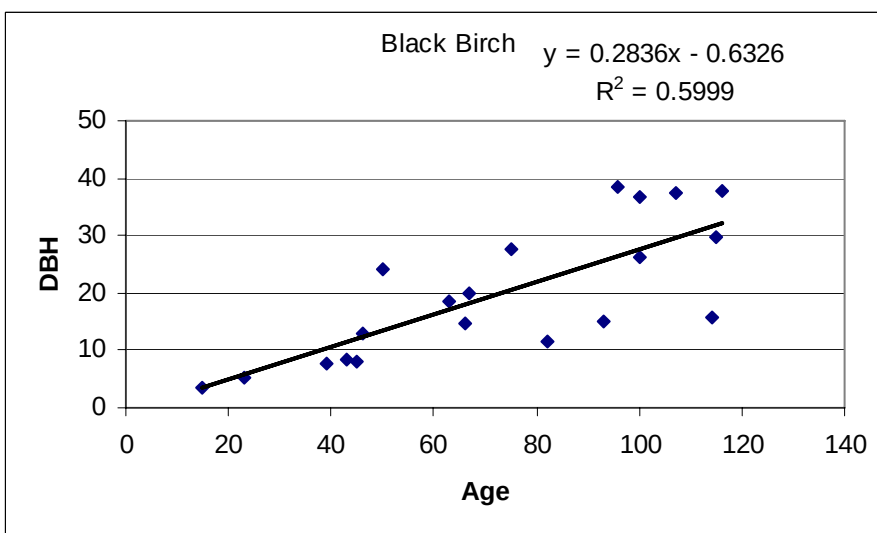
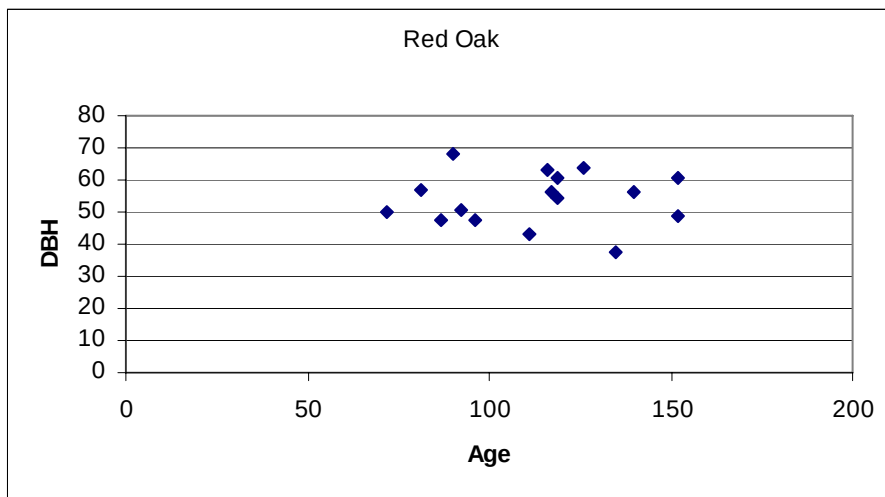


Figure 4. Tree diameter by age for important species (continued).

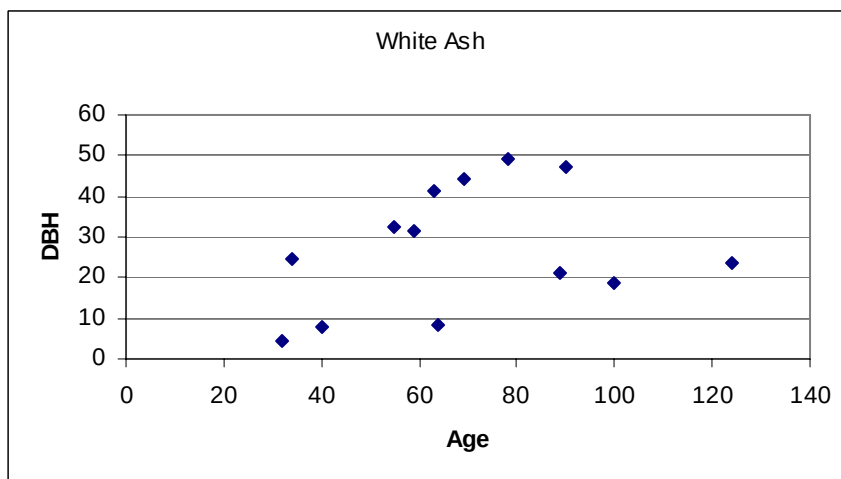
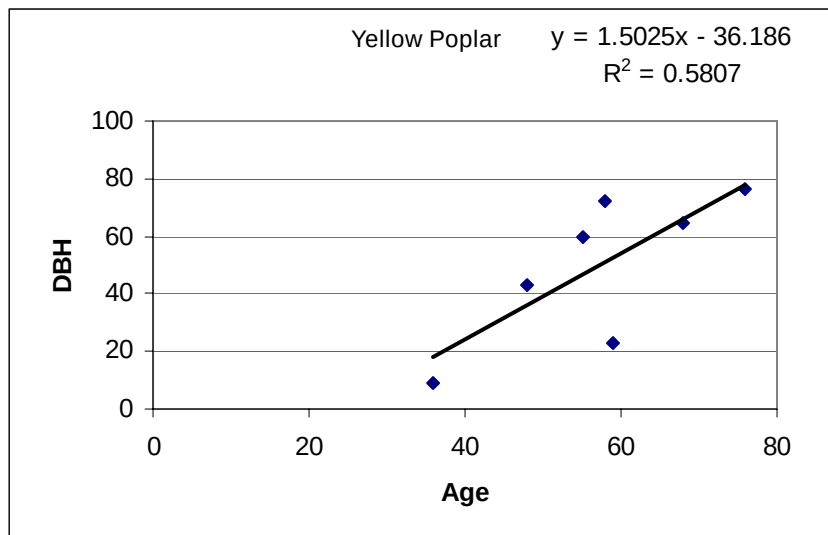
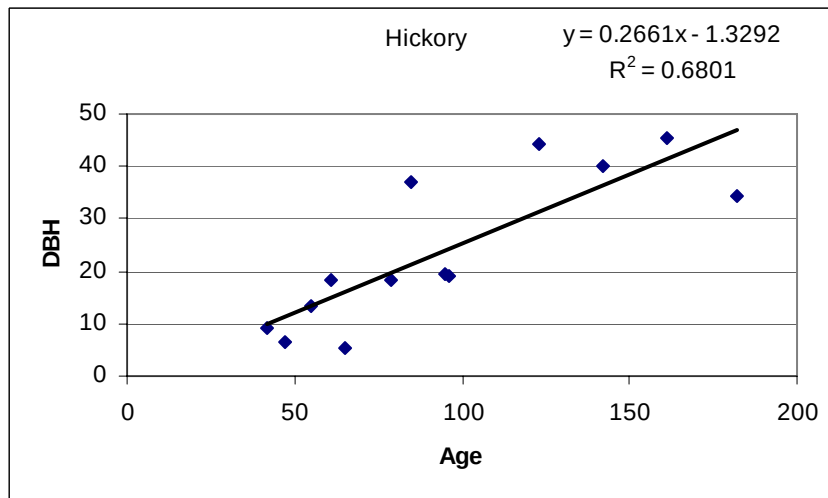
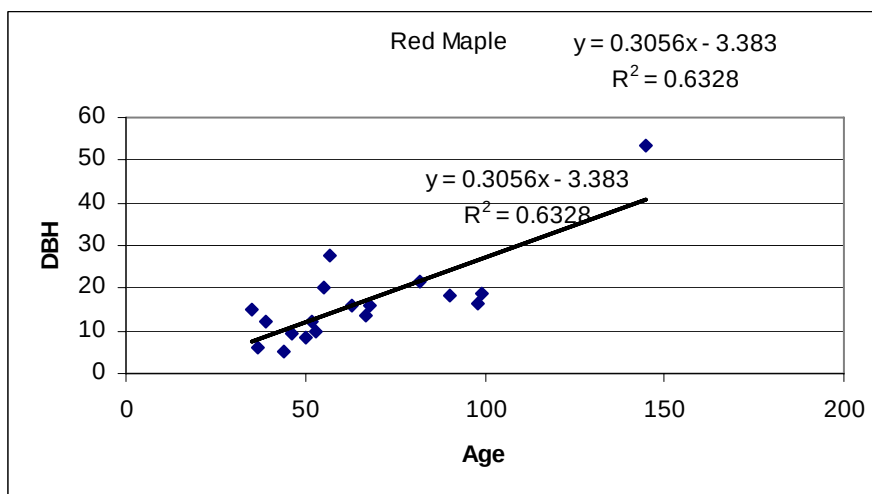
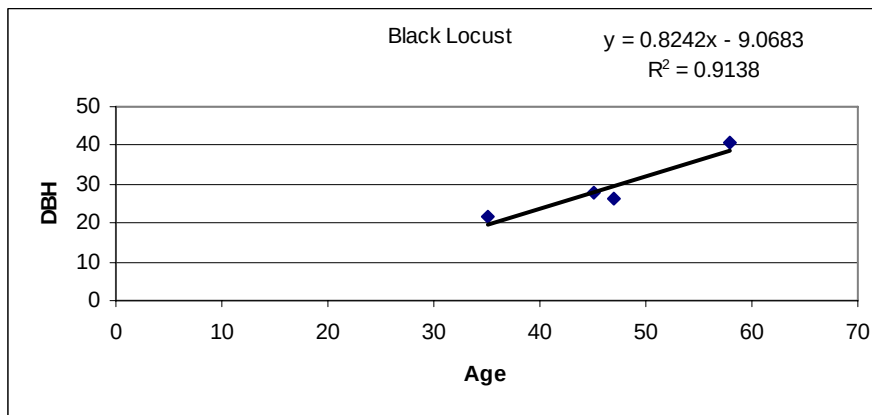
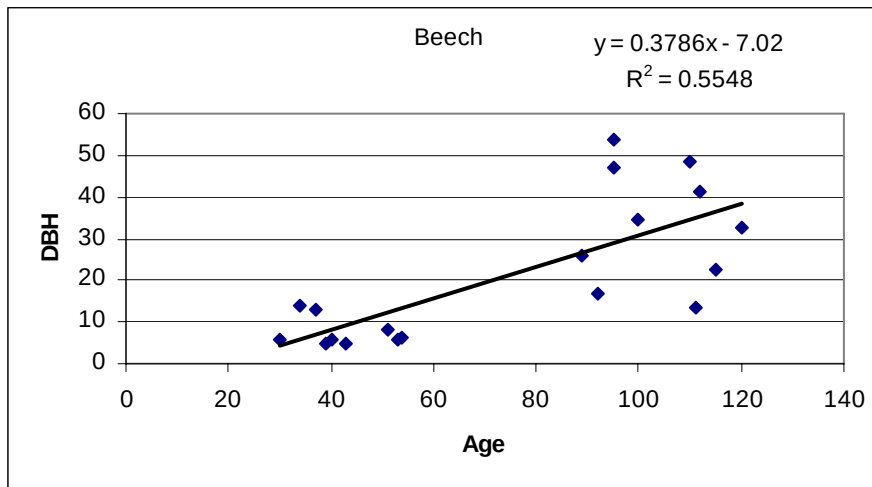


Figure 4. Tree diameter by age for important species (continued).



Based on the age-class structure of the trees and our data on associated vegetation, six of the eleven plots (BN1, CN1, CN2, AN, FN and DN) appear to support the theory behind the mapped zones. All have far lower abundances of invasive species, older canopy and sub-canopy tree cohorts, an uneven-aged (close to two-aged) age-class structure, and more varied and diversified understory vegetation.

Successional Forest

The roughly even-aged stands represented by plots FE and DE (trees aged 36-65 for DE and 35-76 for FE) were the only stands in areas mapped in the successional zone at Jockey Hollow. Although other plots were labeled E (for exotics, an indicator of disturbance), they lie within the mature forest zones on Ehrenfeld's (1977a) map. Canopy composition in plot FE consists of yellow poplar, black locust, and red maple. The stand, dating from about 1927, is essentially even-aged and most likely developed on an abandoned field or pasture. The stand at plot DE is also even-aged with stand-initiation about 1939 – just after the park was established. It is composed of several mesophytic species, including white ash, yellow poplar, sassafras and black walnut (*Juglans nigra*). Stone cobble walls surrounding the area suggest it was once plowed. Plots FE and DE generally appear to have remained in some form of agricultural use longer than most stands at MNHP.

Plot CE2 is essentially even aged, but one of the oldest stands in the park. Its canopy species are more typical of mature forest and established between 1825 and 1855.

The steep hillside plot we established at Fort Nonsense, FN1S, is multi-aged with an age-class structure reminiscent of old growth but lacking the understory development one would expect of true old growth. Its community composition and age-class structure indicate that it probably was never entirely cleared, given the presence of a 215-year-old white oak, but the plot also features a number of young cohorts and several invasive tree species indicating more recent disturbance. Apart from two very old trees, a 185-year-old hickory in addition to the white oak, and a 104 cm dbh yellow poplar (not cored) with an estimated age of approximately 100, most other trees range in age from 32 to 71 years. *Ailanthus altissima* (tree-of-heaven) is encroaching from the view-shed clearing nearby. Litter decomposition is rapid, and abundant earthworms are responsible for a particularly thick cover of worm castings. Further sampling at Fort Nonsense is necessary to more completely characterize the forest communities and ages there.

Wildlife

Wildlife surveys were outside the scope of this study, but in the course of field work it was apparent that a diverse fauna exists at MNHP, from box turtles on the dry uplands to fish in the streams, and a diverse population of birds is using the woodlands. Our field notes include the following observations:

box turtle	<i>Terrapene carolina Carolina</i> (one live, one shell), both in Mt. Kemble area
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birds: (breeding season)

scarlet tanager	<i>Piranga olivacea</i> (which prefers mature, undisturbed forests for breeding)
wood thrush	<i>Hylocichla mustelina</i>
rufous-sided towhee	<i>Pipilo erythrophthalmus</i>
red bellied woodpecker	<i>Centurus carolinus</i>
pileated woodpecker	<i>Dryocopus pileatus</i>
barred owl	<i>Strix varia</i>
red tailed hawk	<i>Buteo jamaicensis</i>
ovenbird	<i>Seiurus aurocapillus</i>
black and white warbler	<i>Mniotilta varia</i>
black throated green warbler	<i>Dendroica virens</i>
black throated blue warbler	<i>Dendroica caerulescens</i>
gray catbird	<i>Dumetella carolinensis</i>

The list is by no means comprehensive.

Given that large, unfragmented blocks of forest habitat in the NJ highlands are scarce, it is unlikely that the MNHP forests would be home to wide ranging fauna. However, the habitat diversity (wetland and seep areas along Primrose Brook and on the Cross Estate; ridgetop, mesic and riparian forests) also contribute to the habitat value. These areas were not sampled as they were not included in the set of permanent plots. The habitat potential of the Jockey Hollow area should also be evaluated with respect to other adjoining open space, including the NJ Audubon land, the Girl Scout land, the County Park, and connectivity to other nearby areas of open space. Despite the lack of a comprehensive evaluation of habitat potential, the presence of raptors, such as the barred owl, and interior forest nesting birds, like the scarlet tanager, suggest a functioning, mature forest ecosystem (King 2000). The presence of bear and coyote suggest that the park provides refuge for these species which are becoming suburban animals in New Jersey (J. Ehrenfeld, personal communication).

Intensive bird and mammal surveys would provide park managers a sense of the suite of species currently using the various habitats in the park and could be compared to surveys of other open spaces in the area to determine what habitat types are becoming scarce in northern NJ. In general, sustainable breeding habitat for populations of wide ranging species requires large undisturbed forest blocks. The MNHP forest is more likely to be a "sink" for wide ranging mammal species that breed elsewhere rather than a "source area", but it provides a valuable refuge and migratory stopover close to urban areas of the Northeast. Enhancement of the core forested area by private and public acquisition would build on this unique core of protected forest land and reduce the edge habitat that encourages deer and invasive species expansion.

Late successional forests are uncommon in managed forest landscapes of the Northeast (Science Notes, Manomet Center for Conservation Sciences, May 2004). Despite their logging history, late successional stands may contain trees 100-200 years old and have species in common with true old growth that are not found in younger forests. The continuity or persistence of big trees and abundant coarse woody debris in a forest stand over a very long period of time is essential to the persistence of many late successional forest species. In the absence of a major disturbance,

this forest is likely to persist at MNHP for a century at least, due to the longevity of many of its existing forest canopy species. But without regeneration from saplings and seedlings, mature forest species may not persist late into the 22nd century.

Deer Population

Although the interior MNHP forest offers poor foraging habitat for deer due to the largely closed canopy and high basal area, even in successional cover types (Christie 1988), a large deer population exerts considerable pressure on forest regeneration. The carrying capacity of the forest *vis a vis* deer is overridden partly by landscape fragmentation, abundant edge habitat, and sources of food outside the forest and in clearings that support a larger number of deer than the closed forest itself could support (Russell 1995). This may represent the area of greatest divergence from the assessment of Ehrenfeld (1977), who concluded that the deer population was in balance with the available resources, based on the appearance of healthy deer, no browse line, and abundant understory shrub and tree reproduction. No estimate of deer density is available for the mid-1970's, but it appears that an explosion of deer densities occurred during the 1980's, just a decade after Ehrenfeld's original study. An estimated 65 deer per km² (=65/100 hectares) were documented by Christie (1988) in contrast to 8/100 ha estimated as the deer density which would allow tree regeneration and the development of a diverse understory in mixed hardwood stands (Tilghman 1989, cited in Russell 1995). Christie concluded that the deer population had exceeded the carrying capacity of the park forestland; starvation was occurring especially among first year fawns; productivity was low; and the impact on vegetation composition, structure, and species richness appeared to indicate overbrowsing despite the intensive use of a feeding station on private land adjacent to the park. The feeding station has since been discontinued (R. Masson, NPS, personal communication) and current deer population levels are estimated to be 23 deer/km² or 57 deer/mi² (R. Masson, NPS, personal communication).

Ehrenfeld (1999) reports that by 1994 her sampling of tree seedlings clearly showed severe deer browse (nearly 100% of native species understory stems were browsed), and that the forests were devoid of native understory tree or shrub regeneration. When we visited in fall 2003, it appeared that severe browsing had nearly eliminated native and non-native palatable species up to the height of approximately seven feet in some areas of the forest. Understory composition has been altered by selective pressure such that the native but unpalatable white snakeroot (*Eupatorium rugosum*) is the predominant understory species in many areas, followed (in areas invaded with exotic species) by those exotics which are prickly or otherwise unpalatable: barberry, multiflora rose, Japanese wiregrass (*Microstegium vimineum*) et al.. Visiting in the spring of 2004, we observed a diversity of spring ephemeral herbaceous species that would not be apparent later in the year. Some wildflowers were planted within and outside exclosures in the Primrose Brook area in 1997, according to Russell (2003), but do not appear to have spread to other areas. There is limited shrub or sapling development in most areas of the forest, and where saplings were observed, many showed damage from deer antler rubbing.

While pressure on forest regeneration by deer is not a new phenomenon, it is likely that it currently exceeds levels prior to settlement by Europeans (Tillet 1963) due to landscape fragmentation, loss of natural predators, including wolves and mountain lions, and the general

decline of hunting by humans. When the predator-prey balance was first disrupted by the eradication of large predators, hunting played a role in managing deer populations. But hunting has not been allowed in the park since its inception and is not allowed in adjacent, privately owned land (Russell 1995), although it is permitted in the county parks. The encroachment of residential and commercial development has further limited hunting in the surrounding areas, which, along with habitat modification, has allowed the deer population in the park to burgeon. Livestock browsing of the forest understory within the Jockey Hollow area probably resulted in similar suppression of regeneration following the encampment of 1779-1780 (Ehrenfeld 1982). The MNHP General Management Plan (2004) notes that domestic stock (e.g. the pigs, cows and sheep necessary to feed the troops) were allowed to forage as the surrounding woodlands were cleared for lumber and firewood (also Thayer 1975, Russell 1995). In fact, farmers used fences to protect their crops from free-ranging livestock, as reflected in state laws regulating the height of fences required in order to receive compensation for crops damaged by livestock (Schmidt 1973, cited in Russell 1995).

Native American use of fire to maintain favorable hunting conditions may have increased forage for the park's deer, as would colonial clearing, but these disturbances would have different effects than chronic overbrowsing. Fire opens up the understory to more indirect light, tends to consume understory litter and small fuels, and encourages mineral soil-germinating species such as grasses, light-loving birch, and mid-tolerant oak, while also releasing a flush of nutrients in the ash of burnt biomass. Clearing opens the canopy, flooding the understory with direct light and encouraging new growth and may also disturb groundcover and expose some mineral soil. These disturbances would not have been likely to recur annually as does deer browse. Heavy deer browse in the mature and successional forest today appears to be maintaining a depauperate herbaceous and woody understory. Forest canopy and understory regeneration is impaired by the reduction of flowering and elimination of advance regeneration, creating a structural and age gap between ground cover and sub-canopy that could retard forest regeneration in the event of a stand replacing disturbance. The combined effect of deer (reducing advanced regeneration) and invasive exotic species in the understory creates a state of arrested development, making the possibilities for active management for oak regeneration by any silvicultural method highly problematic (Kelty et al. 2003). In addition, heavy browse has nearly removed the abundant chestnut sprouts that were observed by Ehrenfeld in 1977. These sprouts are highly significant for interpreting the Revolutionary War-era forest to visitors and retaining the native species composition, and should be protected to allow them to survive until such time as the deer problem is brought under control (J. Ehrenfeld, personal communication).

A Brief History of Deer in New Jersey

Both red deer (*Corvus elaphus*—eastern elk) and white-tailed deer (*Odocoileus virginianus*) were native in the eastern United States before European settlement. Their main predators were mountain lions, wolves, and Native American hunters. A 1737 report notes bounties paid in Morris County on over 100 wolves and 16 panthers killed by settlers (Thayer 1975). The predators and dwindling numbers of Native American hunters, along with increasing numbers of European/American hunters, persisted in Morris County through the 1750s (Thayer 1975). Tillet (1963) states that as far back as 1679, an effort was made to control the killing of deer in New Jersey, with seasonal restrictions on hunting as early as 1722, implying that deer were not

plentiful. At the time Morris County was established in 1739, the county had about 1000-1100 inhabitants. Within 25 years, the population had increased to 10-11,000 (Thayer 1975). Increased hunting pressure eliminated the red deer by the late nineteenth century. In 1881, deer hunting was prohibited throughout the state for three years. The season for white-tailed deer was closed again in 1899 and not reopened until 1909. White-tailed deer were at a low point around 1900, and in 1904, the New Jersey Board of Fish and Game Commissioners began restocking from deer parks and game preserves (Tillett 1963), despite the fact that farm abandonment in the latter half of the 19th century provided ideal habitat—a varied pattern of forests in various stages of growth combined with open fields (as at MNHP). Uncontrolled by predatory pressures or hunting in proximity to residential and commercial areas, deer populations have recovered to levels above the carrying capacity of the land. As forests matured and development encroached, deer have been forced to adapt to life alongside human populations in urban parks, tree-lined suburbs—wherever a forest provides sufficient forage and cover to maintain them. High populations near MNHP are evidenced by data from Tillett (1963) showing accidental deer kill in six northern NJ counties between 1953 and 1961. Morris County exceeds all others by a factor of 2 to 3. Legal kill records between 1947 and 1961 likewise show Morris County far outstripping other northern NJ counties.

Limiting Factors

Christie (1988) indicates that within MNHP starvation (mostly of fawns <1 yr old) and mortality from automobiles were the most important factors regulating the Morristown herd in the mid-1980's. He found these two factors inadequate to restrict growth of the deer population and keep it within the limits of its food supply (perhaps partly due to the efforts of a neighboring landowner who supplemented their forage with large quantities of baked goods. The supplemental feeding is no longer occurring (R. Masson, NPS, personal communication). When forage is inadequate to feed the population of deer, production is reduced, malnutrition is reflected in small deer and poorly developed antlers, and more conflicts with humans (including automobiles) ensue as deer move out of the woods to feed on crops or landscape plants (Tillett 1963). Christie (1988) provides evidence for the poor condition of the Morristown deer herd, where he estimated a birth rate of 27 fawns/100 does in 1985 and 47 fawns/100 does in 1986, meaning reproduction was far below normal (a population of does can regularly average 2 fawns per doe) (Tillett 1963). Current deer populations are estimated to be 23 deer/km² or 57 deer/mi² (R. Masson, NPS, personal communication).

Any effort to increase regeneration by forest cutting or burning would elicit a predictable response in the deer population. Mature forests have little value to deer, as closed canopies limit understory growth. Woodlands have a higher deer carrying capacity after logging, blowdowns, or burning, because palatable browse is encouraged (Tillett 1963).

Effect of Browsing on Forest Understory

Christie (1988) found in his stratified random sampling of vegetation in various cover types that the five most important herbaceous species were used significantly less than their availability, while less important species were used significantly more. (Importance values in Christie's study are the sum of relative cover and relative frequency.) This suggests that deer have applied

selective pressure to understory herbs, such that more palatable species are limited and less palatable species have become more common. Therefore, among herbaceous species, *Eupatorium rugosum* - white snake root, which is unpalatable and/or toxic to deer - had the highest absolute frequency, cover and importance value across Christie's transects, and one of the lowest utilization indices. Woody understory species, both palatable and unpalatable were used more in proportion to their availability: yellow poplar and red maple were used lightly by deer, while blueberry (*Vaccinium* spp.), beech, mapleleaf viburnum (*Viburnum acerifolium*) and the invasive Japanese barberry (*Berberis thunbergii*) and bittersweet (*Celastrus orbiculata*) show the most browse pressure. In her exclosure studies, Russell (2002) observed that complete removal of deer has both positive and negative impacts on understory vegetation. Russell observed luxuriant growth of invasive shrubs and lianas (vines) such as barberry, multiflora rose, wineberry, Japanese honeysuckle (*Lonicera japonica*) and bittersweet in some exclosures. Deer browse may be exercising some control on the density of barberry and other invasive species, if not on their spread.

Spicebush (*Lindera benzoin*) was the most frequent woody species encountered and in the mid-range of utilization. Despite a prevalence of mixed oak cover types, oaks were sparsely represented in samples of woody understory, and overall species diversity was low with a mean of only 4.3 species per plot. Christie (1988) concludes that an overall increase in diversity of less palatable herbaceous species accompanied by a decrease in diversity of woody species is strong evidence of browsing pressure adversely affecting forest regeneration, structure, and compositional diversity. (See also Veblen et al. 1989, cited in Russell 1995).

When data were stratified by successional stage of forest communities, it appeared that successional communities were used in proportion to their availability, whereas mature forest stands were used only seasonally (in winter) indicating that successional forest (and streamside thickets) were some of the most preferred habitats for deer. Winter survival of deer appears to be dependent on heavy use of mast for fall and early winter forage, so few acorns remain from each fall crop. This may contribute to low oak seedling establishment in mature forests, whereas browsing pressure limits the development of any seedlings which do establish.

Other studies have shown the difficulty of managing forests for ecological sustainability in the presence of heavy deer browsing. Kelty et al. (2003) reported one example: at the Quabbin Reservoir in western Massachusetts, a 23,000 ha (58,000 acre) state-owned watershed forest. Forest managers are committed to an uneven-aged approach to management to maintain a multilayered forest cover of high tree species diversity that is resistant and resilient to disturbances ranging from localized damage from insects and diseases and ice storms to catastrophic windthrow (Barten et al. 2000, reported in Kelty et al. 2003). The deer population in the watershed grew following restriction of public access in 1941. Understory vegetation showed signs of excessive browsing in the mid 1940's when the deer population was estimated to be 7 deer/km² (18 deer/mi²). Population densities in 1991 were estimated at between 15-23 deer per km² (39-59 deer/mi²). A watershed-wide regeneration survey in 1989 revealed that 54% of all sample plots in thinned stands had no regeneration taller than 30 cm, and 89% had no regeneration taller than 137 cm. (Kyker-Snowman 1989, in de la Cretaz 2002). Management of the even-aged, maturing forest consisted mostly of thinnings and improvement cuttings, because heavy browsing by the large deer herd had eliminated the possibility of regeneration using any

silvicultural method. A change in regulations in 1990 allowed controlled hunting from 1991-1993 and a reduction of the deer herd to an estimated 2 deer/ km² (5deer/mi²) after two years of hunting. Annual hunts have been allowed since that time. It is assumed that at this population level deer browsing no longer presents a major impediment to growth of seedlings of woody plants in many parts of the watershed. Only after deer numbers were controlled could the desired conversion to a multi-aged forest structure with a complex understory of diverse species be addressed (Kelty et al. 2003). The inhibiting effect on seedling growth of the interaction of heavy fern cover and deer browse was also documented at the Quabbin reservoir in a study by de la Cretaz and Kelty (2002).

In a Pennsylvania study, experimentally maintained populations of deer in enclosures reduced the height (but not the number) of tree seedlings over five years, whereas no difference in the number of seedlings was found among the different deer densities (1,10,20,40, and 80/259 ha) (Tilghman 1989). In the same study, brambles (*Rubus* spp.) decreased, whereas ferns increased and inhibited tree seedling growth and survival. In a controlled experiment at Saratoga NHP in which vegetation parameters were measured with and without the presence of deer (deer effects were measured and compared between fenced deer pens and exclosures), Austin (1992) found that deer limited height growth of woody seedlings, and that species richness in the exclosures was greater than outside after four years. Citing these two studies, Russell (1995) concludes that deer inhibit tree seedlings in two ways: by eating them and by increasing competition from species that thrive under browsing pressure.

Augustine and Frelich (1998) found in their investigation of old-growth patches of the highly fragmented Big Woods forest ecosystem in southeastern Minnesota that flowering rates of *Trillium grandiflorum* at a site with high overwinter deer densities for at least five years (25-35/km²) reduced reproduction in subsequent years. Transplant experiments with *Trillium* also showed that deer had significant effects on growth and reproduction where deer occur at high density. They conclude that changes in landscape structure and local deer abundance have altered plant-deer relationships such that grazing can lead to the local extirpation of sensitive forbs such as *Trillium*, and that long-term management of deer at low densities appears necessary for the conservation and restoration of fragmented forest communities in eastern North America.

In the absence of predators, regulated hunting remains the most efficient means to manage deer according to NY DEC, with adequate harvests of antlerless deer being essential to success. Harvest and other losses must exceed the number of fawns produced if deer numbers are to be reduced. Sterilization of does has been proposed but is a costly and labor intensive approach that can only succeed if sufficient numbers of does are adequately treated to prevent conception. Limiting access to much of (or designated areas within) the MNHP forest by fencing is a third option, but this too is costly and potentially unsightly. Unless the deer population is reduced or their access limited, efforts to increase ecological sustainability of the MNHP forest will not be effective. However, deer herd reduction must be accompanied by invasive species control, or heavily browsed invasives will burgeon if browsing pressure is reduced.

Non-native and Invasive Species

By the mid-1970's, invasion of the forest by exotic species was noted by Ehrenfeld (1977) but not considered to warrant active intervention except in "historically important sites on public display" and along trails. Her 1982 paper mentions invasives as scattered populations and individuals. By 1999, she noted that two species of invasives were rapidly spreading throughout the park. Today it appears that exotics have replaced most native understory species in some areas of the forest, by way of their ability to spread, lack of natural predators, and reduced competition due to preferential deer browsing of native species.

In her summary "Changes in the forests of the Jockey Hollow Unit of MNHP over the last 5-15 years", Russell (2002) indicated that, by 2001, barberry had not spread into areas in which it had been absent in 1995. She observed that no other non-native shrubs occurred in uninvaded plots in 1995, and that only two stems of other woody invasives were found in the uninvaded plots by 2001. Surveying the same permanent plots in 2003-4 we found barberry in all permanent plots sampled, both those originally invaded (the "E" plots) and formerly uninvaded (the "N" plots) and *Rubus phoenicolasius* (a new woody invasive) in three plots at Jockey Hollow (including DN, which had not been sampled in 2001) and one at Fort Nonsense. Russell also noted no herbaceous, non-native species in 1995 or 2001 other than *Microstegium vimineum* and *Alliaria petiolata* (*A. officinalis*). In 2004, we observed *Cardamine impatiens* in plots DE, CE2, FE and DN at Jockey Hollow and FN1S at Fort Nonsense (not sampled in 2001). This may have been previously misidentified as a common, but native, Brassica - *Cardamine pensylvanica* - in earlier studies. *C. impatiens* is distinguished from *C. pensylvanica* by the formers clasping, sagittate-auriculate leaves at the base of the petioles. While not currently creating heavy cover, it appears quite prevalent, particularly in areas of the forest with more recent disturbance. It can form dense areas in woodland habitats and outcompete native species and has been spreading throughout the Northeast. *Cardamine impatiens* can grow in shady woods with dappled shade and along shady edges of forest. It also does well in areas that have moist soil and is easily dispersed due to its seed-shooting ability. Forest understories should be monitored for its presence. Ehrenfeld (personal communication) reports first seeing it in large numbers in the late 1990's.

Viburnum sieboldii is the most recent woody invasive, first observed at very low densities in 1993-4 (J. Ehrenfeld, personal communication). It is being removed from all areas of the park. As demonstrated by the rapid proliferation of barberry and *Microstegium* through many areas of forest, prevention (or early detection and removal) is the best, cheapest, and most timely method for control of invasive species. Another apparently introduced woody shrub was noted several times along trails. It has serrated, obovate alternate leaves, and should be monitored. The Brooklyn Botanical Garden has tentatively identified this species as Oriental Photinia (*Photinia villosa*) (R. Masson, NPS, personal communication). The impressive Kiwi vine (*Actinidia arguta*), which has created a large curtain from forest floor to canopy near plot BE on Fort Hill and along the old Tempe Wick Rd., should be monitored closely. We observed this species in other areas of the forest some distance from Fort Hill, including near one of the exclosures behind the NY Brigade comfort station. Although localized at present, if it is allowed to spread, its ability to reach the canopy and grow dense foliage between trees would have an effect similar to that of Kudzu vine in the Southeast, which damages the forest canopy over time. Plot BE on

Fort Hill has a population of black swallowwort (*Cynanchum louiseae* syn. *Vincetoxicum nigra*). This dark green, glossy, entire-leaved vine in the Milkweed family (*Asclepiadaceae*) can grow almost anywhere, including woodlands, fields, and along roadsides, floodplains, urban areas and utility rights-of-way. It is a vine that can grow rapidly, overgrowing native vegetation. It has the ability to dominate the understory of a woodland. Wind-dispersed seeds allow it to disperse over long distances. When it is cut, it resprouts vigorously, making control difficult. It is best controlled when still localized; therefore the population on Fort Hill should be removed.

Resources:

The Invasive Plant Atlas of New England (IPANE) website: <http://invasives.eeb.uconn.edu/ipane>:

- has information, identification keys and control methods for some of the above-mentioned exotics and many other non-indigenous, invasive species.

The Nature Conservancy's Invasive Species Initiative website: <http://tncweeds.ucdavis.edu>:

- offers a Weed Information Management System (WIMS), a fully integrated hardware and software application for mapping invasives and tracking management actions.
- provides a review of remote sensing technology as applied to invasive species detection and mapping.
- offers templates for adaptive management plans and examples.

Historic Role of Disturbance

Disturbance History of Forests

Compared to earlier forests described by Ehrenfeld (1977, 1982) and summarized in the introduction, chestnut only persists as short-lived sprouts, and hickory species at MNHP appear to have declined in importance, possibly due to selective cutting. Red maple, black birch, and chestnut oak appear to have increased in importance compared to the original forest, as have yellow poplar, beech, and possibly red oak. Ehrenfeld (1982) concludes that the modern forest is compositionally similar to the pre-Revolutionary forest but lacks chestnut and has species occurring in altered proportions. Changes in forest composition and structure have been influenced by a number of factors. Replacement of chestnut in the canopy occurring over several decades since the chestnut blight was probably by codominant oaks and hickories (Good 1968, Keever 1953, McCormick and Platt 1980, Mikan et al. 1994), resulting in greater dominance by oak and hickory than in colonial times. Replacement of oaks by beech, black birch, and red maple in some stands could imply lack of fire (Abrams 1992), a reduction of oak regeneration (observed by many other researchers since the 1920's), due to altered forest structure, heavy deer browse and mast consumption, selective harvest of other desirable species, such as hickory during the chestnut "salvage", or a combination of these and other factors.

Fire

No comprehensive fire history for MNHP has been undertaken, but it is evident from other references noted below that fire was used extensively by presettlement resident populations of Native Americans as well as early colonists. Thayer (1975) described an extensive scrub oak barren in the highlands north of Morristown around Pompton Plains that in later years grew large trees and yielded good crops. Apparently, it had been repeatedly burned over by Native Americans and kept in an early successional sere. Thayer (1975) described an early colonist's account of the woods around Morristown being open and pleasant to ride through. Both accounts suggest the effects of underburning, a common practice used to promote soft mast production and facilitate travel through the woods (Hawthorne 2004). While the return interval and areal extent of presettlement forest burns at MNHP is unknown, the oak-chestnut-hickory forest composition is generally thought to be a fire-influenced association.

In our survey we observed only one permanent plot that had been burned in the recent past: plot AN. Fire effects included a number of standing dead, dead and down or live but damaged (rotten core) trees, both codominant red oak and black birch and shade tolerants in the suppressed canopy layer including red maple, yellow birch, black birch, witch hazel. Tree ring analysis did not reveal a consistent release period; the oldest tree in the plot, a 129 year-old red oak (established around 1874) experienced rapid early growth and then a relatively even, slightly reduced growth rate until the present. One understory black birch we were unable to age due to a rotten center may have had a period of release between 30-35 years ago (1963-68). Most of the remaining trees showed fairly even, slow growth rates from the time of establishment to the present. Trees with visible fire scars all had rotten centers. Although most of these could not be aged accurately, one was over 85 years.

European Settlement

The precise date of European immigration into Morris County is unknown, but abundant evidence points to the turn of the 18th century. Thayer (1975) cites evidence of exploration for iron ore in the Whippany area (just east of Morristown) as early as 1685. The township of Whippany was created in 1700. A map made in the 1740's shows a purchase of the Whippany area made in 1690, and an Indian deed of 1713 selling the lands south of the Whippany River refers to "the inhabitants of Whippany". By the time of the land purchase, the Native Americans had established farming practices, including spring or fall burning, planting areas for as long as productive, and then abandoning them for fresh ground (Thayer 1975). Burning often extended broadly through the woods, giving rise to more grass and improving habitat for deer. Thayer cites records of early settlers harvesting the abundant grass for winter fodder for their cattle and sheep. The old fields where Native Americans had farmed and lived were the first areas sought by settlers, who repeatedly burned over the crop and pasture land following the Indians' practice. Large trees were left unharmed and tended to form park-like areas with widespread trees and abundant grasses and sedges in the understory. A Revolutionary soldier noted in his diary that the smoke was so thick from back-country burning that the days were as dark as twilight (William Gordon, cited in Thayer 1975). The Europeans completed the purchase of Morris County from the Native Americans in 1714. John Reading, a surveyor, noted in his journal in 1719 that by this time some Indians had fenced fields of grain, apple, peach, and cherry orchards, as well as cattle and swine feeding in the woods.

Morris County was established in 1739, at which time it had a population of approximately 1000 people. Within another decade there were 5000, and at the time of the American Revolution, the population had expanded to 10,000-11,000. When Washington's troops arrived in 1779-80, another approximately 8,000 soldiers plus officers and servants nearly doubled the existing population of the area, with all settling in the Jockey Hollow area (Thayer 1975). (Others estimate 10-12,000 soldiers encamped in Jockey Hollow [R. Masson, NPS, personal communication]). Dwindling populations of Native Americans in the late 17th and early 18th century would have had an effect on succession in the 100 years prior to European settlement, but the details are not known.

The Jockey Hollow Area

The Wick and Guerin farmlands were first surveyed in 1715, although settlement did not occur until later. The iron forges and blast furnaces started proliferating around Morristown in 1740 (Thayer 1975). The Wick Farm was cleared for agriculture by Henry Wick and Nathan Cooper after being purchased in 1746 from Rawles (Ehrenfeld 1977). A 1787 map (the Ludlow Map, Ehrenfeld 1977) shows that only the level and gently sloping land was cleared, woodland was retained on the steep slopes of Blatchley's Hill and along the ridge running adjacent to the western edge of the farm. The Kemble estate, purchased in 1757, was largely cleared for agriculture (Ehrenfeld cites McClintock 1894) with the lower slopes of Tea Hill and Mt. Kemble evidently cleared along with the land between the western boundary of the property and Route 202, but the steeper slopes and western sides of the hills were kept in woodland. No information is available for the early history of the lands of the Guerin farm, but Ehrenfeld surmises that it

was a small farm, worked without slaves, so probably was similar to the Wick farm in the distribution of fields and woodlots, with the gently sloping land at the base of Sugar Loaf Hill the most likely to have been cleared and cultivated.

Although the pre-encampment forest had been disturbed by the activities of Native Americans and European colonists, the arrival of the continental army represented a major departure from the previous disturbance regime of Jockey Hollow. Washington's troops began arriving in 1779 and building huts on the south-facing hillsides and slopes (to take advantage of sun angles and to allow for drainage) with tiers of huts built into steeper slopes by terracing (Thayer 1975). Thayer reports that the area containing the huts was apparently heavily forested at the time. Around 1000 huts were built in all, each of them 16'x14'x6.5'. Most were constructed of chestnut. This would have required approximately 4208 board feet of wood per hut (assuming walls 8" thick and roof 2" thick), or 4,208,000 board feet.

That the Jockey Hollow forest was considered suitable for such a vast construction effort might suggest that the forest was younger than sometimes assumed, possibly in the 50-100 year range, with abundant trees in the 12-20" dbh size class (see Figure 5). Larger trees would have been very difficult to cut and shape for log houses and firewood. (An increment core from an original timber in an 18th century house might indicate the rate of growth of the local chestnut stand in the 50-100 years prior to the tree being cut. That would in turn give some indication whether the forest canopy was relatively open or closed during this period. Without such evidence, assumptions about the age and condition of the pre-encampment forest are largely speculation.)

After the huts were built, storehouses and hospitals were constructed (Thayer 1975), and land near each brigade was cleared for a parade ground. More trees were cut to make charcoal for cooking fuel. As the winter of 1779-80 was said to be the coldest in the 18th century, the brigades found it difficult to procure enough firewood (Thayer 1975), implying that most trees within reasonable hauling distance to the huts had been cut and utilized. If four cords of firewood were cut per hut, another 6,144,000 board feet of wood would have been removed, or a total of 10,352,000 board feet for huts and firewood. In a heavily stocked forest (e.g., 24,000 board ft/acre), this would have required clearing 431 acres. Apparently, some wooded areas of the Wick Farm were left standing for tactical purposes in the event of a British attack, between Fort Hill and the ridge west of the Wick House, and between the ridge and the next hill west of it (Ehrenfeld 1977). Thayer reports the army's compound contained livestock, mentioning at one point 100 head of cattle probably allowed to browse in the newly cut or remaining woodlands.

Thayer reports 50 - 100 forges operating in the county during the war. Ehrenfeld places one near Leddel's Pond, but implies that the iron industry had little impact on the park's woodlands until much later, in the early 1800's, concurrent with peak agricultural clearing.

After Mary Wick's death, the Wick farm was divided into several homesteads each of which were likely kept open for farming much of the land cleared by Washington's army. Although some areas identified by Ehrenfeld likely reverted to forest without an interim period of fields, (e.g. the mature forests of Blatchley's Hill, the west facing slopes of Mt. Kemble and Tea Hill, and the chestnut oak-black birch stand between the Aqueduct Trail and Cemetery Road) there is little evidence of undisturbed forest in the areas we sampled. More likely, wooded stands have

Figure 5. Maturing chestnut forest.



been repeatedly selectively cut. Some areas, like plot EE, mapped as mature forest (Ehrenfeld 1982) that originated following the departure of the soldiers, are structured and have vegetation (including invasive, non-native species) more similar to successional plots. Deeds from the 1840's mention stands of mature forest, indicating that no farming had intervened on these sites since the time of the brigades. By the mid-nineteenth century, farming had reached its peak and had begun to decline, and some farmland was increasingly allowed to revert to forest (Ehrenfeld 1977 cites Vermeule 1900 and Robichaud and Buell 1973). Several accounts show little change in the distribution of fields and forest between 1878 and 1900, and Ehrenfeld believes there was little change in the arrangement or size of the farms from the second half of the nineteenth century until the inception of the park in 1933.

This history suggests that several hundred acres were probably cleared in 1779-80 but grew back directly to forest and were never broken by a plow. They may have been wooded pasture in the early 1800s. Until the early 1930's, they were likely logged in relatively short rotations.

On the Kemble estate, much of the eastern face of Mt. Kemble was owned between the late 1800's and early 1900's by William P. Jenks, who kept goats and sheep on the land and farmed most of the property. Other evidence provided by Ehrenfeld implies that these areas were farmed longer and reverted to forest more recently than successional stands in other areas in the park - some stands were estimated to be only 20 years old by Ehrenfeld in 1977. A Report on Forests (Vermeule 1900, cited in Ehrenfeld 1977) maps and describes forested regions of New Jersey during the 1890's, including the land around Jockey Hollow. Most of the timber south of Morristown was reported to be 5.9-9.8 inches (15-25 cm) dbh and about 40 years old in the late 1890's, and abundant regeneration (trees in the 5-10 cm size class) was noted (Ehrenfeld reporting Vermeule). Our data from Jockey Hollow confirm these estimates for the oldest cohorts in the mature canopy, which are now approaching 150 years in some stands. By 1900, cutting in Jockey Hollow area appears to have been minimal, although most areas of what Ehrenfeld terms successional forest were kept cleared until the early 1900's.

Chestnut Decline

Any discussion of the disturbance history of eastern forests must include the impact of the chestnut blight, which dramatically altered the composition of the matrix forest of the region in the beginning of the 20th century. The gaps left by the demise of the chestnut and its salvage caused variable changes in community composition.

In her study of former oak-chestnut stands in the southern Blue Ridge Mountains, Keever (1953) notes that the forests she studied were successional, and that 20 years was too short a time for a new equilibrium to be established following the major disturbance of the chestnut blight. Keever predicted that canopy dominance would be asserted by the codominant oaks (northern red, white, and chestnut oak) and the widespread understory hickories, based on her finding that reproduction in all size classes made it likely these species would retain their place among the dominants of the future canopy.

A later study by McCormick and Platt (1980) confirmed Keever's predictions. In a study of forest change in Appalachian mountain plots sampled in 1939 and again in 1970 and compared

with pre-blight forest composition, they found that prior to the chestnut blight hickory was not an important species at any elevation but occurred in the understory as numerous, widely dispersed small trees. In 1970, hickory had the highest importance value of any species on the plots they sampled. They hypothesize that hickory filled a role as a "gap opportunist" by accelerated growth of seedlings and saplings in the gaps created by the blight and salvage operations. During the half-century following the chestnut blight at certain elevations in the Appalachian Mountains, the oak-chestnut forest was replaced by an oak-hickory forest. McCormick and Platt note that pignut hickory (*Carya glabra*) replaced chestnut, red maple invaded clearings, and sugar maple became a dominant species in mixed mesophytic forests at lower elevations.

Nelson (1955) documents change between 1934 and 1953 at the Coweeta Hydrologic Laboratory in the mountains of western North Carolina. He found that *Liriodendron tulipifera* (yellow poplar) changed the most in an area that had not been burned since 1918 nor grazed since 1933. Not previously an important species in the oak-chestnut community, its basal area increased over the time period investigated. By 1953, many of the yellow poplars occupied dominant and subdominant positions in the forest canopy. He concluded that chestnut was being replaced primarily by codominants and secondarily by the advancement of subordinate species.

In the NJ Highlands, Good (1968) studied chestnut replacement and reported that while the principal associates of chestnut in the pre-blight forest became the leading dominants, trees which occupy the second or third most important position in the canopy were not always important constituents of the pre-blight forest. Although oaks are persistent and conspicuous in the canopy and show signs of diameter release, they did not fill gaps by seeding in and have steadily declined in reproductive success. She found that black birch (*Betula lenta*) filled a role similar to that reported for hickory in the Appalachian Mountains studies and had become codominant with oaks in the forest canopy. Black birch was the only species more associated with old chestnut gaps (stumps) than its presence in the forest as a whole (trees, saplings and seedlings alike). Red maple and beech showed signs of increasing in importance. Good's vegetation reconstruction indicated that in the pre-blight forest chestnut was either the first or second ranking tree on all sites, except the base of slopes where it was a minor associate with beech and yellow poplar. Principal associates were chestnut oak on the ridgetops, black oak on the southeast midslope, chestnut oak and black birch on the northwest midslope. Good notes that the trend toward more mesic species appears to have originated before the blight and may be related to changes in fire history (Buell 1966 cited in Good 1968).

Mackey and Sivec (1973) describe changes in composition of an extensively logged former oak-chestnut forest in the Alleghenies of western PA, approximately 50 years following the chestnut blight. They documented little resemblance to the former oak-chestnut association by a successional forest dominated by black cherry (*Prunus serotina* Ehrh.), red maple, sugar maple, black birch and sour gum (*Nyssa sylvatica* Marsh.). They postulate that the extensive removal of chestnut along with other desirable species at the time of the chestnut blight created an immediately open environment that allowed invasion by typical early to mid-successional species mixed with canopy individuals remaining at the site. The presence of black cherry and red maple in the canopy are attributable to this model. Black cherry in these forests is expected not to persist as a canopy species judging by mortality in younger size classes. Similarly, black locust (*Robinia pseudoacacia*), which established in the early years following the blight and

subsequent lumbering, never reached large diameter classes and has not persisted (see species autecology – appendix X). Forests experiencing heavy salvage operations contrast with those described by Keever (1953), Nelson (1955), et al. in which chestnut was removed by the blight and lumbering did not occur between the time of the blight and the beginning of the study. In the latter stands, single tree canopy gaps were largely filled by codominants and abundant subcanopy species such as hickory.

Insects and Disease

Other insect and disease outbreaks that have altered the forest composition at MNHP include the gypsy moth (*Lymantria dispar*) outbreak in 1967-69, which took a heavy toll on oaks in some stands, and again in 1977-78, despite prior release of introduced parasite populations that had become well-established throughout the park. Chestnut oak and white oak are the two species most preferred by the gypsy moth. Ehrenfeld described understory response to canopy gaps caused by gypsy moth (1980) and mapped patches of heavy oak mortality due to gypsy moth defoliation (1982). The patches are scattered through the forest and are not extensive in size as mapped. Ehrenfeld found that for large gaps an inverse relationship exists between relative density of understory species stems and relative density of canopy species stems. *Cornus florida*, now not a common understory species, was the most frequent gap colonizer, particularly where it pre-existed the disturbance in large understory patches. Even the larger, multiple-tree gaps in Ehrenfeld studies may not have been large enough for regeneration of the dominant (oak) species killed by gypsy moth. Kelty et al. (2003) found that a minimum canopy opening of 0.3 acre with understory treatment would regenerate equal proportions of intolerant and tolerant species. Below that size, the edge effect favoring shade tolerants counted for nearly the entire area of the gap. Above 0.3 acre, intolerants dominated. Ehrenfeld (1980) concluded that the forest structure provides the resilience to minimize any irreparable change from insect defoliators. However, since 1980, the structure of the forest has been significantly altered by deer impacts and invasive species in many areas of the park. Where these impacts are severe, recovery of the canopy and understory following defoliation events may be arrested, and stable native species associations are likely to be disrupted.

During the 1930's, the park employed disease control measures for locust borers and for Dutch elm disease, and in the process, some "forest stand improvement" was undertaken. Timber Stand Improvement, or T.S.I., is a loose term comprising all intermediate treatments made to improve the composition, constitution, condition, and increment of a timber stand (Silvics Manual).

Future concerns include oak wilt (*Ceratocystis fagacearum*), which is widespread in the eastern U.S., and sudden Oak Death pathogen (*Phytophthora ramorum*), which has been introduced in Connecticut on ornamental *Rhododendron* shrubs imported from a nursery in Oregon.

Oak wilt, a vascular disease caused by the fungus *Ceratocystis fagacearum*, is one of the most destructive diseases of both the red and white oaks and kills trees the same year they are infected. It is widely distributed throughout the central and eastern United States. White oak is less susceptible to oak wilt than the red oak species, and may lose only a limb at a time, or may sustain infection by the pathogen without ever showing symptoms. Oak wilt usually kills individuals or small groups of trees in scattered locations throughout a stand but may affect areas

up to several hectares in size. It is spread from tree to tree through root grafts and over longer distances by sap-feeding beetles (*Nitidulidae*) and the small oak bark beetles (*Pseudopityophthorus* spp.) (Silvics Manual).

Sudden oak death (*Phytophthora ramorum*), if introduced into the oak-dominated MNHP forest, would cause a rapid acceleration of the replacement of the oak canopy with more shade tolerant subcanopy species. *Phytophthora ramorum* manifests as round fungal lesions on leaves of host shrubs including (*Rhododendron*, laurel, and *Viburnum*). It can appear to cause oaks to wilt and die within just a few weeks, although it may actually take a year or two for the disease to destroy the root system. With close inspection of infected trees, cankers and seeping may be observed. Foresters, arborists, tree wardens and loggers should be aware of the condition of oak foliage in and around residential areas with *Rhododendron* plantings. Unusual foliage lesions or sudden wilting and dying of oak should be immediately reported to USDA Animal and Plant Health Inspection Service (APHIS). Suspect trees should NOT be cut and transported, as doing so may spread the pathogen to new areas. There is no known practical control for infected forests. This species of *Phytophthora* seems much more dangerous than other *Phytophthora* species (e.g. root rot and potato blight), because it can be spread aerially. That means that spread can be accelerated via severe weather events that may coincide with spore production. Several tree species are vulnerable to this disease—most notably many red and black oaks—especially northern red oak. For more information, go to <http://www.aphis.usda.gov/ppq/ispm/sod/>. If observed, contact NJ APHIS representative Vionette James (215) 334-0300 (215) 334-9799 vionette.james@aphis.usda.gov.

Beech Bark disease was not observed in previous studies, nor did we see evidence of it. Beech bark disease is initiated when a scale insect, the beech scale, *Cryptococcus fagisuga*, attacks the bark of beech trees and renders it susceptible to bark canker fungi of the genus *Nectria* (Silvics manual). The insect component of this *scale-Nectria* "complex" was introduced to Nova Scotia from Europe around 1890 and is now found throughout New England, New York, and northern Pennsylvania. In 1981, a 70,000-acre infestation was detected in northeastern West Virginia, many miles south of the nearest previously known infestation. More recently, the disease has been reported as far west as Toronto, Ontario, and the scale is now present in northeastern Ohio and northwestern Virginia. In North America, *Nectria coccinea* var. *faginata* is the fungus most commonly associated with the disease in the Maritime Provinces, New England, and northern New York. In western Pennsylvania, West Virginia, and some New York stands, however, *N. galligena* is the predominant associated species. As the disease and forest interact for the first time, a large proportion of the large, mature beech trees may be killed. Mortality is now especially high in some southern and western areas of the Adirondack Mountain region. The percent stocking of beech was reported to remain the same after the killing front of the beech bark disease moved through a managed stand, as the disease mainly affected the larger trees. Although such mortality is rare in stands emerging in the aftermath of the disease, severe defect may be caused by the now-endemic causal complex together with *Xylococcus betulae*, another scale, which causes roughened spots on stems of young trees and is especially devastating to the sprout thickets that have emerged in the aftermath of beech bark disease (Silvics Manual).

Asian Longhorned Beetle (*Anoplophora glabripennis* [ALB]) may well become the next invasive insect catastrophe for northeastern forests if it continues to expand from its local

introduction site in Brooklyn, NY. This non-native pest species could significantly affect the understory of the MNHP forest as it feeds on and hatches its larvae in a number of the primary understory species of the forest. It has been documented in Jersey City and Carteret, NJ, and New York City, Amityville, Islip and Long Island in New York. It is similar in appearance to the White-spotted Sawyer beetle. Individuals are $\frac{3}{4}$ to $1\frac{1}{4}$ inches long, with a jet black body and mottled white spots on the back. The long antennae are $1\frac{1}{2}$ to $2\frac{1}{2}$ times the body length with distinctive black and white bands on each segment. The feet have a bluish tinge. Egg-laying sites or niches are oval to round pits in the bark chewed out by the female beetle, with a single egg deposited in each niche. Sap may flow from egg niches, especially on maple trees, as the larvae feed inside the tree. Coarse sawdust may accumulate around the base of infested trees, where branches meet the main stem, and where branches meet other branches. This sawdust is created by the beetle larvae as they bore into the main tree stem and branches. A $\frac{3}{8}$ ", large round hole on trunk or large branches may be evident where adult beetles emerge from the tree. Preferred and host species include:

Highly preferred

Acer negundo (box elder)
Acer platanoides (Norway maple)
Acer saccharum (sugar maple)
Acer saccharinum (silver maple)
Acer rubrum (red maple)
Acer pseudoplatanus (sycamore maple)
Aesculus hippocastanum (horse chestnut)
Salix spp. (willows)
Ulmus americana (elm)

Moderately preferred

Betula spp. (birches)
Populus spp. (poplars)

Currently, the only effective means to eliminate ALB is to remove infested trees and destroy them by chipping or burning. To prevent further spread of the insect, quarantines are established to avoid transporting infested trees and branches from the area. Early detection of infestations and rapid treatment response are crucial to successful eradication of the beetle.
(<http://www.na.fs.fed.us/spfo/albpestaalert/index.htm>)

If observed, contact NJ APHIS representative Vionette James, acting, PA (215) 334-0300 (215) 334-9799 vionette.james@aphis.usda.gov.

Wind and Ice Storms

Wind and ice storms are the most frequent natural disturbances to affect the forest of northern New Jersey and New England (Foster 1988). Since the mid-twentieth century when fire suppression has been the rule, wind throw and ice damage have provided the most frequent disturbance, although they are usually localized and scattered in effect. Lemon (1961) reported that ice storms or glaze affect species differentially based on the arrangement of branches and strength of live wood in relation to the weight of the ice. When ice reaches $\frac{1}{4}$ to $\frac{1}{2}$ in (0.6-1.3 cm) in thickness, there is conspicuous breakage in smaller branches. With moderately strong winds, that level of ice glaze can result in bole breakage in many species. Species more resistant

to ice breakage are white ash, hickories, yellow poplar and yellow birch. Moderately resistant species include oaks, sugar maple and beech. Species very susceptible to ice breakage include black cherry, red maple, elms, most birches and poplar.

As the MNHP forest codominants senesce, suppressed and intermediate stems would be expected to take their place in the canopy if they live long enough. As many of the intermediate and suppressed stems are species less resistant to glaze, the future canopy can be expected to be somewhat more degraded over time than the existing canopy and therefore, more open. Additional sunlight might encourage regeneration, but deer and invasive species densities would also be likely to respond, making increased tree recruitment unlikely. If this course of succession proceeds, the oak canopy may be replaced with a broken oak-red maple-black birch canopy above increasing invasive species cover for a long period of time. This is likely to negatively impact the appearance of the forest, as was observed by McCune and Cottam (1985) in their Wisconsin study.

Orwig and Abrams (1995) studied the ecological impacts of windthrow creating single and multiple tree gaps in oak stands in northern Virginia. They found few significant differences in microclimate or regeneration responses in gap and control sites, although ecophysiological changes in photosynthetic rate, vapor conductance and area of leaves were observed. Accelerated height growth occurred in all gap species, and a radial growth response was observed in young white oak and height growth in sassafras and sweet gum. Age analysis revealed that smaller gap individuals were quite old and had experienced several gap-phase releases at approximately 20-30 year intervals. The pattern of small diameter understory trees of great age and variable growth rate holds true in the mature plots sampled at MNHP. Releases since 1933 are likely due to small gaps caused by wind, ice, or oak mortality due to gypsy moth. Catastrophic wind storms could dramatically alter the physiognomy of the MNHP forest and would create conditions for regeneration of a new cohort of trees. However, redevelopment of the forest canopy (particularly oak regeneration) would be very slow and vulnerable to interference from invasive species, as there is little advance regeneration, and oak seedlings compete poorly in conditions of understory shade.

Sustainable Forest Management Objectives Desired Future Conditions

Mature Forests

Jockey Hollow (approx. 1330 acres)

The desired future condition of the forest stands in Jockey Hollow is development of a healthy, naturally regenerating, mature forest, accumulating some of the characteristics of old growth, including understory reinitiation, multi-age structure, gap-phase regeneration, complex understory structure and composition with species diversity appropriate to landscape position, and increased forest "legacies". Legacies include large old trees, standing dead and downed trees, nurse logs, and pit and mound topography providing greater heterogeneity and habitat niches at the forest floor. (The U.S. Forest Service definition of old growth is: "Old forests often containing several canopy layers, variety in tree sizes and species, decadent old trees, and standing and dead woody material." My definition includes the process of old growth development from natural canopy gaps.)

As much of the MNHP forest would be characterized as late successional, old growth features are beginning to develop in many areas. Those most closely approaching old growth structure should be prioritized for protection as old growth, and old trees should not be cut down. In earlier successional areas where forest regeneration is to be attempted, older trees may be cut to encourage regeneration and hasten development of multi-age structure.

Over time, the composition of the canopy and understory will gradually change to include more shade tolerant species. In areas where it is now prevalent, oak will decline in importance; however hickory will remain important as long as it is able to regenerate in the understory. As there are very few saplings of any species in the current understory other than hickory, which can persist a long time in shade, it is difficult to predict what species will replace the current canopy layers when the youngest subcanopy cohort senesces. In the event of natural disturbance of a size that removes sufficiently large areas of the canopy (>0.3 -acre gaps), the mature, uninvaded forest is likely to regenerate slowly with a new cohort of intolerant and mid-tolerant species selected through the filter of browsing pressure. The level of browsing and the pace of expansion of invasive species into these uninvaded areas may determine the pace of natural forest regeneration. If the browsing and competition from invasive species outstrip natural regeneration of sprouts and seedlings, a period of broken canopy underlain by an understory dominated by exotics is a possible, undesirable outcome.

Portions of the Jockey Hollow forest researched and mapped as "mature forest" zones include either mature second-growth stands, originating from areas cleared in 1788-89 by the Continental Army but never plowed or cultivated and returning directly to forest after the end of the encampment, or areas never cleared, but repeatedly logged. These areas, in which plots FN, AN, EE, BE, BN1, BN2, CN1, CN2, CE2, CN3 and possibly DN are all mapped (some GPSed, some added by hand to the GIS map provided by R. Masson), have been in a wooded condition for the longest period, and should therefore have a somewhat similar character with differences

based on ecological and plant community differences due to environmental variables, the patchy nature of natural disturbances, such as fire, insect damage, and logging, but not due to major differences in the degree of soil disturbance or extent of pasturage. However, variability we have noted in these plots suggests more recent disturbance that has favored invasion by non-native species, as reflected in their plot names (CE2 and EE indicate the presence of exotic species).

Based on the age-class structure of the trees and our data on associated vegetation, plots BN1, CN1, CN2, AN, FN and DN appear to support the theory behind the mapped zones. All have far lower abundances of invasive species, older canopy and sub-canopy tree cohorts, and more varied and diverse understory vegetation. CE2, mapped as mature forest (in landscape unit A1) (Ehrenfeld 1982) on land supposedly never cleared but successively logged, is quite different from other stands mapped in this unit and appears to have had a different history. It is even-aged, has the oldest cohort of trees of any of the plots sampled - essentially one cohort of very old oak and hickory 142 to 175 years old with only one 89-year-old intermediate white ash - and has a total lack of subcanopy diversification or shrub strata, excepting two surviving flowering dogwood stems. Had it been selectively logged, it is unlikely these large old, straight-boled, majestic trees would have remained, and it would be more uneven-aged. This plot may have been cleared by the original settlers and allowed to reforest during 1829 to 1860 when its canopy trees originated, but was likely later grazed by livestock more intensively and more recently than other wooded pastures in the mature forest matrix. Had it never been plowed and been totally abandoned when its oldest trees initiated, one would expect it to have developed more like the other mature forest plots. It is surrounded by areas cleared by the original settlers, and abandoned only in the 1930's (e.g., plots DE and FE), but it is quite different from these successional plots. It has the mature-forest tree species, closed canopy, and lack of understory that are typical of late-successional forests in the stem-exclusion phase before initiation of new understory through gap-phase succession that creates old growth. However, the prevalence of Japanese wiregrass, barberry and other invasive species on the forest floor may inhibit the development of seedlings or advanced regeneration of late-successional tree species. Plot EE also shares characteristics of both mature and successional stands. Like CE2, it is mapped as mature forest; in this case in landscape unit B1, indicating it was cleared at the time of encampment but immediately returned to forest cover. It has a two-aged age-class structure more like stands in the mature forest, and unlike the successional examples in FE, DE and AE, its canopy has stratified into codominant, intermediate and suppressed stems that tend to reflect the age ranges of its cohorts. A subcanopy of 40-to-50 year-old *Cornus florida* and *Celtis occidentalis* and some suppressed *Acer* and *Fagus* apparently established free from grazing or browsing pressure. Although invasive species are present, their cover is not as dense as in the successional stands, and there remains a diverse assemblage of native forbs (in low abundance, but present) not usually found in the successional stands. For these reasons it is included here with mature forest examples.

Permanent plots in the mature forest are in the following plant associations or communities (Sneddon et al. 1998):

Plot CN1	(CEGL006921) <i>Fagus grandifolia</i> - <i>Betula lenta</i> - <i>Quercus (alba, rubra)/</i>
Plot BN1	<i>Carpinus caroliniana</i> Forest
	Translated Name: American Beech - Sweet Birch - (White Oak, Northern Red Oak) / Ironwood Forest
	Common Name: Northern Piedmont Mesic Oak - Beech Forest
Plot CN2	(CEGL006336) <i>Quercus (alba, rubra, velutina) / Cornus florida / Viburnum</i>
Plot CE2	<i>acerifolium</i> Forest
Plot DN	Translated Name: (White Oak, Northern Red Oak, Black Oak) / Flowering
Plot FN	Dogwood / Mapleleaf Viburnum Forest
Plot AN	Common Name: Northeastern Dry Oak-Hickory Forest
Plot EE	

Successional Forests

The desired future condition of successional forest stands includes conversion to a multi-aged structure, greater diversity and stratification of the canopy and subcanopy, and more structural complexity and species diversity in the understory in order to provide greater resilience to disturbance events. A reduction of invasive species and increase in regeneration of trees and native woody understory species is essential to the health and integrity of these stands. Currently the canopy and subcanopy are differentiated by differences in species growth rates and shade tolerance. Having attained the canopy, yellow poplar, white ash, hickory, oaks and sugar maple are likely to remain as codominants for a long time, barring disturbance. However, many of the subcanopy species (red maple, elm (*Ulmus rubra*), black locust, black walnut (*Juglans nigra*), sassafras (*Sassafras albidum*) and hop-hornbeam (*Ostrya virginiana*) are not able to attain or hold space in mixed-species canopies, and the lack of tree saplings or seedlings and the paucity of native woody species in the understory in some areas indicates arrested development. In successional forest heavily invaded by exotic species, a canopy-destroying event may result in an extended period of dense growth of exotic shrubs and vines, which would prevent any tree re-establishment, similar to the successional forest near the Tempe Wick house. Thus the desired future condition of the successional forest community with or without a canopy-destroying disturbance will be difficult to achieve.

According to the theory that the combination of deer and invasive species may have halted succession, it may be desirable to manage to promote a broader array of species in the understory in these areas to promote regeneration of a healthy and diverse canopy in the future. The first step in converting an even-aged to an uneven-aged stand is to stimulate regeneration in parts of the stand. Any management to promote tree regeneration would be ineffective or counterproductive without reduction of deer and invasive species impacts. Invasive shrubs and grasses which leaf out early and are tolerant of low light levels can have a deleterious effect on understory tree species (and presumably native shrub) regeneration.

Black locust, a non-indigenous species in New Jersey, appears to be dying out naturally in the interior forest, as it is in most cases overtopped by more rapidly growing trees. It does not tolerate shade. A nitrogen fixer, it may exacerbate the growth of invasive species and is an

expressed concern among park staff. It establishes in open conditions and will not naturally regenerate in interior forest. Therefore, it will eventually die out in those areas. Where there is more light penetration, the species should be removed to prevent spread and excessive nitrogen enrichment of the soil.

Successional forest communities generally represent early successional vegetation types that occurred on disturbed agricultural soils, or originated from clearcutting in the 20's and 30's (Zaremba, in process). These species associations have little conservation value due to their transitional and often highly disturbed nature. Plot FN1S is an exception, as it falls within a respectable plant association associated with mature forest stands, indicating that it was never completely cleared. However, logging, soil disturbance, and invasion by exotic species have degraded the stand, and it would benefit from restoration.

Desired future species composition should reflect historic assemblages appropriate to landscape position and be related to the community classification of surrounding, topographically-related, MNHP mature stands (Zaremba, in process) or documented in the literature of the NJ Highlands region. A healthy successional forest can have higher species richness and cover in the understory than a mature forest. At MNHP, the reverse seems to be the case. It would be appropriate to combine management to increase age-class diversity with understory restoration. While opening canopy gaps and reducing deer and invasive species impacts would allow natural regeneration to occur, restoring understory diversity may require more active management, including planting and protecting native shrub and small tree species typical of less disturbed communities inhabiting similar topographic position in the park. *Lindera benzoin* and *Carpinus caroliniana* are common understory species in more mesic to hydric areas, while *Viburnum acerifolium*, *Vaccinium pallidum*, *Cornus florida* and *Hamamelis virginiana* would be likely to occupy the understory in drier habitats. *Viburnum prunifolium* (blackhaw) has a wide range of soil moisture tolerance. In order for canopy and understory succession to resume, browsing and competitive weed pressure must be controlled.

Successional plots are in the following communities (Sneddon et al. 1998):

- | | |
|---------|--|
| Plot AE | (CEGL006406) Southern New England Red Maple Seepage Swamp
<i>Acer rubrum</i> - <i>Fraxinus (pennsylvanica, americana)</i> / <i>Lindera benzoin</i> / <i>Symplocarpus foetidus</i> Forest
Translated name: Red Maple-White (green) Ash-Spicebush-Skunk Cabbage Forest
Common name: Red maple Swamp |
| Plot DE | (CEGL006599) <i>Prunus serotina</i> - <i>Liriodendron tulipifera</i> - <i>Acer rubrum</i> - <i>Fraxinus americana</i> Forest
Translated Name: Black Cherry - Tuliptree - Red Maple - White Ash Forest
Common Name: Modified Successional Forest |

- Plot FE (CEGL007221) *Liriodendron tulipifera* - *Quercus* spp. Forest
Translated Name: Tuliptree - Oak species Forest
Common Name: Interior Mid- to Late-Successional Tuliptree - Hardwood Upland Forest (Acid Type)
- Plot FN1S (CEGL006336) *Quercus (alba, rubra, velutina) / Cornus florida / Viburnum acerifolium* Forest
Translated Name: (White Oak, Northern Red Oak, Black Oak) / Flowering Dogwood / Mapleleaf Viburnum Forest
Common Name: Northeastern Dry Oak-Hickory Forest

Management Options for Successional and Mature Forests

MANAGEMENT GOALS: The desired resource condition for the forests in all forested park units (Jockey Hollow, New Jersey Brigade, and Fort Nonsense) is to develop a naturally regenerating mixed hardwood forest reflecting historic character, biodiversity, and natural processes (MNHP Invasives Management Plan).

The Existing Condition

In silvicultural terms, the existing condition of the MNHP forest in the stands studied is generally mature in both successional and mature stands, mid- to late-successional, tending toward old growth, but lacking the understory diversity and structure typical of older stands due to excessive deer browse and invasive species cover in some areas. Three of the 12 plots we sampled were essentially even-aged. Due to the lack of advance regeneration or a stratified subcanopy, these stands will likely degrade over time without young trees to replace senescent canopy trees. Two of these (plots FE & DE) are in relatively young stands (average tree age 58 years) that probably originated from cleared agricultural fields. The other (CE2) is a mature plot with some of the oldest trees sampled at Jockey Hollow (average age 145 years), which may also have originated from a cleared field or clearcut, given the prevalence of oak and the uniformity of the canopy cohort, and was probably thinned, leaving an even-aged cohort of widely spaced canopy trees. These stands lack understory structure and diversity, have little or no regeneration of native woody species, and have understories dominated by invasive species. Stands of this type are the most vulnerable to catastrophic natural disturbance and least resilient should it occur. More specific information on existing condition in each permanent plot sampled is in Appendix C.

Most of the permanent plots we studied were in variations of oak-hickory forest. There are other forest communities not included in the suite of permanent plots that should be managed with an eye to maintaining differentiation of forest cover with topography and soil moisture gradients--from the hydric and mesic forests along Primrose Brook to the xeric forests at the top of Mt. Kemble. Restoration or silviculture in these areas should be guided by Bob Zaremba's community classification and reference to the International Classification of Ecological Communities (Sneddon et al. 1998). Understory restoration in these areas may require protected plantings, preferably of locally grown native species appropriate to the plant community, and reduction of deer impacts and invasive species competition.

Most of the mature stands we sampled are two or three-aged stands that developed when residual trees were left during a harvest of the previous stand. The appearance of these stands is of impressively large, attractive trees, with a stratified canopy and fairly open understory due to heavy deer browsing. In general, uninvaded forest stands appear to have a more diverse mix of hardwood species in the canopy than invaded stands, which gives them more canopy and subcanopy structure, and a more diverse understory of native shrubs and herbs. However, as observed by Ehrenfeld and Russell and as noted by many other researchers of chestnut replacement in northeastern forests, the MNHP forests are tending away from the mixed oak and oak-hickory canopy that dominated the forest following the decline of *Castanea dentata*, and are moving toward greater dominance of shade tolerant species. Because there are at least two cohorts of canopy trees, two-aged stands will have a greater longevity than even-aged stands

even given the arrested succession in their understories, unless they are subjected to stand replacing disturbance. Because they are more structurally and species-diverse, they will recover more quickly from localized natural disturbances, such as ice and insect outbreaks. However, the combined impacts of deer and invasive species suppressing the understory and fire exclusion have and will act as an ecological filter limiting regeneration to those species that can withstand their combined effects. The younger cohort is less diverse than the older cohort, and the future forest is likely to be less diverse.

Mature, uneven-aged stands with a number of cohorts, such as plot CN2 on Mt. Kemble, tend to have more structural and species diversity in their canopies than the two-aged stands. CN2 has some younger cohorts of oak and hickory, and a youngest cohort of beech and red maple. The canopy of this stand will likely retain its character for decades barring catastrophic disturbance, eventually to be replaced with shade tolerant species. If natural regeneration could occur, shade tolerant species as well as hickory would develop in the understory, but heavy browsing impedes this development. If disturbance that substantially opened the canopy followed by fire occurred, this area would likely regenerate oak. In managed, second growth forest stands, recent research indicates that shelterwood-burn techniques provide the most effective combination of overstory (canopy gaps) and understory disturbance (reduction of low shade) and facilitates oak success (Brose et al. 1999, van Lear et al. 2000, cited in Rentch 2003). In areas where beech is dominant, such as Mt. Kemble's lower western slope, the oldest oak cohort is likely to be replaced by beech. Since beech shoots are not preferred by deer, the species has a competitive advantage in this area and wherever it establishes.

Younger, successional, uneven-aged stands, such as plot AE and FE, have many cohorts and a stratified canopy. However, they are not as species rich as the mature uneven-aged stands and are composed of few long-lived species except yellow poplar. Lacking development of longer-lived shade tolerant species in the understory, these stands will continue to be characterized by yellow poplar and white ash until these senesce or experience major disturbance, then will be dominated by subcanopy species like red maple, black cherry, black locust, and slippery elm.

As Ehrenfeld (1977) noted, aside from the loss of chestnut, the forest still has many of the same species as the pre-colonial forest had, albeit in different proportions. Black birch and red maple appear to be increasing in importance as the larger oaks decline, and these species (along with American beech, along streams and in scattered other stands) represent the greatest number of seedlings and saplings found in the understory (Russell 2003). Hickory continues to be present in all canopy layers in exclosures, but elsewhere is suppressed along with most other seedlings and saplings by deer browsing.

The forest understory is less species rich and more thinly stocked than it may have been in colonial times and the early 19th century due to the resurgence of the deer population. However, before the arrival of the Continental Army, Native American and early settlement agricultural practices, such as burning to maintain an abundance of young growth in order to increase the carrying capacity of the forest for deer or livestock, may have kept some areas in a condition structurally similar to that seen today, with large trees, a generally uneven-aged forest structure, and an open, grassy or low shrubby understory.

Alternatives

This section describes the alternatives developed to address ways to restore the MNHP forest to ecological sustainability, given the concerns and issues raised in earlier sections. The alternatives represent a range of approaches from passive management (no action) to intensive silvicultural intervention to encourage regeneration, with expected advantages and limitations described for each. Uneven-aged management systems, such as single tree selection, diameter limit, and group selection are not recommended, as the literature indicates that these methods encourage the shift in composition toward shade tolerant species. The impact of deer and invasive species, likely the most important sources of stress in the forest, are addressed in each alternative. Silvicultural techniques suggested in the alternatives are defined in Appendix E.

Alternative A: No Change

Alternative A prescribes continuation of the passive management approach as at present. This approach would not alter the forest's existing condition or age-class profile but would allow changes (both beneficial and otherwise) to occur without active interference by humans.

Maintaining the current appearance of the forest by withholding silvicultural management for the foreseeable future (say 50 years) will result in a forest canopy that will gradually mature and senesce, opening up single and multiple tree gaps and increasing the gap-phased, uneven-aged structure characteristic of old growth, provided that forest succession is not completely arrested by the combination of invasive species and deer. Many of the forest's species (both early successional, e.g. yellow poplar; and mid-late successional, e.g. oaks, hickories, sugar maple, and beech) are long-lived. Barring stand replacing disturbance or major disease outbreaks, this overstory will probably persist another 100 to 200 years as large, mature trees, with increasing loss of crown area as they begin to senesce. Single and multiple-tree gaps will begin to occur in the forest, releasing subcanopy trees (if they live long enough or if new regeneration occurs) and allowing some seedling establishment on the mineral soil of tip-up mounds. However, the differences in ages and longevity of canopy and subcanopy trees may cause a lag in canopy closure, leading to a period of broken oak-red maple-black birch-tulip tree and beech canopy that is not as well formed as today's, with a declining number of subcanopy trees unless regeneration increases naturally. Within smaller gaps, shade tolerant species will thrive (Kelty et al. 2003). Generally, this will encourage black birch, a good competitor on mineral soil and rotting trunks (Silvics Manual). Where gaps are sufficiently large, black cherry and red maple may appear as some of the most frequent (if temporary) seedlings in the understory, and tulip tree may increase (Orwig and Abrams 1995, McCune and Cottam 1985). Sugar maple (*Acer saccharum*) may increase if seedlings are able to survive, but few sugar maples were observed (although many red maples in permanent plots were coded as sugar maples). Caveat: without control of deer, the current apparent state of arrested succession is likely to persist, and a more sustainable, diverse, and structurally complex future forest is unlikely to develop.

The MNHP forest, without major disturbance by humans since 1933 and in some cases longer, will grow increasingly susceptible to wind and ice damage as it grows older, will slowly accumulate forest legacies, but will continue to have a similar appearance over the next 50 years under this (default) management regime if spared major natural disturbance. If a stand-replacing

disturbance, such as a major blow-down, does occur, the forest will be dramatically altered. The current lack of a complex understory or advance regeneration in most areas make the vegetation as a whole both more susceptible to wind damage and less responsive to the canopy opening that it would provide. Recovery of the canopy from a catastrophic windstorm would take decades. Although stand replacing disturbances are natural and northeastern forests are adapted to and rejuvenated by such events over a long return interval, the maturity of much of the MNHP forest and the lack of advance regeneration in the understory would exacerbate the damage. The visitor's experience of the MNHP forest would be impaired for a long period of time. With a stand-replacing windstorm, park roads and trails would likely become impassable for an extended period, snags would be plentiful, and rehabilitation to ensure visitor safety would be very costly. It is likely that regeneration following a stand replacing disturbance would outpace the deer herd's ability to arrest development in some areas. However, deer would continue to act as an ecological filter to some extent.

Maintenance of trails and selective removal of dead/dying trees that threaten forest visitors will continue to be required under a passive management option. Invasive species management, especially in currently uninvaded forest, in small gaps, and where newly introduced invasives may be controlled before becoming major problems, will be important in maintaining optimal conditions for natural ingrowth. Without treatment, non-native, invasive species can be expected to spread and increase in density throughout the forest. Unless existing invasive species populations are reduced, increase in invasive species cover in recently invaded areas could be dramatic in just 5-10 years. However, reducing invasives alone will not result in restoring the balanced proportion of advanced regeneration, sapling, and pole-sized trees needed to provide sustainable structure and replace the forest canopy as it ages. This option assumes no change in deer management practices but includes implementation of the MNHP Invasives Management Plan.

Time scale to achieve management goals: NA. Development of a more sustainable forest age-class structure would depend on natural disturbance and other stochastic factors.

Visual impact: Increasing degradation of forest canopy over longer (100year) timescale is likely, as crown area of aging canopy oaks decreases.

Alternative B: Restoration of Successional Stands through Small Patch Cuts, Understory Treatment, and Planting of Desired Species

Plots FE, DE, and CE2 appear to be in essentially even-aged stands. Patch selection clearing in stages to create multiple age classes in currently even-aged stands combined with total understory removal in treated stands would increase sustainable structure and a multi-aged, multi-species composition at the stand level. (A minimum patch size of 0.3 or 0.5 acre or greater--at least twice the height of the codominant trees, would be sufficient to enable regeneration of intolerant and mid-tolerant species.) Traditional uneven-aged silvicultural techniques such as single tree selection or small group selection are not recommended because they tend to shift composition to shade tolerant species. Rather, area control (controlling proportion of stand to be harvested) techniques rather than a target diameter distribution would be used to regulate the stand cutting level. Using a "q-value," or diameter limit cutting, in even-

aged stands is problematic because yield tables for the negative exponential reverse-J-shaped curve that characterizes balanced stands were developed to describe uneven-aged stands in which trees are grown in partial shade. These tables don't apply to open-grown, even aged stands (Kelty et al. 2003).

Patch selection involves completely removing small portions of the target stand in scattered patches, with successive cuts phased at 20-30 year intervals, depending on management staff and/or financial limitations. Area control (cutting limited by size and number of patches cut within a stand) vs. diameter limit cutting (targeting trees of a certain diameter at breast height throughout a stand) produces abundant regeneration without promoting shade tolerant species, as diameter limit cuts can. Understory treatment combined with aggressive control of non-native species and deer browsing is required for this approach to succeed, as intolerant and mid-tolerant species, such as oaks, are usually too slow-growing under low shade to compete with less desirable species. Although deer browse may cause sprouting and increased vigor of seedlings, sufficient regeneration is unlikely to occur until browsing is reduced dramatically from current levels.

To increase species diversity within stands where species typical of the presettlement forest, such as oaks and hickories, are currently lacking and seed sources are distant, these species would be planted in the cleared gaps and protected by translucent plastic tree shelters to prevent deer browse and provide an enhanced early growth environment (Kelty and Kittredge 1986, Ward et al. 2000). Given the paucity of oak or hickory advance regeneration or seed sources in some successional stands (e.g. DE and FE), it will be important to plant desired canopy species to achieve greater species diversity within these stands. The survival and rapid growth of a small number of widely spaced seedlings of desired species would greatly improve the composition and structural diversity of these stands. A planting or protection rate of as few as 20-30 seedlings per 0.3-acre patch would be sufficient. Carefully grading seedlings so that only good quality stock is used will increase planting efficiency (Ward et al. 2000).

Efforts to convert even-aged stands to a more diverse composition and a multi-aged structure by dividing the stand into multiple small patch clearcuts or shelterwood cuts executed at intervals over a period of time have been successfully used in several locations (Kelty et al. 2003). The first step in the process is to obtain regeneration in parts of the stand—at MNHP, this would necessitate control of browsing levels. For example, at the Quabbin Reservoir in Massachusetts, managers created three age classes in even-aged stands by cutting a third of the stand (in minimum patch sizes of 0.5 acre) on a 30-year cutting cycle. Both merchantable overstory and unmerchantable understory trees were cut, except for advance regeneration of desired species. Areas between the patch cuts were thinned using basal area as a guide (the total harvest, patch cuts, and thinning amounted to about 50% of total stand basal area). Review of experiments in many regions of the eastern forest, including the Quabbin Watershed (Kelty et al. 2003, de la Cretaz and Kelty 1999 and 2002), indicates the importance of removing invasive species, small trees, and shrubs in treated areas in order to obtain high seedling densities that can develop rapidly in height—an important factor in avoiding deer browse. Any advance regeneration of desired species should be left, as it will grow much more quickly than seedlings. Patch sizes should be 0.3 acres or larger.

This alternative requires treating aggressive invasive species and reduction of deer impacts in treated areas with monitoring and adaptive management to insure success, and invasive species monitoring and management to limit spread. Tree shelters are generally 4-5 feet high, and are removed once tops emerge to allow them to expand their branches. Deer impacts would need to be controlled at this point or many of the unsheltered saplings would not survive.

Under this alternative, untreated, mature forest stands would be allowed to grow to biological maturity to increase habitat availability for late successional and old-growth species. Human intervention in these areas would include implementation of the Invasives Management Plan (mapping and treatment along edges of invaded/uninvaded areas to prevent further expansion into uninvaded native forest stands), reduction of deer impacts to allow understory reinitiation and the resumption/development of complex understory structure, and trail maintenance. Long-term monitoring to determine the effects of reducing or removing the two potential causes of arrested succession (deer and invasive species) would be important. Maintenance of trails and selective removal of dead/dying trees that threaten forest visitors will continue to be required.

Removal of black locust along park roads could be done at the time of the successional forest treatments, and more historically appropriate tree species (e.g. hickory or oak species) planted along the road in tree shelters. Planning of treatment areas would be coordinated with park historians and archeologists to ensure that important archeological sites are preserved. Where tree removal might benefit historical sites, it could be accomplished under this alternative, but gap response regeneration would have to be controlled in those areas.

Caveat: tree shelters can help protect natural or planted seedlings and thereby increase the diversity of the future canopy, but this will not increase diversity in the understory. To increase understory diversity, tall shrubs and small trees, such as maple leaf viburnum (*Viburnum acerifolium*) and dogwoods, could also be planted in tree shelters. However, a more naturally diverse understory and herbaceous layer cannot develop without control of browsing and competition from invasive species. Therefore, this alternative assumes implementation of the Invasives Management Plan and reduction in deer numbers.

Time scale to achieve management goals: 50-100 years. Successional stands would develop new cohorts and a broader mix of species within 30 years, and these individuals would mature and reach the canopy while new patches were beginning to mature within 50 years. All areas in a given stand would have been treated and begun to develop within 100 years. The mature forest would respond to invasives removal and reduction of deer impacts with regeneration of a native, shade tolerant understory, but gap-phase regeneration and development of old-growth structure is a long process—it is possible that healthy patches of old growth could develop within the same 50-100-year time period with active deer and invasive species control. Beyond 100 years, forest composition in areas not managed for oak regeneration will tend to shift toward domination by shade tolerant species.

Visual impact: low: treatment areas are mostly off-trail and/or in areas already visually impacted by deer exclosures, etc. Cuts are done in small patches and can be buffered by uncut corridors. Plot CE2 is a special case due to its visible location, oak canopy, and large, old trees. Adaptive

management and phased implementation to test treatment success and achievement of management goals should be a priority.

Alternative C: Experimental Regeneration of Mature Mixed Oak Forest in Patches Through Staggered Shelterwood or Seed Tree Cuts (with Reserves) Combined with Understory Treatment

This alternative would require restoration of successional stands as described in Alternative B, plus some regeneration cutting in selected areas of mature forest with good microclimate conditions for oak and sufficient oak seed trees.

The mature forest treatments would involve the partial removal of canopy and subcanopy cover and understory competition to encourage oak regeneration. This could be achieved by dividing a target stand into thirds and conducting shelterwood or seed tree clearing within 1-acre patches in each third at 30-year intervals to create a three-age structure at the stand level. Prescribed burning, or mechanical low shade treatment, conducted every 2-3 years, could favor oak sprouting and discourage a number of more tolerant species that are susceptible to fire when young, such as yellow poplar. This alternative would mimic the conditions most researchers conclude are necessary for oak regeneration and thus requires more intensive management, sustained over a longer period of time. Once advanced regeneration established, the remaining overstory could be removed to enhance the development of regeneration. A given percentage of the remaining overstory seed or shelter trees would be left to enhance biodiversity goals, becoming future animal trees or forest legacies. While no prescription available can guarantee oak regeneration, repeated disturbance and fire appear to be common factors in the establishment of oak stands (Abrams and Nowacki 1992, Rentch 2003). If successful, this approach would increase age-class diversity at the stand level and provide for oak regeneration, keeping oak as a component of the greater MNHP forest. If prescribed fire cannot be used, other methods of understory control (growing season cutting or herbicide) would be required. This alternative would only be successful if combined with deer population (or browse) control and rigorous invasive species control in treated areas. Without intensive management of invasives in and around treated areas, this level of disturbance would likely increase non-native plant populations and distribution which would in turn inhibit oak seedlings (de la Cretaz and Kelty 1999, 2002). Thus, management objectives and monitoring would have to be carefully tracked as described below (under adaptive management).

The untreated remainder of the forest would be allowed to grow to biological maturity to increase habitat availability for late successional and old-growth species. Human intervention in these areas would include implementation of the Invasives Management Plan (mapping and treatment along edges of invaded/uninvaded areas to prevent expansion into uninvaded native forest stands), reduction of deer impacts to allow understory reinitiation and the resumption/development of complex understory structure, and trail maintenance. Long-term monitoring to determine the effects of removing or reducing these two potential and interacting causes of arrested succession (deer and invasive species) would be important.

Planning of treatment areas would be coordinated with park historians and archeologists to ensure that important archeological sites are preserved. Where tree removal might benefit

historical sites, it could be accomplished under this alternative, but gap response regeneration would have to be controlled in those areas.

Time scale to achieve management goals: 50-100 years. If oak regeneration is successful, beyond 100 years, there will continue to be 3 cohorts of oaks in the forest canopy in both successional and mature stands.

Visual impact: moderate: a greater proportion of forest units are treated, but treatment areas are relatively small and scattered, and treated patches can be buffered by uncut corridors.

Alternative D: Understory Treatment, Removal of Sources of Ecological Degradation, Restoration of Natural Processes

This alternative would reduce and maintain the deer herd (especially does), ideally to a target of 2 per km² (3/mi²), institute aggressive invasive species control, and use prescribed fire or mechanical treatments to reduce low shade and encourage understory regeneration of fire-adapted understory species and mid-tolerant trees. This alternative is intended to stimulate succession in areas where it has been arrested by the interaction of deer and invasive species cover, to increase understory structure and diversity over time, and to provide conditions that may restore the suite of species adapted to more frequent understory disturbance without complete removal of the canopy. Eventually, stand-replacing wind, ice storm, or fire (unlikely) would occur, and the affected stands would regenerate naturally to a structure more analogous to presettlement forest, which may have developed in this way. But it would not lead to the same composition.

Under this alternative, more frequent (3-5 year) prescribed fire or mechanical understory treatment is intended to encourage regeneration and sprouting of oaks without overstory removal and to discourage beech, yellow poplar, and black birch. Lorimer et al. (1994) noted uneven-aged oak-dominated stands that persisted through the 18th and 19th centuries as evidence of oak regeneration under a mature oak canopy. Under experimental conditions, the researchers found that oak seedling survival was strongly correlated with removal of understory competition by cutting or herbiciding, and noted that prescribed fire alone had mixed results, depending on timing and frequency. This alternative would alleviate stresses and mimic natural (or at least pre-settlement) processes in the forest ecosystem, would provide an opportunity to examine oak regeneration under a mature canopy, and would encourage regeneration of understory once desired tree species have reached a competitive stature.

This alternative is addressed to restoring oak regeneration in a mature forest with a mixed oak canopy, in which succession appears to be arrested by invasive species and deer, but where seedling sources are available. Other, relatively uninvaded areas of the forest with different forest cover and community composition also in a state of arrested succession due to deer impacts would benefit under this alternative from a reduction of deer impacts and implementation of the Invasive Species Management Plan to prevent invasion, but those areas would be allowed to resume understory recovery naturally without understory manipulation. They would continue to develop late successional-to-old-growth species associations, legacies, and structure as small gaps arise through overstory senescence, and changes in their understories

would follow patterns similar to those described by Ehrenfeld (1980) in response to small canopy gaps.

Monitoring and adaptive management in treatment areas would require sampling growth of desired species and understory competition levels at various intensities of treatment to determine best practices. Deer browse in these areas would be carefully monitored and managed.

Care would have to be taken to protect archeological resources in areas where understory treatments might be employed.

Time scale to achieve management goals: very long term. Regeneration of species capable of reaching and holding a place in the canopy for long periods of time will be very slow under this management regime, and the canopy may appear more ragged for a time as old canopy trees and their shorter-lived subcanopy cohorts senesce, and there is an age-class gap with no regeneration to quickly replace them. Natural disturbance such as a microburst (limited wind damage) or pest outbreak may accelerate regeneration in patches, although this is unpredictable. A risk with this long-term management alternative is that if a major blow-down occurred, it would leave the disturbed area in an unforested state for a long period as little advance regeneration exists throughout many areas of the forest. Where invasive species are already present, forest re-establishment could be retarded or even prevented depending on the species and their habit.

Visual impact: minor, barring catastrophic disturbance. An aggressive invasive species removal program and reduction in the deer herd would have positive visual effects on the forest, more so as a native understory developed. However, it is difficult to predict how quickly the forest understory would respond to removal of browsing and competitive stress under a largely closed canopy.

Alternative E: Extensive Clearcuts

Under this alternative, extensive patches of forest (10-20 acres) would be clear cut to duplicate the types of disturbance known to have given rise to current stands. This alternative must include non-native, invasive species removal and control of deer browsing, as both would respond to increased sunlight and regeneration by population expansion. Tree regeneration is inhibited by dense invasive species cover and deer browsing (de la Cretaz and Kelty 2002), and rapidly growing seedlings, such as black birch, would be selected for by low shade, thus invasive species cover and heavy browsing are likely to select for a different forest composition than that which developed following 18th century clearing and 19th century farm abandonment when invasive species and deer were not abundant. This management approach would be very counterproductive if not combined with aggressive deer herd and invasive species control, as it would likely lead to an increase in both.

Planning of treatment areas would be coordinated with park historians and archeologists to ensure that important archeological sites are preserved. Where tree removal benefited historical sites, it could be accomplished under this alternative, but gap response regeneration would be controlled. This alternative might provide an interpretive opportunity to recreate, in the area of a hut site, the appearance of the forest at the time the huts were being built.

Time scale to achieve management goals: Forest regeneration would resume immediately following clearcutting (provided that invasive species and deer impacts were strictly controlled), but this even-aged treatment would mean that longer term goals of achieving ecological sustainability, multi-cohort stands, and structural and species diversity would be delayed for at least a century.

Visual impact: severe.

Monitoring Forest Change: Adaptive Management

An effective forest management strategy should include an adaptive management/monitoring component to evaluate its effectiveness over time, detect unanticipated impacts, and allow modification based on response to treatments. The adaptive management cycle includes: specific, quantifiable objectives to describe the desired condition of the resource, management designed to meet the objectives or continuation of existing management strategy, monitoring, and measurement to determine the response of the resource and to determine if the objective has been met. If objectives are not reached, management is adapted to better meet objectives (Elzinga et al. 1998). Because monitoring is labor intensive, its use should be a priority where alternative management options are possible.

Any manipulation of the MNHP forest today will require long-term management of invasive species and deer herd response. park managers do not have the luxury of only thinking about the overstory trees and assuming stand replacement will occur naturally: regeneration of the overstory is intimately connected to the response of understory species, their autecology and growth habits, and ecosystem stresses. Because invasive species tend to follow disturbance, any disturbance to the canopy or understory will likely be followed by invasive species expansion into the disturbed area, unless careful monitoring and control are implemented. Likewise, an increase in understory regeneration is equivalent to an increase in carrying capacity for deer, and without population control or other means of controlling impacts, increased deer impacts would also be expected throughout the forest.

Short-term Change

Effects of reducing deer impacts will vary and may be detectable in just a few years or much longer, depending on the area sampled. Some of the exclosures and paired control plots established by park staff show little change compared to unexclosed control plots nearby, whereas others show considerable change. This variability may be due to a combination of leaf litter depth and light levels under closed canopies that inhibit understory reinitiation until a canopy gap opens and/or litter is disturbed, or it may indicate (in the unchanged exclosures) a degree of environmental degradation that has resulted in an alternate stable state that cannot return to its original composition and structure even after the causal factor is removed. Using the existing permanent vegetation monitoring plots and paired exclosures as a baseline, percent cover and density of understory herbs, shrubs, or tree seedlings could be monitored for change in areas where overstory and understory treatment are prescribed. If canopy and understory trees are removed where permanent plots do not currently exist, plots should be established in treated and adjacent untreated areas to compare change over time, with and without deer browsing. Large permanent macroplots with point-intercept transects laid out inside them with the points as sample units can give a sufficiently large sample size to detect change at a desired level with adequate statistical power and can be relatively quickly sampled. Elzinga et al. (1998) provides excellent guidelines for specific adaptive management sampling designs.

Invasive species monitoring and management should continue with the goal of preventing further spread of existing invasive herbs and shrubs and early detection and removal of new invaders,

such as black swallowwort, Siebold's viburnum (*Viburnum sieboldii*) and Kiwi vine (*Actinidia arguta*). One had only to observe the impressive, approximately 60 foot-high curtain of Kiwi near plot BE to imagine what this escaped ornamental could do to the forest canopy if it began to spread aggressively. The literature on biological invasions has many examples of introduced species, seemingly benign at first, which spread only locally until a certain threshold is reached and then become aggressive competitors. The rate of spread and growth of Kiwi is not well known, but it is prudent that the population on Fort Hill was removed in the winter of 2005 (R. Masson, NPS, personal communication). Any new areas of establishment (such as that observed near exclosures behind the maintenance shed) should be surveyed and treated to prevent further spread.

Adaptive management is a method of interacting with natural systems in a carefully controlled, experimental way in order to understand system responses and to modify actions accordingly if necessary. Thus, where community responses are not fully understood, information gained through careful monitoring design may inform better management decisions in the future. To this end, management objectives should be paired with management responses, and where monitoring is used to detect change, sampling objectives should be articulated and implemented.

An example might be:

Management Goal: Increase diversity in forest structure and species composition in even-aged stands to improve resistance and resilience to natural disturbances by encouraging understory development.

Objective 1: Decrease browsing by deer by 90% to allow understory regeneration.

Sampling Objective 1: Obtain estimates of leader herbivory with 90% confidence intervals no wider than 10% of the estimated browsed percentage.

Management Response: Deer herd will be reduced or excluded if browse exceeds 10% of sampled understory.

Objective 2: Prior to overstory removal, reduce non-native understory competition to a frequency of no more than 5% (sampled annually in a permanent macroplot) to allow native understory species to re-establish following overstory removal.

Sampling Objective 2: Be 95% confident that frequency estimates are within +/- 5% of the estimated frequency values (evaluate sample size and power) (Elzinga et al. 1998).

Management Response: Initiate mechanical or chemical weed control following sampling season if the frequency of invasive understory species exceeds 5% in the permanent macroplot.

Long-term Change

Permanent plots provide an advantage for detecting change from one time period to the next, (particularly with long-lived plants, such as trees and shrubs) in that the statistical tests are much more powerful than the tests used on temporary sampling units. Thus, the number of sampling units that need to be sampled to detect a certain magnitude of change may be reduced (Elzinga et al. 1998). With deer and invasive species control, the permanent plots could be used to document regeneration and growth rates and mortality/recruitment. If the stands where the permanent plots are located are not treated in any way, they may still provide useful information on changes in forest cover and species composition over time. The permanent vegetation plots established as part of Ehrenfeld's exotic species study (1999) should be resampled at 5-10-year intervals.

Plotless measurement of forest species composition and basal area is an efficient way to estimate current condition, but to be relevant to the entire forest, many points must be sampled. Transects established by Ehrenfeld (1999) could be revisited (depending on management alternative and area selected) to monitor change in density, basal area, mortality, and forest composition at 5-year intervals. One limitation of variable radius and point-centered quarter methods is that the former underestimates and the latter overestimates small-diameter species and their abundances.

Research Needs

- Reduction of deer impacts and an increase in native understory shrub species may reduce the density and spread of *Microstegium vimineum*. The observation by Russell (2002) that Japanese wiregrass abundance declined from 80% cover to zero in certain deer exclosures should be investigated further with replicate plots. Several studies suggest increased low shade discourages *Microstegium vimineum*, and this could be the cause of the effect observed in the atypical exclosures. The effectiveness of increasing low shade as a wiregrass control could be tested further at MNHP by experimentally planting native shrubs in a few exclosed plots within an area invaded by *Microstegium*. Exclosed plots should be of sufficient size to evaluate ecological processes in the absence of deer--400m² is the standard plot size for sampling forested communities.
- Experimentation and long term study of understory dynamics to ascertain if oak can be regenerated under a mature oak canopy by manipulating low understory competition levels, as in Alternative D, would be a valuable addition to the literature on oak regeneration (Lorimer 1994). It may also provide a less drastic way to encourage succession in the mature MNHP mixed oak forest.
- Restoring appropriate understory diversity and structure within each distinct vegetation association (plant community) at MNHP has been described as part of the desired future condition of the forest. Adaptive management principles should be used to determine the most effective and cost-effective method or combination of methods for restoring understory vegetation including reducing deer impacts by fencing, reducing competition from invasive species, and planting native shrubs (within or without protective sleeves).
- Dendrochronological studies of old timbers in historic structures to estimate size/growth rates of trees (chestnut, etc.) in the 17th and 18th century forest would add to an understanding of pre-encampment forest conditions. Here, dendrochronology refers to taking a sample core from an original timber in a historic structure and analyzing growth rings to determine growth conditions in the forest over the tree's lifespan. This can yield information about pre-Revolution forest condition that cannot be gathered in any other way.
- Paleoecological study of a MNHP wetland sediment core would provide more information on presettlement forest composition and associated communities.
- Establish permanent plots in areas of distinct vegetation at New Jersey Brigade and Fort Nonsense. Using protocols established by Ehrenfeld and Russell, sample vegetation and compare to Jockey Hollow stands. Conduct dendrochronological analysis of trees in the plots in order to reconstruct age-class structure and evidence of disturbance history. Desired future condition and management goals for all three forested units of MNHP should be similar, however differences in stand history, structure, and existing condition should be noted; understory restoration should reflect differences in community types; and any management of steeper slopes at New Jersey Brigade and Fort Nonsense should take into

consideration soil erosion, protection of archaeological resources, and preservation of individual very old trees.

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Appendix A. Objectives and Plan of Work

The following specific objectives have been developed for this work. In *Italics* following each objective is a description of how we will meet the objective (i.e. our Plan of Work).

1. Articulate the need for sustainable management of forest resources in light of the park's mission to preserve the lands and features associated with Washington's winter encampments during the Revolutionary War.

This will be facilitated by our discussions with park staff on their vision for the future park forest resource. It will be articulated in the preamble of the forest plan, and individual actions recommended in the plan will be identified with respect to how they fulfill the need for sustainable forest management.

2. Synthesize available information related to historic forest structure and composition of Morristown during the period of the encampments.

We will review existing studies (e.g. Ehrenfeld 1977a.) and evaluate these within the context of recently published works on the land-use history and stand dynamics of hardwood forest of the region. A number of resources are available including books by Gordon Whitney and Emily Russell and published research by Mark Abrams and others.

3. Consolidate and review information related to existing conditions and influences of Morristown's forests.

A wealth of data is available from the 25 year of study by Ehrenfeld and Southgate (Russell). We will compile in one, well documented folder existing information, and review that information with an eye toward identifying gaps in knowledge that would hinder our development of a comprehensive forest management plan.

4. Gather additional field data as necessary to further describe current forest conditions and influences.

Through our review of existing information, we will determine if there are portions of the park for which data on current conditions are lacking (e.g. Fort Nonsense?) for which specific information on forest stands in general are inadequate (e.g. diameter class/age structure information for "mature" and "successional" stands). A sampling protocol and schedule will be developed and delivered to park staff before the summer, 2004 field season.

5. Describe desired future conditions for the forests of Jockey Hollow, New Jersey Brigade, and Fort Nonsense units, based on the goals enumerated in this document, historic and current forest information, and NPS planning documents for the park. Desired future conditions should be developed for each of the appropriate existing forest zones within these units, such as 'mature' and 'successional' forest zones.

Desired future conditions will be characterized with respect to quantifiable attribute, which can be monitored by park staff (see 6. below)

6. Quantify the desired future conditions (DFC) of the forest for the above units and existing forest zones.

This likely to evolve into a set of quantifiable stand characteristics which are attributes of stands representative of the desired future condition. Examples include a diameter class/age distribution for native tree species that suggests a forest that will perpetuate itself, absent catastrophic disturbances, into the future. At the same time, it must be recognized that disturbance has long played a role in deciduous forest stand dynamics and that the present stands regenerated following disturbances (chiefly timber cutting in the late-19th and early 20th centuries. Desired future conditions must take into account the impacts and possible need for control of deer browsing on the one hand and competition from exotic tree, shrub and grass species on the other. Thus DFC might well include, in addition, to an all-aged stand structure, levels of competition (e.g. stem density/height/cover) of exotic species as well as intensity of deer browse/browse heights on seedling/saplings of desired species.

7. Develop management strategies to achieve the desired future conditions. These strategies should be able to be implemented through discrete management treatments that may be monitored to assess their relative success, in the context of an adaptive management strategy. Management strategies should also focus efforts along historic corridors.

This will, of necessity, involve an application of knowledge of best management practices for the silviculture of central hardwood forests including methods of minimizing deer browsing on seedlings/saplings and for control of competition from exotic species. A series of alternative management options will be developed and evaluated with respect to meeting management objectives derived from DFC. park staff will then be in a position to chose appropriate management strategies and develop environmental assessments as needed.

8. Describe and quantify, if possible, the desired interim conditions (DFC) at various time stages in the process of forest recovery.

These will evolve from our descriptions of DFC and an application of knowledge about how hardwood stands develop from successional to mature forest conditions. Two models will have to be considered: 1) how stands mature in the absence of catastrophic disturbance, and 2) landscape dynamics that might involve some stands being affected by catastrophic disturbance (e.g. wind storms) while other are not. Thus, we might see all stands in the park at some stage of progressing toward an all-age structure in model 1, but in model 2 – some stands following predictable development toward an all-age structure while others are regenerating, en masse, following a stand-replacing disturbance. An initial, cursory review of published reports by Ehrenfeld and Southgate (Russell) suggests that the second model may have dominated during the past one-two centuries (i.e. through land clearing, agricultural activities, agriculture abandonment, the catastrophic decline of chestnut, and subsequent salvage logging).

9. Describe monitoring methods that will measure the success of management treatments at achieving the stated goals, and that will provide thresholds for changes in management actions, as part of an adaptive management strategy.

An extensive network of monitoring plots has been established in the past through the efforts of Ehrenfeld and Southgate (Russell). We will evaluate these plots and the data that have been obtained from them with respect to their ability to meet future monitoring needs. Our evaluation of future needs will be tempered by the realization that all existing data/plots, no matter how large or small or how well replicated, have the great advantage of providing information based on direct observation of past conditions. Thus, any additions to, or modifications of, existing sampling protocols should be linked to past practices/methods to the greatest extent possible. We would anticipate, at this stage that proposed additions to existing protocols would focus on individual stand characteristics critical to documenting the meeting of quantifiable objectives and the characterization of stands/management units that are currently underrepresented by the existing suite of plots.

10. Develop management treatments that will reduce the negative impacts of forest vegetation growth and erosion on the areas with sub-surface archeological resources.

On National Park Lands, the preservation of archeological resources is of paramount concern, whether management activities involve suppression of wildfires or the salvage of blown-down timber. All recommendations for active management of forest stands will be evaluated with respect to impacts on archeological resources, with an emphasis on identify stands/units of the park where archeological concerns are greatest.

11. Identify additional research priorities.

The identification of future research needs should evolve naturally during the course of our literature searches of existing knowledge and our summary and evaluation of park-specific knowledge. Some ongoing research (e.g. the large deer exclosure/exotic replacement plot of Ehrenfeld and the seedling plots of Southgate (Russell)) may answer current questions or identify new priorities for future research. Work that we do in 2004 to characterize stand size/age structure may shed new light on how individual stands developed, or point to additional work that should be pursued to understand the interactions between past and modern disturbances (e.g. the decline in chestnut and recent gypsy moth defoliations on the one hand and deer browsing and exotic species competition on the other).

Appendix B. Tree Species Names and Codes

<u>Species Names</u>	<u>Code</u>
<i>Quercus rubra</i>	1
<i>Acer saccharum</i>	2
<i>Betula lenta</i>	3
<i>Liriodendron tulipifera</i>	4
<i>Betula alleghaniensis</i>	5
<i>Hamamelis virginiana</i>	6
<i>Cornus florida</i>	7
<i>Quercus prinus</i>	8
<i>Fagus grandifolia</i>	9
<i>Quercus alba</i>	10
<i>Nyssa sylvatica</i>	11
<i>Amelanchier arborea</i>	12
<i>Vitis labrusca</i>	13
<i>Acer rubrum</i>	14
<i>Lindera benzoin</i>	15
<i>Juniperus virginiana</i>	16
<i>Quercus velutina</i>	17
<i>Robinia pseudoacacia</i>	18
<i>Prunus serotina</i>	19
<i>Fraxinus americana</i>	20
<i>Celastrus orbiculata</i>	21
<i>Carya spp.</i>	22
<i>Viburnum prunifolium</i>	23
<i>Ulmus americana</i>	24
<i>Sassafras albidum</i>	25
<i>Prunus avium</i>	26
<i>Castanea dentata</i>	27
<i>Carpinus caroliniana</i>	28
<i>Toxicodendron radicans</i>	29
<i>Parthenocissus quinquefolia</i>	30
<i>Acer platanoides</i>	31
<i>Ailanthus altissima</i>	32
<i>Celtis occidentalis</i>	33
<i>Ulmus rubra</i>	34

Appendix C: Plot and Forest Zone Descriptions, Existing Condition

Plot CE2 is an example of a mature, essentially even-aged stand dating to the mid-1800's, with canopy oaks, hickory, red maple, and white ash ranging from 89-175 years. There is no continuous subcanopy, and the few suppressed trees in the plot have died. There is little or no native shrub layer. Japanese barberry (*Berberis thunbergii*) exists at approx. 30% cover, and there is a small amount of wineberry (*Rubus phoenicolasius*). The herbaceous layer is dominated by Japanese wiregrass (*Microstegium vimineum*), 80% cover, with a few native herbs and other invasives scattered at <1 to 1% cover. Situated on the lower south slope of Mt. Kemble, the area probably reverted to forest at the peak of farm abandonment in the mid-19th century and has likely been forested pasture since that time. The plot is mapped in landscape unit A in Ehrenfeld (1982) on land supposedly never cleared but successively logged, yet it is quite different from other stands mapped in this unit and appears to have had a different history than other plots in the mature forest. It is even-aged, suggesting that it was once cleared. It has the oldest cohort of trees of any of the plots sampled—essentially one cohort of very old mixed oak and hickory ranging 142 - 175 years, and is the only even-aged, mature stand sampled. It has a total lack of subcanopy or shrub strata, except one suppressed 89 yr old white ash and two surviving flowering dogwood stems. If it has been selectively logged as have other mature stands, it was done with different goals in mind, as it has an essentially even-aged profile. It is possible that this plot was cleared by original settlers, allowed to reforest during 1829 to 1860 when its canopy trees originated, and was then later grazed by livestock, which arrested development of younger tree cohorts and introduced exotics from surrounding pastureland. Had it never been cleared or plowed or reverted after initial clearing, one would expect it to have developed more canopy diversification as have the other mature forest stands. It is surrounded by areas cleared by the original settlers, but only abandoned as farmland in the 1930's—similar to plots DE and FE—but it is also quite different from these successional plots both in dominant species and age-class structure. It exhibits the mature forest canopy species, continuous canopy and lack of understory typical of late successional forests in the stem exclusion phase, before understory re-initiation and multi-aged structure develops through gap-phase succession. However, the prevalence of *Microstegium*, *Berberis*, and other invasive species at the ground level and the lack of advance regeneration due to browsing pressure will complicate and retard the development of functional old-growth.

Plot EE also shares characteristics of both mature and successional stands. Like CE2, it is mapped in the mature zone, in this case in landscape unit B1, indicating clearing at the time of encampment but immediate return to forest afterward. It has a two-aged class structure more like stands in the mature forest, and unlike the successional stands FE, DE and AE. Its canopy of mixed oak, sugar maple, white ash, and hickory (established ca. 1866-1888) has stratified into codominant, intermediate, and suppressed crowns that reflect the ages of its cohorts plus their shade tolerance, relative growth rates, ability to exert apical dominance, and light availability (spacing). A subcanopy of 40-50 year-old flowering dogwood and hackberry and some suppressed red maple and beech apparently established free from grazing or browsing pressure. Though invasive species are present, their cover is not as dense as in the successional stands, and there remains a diversity of native forbs (in low abundance, but present) not found in the successional stands.

On the north side of Mt. Kemble, data for trees cored on plots CN1 and CN2 show the release of many stems in the early 1930's. This suggests that these stands were last harvested around the time of park establishment. A number of the younger trees also established about that time. This release occurred within a decade of the Chestnut Blight, so it is possible that salvage harvesting of Chestnut, once abundant in this area as evidenced by chestnut stumps and downed logs, was the last significant disturbance. These stands appear two-aged, and were probably never completely cleared, as evidenced by their relative lack of exotic species (although there is extensive cover of barberry and multiflora rose at the summit of Mt. Kemble, originating in the cleared field and extending into the forested areas). CN2 on the upper northwest slope of Mt. Kemble has a more diverse herbaceous layer than CN1 on Kemble's more gently sloping lower northwest slope. CN2 has species characteristic of oak-hickory communities in the Northeast, which are often relatively rich in herbaceous and native shrub flora. The oldest trees in the upper slope (CN2) are 115-120 years old; the younger trees range in age from 37-55. There are enough young hickories in the area to suggest that it will become a dominant species following the demise of the older oaks. White oaks probably killed by gypsy moth defoliation in 1967 to 69 (Ehrenfeld 1977) on the hill have tried to sprout, but heavy deer browse has prevented advance regeneration from establishing.

The lower north slope of Mt. Kemble (Plot CN1) is composed of a beech-oak-red maple community, dominated by beech, with the depauperate herbaceous understory typical of beech stands. The older beech and most of the young stems appear to have established after the last major logging in the early 1900's. Interestingly, many of the small saplings (root suckers) are nearly the same age as the dominant canopy beeches in the stand. Stems ranging in age from 95-119 years ranged in size from 13.4 -60.7cm dbh. Beech is not widespread at Jockey Hollow, but it is present in low numbers throughout the forest and dominant in restricted areas. At this time, it seems most concentrated along the streams where it was likely selected for by the harvest of more desirable species. Since beech reproduction is largely vegetative, it is likely that it will remain dominant in those areas it currently inhabits (largely lower elevations and along streams at Jockey Hollow; and perhaps Tea Hill, although that area was not quantitatively sampled, and possibly also on the hills of the NJ Brigade area). It is not expected to expand its territory rapidly unless harvesting and some cutting encourage it to sprout further. Ehrenfeld (1977) reported no apparent incidence of beech bark disease, which would limit its spread, and none was observed in our sampling. As the oaks senesce, codominant and intermediate trees of species other than beech—including hickory, red maple, black birch, and possibly tulip tree—if they can escape the deer, will more likely fill the canopy niches unless codominant beech are already present.

Plot BN1 and FN are similarly composed of two age-cohorts, each spanning about 30 years. In BN1, the oldest trees, a variety of oaks and black birch, range from 93-126 years, while the younger cohort ranges from about 31-67 years and is composed of black birch, beech, red maple and yellow poplar. In FN, the older red oak and black birch (92-117 years old) are likely to be replaced by black birch and tulip poplar, which is now 15-82 years old. Plot AE (mapped as on the edge of mature forest) is in a younger stand, with all trees fairly evenly spanning a range of 44-90 years. The canopy is red oak and white ash and the subcanopy red maple and slippery elm on alluvial soils.

Plot DN is in a mature stand that is more uneven-aged in character (several cohorts of a few trees each, ranging in age from 34-152). Until we resampled it in 2004, this plot had not been relocated since it was first sampled. It has a better-developed understory than many areas of Jockey Hollow, with abundant blackhaw (*Viburnum prunifolium*) growing in the shrub and suppressed canopy layers. This plot also has a rich herbaceous flora, which may indicate freedom from the level of deer browsing other areas of the park have experienced. The canopy consists of older red oak, white ash, hickory; sweet cherry, flowering dogwood, and blackhaw share the subcanopy layer. Located uphill from the reconstructed colonial army huts, it is situated near a hilltop which may have been historically cleared for visibility. According to Ehrenfeld's (1982) land use maps, some such areas only reverted to forest at the time of the park's establishment in 1933. Though parts remained wooded, all of Sugar Loaf Hill was once grazed. Invasive, non-native species include *Berberis thunbergii*, *Microstegium vimineum*, *Alliaria petiolata*, *Rubus phoenicolasius*, *Cardamine europaea*, and *Rosa multiflora*, but none have established the near-monotypic coverage nor reached the heights seen in the plots mapped in areas plowed or kept in pasture for a long time, and a greater diversity of native shrubs and forbs were observed in this plot.

Plot AN is mapped in the mature forest zone but shows the effects of recent disturbance in its age-class distribution and individual-tree condition. The oldest dominant tree is a 126 year-old red oak. The other codominant trees - another large, 76.8-cm dbh red oak probably a couple of decades older¹ and a 36-cm dbh black birch probably in its 90's - were both rotten at the core so are of unknown age. Four other intermediate and suppressed subcanopy trees of similar size could not be aged due to heart rot, but are probably close to the same age as their cohorts of similar diameter - intermediate and suppressed black birch, yellow birch, and red maple range in a rather even succession from 20-96 years old in the subcanopy. Several trees on this N-to-NW facing, rocky slope had fire scars, and all of the fire-scarred trees had heart rot. Native shrubs, including flowering shad (*Amelanchier* sp.) and witch hazel, were present in the understory. Comparing our data to Ehrenfeld's 1995 data for this plot, it is obvious that it has experienced a great deal of mortality among its canopy and understory trees. This is probably due to the delayed effects of the fire, but oak mortality also may be due to prior gypsy moth outbreaks as the plot is near the mortality zones mapped by Ehrenfeld (1982). Patchy mortality due to "natural" disturbance such as fire or (native) forest pest outbreaks are a natural part of forest dynamics that create opportunities for new understory stem establishment. Over time the plot may provide an opportunity to observe tree replacement in areas of heavier than average mortality - depending on the ability of new recruits to survive deer browse and any saplings that make it beyond the browse line to survive antler rubbing. Although we did not record quantitative data on forest legacies (downed and standing dead trees), we observed a number of tagged dead stems on the ground in this plot. A healthy, undisturbed forest does have higher numbers of "legacies" than most managed forests. Old growth forests tend to have the highest mass of standing dead and downed trees.

¹ Mean annual increment for large old oaks in mature stands averaged 0.5cm/yr, and if the 63 cm dbh oak was 126, the 77 cm dbh oak could be over 150yrs.

Appendix D. Species Autecology and Stand Development

Oak Species

The presence of oak in the canopy of MNHP is presumed to be an artifact of past land uses favoring it: clearing and fire. Canopy oaks were found in 9 out of 12 plots, giving a 75% constancy for the genus. Oaks are the dominant species of the MNHP forest canopy in all strata except the understory layers. (Dominance defined by % constancy and % in dominant or codominant canopy position: oaks have the highest constancy of all species except red maple, and 90% of the oaks sampled were in the dominant or codominant canopy layer, while only 11% of the red maple were codominant.) The lack of oak regeneration at MNHP has been noted by Ehrenfeld (1972, 1982, and 1992) and Russell (2002 and 1995). Oaks can live 200-600 years (depending on species, black oak can live 200, white oak 600 on good sites) barring catastrophic disturbance or disease. Thus, oaks could continue to be a dominant component of the forest canopy for another century. As the oaks senesce, the composition of the forest could change to one dominated by those species currently found in the understory, however suppressed trees in the MNHP forest tend to be shorter-lived species, and tree regeneration is somewhat arrested due to heavy deer browse, antler rubbing on saplings, and competition with invasive species in some areas.

The current cohort of oaks established well from the mid-19th century until the first quarter of the 20th century, particularly in the 1880's when establishment spiked, as it did for a number of other species at that time. Oaks filled canopy gaps left by codominant chestnuts after they were killed off by the blight, but do not appear to have continued to establish long thereafter. White and chestnut oak are longer-lived but less frequent than red and black oak, and established somewhat earlier—the oldest white oak we cored established around 1784 (age measured at 4.5 ft., minus 4 years) and the youngest chestnut oak around 1920 (1916). The median age of oaks of all species was 116 years, the oldest median age of any species in the forest. A number of dead white oak stems were observed with stump sprouts, but deer browsing has prevented establishment of advanced regeneration. Most oaks sprout readily following damage, from the seedling stage to mature trees, but sprouting frequency declines with the size of the damaged stem. A discussion of the importance of white oak sprouts follows, verbatim, from the USDA Forest Service Silvics Manual, and in general it applies to the other oak species as well.

Vegetative Reproduction

Small white oak trees sprout prolifically and vigorously when cut or damaged by fire. The ability to sprout depends on the d.b.h. of the parent trees as follows:

D.b.h. classes		Stumps likely to sprout
<i>cm</i>	<i>in</i>	<i>percent</i>
5 to 14	2 to 5	80
14 to 29	6 to 11	50
29 to 42	12 to 16	15
42-	16-	0

Shoot elongation of stump sprouts increases with increasing stump diameter up to 15 cm (6 in) after which it declines. Annual height growth of stump sprouts when overstory competition is removed averages 0.7 m (2.2 ft).

Another source of vegetative reproduction is seedling sprouts. Seedling sprouts are stems with root systems that are several to many years older. These develop as a result of repeated dieback or mechanical damage. In general, low stump sprouts from pole-size trees and seedling sprouts are about as good as trees grown from seed. However, sprouts originating high on the stump are likely to have heartwood decay.

The seedlings and seedling sprouts already present in a mature stand (advance reproduction), together with stump sprouts, regenerate the stand with oaks following overstory removal. Although many stands may have adequate numbers of stems, the size of the reproduction when the overstory is removed is the key to adequate growth and subsequent stocking. Nevertheless, stands deficient in advance reproduction may be adequately stocked if a sufficient number of stumps sprout (Silvics Manual).

White oak is intermediate in tolerance, more tolerant than black, red or scarlet oak, and about equal to chestnut oak. White oak seedlings, saplings, and even pole-size trees are able to persist under a forest canopy for more than 90 years, but become less shade tolerant as they age.

Red Oak

In forest stands, northern red oak begins to bear fruit at about age 25 but usually does not produce seeds abundantly until about age 50. Good to excellent seed crops are produced at irregular intervals, usually every 2 to 5 years. Acorn production is highly variable among trees even in good seed years. Some trees are always poor producers, while others are always good producers. Crown size seems to be the most important tree characteristic affecting acorn production. Even in good years, only about 1 percent of the acorns become available for regenerating northern red oak, and as many as 500 or more acorns may be required to produce one 1-year-old seedling. Many acorns are consumed by insects, squirrels, small rodents, deer, and turkey and other birds. They can eat or damage more than 80 percent of the acorn crop in most years and virtually 100 percent of the crop in very poor seed years (Silvics Manual). Gravity and the caching activities of squirrels and mice are the primary means of dispersal.

Northern red oak seedlings that are established naturally or by planting at the time an old stand is clearcut, regardless of how large the clearcut area, do not grow fast enough to compete with the vigorous woody sprouts and other vegetation. The species will be present in new reproduction stands in proportion to the amount of advance reproduction present before complete overstory removal. To compete successfully in new stands, stems of northern red oak advance reproduction must be large and have well-established root systems. Thus, achieving successful northern red oak reproduction depends on creating conditions necessary for establishing seedlings and for their survival and growth (Silvics Manual).

Northern red oak sprouts readily. New sprouts from advance reproduction arise when old stems are damaged during logging. Height growth of new sprouts is related to the size of the old,

damaged stem; the larger the old stem, the faster the new sprout will grow. New sprouts grow rapidly and are usually straight and well formed. Northern red oak stumps sprout more frequently than black oak or white oak stumps but about the same as scarlet and chestnut oak stumps. Sprouting frequency is related to parent tree size with more small stumps sprouting than large ones. Northern red oak stump sprouts grow rapidly, averaging about 61 cm (24 in) or more annually for about 30 years. These stump sprouts can be a valuable component of new reproduction stands particularly if they originate at or near the ground line (Silvics Manual).

Chestnut Oak

Chestnut oak acorns mature in one growing season and drop from early September to early October, 2 to 5 weeks before the acorns of other upland oaks. Production of chestnut oak acorns is erratic, and heavy crops occur only once every 4 or 5 years. In general, chestnut oak produces fewer acorns than other upland oaks, although occasional trees can be prolific seed producers.

Chestnut oak begins producing seed at about age 20, but stump sprouts as young as 3 years can produce viable seed, and coppice stands as young as 7 or 8 years can have abundant acorn production. The germinative capacity of sound acorns is around 90 percent. Chestnut oak acorns have no dormancy and therefore germinate in the fall. Chestnut oak acorns are much more capable of germinating in dry soil than acorns of white, black, or northern red oak. Germination of chestnut oak acorns is enhanced by a covering of leaf litter 2 or 3 cm (1 in) deep, but a covering of more than about 5 cm (2 in) results in many etiolated seedlings. Large numbers of seedlings can become established after good seed years, but such years occur infrequently. Seedling establishment and survival are greatly reduced by dense herbaceous and shrub layers (Silvics Manual).

When tops die back or are damaged, chestnut oak seedlings and advance reproduction sprout vigorously from dormant buds at the root collar or on the stem. For stems of advanced reproduction that have been cut, the number of sprouts per plant and the growth of the sprouts increase with increasing size of the original stem and root system. Stumps of cut trees up to 60 years of age sprout vigorously, but the percent of stumps that sprout declines with increasing size for trees more than 46 cm (18 in) in dbh. Incidence of decay is low for stump sprouts that originate within 5 cm (2 in) of the ground and such sprouts can develop into high-quality trees. Sprouting frequency and vigor are greater from stumps of trees cut during the dormant season than from those cut during the growing season (Silvics Manual).

Black Oak

In forest stands, black oak begins to produce seeds at about age 20 and reaches optimum production at 40 to 75 years. It is a consistent seed producer with good crops of acorns every 2 to 3 years. Black oak acorns germinate in the spring following seedfall. Most favorable conditions for germination occur when the acorns are in contact with or buried in mineral soil and covered with a light layer of litter. Acorns on top of the litter generally dry excessively during early spring and lose their viability before temperatures are favorable for germination. Seedlings can survive droughty conditions, but growth is slow or even ceases altogether. Black oak seedlings are more drought tolerant than northern red oak seedlings and about the same as

white oak seedlings. Black oak seedlings that survive seldom remain true seedlings for more than a few years because drought, low light intensity, fire, animals, or mechanical agents kill the tops. Then, one or more dormant buds near the root collar produce new sprouts. This dieback and resprouting process can occur several times; thus the roots of black oak saplings may be 10 to 20 years older than the tops (Silvics Manual).

New seedlings established at or just before harvest cutting grow too slowly to compete with sprouts of other tree species and other vegetation. To compete successfully in new stands black oak stems must be 1.2 to 1.5 m (4 to 5 ft) tall and have well-developed root systems. New sprouts from advance reproduction develop from dormant buds near the root collar when the old stems are cut or damaged during logging. These new sprouts grow rapidly and their height growth is related to the size of the old stem; the larger the old stem, the faster a new sprout will grow. Stumps of black oaks sprout less frequently than those of northern red, scarlet, and chestnut oaks and with about the same frequency as those of white oak. Black oak stump sprouts grow rapidly (Silvics Manual).

Red Maple

Red maple is also widespread throughout the forest. With the same constancy as the oaks (75%) red maple was found in both successional and mature forest areas. The age and size-class pattern for red maple shows development that is due to successful recruitment under a variety of environmental conditions. Red maple can thrive on a wider range of soil types, textures, moisture, pH, and elevation than any other forest species in North America (Silvics Manual). It seeds prolifically and annually, with a bumper crop usually every other year. The youngest seedlings are shade tolerant, and abundant 1- to 4-year-old seedlings are often found under the canopy of older stands. Many of these seedlings die each year if they are not released by opening of the main crown canopy or from other causes, but new ones replace them. Thus, a reservoir of seedlings and ungerminated seed is available to respond to increased sunlight resulting from disturbance. Red maple also reproduces vigorously through stump sprouts, and sprouting can be stimulated by fire. Many species are unable to develop new age classes in small gap disturbances, because the canopy closes in from the sides too quickly. Red maple's shade tolerance allows it to respond and increase in prominence after small disturbances. This trait makes it likely to increase in importance as the codominant oaks senesce and leave single-tree gaps. However red maples do not tend to hold canopy space for long, but tend to be replaced by other longer-lived species. Our sampling confirms this to be the case in the MNHP forest. They have less representation in the codominant forest canopy layer than would be expected by their abundance. Red maple seldom lives longer than 150 years. It reaches maturity in 70 to 80 years. Only one of 30 red maples we sampled was codominant in the canopy. Establishing around 1856 (age at 4.5 ft. - 3 years), this individual apparently is a relict of a much older cohort. This is about the limit of initiation dates we could establish by coring, as most older red maples would have died. The majority of red maples cored and aged developed in the period after oaks ceased recruitment, in the late 19th-early 20th century. Red maple seeds prolifically, has rapid early growth equal to that of oak for the first 20 years, but then tends to be overtopped by oak and remain in the subcanopy. Red maples have less dense wood than oaks and hickories, making them more subject to breakage and damage from ice glaze and wind. Thus the future canopy,

with codominant red maple, will be more degraded by natural disturbance such as ice and wind storms and will likely permit more light to reach the understory.

White Ash

White ash was third in constancy, occurring in 50% of the plots sampled. Like red maple and black birch, most of the white ash we sampled established beginning in the period after oaks ceased regenerating in the early 20th century. The oldest white ash we cored was 124 years, and the median age for cored individuals is 64 years. This suggests that although widespread, it has not established canopy dominance in most areas and has not reached its potential longevity (150-300 years) throughout much of the oak-dominated MNHP forest. However, the species continued to recruit new individuals until at least the 1960's. This age-class structure is typical of ash in mature forest stands, and is explained by its decreasing shade tolerance with increasing age. When young, white ash seedlings can survive under a canopy with a small percentage of full sunlight. Seedlings that receive sufficient sunlight grow rapidly. With increasing age, white ash becomes less tolerant of shade and is classed overall as intolerant. Young white ash is often abundant in the understory of northern hardwood stands, but few grow into the overstory unless provided with light from above (Silvics manual). At MNHP, ash were present as codominant, intermediate and suppressed stems. If its presence throughout the forest is maintained in many canopy layers through canopy openings that afford it adequate light, it is likely to become more important in the overstory as the oaks begin to senesce. However conditions are not favorable for its regeneration from seed under the forest canopy, as it is, like oak, a pioneer species and is highly susceptible to deer browsing.

Like oak species, white ash has delayed leaf development relative to other species, thus it must grow quickly to overtop competing understory growth (e.g. invasive species such as hay-scented fern) (de la Cretaz and Kelt 2002), and must reach the overstory to survive as a codominant for a long time. White ash has demanding soil fertility requirements. It grows most commonly on fertile soils with high nitrogen content and a moderate to high calcium content. Soil moisture is also an important factor affecting local distribution. It fruits every three years, and sprouts readily from cut stumps (Silvics manual).

Black Birch

Black birch is more frequent in mature than in successional forest, as it was found in 42% of the permanent plots we sampled, all in the "mature" forest. Its median age in the MNHP permanent plots is 56. Black birch had 6 individuals over 100 years, but only 2 of these were in the codominant strata in the overstory. Black birch grow at about the same rate as oaks for the first 20 years, but then oaks begin to exert dominance and black birch are usually relegated to the subcanopy layers, where many stems succumb to lack of light. The species is classed as an intolerant. They are susceptible to glaze damage, *Nectria* canker and a host of other pathogens, and tend to decline on thin soils (Silvics Manual).

Most of the black birch in the permanent plots recruited in the period after oaks apparently ceased regenerating, since about 1900, suggesting they have responded to conditions that do not favor oaks. A spike in recruitment in the 1880's for most species including black birch suggests

that they responded along with the oaks to clearing at that time, but are not as long lived so most older black birch cohorts have died out. Young black birch is very susceptible to fire. Their frequency in the subcanopy of the mature forest suggests that fire has not been a factor since their establishment. Black birch will likely fill some of the gaps left as older oaks senesce; however they are not as long-lived as oaks. Once in the canopy, they may survive for a time, (estimated to a maximum of 150+ years?).

Hickory

Hickory (*Carya glabra*) has done well throughout the forest for two centuries, both in the conditions favoring oak establishment in the early 1800's and under modern conditions that do not favor establishment or regeneration of oak. It is a species of intermediate shade tolerance, but seems able to persist in the understory for a long time until released. Tied with black birch in constancy, it was found in 42% of the permanent plots we sampled. It exists only among the older cohorts in the successional plots, but is found at many ages in the mature plots. It is currently present in all forest canopy positions (codominant, intermediate and suppressed), is infrequently found as saplings in the understory, and seedlings were observed within exclosures. It is a strong competitor for gap replacement due to its heavy branches which resist abrasion from other trees. It is resistant to ice damage and is considered wind firm due to its strong taproot but is easily damaged by fire. Its adaptability to a wide range of elevations and soil types has made it a ubiquitous presence in eastern forests, though not in great abundance. Its strong apical dominance, ability to persist in shade, presence in all canopy and subcanopy strata, and longevity (200-300 years) suggests that it will continue to be an important species in the MNHP forest for centuries as it is well poised throughout the forest to replace oaks as they senesce. Its infrequency in the tall shrub or sapling layer is primarily due to deer browsing. Hickories in the permanent plots had a median age of 85. Individuals as small as 5.5 cm dbh were 65 years old. Similar to black birch and red maple, the majority of hickories we cored established in the early 19th to the early 20th century. However, understory hickories were still establishing in the 1960's and are present in the plots as saplings.

Yellow Poplar

Yellow poplar was a relatively common component of the colonial forest according to historical accounts. In the areas of the MNHP forest we sampled, most individuals established during the early 20th century, both in areas that were once cleared for agriculture and on forested slopes never completely cleared over the past two centuries, such as at Fort Nonsense. The species has constancy in the sampled areas of the forest of 42% and occurs both in successional and mature plots. The median age of yellow poplars we cored was 58 years. Yellow poplars are prolific seeders starting at about 15 years and continuing annually until about 200 years. Seeds can persist in the forest floor from 4-7 years, so can wait for proper germination conditions. Seeds germinate best in mineral or organic soil, not in deep litter or dense herbaceous growth. Due to its rapid early growth, strong apical dominance, and apparent resistance to crowding, these long-lived, tall trees are likely to reach the canopy earlier than other species and once there, dominate it for a long period of time. They can live 300 years barring catastrophic disturbance. Classed as intolerant, seedlings can nevertheless reach maximum or near-maximum photosynthetic efficiency at relatively low light intensities, as low as 3 to 10 percent of full sunlight (Silvics

manual). Of the seven yellow poplars we cored, five were dominant or co-dominant, one was intermediate and one suppressed. However, they are not as widespread, particularly in the mature forest, as other species. Because their fruits and young leaves are very palatable to deer they are notably lacking in the understory even in areas where they are present in the canopy. When young, yellow poplar are very susceptible to damage by fire. Thus, fire exclusion in recent centuries has both discouraged oak regeneration and encouraged yellow poplar.

American Beech

American beech is prevalent only in certain areas of the Jockey Hollow forest, primarily along Primrose Brook, and part way up Mt. Kemble and Tea Hill. It has a constancy among the sampled plots of 33%, and occurs in all canopy and subcanopy strata. This suggests that it will continue to be an important component of the MNHP forest locally, and may become increasingly important due to its shade tolerance, longevity (approximately 300 years) and presence in multiple age-classes and canopy strata. Beech mostly regenerates by root sprouts. When young, these are susceptible to fire. Single tree selection cutting (or by inference, single tree gaps) favor beech, as it faces less competition from less tolerant species. This was observed on the lower slope of Mt. Kemble, where beech is more abundant: large standing dead oaks were surrounded by beech advance reproduction (root sprouts) competing to fill the gap. Beech sprouts do not compete well in the full light of heavier cutting regimes or stand replacing disturbance as they grow best in partial shade. Its greatest advantage in the MNHP forest may be that it is not favored by deer and is less browsed than other species. Beech does not begin to seed until about 40 years; it seeds most prolifically at about 60 years. Seeds are not dispersed great distances by rodents though they may be disbursed a couple of kilometers by blue jays. In localized areas in Jockey Hollow where beech is established, it has become dominant. These areas have a higher density of beech saplings than other parts of the forest and a depauperate shrub and herbaceous understory due to a heavy leaf litter and dense shade. It also appeared to be more widespread along northwest-facing slopes in the southern portion of the New Jersey Brigade, although we did not sample plots in that area. Beech are long-lived (300-400 years) and very shade tolerant and are able to persist under a closed canopy in the understory for decades with very little height or lateral growth, similar to hemlock. The median age of the beech we cored in the permanent plots was 89 years. The youngest saplings we cored were 30-54 years of age. These smaller saplings were 4.7 - 6.1 cm dbh. This species is most variable in dbh/age ratio. The oldest individual (35 cm dbh) was 120 years at breast height, while the largest individual (53.8 cm dbh) was 95 years. A root sprout only 13.4cm dbh was aged at 111 years. The thinness of beech bark makes it vulnerable to a large number of sucking insects, including the beech blight aphid, *Fagiphagus imbricator*, and the giant bark aphid, *Longistigma caryae*. Continuous heavy outbreaks of the oystershell scale, *Lepidosaphes ulmi*, have resulted in severe crown dieback and even in the death of entire stands. *Xylococcus betulae*, another scale, causes roughened spots on stems of young trees and is especially devastating to the sprout thickets that have emerged in the aftermath of beech bark disease, the most serious problem of this species. While it was not observed at MNHP, beech bark disease has caused major damage to the species in other areas, and could, if introduced, eliminate the older beech cohort and reduce its ability to increase in importance.

Beech bark disease is a bark canker fungi introduced by the beech scale *Cryptococcus fagisuga*. The insect attacks the bark and renders it susceptible to bark canker fungi of the genus *Nectria*. The insect component of this *scale-Nectria* is found throughout New England, New York and northern Pennsylvania, northeastern Ohio, northwestern Virginia, northeastern West Virginia, and as far west as Toronto, Ontario. As the disease and forest interact for the first time, mortality may be so severe that a large proportion of the big, mature beech trees are killed. Although massive mortality is rare in stands emerging in the aftermath of the disease, severe defect may be caused by the now-endemic causal complex together with *Xylococculus betulae* (Silvics Manual).

Defoliation by insects can occasionally be a serious problem. The most damaging is the saddled prominent, *Heterocampa guttivitta*, although the forest tent caterpillar (*Malacosoma disstria*), gypsy moth (*Lymantria dispar*), fall cankerworm. (*Alsophila pometaria*), and the Bruce spanworm. (*Operophtera bruceata*) occasionally cause heavy defoliation in local areas. Insect defoliation often renders trees susceptible to attack by the shoestring root fungus (Silvics Manual).

Beech is seldom severely browsed by white-tailed deer. When other, more desirable tree species are available, beech is usually nipped only sparingly. This may be a factor in its success locally at MNHP.

Flowering Dogwood

Flowering dogwood (*Cornus florida*), like beech, is distributed with a 33% constancy throughout the mature and successional forests. This attractive, small understory tree with its showy white bracts was always found in the subcanopy strata. Only two trees were cored successfully and yielded ages of 41 and 50 years. The species may live 125 years and on good sites may grow to 30-40 feet tall. Seven live dogwoods were encountered in four plots, and nine dead dogwoods were recorded. Conditions for its continued survival at MNHP are not promising as it appears to be failing to regenerate due to heavy browsing pressure. Its shallow rooting system makes it best adapted to moist soils on flats or lower slopes, where soil moisture is not limiting. It usually sets seed heavily every other year, but seeds from isolated trees are often empty. Seedlings grow best at intermediate light intensities, but the tree is classed as very tolerant. Under a closed canopy, seedlings (if they survived) would grow slowly. However, trees grown from seed are capable of flowering and producing seed in six years. It also may reproduce from stump sprouts, but sprouts are most successful if stumps were cut during winter dormancy. Because of its thin bark, flowering dogwood is readily injured by fire. Its profuse sprouting ability may actually increase the number of stems in fire-damaged stands, however. These factors suggest that it may have already passed its threshold density for sustainable reproduction in the MNHP forest and may be a relict understory species. Dogwood leaves decompose very rapidly and are considered "soil builders", as they concentrate and quickly release calcium when they decompose.

Dogwood is most susceptible to basal stem canker, caused by the fungus *Phytophthora cactorum*, which may girdle the tree. Target cankers (*Nectria galligena*) sometimes occur on the trunk and limbs, and *Armillaria mellea* has been found on dogwoods. Leafspot (*Cercospora cornicola*) attacks seedlings, and *Meliodogyne incognita* causes severe root galling, associated

with dieback and premature leaf fall in seedlings. Twig blight, caused by the fungus *Myxosporium nitidum*, may cause dieback of small twigs. Leaf spots and dieback of flowers are caused by *Botrytis cinerea*, *Elsinoe corni*, and *Septoria cornicola*, while *Ascochyta cornicola* may result in shriveling and blackening of the leaves. Verticillium wilt (*Verticillium albo-atrum*) attacks dogwood, among several other leaf viruses. Noninfectious diseases include sunscald, mechanical and drought injury, and freezing. Dogwood reproduction is often browsed heavily by deer and rabbits (Silvics Manual).

Black Locust

Black locust was among a number of minor species present in only one permanent plot, indicating a low frequency in the forest except locally in some areas. However, its autecology will be discussed here as it is known to be a concern for park managers, and is a dominant species in some other types of vegetation not sampled in the permanent plots, as described by Ehrenfeld (1977) and Bob Zaremba (personal communication). Black locust is native to north America, but has been planted outside its normal range and naturalized in many areas. Because it is a nitrogen fixer and has rapid juvenile growth, it was widely planted as an ornamental, for shelterbelts, and for land reclamation. This is believed to be its origin at MNHP, as it is found along roads and from there has invaded abandoned fields and formerly tilled areas. It is a vigorous competitor initially in full sun on disturbed sites or old fields where herbaceous competition is limited. Black locust sprouts readily from both stump and roots, especially after being cut or damaged. Although seedlings are produced, it reproduces best from root suckers. Suckers usually appear in the fourth or fifth year. In the southern Appalachians, dense thickets of suckers develop in clearcuts. Its rapid early growth decreases rapidly after 30 years, and its extreme intolerance and short life-span (approximately 100 years) causes it to succumb to low light in the understory on stands where associated species overtop it.

A locust-dominated community is described in Ehrenfeld (1977), associated with white ash, yellow poplar, red maple and black birch, but we did not observe or sample the community. This community was noted by Bob Zaremba to have a lot of standing dead locust and ash, and very little recruitment, due to heavy herbaceous (wiregrass) and woody (barberry, multiflora rose) understory cover (Zaremba, in process).

Black locust's nitrogen-fixing ability can alter substrate in ways that may promote invasive understory species like barberry. With adequate light and moisture, nitrogen availability seems to be the most important factor determining the growth rate of barberry. This may be because barberry has the superior ability to metabolize nitrogen due to the presence of nitrogen reductase in their leaves and an early leaf-break which takes advantage of high early spring light levels (Cassidy 2002).

Black locust was found in the codominant, intermediate, and suppressed canopy position in only one successional plot at MNHP, and all established between 1945 and 1968 (median age 46). As such it does not appear to be a serious threat to the MNHP forest, and should die out under a closed canopy in most stands in another 50 years. However restoring locust-vine communities (old pastures) where it is dominant and underlain by heavy invasive cover may be a difficult proposition. It may be that the combination of heavy herbaceous (invasive Japanese wiregrass)

and shrubby understory cover (barberry and vines) may have these areas in a state of arrested succession that will take careful and intensive intervention to restore.

Other tree species infrequently encountered include sugar maple, (found in the co-dominant and suppressed position in the canopy), black walnut, black cherry and sweet cherry as intermediate stems, and Norway maple, witch hazel, tree of heaven, slippery elm, flowering shad (*Amelanchier sp.*) yellow birch, blue beech (*Carpinus caroliniana*), hackberry, (*Celtis occidentalis*), sassafras and hop-hornbeam (*Ostrya virginiana*) mostly as suppressed stems.

Other communities at MNHP not included in the permanent plot locations will be documented by Bob Zaremba in his report and classification of community types according to The Nature Conservancy's international classification (in process). These include some green ash/sugar maple coves and some wetland communities that are likely to have additional species adapted to saturated soils. These communities were not sampled in our study.

Appendix E. Glossary of Silvicultural Techniques

from www.bugwood.org (with some additions)

Silviculture Terminology, Society of American Foresters, Silviculture Working Group, September 1994

Advance Regeneration (Reproduction) syn. Advance Growth:

Seedlings or saplings that develop or are present in the understory.

Age Class (Cohort):

A distinct aggregation of trees originating from a single natural event or regeneration activity, or a grouping of trees, e.g. 10-year age class, as used in inventory or management.

Artificial Regeneration (Reproduction):

An age class created by direct seeding or by planting seedlings or cuttings.

Basal Area:

The area of the cross section of a tree stem, including the bark, generally at breast height (4.5 feet above the ground).

Canopy:

The foliar cover in a forest stand consisting of one or several layers

Canopy Closure:

see Crown Cover

Crown:

The part of a tree or woody plant bearing live branches and foliage.

Crown Class:

A class of tree based on crown position relative to the crowns of adjacent trees.

Emergent:

Trees with crowns completely above the general level of the main canopy receiving full light from above and from all sides.

Dominant:

Trees with crowns extending above the general level of the main canopy of even-aged stands or, in uneven-aged stands, above the crowns of the tree's immediate neighbors, and receiving full light from above and partly from the sides.

Codominant:

Trees with crowns forming the general level of the main canopy in even-aged stands or, in uneven-aged stands, the main canopy of the tree's immediate neighbors, receiving full light from above and comparatively little from the sides.

Intermediate:

Trees with crowns extending into the lower portion of the main canopy of even-aged stands or, in uneven-aged stands, into the lower portion of the canopy formed by the tree's immediate neighbors, but shorter in height than the codominants. They receive little direct light from above and none from the sides.

Suppressed:

Trees with crowns entirely below the main canopy, receiving little direct light from above and none from the sides. They are shorter than intermediate trees, and a large proportion of them die unless released by a canopy gap.

Crown Density:

The amount and compactness of foliage of the crowns of trees and/or shrubs.

Cutting Cycle:

The planned interval between partial harvests in an uneven-aged stand (see Thinning Interval).

Even-Aged Stand:

A stand of trees containing a single age class in which the range of tree ages is usually less than 20 percent of rotation.

Even-Aged System:

A planned sequence of treatments designed to maintain and regenerate a stand with one age class. The range of tree ages is usually less than 20 percent of the rotation. (see Clearcutting, Seed Tree, Shelterwood, Coppice.)

Forest Legacies:

Legacies indicative of old-growth condition include large old trees, standing dead and downed trees, nurse logs and pit and mound topography providing greater heterogeneity and habitat niches at the forest floor.

Improvement Cutting:

A cutting made in a stand pole-sized or larger primarily to improve composition and quality by removing less desirable trees of any species (see Cleaning, Liberating, and Weeding).

Intermediate Treatments (Tending):

a collective term for any treatment designed to enhance growth, quality, vigor, and composition of the stand after establishment or regeneration and prior to final harvest (see Tending, Stand Improvement).

Liberating:

A release treatment made in a stand not past the sapling stage in order to free the favored trees from competition of older, overtopping trees.

Nurse Tree (Nurse Crop):

A tree, group or crop of trees, shrubs or other plants, either naturally occurring or introduced, used to nurture, improve survival or improve the form of a more desirable tree or crop when young by protecting it from frost, insolation, or wind.

Old Growth:

A forest condition characterized by multi-age structure, gap-phase regeneration, understory reinitiation, complex understory structure and composition with species diversity appropriate to landscape position, and increased forest "legacies". Legacies include large old trees, standing dead and downed trees, nurse logs and pit and mound topography providing greater heterogeneity and habitat niches at the forest floor.

Overstory Removal:

The cutting of trees comprising an upper canopy layer in order to release trees or other vegetation in an understory (see Clearcutting).

Pole:

A tree between the size of a sapling and a mature tree.

Precommercial Thinning (PCT):

A thinning that does not yield trees of commercial value, usually designed to reduce stocking in order to concentrate growth on the more desirable trees.

Reforestation:

The natural or artificial restocking of an area with trees (syn. Regeneration).

Regeneration:

Seedling or saplings existing in a stand; or the act of establishing young trees naturally or artificially (syn. Reforestation).

Regeneration (Reproduction) Method:

A cutting method by which a new age class is created. The major methods are Clearcutting, Seed Tree, Shelterwood, Selection, and Coppice (see Harvesting Method).

Clearcutting:

A method of regenerating an even-aged stand in which a new age class develops in a fully-exposed microclimate after removal, in a single cutting, of all trees in the previous stand. Regeneration is from natural seeding, direct seeding, planted seedlings, and/or advance reproduction. Cutting may be done in groups or patches (Group or Patch Clearcutting), or in strips (Strip Clearcutting). In the Clearcutting system, the management unit or stand in which regeneration, growth, and yield are regulated consists of the individual clearcut stand (see Group Selection). When the primary source of regeneration is advance reproduction, the preferred term is Overstory Removal.

Seed Tree:

An even-aged regeneration method in which a new age class develops from seeds that germinate in fully-exposed micro-environments after removal of all the previous stand except a small number of trees left to provide seed. Seed trees are removed after regeneration is established.

Shelterwood:

A method of regenerating an even-aged stand in which a new age class develops beneath the moderated micro-environment provided by the residual trees. The sequence of treatments can include three distinct types of cuttings: 1) an optional preparatory cut to enhance conditions for seed production; 2) an establishment cut to prepare the seed bed and to create a new age class; and 3) a removal cut to release established regeneration from competition with the overwood. Cutting may be done uniformly throughout the stand (Uniform Shelterwood), in groups or patches (Group Shelterwood), or in strips (Strip Shelterwood).

Shelterwood with Reserves:

A variant of the Shelterwood Method in which some or all of the shelter trees are retained, well beyond the normal period of retention, to attain goals other than regeneration.

Uneven-Aged (Selection) Methods:

Methods of regenerating a forest stand, and maintaining an uneven-aged structure, by removing some trees in all size classes either singly, in small groups, or in strips.

Area Control:

Meeting management objectives by cutting trees in an area of a given size, rather than cutting trees of a given diameter breast height (see group selection).

Diameter Limit (Single tree selection):

Cutting trees within a specified range of diameter breast height to meet management goals. Sometimes used to manipulate stand stocking requirements to encourage diameter growth of remaining trees.

Group Selection:

A method of regenerating uneven-aged stands in which trees are removed, and new age classes are established, in small groups. The maximum width of groups is approximately twice the height of the mature trees, with small openings providing micro-environments suitable for tolerant regeneration and the larger openings providing conditions suitable for more intolerant regeneration. In the Group Selection System, the management unit or stand in which regeneration, growth, and yield are regulated consists of a landscape containing an aggregation of groups (see Clearcutting).

Group Selection with Reserves:

A variant of the Group Selection Method in which some trees within the group are not cut to attain goals other than regeneration within the group.

Single Tree Selection:

A method of creating new age classes in uneven-aged stands in which individual trees of all size classes are removed more-or less uniformly throughout the stand to achieve desired stand structural characteristics.

Coppice Methods:

Methods of regenerating a stand in which the majority of regeneration is from stump sprouts or root suckers.

Coppice:

A method of regenerating a stand in which all trees in the previous stand are cut and the majority of regeneration is from sprouts or root suckers.

Coppice with Reserves:

A coppice method in which reserve trees are retained to attain goals other than regeneration. The method normally creates a two-aged stand.

Regeneration (Reproduction) Period:

The time between the initial regeneration cutting and the successful re-establishment of a new age class by natural means, planting, or direct seeding.

Regular Uneven-Aged (Balanced) Stand:

A stand in which three or more distinct age classes occupy approximately equal areas and provide a balanced distribution of diameter classes.

Release (Release Operation):

A treatment designed to free young trees from undesirable, usually overtopping, competing vegetation. Treatments include cleaning, liberating, and weeding (see Stand Improvement).

Reserve Trees (Green Tree Retention):

Trees, pole-sized or larger, retained in either a dispersed or aggregated manner after the regeneration period under the Clearcutting, Seed Tree, Shelterwood, or Coppice Methods (syn. Standards).

Sapling:

A tree, usually young, that is larger than a seedling but smaller than a pole. Size varies by region.

Silviculture:

The art and science of controlling the establishment, growth, composition, health, and quality of forests and woodlands to meet the diverse needs and values of landowners and society on a sustainable basis.

Silvicultural System:

A planned process whereby a stand is tended, harvested, and re-established. The system name is based on the number of age classes (see Even-Aged, Two-Aged, Uneven-Aged), and/or the regeneration method used (see Clearcutting, Seed Tree, Shelterwood, Selection, Coppice, Coppice with Reserves).

Site Index:

A measure of actual or potential forest productivity expressed in terms of the average height of a certain number of dominants and co-dominants in the stand at an index age.

Size Class:

Tree size recognized by distinct ranges, usually of diameter or height.

Snag:

A standing dead tree from which the leaves and most of the branches have fallen.

Stand:

A contiguous group of trees sufficiently uniform in age class distribution, composition, and structure, and growing on a site of sufficiently uniform quality, to be distinguishable unit (see Mixed, Pure, Even-Aged, and Uneven-Aged Stands).

Mixed Stand:

A stand in which there is a mixture of species.

Pure Stand:

A stand composed of essentially a single species.

Stratified Mixture:

A stand in which different species occupy different strata of the total crown canopy.

Stand Density:

A quantitative, absolute measure of tree occupancy per unit of land area in such terms as numbers of trees, basal area, or volume.

Stand Improvement:

A term comprising all intermediate cuttings made to improve the composition, structure, condition, health, and growth of even- or uneven-aged stands.

Stocking:

An indication of growing-space occupancy relative to a pre-established standard. Common indices of stocking are based on percent occupancy, basal area, relative density, and crown competition factor.

Stratum (Canopy Layer):

A distinct layer of vegetation within a forest community.

Structure:

The horizontal and vertical distribution of components of a forest stand including the height, diameter, crown layers and stems of trees, shrubs, herbaceous understory, snags, and down woody debris.

Succession:

A series of dynamic changes by which organisms succeed one another through a series of plant community (seral) stages leading to potential natural community or climax.

Thinning:

A cultural treatment made to reduce stand density of trees primarily to improve growth, enhance forest health, or to recover potential mortality.

Crown Thinning (Thinning from Above, High Thinning):

The removal of trees from the dominant and codominant crown classes in order to favor the best trees of those same crown classes.

Low Thinning (Thinning from Below):

The removal of trees from the lower crown classes to favor those in the upper crown classes.

Mechanical Thinning (Geometric Thinning):

The thinning of trees in either even- or uneven-aged stands involving removal of trees in rows, strips, or by using fixed spacing intervals.

Thinning Interval:

The period of time between successive thinning entries, usually used in connection with even-aged stands (see Cutting Cycle).

Tolerance, Shade:

The relative capacity of a plant to become established and grow beneath overtopping vegetation.

Two-Aged Stand:

A stand composed of two distinct age classes that are separated in age by more than 20 percent of rotation.

Two-Aged System:

A planned sequence of treatments designed to maintain and regenerate a stand with two age classes.

Uneven-Aged Stand:

A stand of trees of three or more distinct age classes, either intimately mixed or in small groups.

Uneven-Aged System:

A planned sequence of treatments designed to maintain and regenerate a stand with three or more age classes (see Single Tree Selection, Group Selection).

Weeding:

A release treatment in stands not past the sapling stage that eliminates or suppresses undesirable vegetation regardless of crown position.

As the nation's primary conservation agency, the Department of the Interior has responsibility for most of our nationally owned public land and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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