A MULTI-SCALE APPROACH TO RECONSTRUCTING LANDSCAPE HISTORY IN THE GREAT SWAMP NATIONAL WILDLIFE REFUGE, MORRIS COUNTY, NEW JERSEY

By

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ABSTRACT OF THE DISSERTATION

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As the cultural value of ‘wilderness’ has grown, so has the need to understand the forces that create, modify and destroy landscapes. Processes acting separately and in concert drive landscape patterns, making it no simple task to unravel the forces driving current landscape composition and structure.

This thesis uses the space-time hierarchy to reconstruct the landscape history of the Great Swamp National Wildlife Refuge and to identify driving forces important to current landscape patterns. Pollen and sediment analysis coupled with historical documents were integrated to reconstruct vegetation history at two temporal scales. At the meso-temporal scale, post-glacial processes greatly influenced Great Swamp’s abiotic template. Partial drainage of post-glacial lakes and subsequent erosion created a bifurcated landscape, where patterns of post-glacial deposits, soil and peat differed on a distinct east/west basis. Plant communities over this time period were dynamic, responding to local hydrological changes. As a result, a diverse wetland landscape developed across Great Swamp.

Meso-scale driving forces also influenced initial land-use patterns. Settlers in the 18th century extensively modified the western region of Great Swamp to create arable land. The eastern area, as a source for timber, initially escaped intense land-use. Agriculture eventually expanded eastward, but the land-use history of Great Swamp remained divided along the east/west bias created by post-glacial driving forces.

Land-use of this intensity frequently leaves legacies that persist decades or centuries following abandonment; Great Swamp is no exception. Old ditches and abandoned fields continue to support unique vegetation assemblages. However, land-use legacies are also patterned on an east/west basis. The west, for example, continues to have greater coverage of agricultural-restricted communities while vegetation patterns in the east are more related to glacial patterning.

Integrating the results across temporal scales captures the complex realities of wetland development. In Great Swamp, driving forces have acted alone and together to produce current landscape patterns. Land-use legacies, while important, are coupled to landscape patterns generated by other driving forces. The space-time paradigm, as used here to reconstruct the vegetation history of Great Swamp, forced a long temporal perspective that revealed the interconnectedness and complexity of the forces driving landscape pattern.

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1.0 Introduction

Every landscape has a history. Natural disturbance and land-use have acted separately and in concert to pattern current landscapes. Understanding the spatial and temporal extent that past processes, including land-use, drive current landscape patterns is of particular interest to ecologists, land managers and conservation groups. EuroAmerican settlement in the 17th and 18th centuries marked a distinct increase in the rate and magnitude of human impact on the landscape (Turner 1990, Vitousek et al. 1997, Fuller et al. 1998, Bürgi et al. 2000). Land-use legacies, while a relatively new concept in ecology, are clearly an emerging research area (Turner 2005a, b). Paleo- and historical ecology, which integrate methods and models from a variety of disciplines across temporal and spatial scales, are critical to studies of landscape legacies (Russell 1997). Integrated studies are rare because data collection can be costly and labor intensive and require a familiarity with a broad range of disciplines, from archaeology to vegetation analysis.

The importance of landscape legacies has long been understood in Great Britain (Rackham 1986) and Europe (Birks 1988). The northeastern United States, with a rich and varied ecological and human history, has been a center for landscape legacy research in North America. Studies of the changing vegetation of the northeast reveal legacies of human activity that persist across spatial and temporal scales, often obscuring the importance of other driving forces (e.g. Foster 1992, Foster et al. 1998, Fuller et al. 1998).

Driving forces, that is, processes that result in landscape change (Bürgi et al. 2004), and biotic responses are scale dependent; however, land-use crosses boundaries to impact local and regional vegetation patterns. Land-use has resulted in long-term impacts on vegetation composition and structure on local and regional levels (Foster 1992, Foster et al. 1998, Motzkin et al. 1999, Bellemare et al. 2002, Eberhardt et al. 2003). For example, forests that succeed on abandoned agricultural fields are relatively homogenous in age and size structure (Foster et al. 2003, Loo and Ives 2003a) with patterns of plant establishment often restricted by historical land-uses (Motzkin et al. 1996). At the regional level, land-use has resulted in a broad-scale homogenization of forest composition (Foster 1992, Foster et al. 1998, Fuller et al. 1998). However, human activity does not always lead to homogenization between regions; forest patterning is strongly dependent on the spatial component of human activity (Bürgi et al. 2000).

Land-use has also affected the physiography of the northeast, especially the structure and chemistry of soil. Agricultural practices resulted in a homogeneous layer of soil that persists in being depleted of carbon and nitrogen (Koerner et al. 1997, Compton et al. 1998, Compton and Boone 2000, Dupouey et al. 2002). This nutrient deficiency has been projected to last decades to centuries following agriculture abandonment (Knops and Tilman 2000) and can impact succession and structure of vegetation communities (Motzkin et al. 1996). Soils affected by agriculture may even support a different microbial community and facilitate invasions (Foster et al. 2003).

Human land-use patterns are strongly influenced by existing land-cover characteristics. Contemporary environmental parameters (vegetation composition and structure, soils, hydrology, etc) influence land-use. As such, land-use legacies represent a complex coupling of humans and their environment (Russell 1997). For this reason, an understanding of the causes, processes and consequences of land-use and land-cover change provides critical information for land management and restoration (Egan and Howell 2001). Defining and studying the driving forces behind landscape change makes it possible to address the complexities of human/environment interactions across spatial and temporal scales (Bürgi et al. 2004).

1.1 Conceptualizing land-use history and legacies

The progression of landscape research has demonstrated the importance of multiple driving forces and the interaction of those forces in generating vegetation patterns (Turner 2005a, b). In many instances, land-use is the dominant driving force of landscape pattern (e.g. Foster 1992, Dupouey et al. 2002); however, this is not always true. Studies of land-use legacies must, therefore, also address other driving forces acting separately and in conjunction with land-use.

One way to address land-use legacies is through hierarchy theory. Introduced in 1983 and modified in 1988 (Delcourt et al. 1983, Delcourt and Delcourt 1988), the space-time hierarchy provides a context for landscape and land-use legacy research by graphically correlating space and time (figure 1.1, but also see Methods, later this chapter). In this manner, the relationship between disturbance regimes, biotic responses and vegetation patterns across spatial and temporal scales is made clear. The scale for each pattern or process reflects the sampling interval needed to observe it. Placing land-use in an explicit spatial and temporal context within this hierarchy allows us to identify appropriate scales of biotic responses and vegetation patterns.

In recent years, the concept of driving forces has gained attention in ecology. The concept of driving forces has been traditionally rooted in geography and landscape research (Wood and Handley 2001, Bürgi et al. 2004), where driving forces have been grouped into five categories: natural, cultural, socioeconomic, political and technological. In the space-time hierarchy, environmental disturbance regimes would be considered natural driving forces of landscape change. By expanding that portion of the paradigm to more generally include driving forces, we explicitly address the complex relationship between people and their environment. Driving forces do not act in isolation. They interact, depend on other driving forces and affect multiple spatial and temporal scales (Bürgi and Schuler 2003). Driving forces shift the focus of landscape research from descriptions of spatial patterns to understanding the processes driving change. Further, the history of the concept of driving forces provides a linguistic bridge between natural and social science, a necessary link if we are to fully understand and integrate human actions into landscape studies.

While land-use history plays out over roughly the last 500 years in the northeastern United States, limiting the scope of a study of land-use legacies to a similar temporal scale is inappropriate. Landscape patterns at the time of EuroAmerican settlement greatly influenced land-use. An understanding of landscape patterns and the forces driving those patterns across temporal scales is a key first-step to studies of land-use legacies. Using the space-time hierarchy helps to limit the temporal scale by bounding land-use legacy studies to the micro- and meso- scale. This provides a framework to (1) identify key driving forces that influence land-use; (2) understand how multiple driving forces interact to generate vegetation patterns; and, (3) understand the relative importance of different driving forces to current landscape patterns.

This thesis uses the space-time hierarchy to investigate the forces shaping current vegetation patterns in the Great Swamp National Wildlife Refuge. Specifically, I adapted the hierarchy to constrain the temporal scale of this study to the last 10,000 years (the micro- and meso-scales) and identify potential driving forces of change in Great Swamp. This framework was then used to identify and integrate appropriate methods to reconstruct vegetation and land-use history. Interpretation of the reconstructed ecological history of Great Swamp was then used to (1) identify those driving forces that contributed to vegetation patterning in Great Swamp; and (2) determine the relative importance of land-use to current landscape patterns. Because hydrology is so important to wetland communities, I expected that traditional agriculture practices of early settlers would have an inordinate effect on vegetation communities and would leave a distinct legacy on the modern landscape.

1.2 Eastern deciduous forest history and the importance of scale

As shown by the space-time hierarchy, the importance of a particular driving force to vegetation pattern is related to the scale of interest and the development of eastern deciduous forests in the United States exemplifies this. Current vegetation of the eastern United States is a mosaic of farmland and second growth forests. In New Jersey, oak-chestnut forests dominate the north, while the southern, coastal plain region is composed mainly of oak-pine forests (Braun 1950). These vegetation patterns are the result of multiple driving forces acting on and across several temporal scales. Below, I briefly detail the history of these forests, at two temporal scales, the meso-, and micro-scale.

1.2.1 Meso-scale history

Observing the development of eastern deciduous forests on the meso-scale demonstrates the overriding significance of climatic changes to vegetation patterning. Northeastern vegetation communities existing 18,500 years ago, during the latter half of the Wisconsin glaciation, have no modern analogues (Davis 1983b, Webb 1988). A belt of tundra vegetation, composed primarily of sedges and grasses ringed the southern edge of the glacier, in the area of western New York and Pennsylvania (Davis 1983a, Webb 1988). South of the tundra, along the Atlantic Coastal Plain, were coniferous forests, composed of pine, spruce, and fir (Davis 1983a). Forests of New Jersey, just south of the terminal glacial moraine, were open and park-like, with scattered pine and spruce trees among grass and sedge dominated communities (Russell and Standford 2000). Pollen data provide little evidence for the occurrence of deciduous trees anywhere along the East Coast at this time; pollen data from as far south as Florida fail to provide evidence for significant populations of deciduous trees (Davis 1983a, Delcourt and Delcourt 1987). Following climatic warming, however, deciduous tree pollen increased rapidly, indicating that deciduous trees were present during the last glaciation, perhaps in refugia to the west (Davis 1983b).

With glacial retreat well underway, the opening of the Holocene 10,000 years ago marked the beginning of modern forest development in the northeast. Forest composition varied among regions due to the distribution of taxa - initial forests were composed of species that were readily available to colonize a given region (Davis 1983a). Generally, as the climate warmed, spruce declined while alder increased in abundance (Webb 1988). Balsam fir, poplar, and birch initially colonized forests of northern New England, and were later joined by white pine, oak, and sugar maple (Davis 1983a). In contrast, the first forests of southern New England were initially composed of white pine, oak, elm, ash, birch, ironwood, and sugar maple (Davis 1983a, b). Conspicuously absent were chestnut, hickory, and red maple, which later came to dominate the southern New England landscape (Davis 1983a, Russell et al. 1993).

Forests of New Jersey began forming 12,000 years ago as deciduous trees replaced the open and park-like vegetation (Russell and Standford 2000). Diversity of these forests increased throughout the Holocene as individual species expanded their range (Davis 1983a). Oak and maple were the first to colonize New Jersey forests and were followed by elm, hickory, and American beech 9-7,000 years ago (Davis 1983b). Chestnut trees were the last to colonize New Jersey forests 3,000 years ago. The later arrival of chestnut may have been due, in part, to dispersal mechanisms (primarily bird) or to self-sterility (Davis 1983b, Russell and Standford 2000).

At this scale, vegetation patterns are driven by changes in climate, as mediated by glacial retreat. Individual taxa expanded their range in response to glacial retreat and warmer conditions. This is not to say that events of shorter duration were not important (for example, see Davis (1981), and the impact of a pathogen on *Tsuga* populations); however, at the meso-scale, the main driving forces operate over broad spatial and temporal scales.

1.2.2 Micro-scale history

At the micro-scale, vegetation patterns are influenced by weather trends that act across decades or centuries and by seasonal patterns of precipitation and temperature. Disturbances of short duration, including wildfire, floods and earthquakes impact local and regional vegetation. Land-use, whether by Native Americans or European settlers, also shapes vegetation patterns.

Native Americans, present in the northeast for thousands of years, undoubtedly modified their landscape. The extent and intensity of their activities, especially their use of fire, have been debated for decades (e.g. Russell 1983, DieffenbacherKrall 1996, Vale 1998, Lorimer 2001, Parshall and Foster 2002, Lorimer and White 2003, Parshall et al. 2003, Latty et al. 2004, Black et al. 2006, Dyer 2006). Undoubtedly, Native Americans did impact vegetation, although probably not to the wide-scale extent that is often thought (Russell 1983, Parshall and Foster 2002, Parshall et al. 2003).

In the centuries just prior to European settlement, the vegetation of northern New England was in a state of flux. Spruce and pine abundances were on the rise while beech and hemlock declined, presumably as a result of climatic cooling (Russell et al. 1993). Overall, however, northern hardwoods like beech, yellow birch, and maple dominated the northern New England forests (Davis 1983a). At the same time, forest communities of southern New England remained fairly stable, dominated by oak-chestnut forests (Russell et al. 1993). The vegetation of New England, while dominated by forests, was a patchwork of diverse habitats, including forest stands of varying composition, hardwood swamps, meadows and salt marshes.

These were the forest communities that greeted the first European settlers. As they settled New England, Europeans brought with them unique land use practices. Unlike Native Americans, European settlers owned the land and cleared and worked that plot of land for decades. Settlers logged forests for various timber products and uses. Cold New England nights drove many settlers to cut forests for firewood. The maritime economy of the period meant cutting white oak for the timbers and planking of ships and white pine for ship masts (Cronon 1983). Such drastic and widespread cutting of New England forests changed the prevailing dynamics and many tree species capitalized on these new disturbance regimes. Some species, including balsam fir, chestnut, and birch are early colonizers of disturbed lands and increased in response to land clearing activities (Russell et al. 1993). Species that excelled at reproducing by root sprouts, including maple and chestnut, were able to increase in abundance by such land practices (Foster et al. 1992) and came to dominate many forests. Other species, like spruce and hemlock, were unable to survive in the new disturbance regime and declined as a result of settler land use practices (Russell et al. 1993).

Settlers also introduced new species into the vegetation communities of New England. Hidden amongst grain or intentionally transported from Europe for cattle feed, settlers introduced a series of weedy grasses, dandelions, nightshades, and stinging nettle, to name a few (Cronon 1983, Jackson 1997). Such plants quickly invaded and transformed the New England landscape.

Soils were not immune to the presence of European settlers. Cattle grazing within defined areas effectively fertilized the soil (Foster 1999). Following a harvest, fields were frequently cultivated before winter, leaving the soil exposed to snow, wind, and freeze/thaw cycles; high rates of soil erosion were common (Foster 1999). In recent decades, the introduction of non-native earthworms has had profound effects on North American soil (Bohlen et al. 2004). Exotic earthworms alter soil structure by mixing the organic and mineral soil horizons and decrease the carbon storage capacity of soil (Edwards 2004). Activities that alter soil structure and composition also influence the vegetation capable of inhabiting such lands.

Finally, settlers unknowingly encouraged a landscape susceptible to disease. Prior to European settlement, chestnut and balsam fir populations were scattered throughout New England forests. Following colonization, settler activities promoted the expansion and increased abundance of chestnut and balsam fir. During the early 20th century, both trees were severely devastated by disease (chestnut blight) and insects (spruce budworm). Dense, homogeneous populations of each species probably exacerbated the severity of these blights (Turner 1989, Russell et al. 1993).

As the industrial revolution and expansionist attitude swept across America, farms of New England were continually abandoned as people moved west to better farmland or moved to cities to take up factory jobs (Foster et al. 1992, Foster 1999). The result was an abandoned New England landscape, ripe for reforestation. The forests that have resulted were unlike any previous forest community. Dominance of hemlock, pine, and beech are less than in pre-settlement forests, while birch, maple, and balsam fir have increased (Russell and Davis 2001). In the last 100 years, chestnut has virtually disappeared. Invasive species continuously alter community composition. While the species make-up of modern northeastern forests resembles pre-settlement forests to some degree, past land use has altered forest composition, the relative abundance of each species and has changed the forest response to disturbance events (Foster et al. 1992).

Human activities, whether native or European, have transformed and shaped the vegetation patterns observed today. At the micro-scale, humans are clearly a driving force. Activities from farming to logging have altered heterogeneity within plant communities and across the landscape of the eastern United States.

1.3 Methods for reconstructing ecological history

Environmental forcing functions and biotic responses vary at different temporal and spatial scales, as do the resulting vegetation patterns (Delcourt and Delcourt 1987). Reconstructing the ecological history of a landscape requires using a diverse array of methods from a variety of disciplines. Equally important is an understanding of the appropriateness of each technique for different temporal and spatial scales (figure 1.2) (Russell 1997).

Techniques for reconstructing landscape history have traditionally included pollen and plant macrofossil analysis, dendrochronology and direct vegetation sampling. These methods are excellent at capturing vegetation dynamics over multiple time scales. In many instances, however, these data sets are unavailable or of limited use. Sediment data can be compromised (whether missing completely, truncated or contaminated) and long-term vegetation studies are rare. In addition, questions about a landscape's history are often interested in more than vegetation change. Methods from various disciplines, including geology, history, geography and ecology, combine to provide a detailed physical and biological history of a landscape. As independent data sets, these methods provide multiple lines of evidence for a particular phenomenon and, like traditional methods, these operate at different spatial and temporal scales (figure 1.2). Research that makes use of traditional and alternative methods can create a very robust data set that can be used to understand landscape legacies. Below, I detail the four levels identified by the space-time hierarchy and for each level, I discuss some appropriate techniques to reconstruct ecological history.

1.3.1 Mega-scale

Encompassing the history of the earth (4.6 billion years) and areas upwards of 10^{12} m^2 (the size of continents, for example), the mega-scale domain focuses on patterns generated by global climate change or plate tectonics, evolution and extinction. Pollen and plant macrofossils analysis, while less precise than direct vegetation sampling, is the primary technique used to reconstruct vegetation history over the mega-scale. The spatial scale that is reflected by a pollen spectrum depends on the pollen source area, which is reflected in the size of the depositional basin. As a result, pollen data may reflect local or regional vegetation patterns. Conversely, plant macrofossils are typically deposited close to their formation site and thus reflect local vegetation (Moore et al. 1991).

1.3.2 Macro-scale

The macro-scale domain, which is typically the focus of Quaternary science, focuses on a temporal scale of 10,000 – 1,000,000 years and a spatial scale of 10^{10} – 10^{12} m^2 (regional or sub-continental vegetation). Climate is a vital pattern generator at this scale, especially in temperate regions and is manifested most noticeably through glacial-interglacial cycles (Delcourt and Delcourt 1987).

Topography is also an important pattern generator at broad scales, though one that is often overlooked (Dorner et al. 2002). Topography can act on a landscape both directly by creating natural vegetation breaks, and indirectly by impacting disturbance regimes and successional pathways (Turner 1989, Swanson et al. 1998). Historical topographic maps are one potential data source. In recent years, remote sensing has made it possible to collect high resolution, digital elevation data.

Understanding a landscape's geological history, especially in the northeastern United States, can provide clues to complement pollen and plant macrofossil data. While glacial and interglacial cycles occur over the mega-scale, generally, only the most recent glacial/interglacial cycle is of interest when reconstructing landscape history. Studies of landscape legacies typically treat geology as a constant that is of minimal importance; however, geological processes create the template on which patterns develop. As a result, the underlying geology and glacial deposits can influence a variety of driving forces.

1.3.3 Meso-scale

Events occurring during the last interglacial (500-10,000 years) (i.e. the Holocene) and over landforms the size of mountains or watersheds (10^{10} - 10^{6} m^2) fall within the meso-scale domain (Delcourt and Delcourt 1988). Vegetation at this scale is patterned by regional climate, environmental gradients and disturbance regimes. Within this domain, human culture has transformed many natural landscapes.

Pollen and macrofossil analysis are commonly used at this scale, but can be complemented by several techniques to create robust data sets. In addition, the migration of humans to the northeast during this time period requires using methods that specifically address human activities.

Tree ring data can greatly complement pollen data. In some instances, tree rings chronicle nearly 8,000 years of changes in temperature, precipitation and disturbance. Dendrochronology can even record competitive interactions between trees (Delcourt et al. 1983).

At this scale, the interaction of humans with the landscape is best captured by archaeological data. Unfortunately, most landscape histories make little use of this rich data source. Native Americans interacted with the landscape as gardeners, hunters, horticulturalists and dispersal agents and left distinct, if localized, imprints on the land (Cronon 1983, Kraft 1984). For example, native Americans in a New York City marsh planted hickory around 1285 AD that, despite over 700 years of mixed land-use, persists (Loeb 1998).

Wetland development, and corresponding changes in hydrology, also occurs at this scale. Reconstructing wetland hydrology can be facilitated by sediment analysis, that is, characterizing sediment based on physical characteristics, humification and composition (Troels-Smith 1955), or by testate amoeba (Booth 2001). Wetland habitats produce characteristic sediment that supports distinct vegetation. Simple sediment descriptions or analysis of testate amoeba can reconstruct the local hydrologic history and wetland development over several thousand years. Combining historical hydrology with pollen data allows a more robust interpretation of both data sets. As wetlands develop, the pollen-source area varies. Open habitats tend to collect enough regional pollen that signatures of local vegetation are overlooked. An independent record of hydrologic changes can help focus attention on vegetation that would be characteristic of that hydrologic regime. Together, these methods provide a more complete reconstruction of landscape history over the meso- temporal scales.

1.3.4 Micro-scale

The micro scale domain encompasses the past 500 years and an area of 1 - 10^6 m^2. At this level, local disturbance events, including fire, floods, wind throws and logging (Pickett and White 1985) in addition to short-term climatic fluctuations and weather patterns are primarily responsible for patterning vegetation (Delcourt and Delcourt 1987). Plant communities respond through gap dynamics and succession on abandoned agriculture fields. In the northeastern United States, the micro-scale encompasses many of the effects of European settlement on the landscape.

Over the micro-scale domain, direct vegetation sampling yields a great deal of quantitative information about community structure, diversity and dynamics. Long-term data sets of this sort exist for a limited number of sites (e.g. Buell-Small succession study). Many of the techniques used at broader scales can be used to elucidate patterns at the micro-scale. For example, pollen data, when sampled at fine intervals, can reveal changes in vegetation from decade to decade. Descriptions of sediment, plant macrofossils and dendrochronology are all useful methods, when sampled at appropriate intervals.

Historical documents, while varied in quality and availability, can reconstruct past landscapes and chronicle human activity at the micro-scale. Early land surveys and maps, diaries of farmers and travelers, deeds and census records are a few of the historical sources that can help decipher a landscape's history. Because the observer often biases historical records, it is important to evaluate the source. An understanding of the purpose of a historical document can elucidate potential biases (for example, pamphlets written by New World land prospectors frequently exaggerated a land's features while ignoring potential difficulties (Edmonds 2001)). Comparing documents when possible is important; in this manner, inconsistencies and mistakes can be discovered.

Air photos are an exceptional historical document. Interpretation of these images, while limited to the 20th and 21st centuries, can provide a very quantitative reconstruction of land-cover and land-use over a wide spatial scale. When coupled with a GIS, it is possible to map vegetation and land-use, enabling a researcher to quantitatively assess changes in the landscape over time. There are, however, instances where historical photos or maps cannot be incorporated into a GIS. Oblique air photos, for example, while providing a familiar landscape image, are distorted images. Many historical maps are also distorted, whether by poor surveying techniques or the stress of time. In such instances, a qualitative comparison of maps must suffice.

1.4 Study Site

Just 26 miles from midtown Manhattan, the Great Swamp National Wildlife Refuge spans 7,600 acres of diverse habitat in the Piedmont physiographic region of New Jersey (figure 1.3). Over 240 species of birds, 37 mammals, 40 reptiles and amphibians (including the federally threatened bog turtle and the state-endangered blue-spotted salamander), and 29 fish species can be found in the varied habitats of Great Swamp. The eastern portion of the swamp (roughly 3,600 acres) has been preserved as a National Wilderness Area; management in this area focuses on minimizing human impact.

While the Great Swamp watershed spans two counties, the refuge itself lies entirely within Morris County, one of the 10 wealthiest counties in the nation (United States Bureau of the Census 2000). As of the 2000 census, Morris County supported 470,212 individuals on 469 square miles of land, a density of 1,002 individuals per square mile (compared with the densities of New Jersey and the nation as 1,134.5 and 79.6, respectively (United States Bureau of the Census 2000)).

Bounded on the west by the Passaic River, several brooks and ditches cut through Great Swamp. The Black Brook and Great Brook run through the southern and northern regions of the swamp; several other waterways, including the Middle Brook, Great Brook, Loantaka Brook also run through portions of Great Swamp.

A multitude of vegetation communities currently exist at Great Swamp, ranging from deciduous wooded wetlands, herbaceous wetlands, to open water. Wooded wetlands, including red maple swamps, comprise 39% of the vegetation cover of Great Swamp (FWS 1980). A second dominant community, scrub/shrub wetlands, makes up approximately 27% of Great Swamp, and is typified by highbush blueberry swamps (FWS 1980). Other prominent plant communities include cattail marshes, oak-mixed hardwood swamps, and buttonbush swamps (NatureServe 2004b).

In landscape legacy studies, it is critical to explicitly define the spatial and temporal scales. Although Great Swamp spans two counties and several towns, this study was purposefully limited to the 7,600 acres contained within the Refuge. As a case study investigating the driving forces of vegetation change, data from a variety of disciplines needed to be integrated through time and space. Data availability, especially historical documents, limited the scope of this study to an area where sufficient records could be found.

1.5 Macro-scale history of Great Swamp

Glacial Lake Passaic formed as the advancement of the Wisconsin glacier some 20,000 years BP blocked drainage through the Short Hills gap (Salisbury and Kummel 1895). Bounded on the south and east by the Second Watchung Mountain, on the west by an escarpment of the Highlands Province, and on the north by the glacier, meltwater from the glacier filled the Passaic basin to an altitude of 108 meters (Reimer 1984).

As the glacier retreated, glacial debris filled the Short Hills gap, thus preventing the Short Hills gap from serving as an outlet for the lake (Reimer 1984). At its maximum, Glacial Lake Passaic reached 48 km in length and 16 km in width; the maximum depth exceeded 100 m until sediment accumulation decreased depths to 30 m (Salisbury 1902, Reimer 1984). The lake level probably dropped to 20 – 23 m for a brief period as ice retreated from the Boonton area, but quickly returned to its earlier level (Salisbury 1902). Glacial Lake Passaic existed for 750 – 1250 years until glacial retreat opened a drainage point at the Paterson gap (Reimer 1984).

Although the drainage of glacial Lake Passaic occurred approximately 18 ka (thousand years ago), several small postglacial lakes remained following the drainage of glacial Lake Passaic; the longest-lived post-glacial lake existed in the area of Great

Swamp. The depth of this postglacial lake was controlled by the Millington Gorge in Long Hill (Salisbury and Kummel 1895, Stanford unpublished) and this postglacial stage is termed the Millington stage. During this stage (and the Great Notch stage of glacial Lake Passaic), the Loantaka and Great Brooks deposited sands and silty sands (Stanford unpublished). These depositions formed the sandy, low uplands found primarily in the eastern portion of Great Swamp (Stanford unpublished). The Millington stage drained gradually; during this time, "streams eroded down into terraces, etching out the channels and low-lying areas in which peat has since accumulated." Much of this occurred between 13-14 ka and 10 ka (Stanford unpublished). Drainage of the post-glacial lake at Great Swamp has also been dated, using palynological evidence, to 8 - 9,000 years BP (Meyerson 1970, Peteet et al. 1993). Peat accumulation began at this time (Meyerson 1970, Peteet et al. 1993), although the average peat depth in Great Swamp is generally less than 10 feet (Waksman et al. 1943).

Geological surveys of Great Swamp reveal the dominance of two types of post-glacial deposition types, mineral (Qst) and organic (Qs) (see table 1.1 for descriptions) (Stanford unpublished). The mineral deposits are interesting in that they form terraces 5 – 15 feet above modern floodplains. Shallow post-glacial lakes laid many of these deposits; streams channeling into and eroding the terraces generated the intricate patterning and patchy distribution of these deposits (Stanford unpublished).

The distribution of these post-glacial deposits is not uniform across the Great Swamp landscape (figure 1.4). There are distinct differences between the eastern and western areas of the swamp (Stanford unpublished). In the east, large patches of organic deposits are interspersed with mineral deposits. In the west, the pattern is largely reversed: large patches of mineral deposits dominate, with small patches of organic and several other post-glacial deposition types dotted across the landscape.

Great Swamp soils reflect this glacial and resulting hydrological history. Generally, soils of the Great Swamp fall into the Carlisle-Parsippany-Preakness Association: soils that are very poorly drained and overlie stratified sand, silt, and clay (Eby 1976). Carlisle muck, a very poorly drained and dark-colored organic soil, dominates the eastern portion of Great Swamp. This soil is typical of low swampy areas and forms in areas that were once or are now occupied by lakes or ponds (Eby 1976). These soils are rapidly permeable; the water table is generally at or above the surface most of the time. Agriculture on these soils is possible, but extensive drainage efforts are required. Frequently, drainage is not possible as suitable outlets are unavailable.

Parsippany silt loam and sandy loam soils dominate the western portion of Great Swamp. This soil is generally level with a perched water table at or near the surface for long periods. Permeability and run-off are slow. Economically, these soils are well suited for agriculture, but would require an intense drainage effort (Eby 1976).

Waksman et al. (1943) extensively described the peat of New Jersey from an economical perspective. According to Waksman et al., most of Great Swamp contains no peat; rather, it's composed of boggy or dry, water-deposited mineral soils. Only the eastern portion of Great Swamp contains any peat, and then it is of varying quality and depth. In a cross section of the eastern portion of Great Swamp, Waksman et al. showed that sedge peat is typical of Great Swamp; however, forest and *Phragmites* peat are found at various depths in some sites.

Glacial forces have been integral in the development of Great Swamp, impacting soils and hydrology. This makes it necessary to document community change over the macro-scale in addition to the meso- and micro-scales. Chapter 2 of this dissertation focuses on the macro- and meso-scales, employing pollen, sediment and charcoal analysis to reconstruct the vegetation history of Great Swamp and identify additional driving forces of vegetation change.

Studies of land-use legacies in northeastern forests have found distinct correlations between land-use and vegetation patterns. As a wetland, Great Swamp has experienced intense land-use, including site-altering changes in hydrology. Chapter 3 chronicles land-cover and land-use in Great Swamp over the micro-scale (i.e. last 300 years). Typically, pollen, macro-fossil and sediment analysis are used to reconstruct vegetation over this time period. However, the sediment of Great Swamp is severely truncated and the most recent history is not recorded. In this instance, historical documents, including deeds, diaries, surveyor notes and local histories have been used to reconstruct the vegetation at the time of settlement and through the subsequent centuries.

Unlike many exploited wetlands in the United States, Great Swamp was not further developed when agriculture ceased to be profitable in the 20th century. Aerial photographs capture this unusual history and, when coupled with vegetation mapping, provide data regarding land-cover and land-use change in the 20th century. Chapter 4 quantifies recent changes in vegetation at Great Swamp, from 1932 through 2002.

Coupled together, these chapters document the vegetation history of Great Swamp since the drainage of glacial Lake Passaic and identify those processes critical to shaping modern plant communities. With an understanding of landscape patterns and driving forces, we can then begin to determine the potential importance of land-use legacies and identify further research areas to more fully understand land-use legacies at Great Swamp. Ultimately, knowledge of Great Swamp's past will inform and guide management decisions of the future.

Table 1.1. Postglacial deposits common to Great Swamp. Descriptions from Stanford (unpublished).

Post-glacial deposit type	Abbreviation	Description
Artificial fill	af	Artificially placed sand, gravel, silt, clay and rock fragments; also, man-made materials, including brick, ask, cinder, asphalt, and trash
Trash fill	aft	Trash mixed and covered with sand, silt, clay and gravel
Alluvial fan deposits	Qaf	Sand, silt, pebble gravel
Stream terrace deposit	Qst	Mineral; silt, very fine-to-fine sand
Swamp and marsh deposits	Qs	Peat and organic silt and sand; began accumulating over 9,000 yr BP

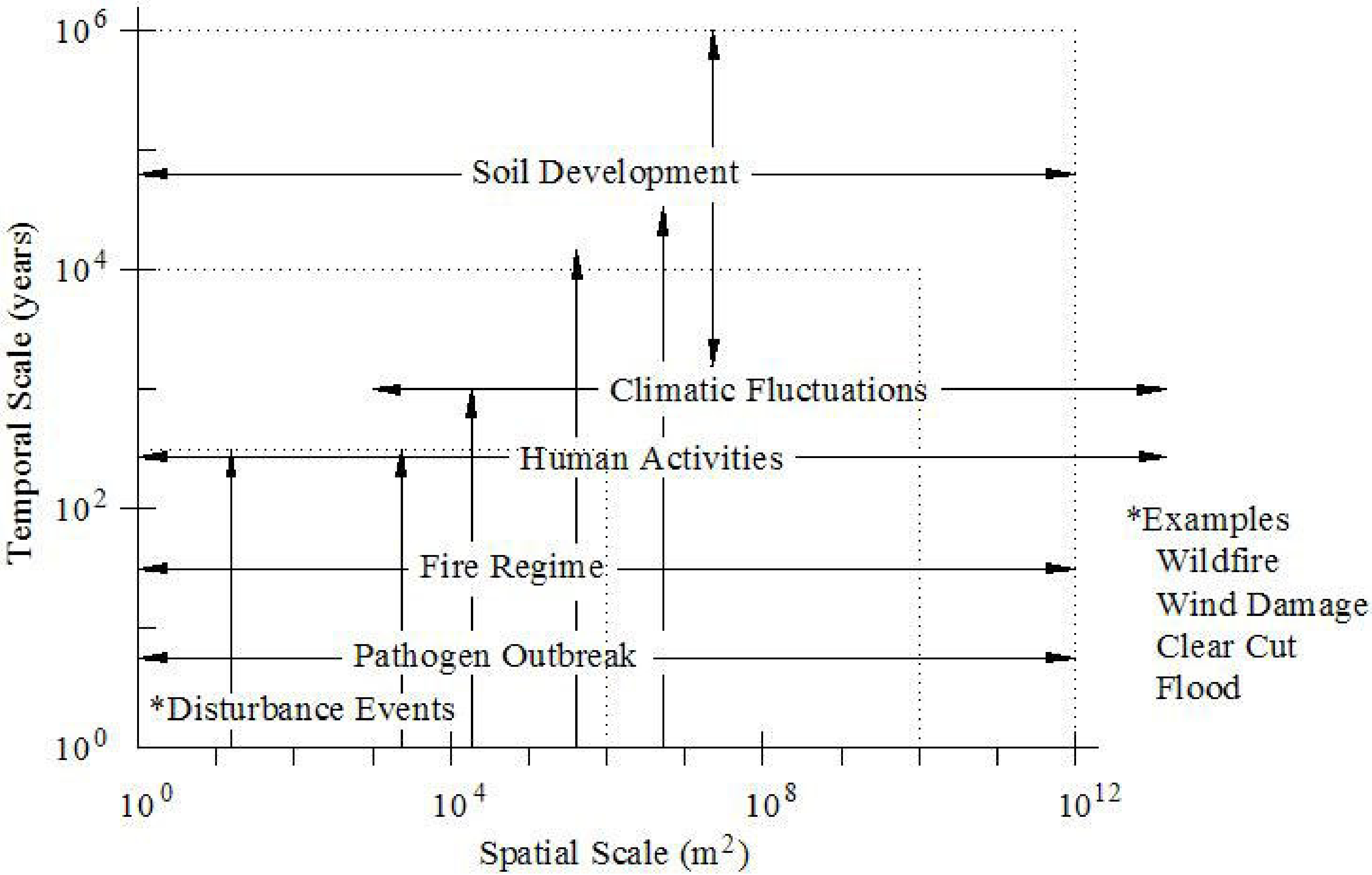


Figure 1.1. Space-time hierarchy. Based on Delcourt and Delcourt (1988).

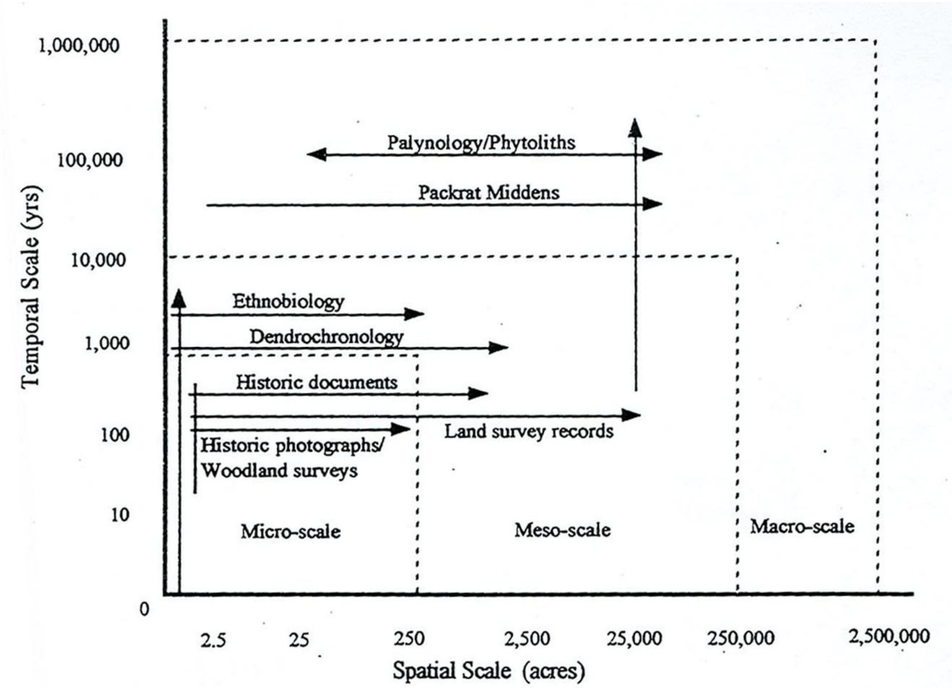


Figure 1.2. Spatial and temporal scales of historical ecology techniques. From Egan and Howell (2001), modified from Delcourt and Delcourt (1991); Swetnam et al. (1999).

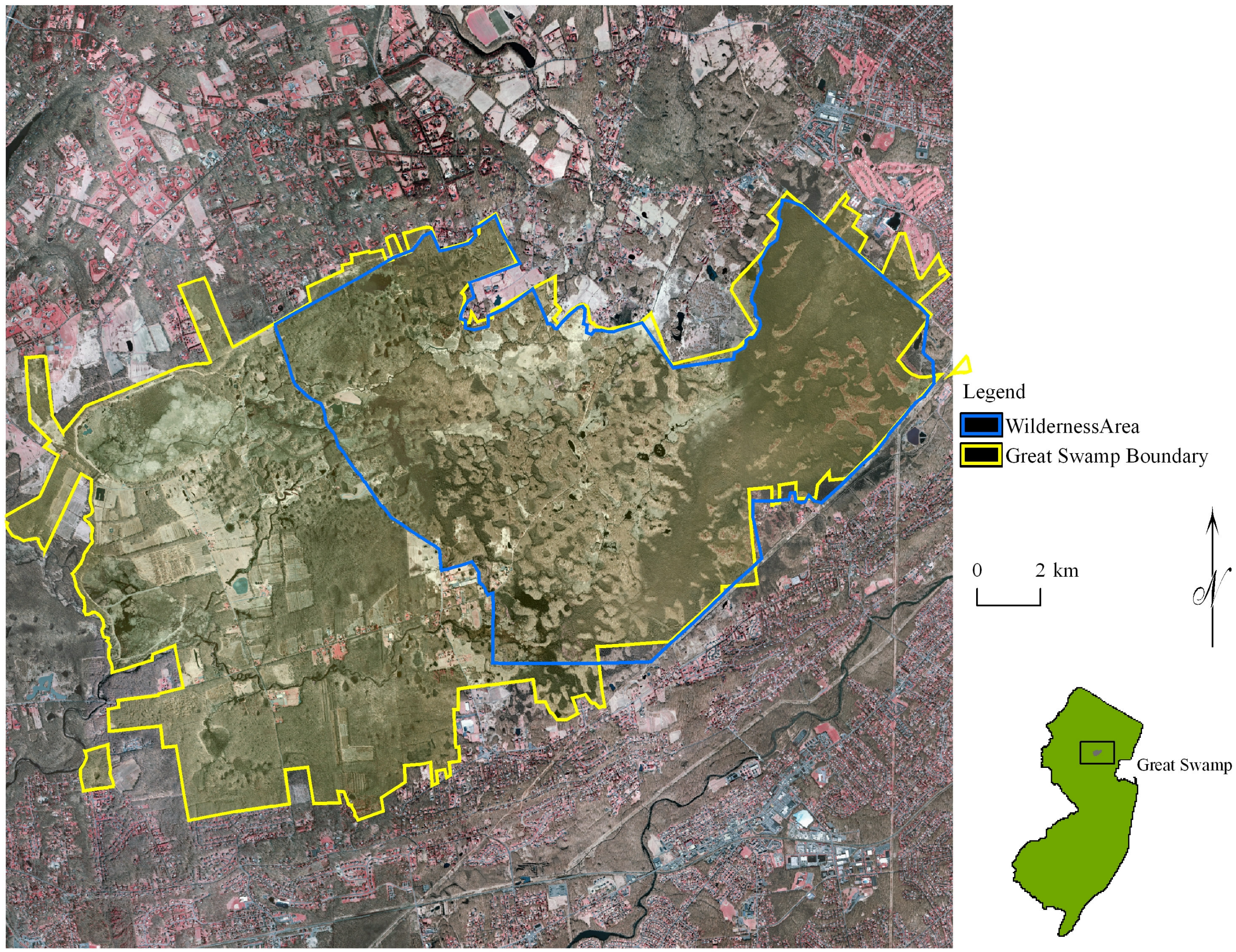


Figure 1.3. Great Swamp National Wildlife Refuge. The Wilderness Area, as outlined in blue, was estimated based on current refuge maps; as such, the boundary does not directly coincide with the swamp boundary.

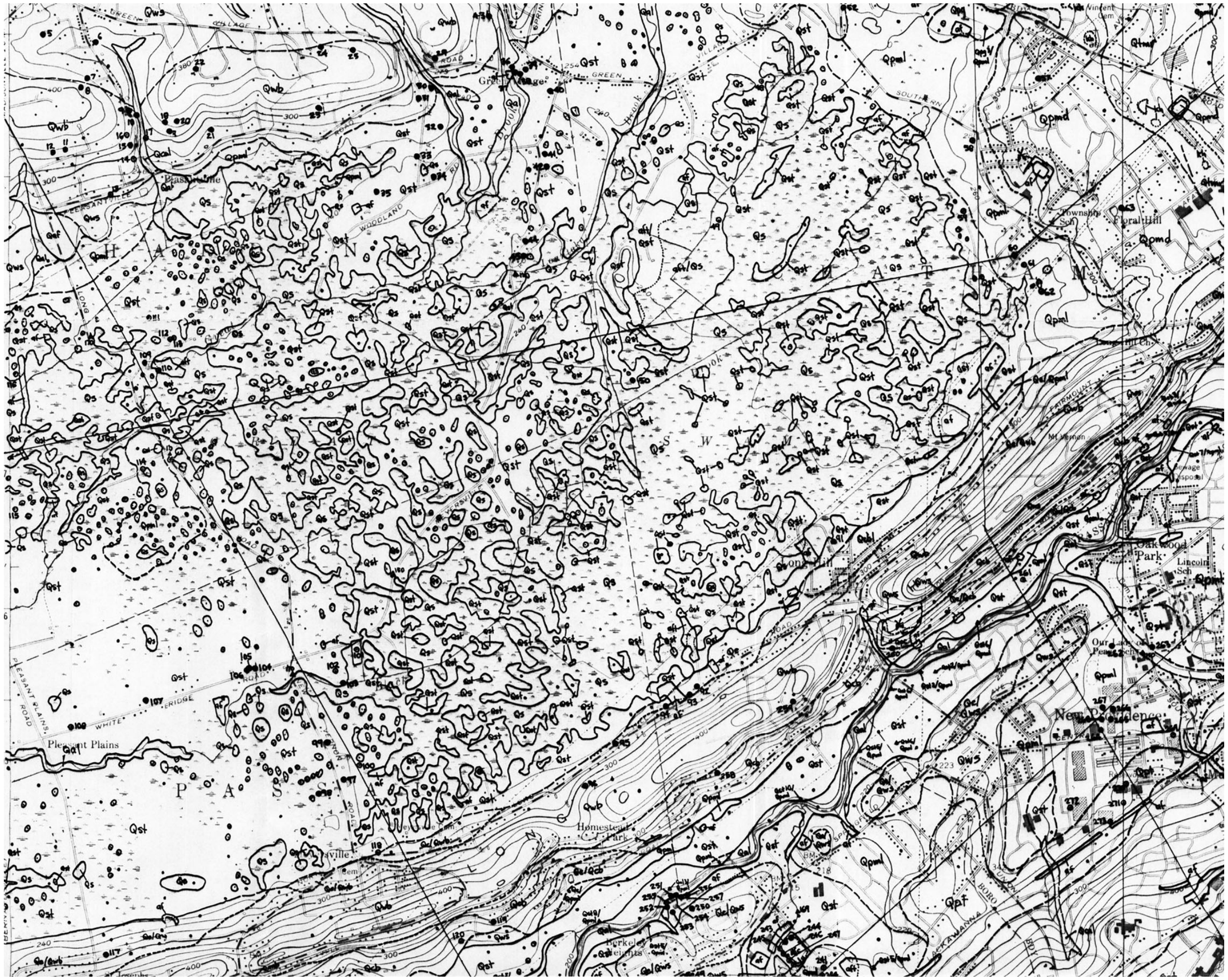


Figure 1.4. Surficial geology map of the Chatham quadrangle, Morris, Union and Somerset Counties, New Jersey (Stanford unpublished). See text for explanation of symbols.

2.0 Great Swamp wetland development and vegetation history

2.1 Introduction

A critical first step in understanding land-cover change is to define the patterns of vegetation that have historically been important to a particular location. Studies of past land-cover are frequently limited to the past 100 years – roughly, the time frame of available aerial photographs, suitable for vegetation and land-use analysis. In some instances, researchers employ historical documents to define vegetation patterns over the past 300 – 400 years; however, land-use activities can obscure the importance of natural disturbances and biotic and abiotic interactions. Palynology and sediment analysis have the ability to document vegetation patterns over longer temporal scales and can provide insight into those processes that were vital to shaping vegetation prior to European settlement. This data can be used to address questions over multiple temporal and spatial scales (Russell 1997, Swetnam et al. 1999).

In the northeastern United States, nearly 300 years of settlement have transformed much of the landscape. This is especially true for wetlands where land-use activities have, in some instances, modified not only vegetation cover but also the physical template of the land, including microtopography, soil composition and hydrology. This study investigates the dynamics and plant community composition of Great Swamp prior to intense settlement. Specifically, pollen and sediment analyses are used to reconstruct the vegetation history and to identify the mechanisms important to the development of modern plant communities at Great Swamp. When combined with studies of historical land-use and land-cover, this information can help elucidate the importance of 300+ years of settlement on ecosystem dynamics.

2.1.1 Regional climate history

The Holocene climate history provides a template to help interpret pollen and sediment data from Great Swamp. Climate tends to drive vegetation patterns over large spatial scales, but can also be important at regional and local scales, impacting community composition and structure (Delcourt et al. 1983). Paleorecords from small lakes have provided significant information regarding Holocene vegetation patterns and climate change. For example, extensive research in the Great Lakes region has linked climate changes with asynchronous changes in local hydrology and vegetation across the area (e.g. Brugam et al. 1997, Brugam and Johnson 1997, Brugam et al. 1998, Booth and Jackson 2003, Booth et al. 2004). Peatland development, however, has been linked to both climate change (Winkler 1988, Zoltai and Vitt 1990) and autogenic processes, including hydrological change (Foster and Wright Jr. 1990). Paleo-data from Great Swamp, when interpreted in the context of Holocene climate variability, can add to our understanding of the importance of climate versus autogenic processes in the development of a wetland.

Holocene climate conditions were once thought to be exceptionally stable, especially in comparison to the pronounced climatic variability during the last glacial episode (Roberts 1989). Recent ice-core research reveals a climate more variable than previously thought, including millennial-scale climate cycling throughout the Holocene (Denton and Karlen 1973, Bond et al. 1997, Mayewski et al. 2004, Willard et al. 2005).

The mounting data seems to support a variable Holocene climate; however, the cause for this cycling is not yet understood. Solar variability, oceanic circulation dynamics and volcanism have each been hypothesized causes of this millennial-scale cycling (Rind and Overpeck 1993, Shindell et al. 2001).

Terrestrial data (pollen), however, does not seem to support this hypothesis, especially for the northeastern United States. Shuman et al. (2005b), in a study of fossil-pollen data from eastern North America, measured the magnitude of short- and long-term changes in pollen composition in order to capture rapid climate change. Their results do show rapid climatic changes occurring at about 14,600, 12,900, 11,600 and 8,200 calendar years BP, but do not provide support for millennial-scale climate oscillations. The authors conclude that while millennial-scale changes may have been pervasive (as indicated by Bond et al. (1997)), they were ecologically less significant than orbitally or multi-millennial paced climatic changes.

The collapse of the Laurentide Ice Sheet between 8400 and 7900 calendar yr BP (Barber et al. 1999) had a profound impact on climate (Alley et al. 1997, Stager and Mayewski 1997, Hu et al. 1999). One result of this collapse, the ‘8.2 ka (thousand years) event,’ was the release of fresh melt water into the North Atlantic, causing the climate to cool (Alley et al. 1997). Multiple proxies, including ice cores from Greenland (Alley et al. 1997), European sediment records (Klitgaard-Kristensen et al. 1998), oxygen isotopes (Hu et al. 1999) and terrestrial records from the United States (Kneller and Peteet 1999, Shuman et al. 2005a, Shuman et al. 2005b) document this event.

The effect of the Laurentide Ice Sheet collapse was acutely felt across North America; however, the response was not uniform across the continent (Shuman et al.

2002). For example, research has documented the expansion of prairie in the central United States around 9000 calendar yr BP (Cushing 1967, Webb III et al. 1983), which has been linked to the collapse of the ice sheet (Shuman et al. 2002). In New England, an increase in moisture around 8000 calendar yr BP may have resulted from a diminishing impact of the Laurentide Ice Sheet (Webb et al. 1993, Shuman et al. 2001).

Some evidence exists for an extensive drought in the North American Midwest occurring between 4300 and 4200 years ago (Booth et al. 2005). Data for this event is currently limited and the spatial extent of this drought in the United States is unknown. Drought conditions at this time have been documented by data from other continents, including Asia and Africa (Gasse 2000, Thompson et al. 2002), indicating that this, like the 8200 year BP event, might have been a global event (Bond et al. 2001).

2.1.2 Pollen analysis in a wetland

Interpretation of fossil pollen assemblages from swamps, bogs and other peatlands is challenging, in part because few studies have investigated the relationship between pollen rain and source vegetation in these types of wetlands. Most studies of pollen source area use data from lakes and forest hollows (e.g. Jacobson and Bradshaw 1981, Jackson 1990) to focus on upland communities over broad spatial extents (e.g. Bradshaw and Webb III 1985, Delcourt and Delcourt 1991). Several recent studies, however, have successfully linked surface pollen spectra with local wetland vegetation (Bunting et al. 1998, Futyma and Miller 2001). However, many wetland plant communities do not produce distinct pollen signatures, though additional discrimination of these communities may be possible with plant macrofossil data, testate amoeba analysis or other community indicators (Bunting et al. 1998).

The successional pathway of many peatlands also complicates the interpretation of pollen data. While the trajectory of peatland development generally follows a predictable path, from lake basin through semi-terrestrial wetland to upland community, it is often intricate and non-linear. Only in rare instances do terrestrial ecosystems develop (Walker 1970, Tallis 1983, Hu and Davis 1995). Peatland development can be initiated by climate change (Winkler 1988, Zoltai and Vitt 1990) or autogenic processes, such as changes in hydrology (Foster and Wright Jr. 1990).

Another difficulty associated with identifying paleo-environments from peatlands is the transportation of pollen. Pollen may originate locally, extra-locally and regionally. The distance a pollen grain travels is heavily influenced by the physical space it must traverse and the mechanism by which it travels (table 2.1). For example, a site with a relatively continuous canopy will have less pollen rain from canopy air circulation (Moore et al. 1991). In a closed habitat, therefore, pollen moves only short distances – approximately 20 – 30 m (Bradshaw 1981). Such a site will therefore have high levels of local pollen with limited extra-local and regional pollen. Peatland development transforms community structure considerably, in some instances from a large, open lake to a shrub-dominated wetland. As a result, the pollen source area also changes. Large lakes collect primarily regional or extra-local pollen while closed-canopy wetlands largely collect local pollen.

In any study of palynology, it is important to recognize the relationship between pollen production and dispersal. Differences in pollination syndromes lead to differential pollen production; for example, wind pollinated species produce relatively high amounts of pollen when compared with species that are insect or animal pollinated (see table 2.2 for the pollination syndrome of some common species of Great Swamp). As a result, wind pollinated species are typically over represented in pollen cores, although dispersal among wind pollinated taxa is not uniform; some taxa, including *Pinus* and *Quercus* travel much farther than others, like *Fagus* and *Acer* (Faegri and Iversen 1989). Insect and animal pollinated species are rare or under represented in pollen cores (Faegri and Iversen 1989, Moore et al. 1991); the presence of these species can be an important indicator of a particular plant community.

2.2 Methods

2.2.1 Pollen Analysis

A Russian peat corer was used to extract sediment at Great Swamp. This sampler minimized sediment disturbance and allowed for a clean cut through fibrous material, avoiding the downward transport and possible contamination by fibrous material (Moore et al. 1991). Samples were then transferred to an aluminum foil lined tube, wrapped, and transported to the lab.

Cores were stored at 4 °C and were subsequently subsampled at intervals of approximately 10 cm. One cc of each subsample was treated following a modified Faegri and Iverson procedure (1989). Samples were deflocculated with 7% KOH and sieved. Carbonates and silicates were removed with HCl and HF. Acetylation with H_2SO_4 and acetic anhydride destroyed cellulose.

Processed subsamples were stored in tertiary butyl alcohol and mounted in silicone oil for microscopic counting. At each subsampled interval, a minimum of 250 arboreal pollen grains were identified and counted at 400x, except where noted. Identification was facilitated by reference slides and several keys (McAndrews et al. 1973, Kapp et al. 2000, Davis 2005). Microscopic charcoal fragments were counted at the same time. Because fire was not thought to be an important disturbance at Great Swamp and cursory examination of the prepared slides showed little variation in charcoal size, an absolute particle abundance method was employed (Davis 1967, Clark 1982, Patterson III et al. 1987). Charcoal data are presented as a ratio of total pollen.

A total of 5 cores were extracted from sites in the Wilderness Area of Great Swamp (figure 2.1). Since becoming a National Wildlife Refuge, the Wilderness Area has been managed to minimize human impacts from recent land-use activities. The Wilderness Area was therefore preferentially chosen as an area where stratigraphic contamination would be minimized and would more accurately reflect the vegetation history of the swamp.

Three short cores, noted as cores A, B, and C, were extracted from vernal ponds. Each core was extracted in a single push and the core lengths were 43 cm (core A), 47 cm (core B), and 50 cm (core C). Two additional cores, cores 1 and 2, were extracted from deciduous wooded wetlands (figure 2.1).

Radiocarbon dating was conducted on two samples from cores 1 and 2 extracted from deciduous wooded wetlands in the Wilderness area. All samples were submitted to Beta Analytic for accelerator mass spectrometry (AMS). Two sections were dated in each core: the bottom of each core and where the first distinct rise in *Ambrosia* levels occurred (table 2.3).

2.2.2 Sediment Description

Research conducted in the Great Lakes region has used multiple lines of independent evidence to reconstruct the vegetation history and to assess the relative importance of climate change, anthropogenic disturbance and dispersal limitations (Booth and Jackson 2003, Booth et al. 2004). Sediment analysis, including humification and testate amoeba, were used to create a high resolution reconstruction of the moisture history of several wetlands (Booth and Jackson 2003). Geological studies of Great Swamp document fluctuating water levels throughout the Holocene (Salisbury and Kummel 1895, Reimer 1984), making a reconstruction of the moisture history desirable. While pollen analysis alone can detect hydrological changes, sediment analysis can provide an independent means to verify and assess the importance of hydrology and climate to vegetation dynamics (Booth and Jackson 2003).

Cores 1 and 2 were subjected to gross sediment analysis, following the Troels-Smith (1955) methodology, as described by Birks and Birks (1980) and Faegri and Iverson (1989). Troels-Smith presented a 'comprehensive field description system' of organic sediments that has been highly favored for its ease of use and because, unlike other methods, it does not impose an interpretation in describing the sediment and it recognizes that sediments are often a mixture of elements (Birks and Birks 1980). The Troels-Smith system characterizes sediments using three parameters: physical properties (table 2.4), humification (the degree of decomposition), and composition (table 2.5). Each parameter is estimated on a 5-point scale, where 0 is the absence of that property and 4 is the maximum presence. Results are then analyzed in order to describe past ecosystems.

2.2.3 Analysis

Pollen, sediment and radiocarbon data are plotted concurrently using the computer program, PSIMPOLL (Bennett 1998). Pollen data is presented as percent diagrams, where arboreal and non-arboreal pollen have been separated and are presented as a proportion (i.e. all arboreal species sum to 100% as do the non-arboreal). The right-hand axis shows the total number of arboreal and non-arboreal pollen grains counted at each level. This method has the potential to over-represent certain species, but provided the influx of pollen is reasonably steady, has been shown to present an accurate depiction of vegetation change (Moore et al. 1991). Because the resulting pollen diagrams can be overly complex, each core was simplified by zonation using optimal splitting by information content in PSIMPOLL (Birks and Gordan 1985). Radiocarbon dates were used to convert core depths to ages using a linear interpolation between dates.

2.3 Results

Three cores extracted from vernal ponds (cores A, B, and C) were coarsely subsampled, chemically processed, and analyzed. Initial examination of these cores revealed contamination or hindered stratigraphy at surface levels and they were deemed unsuitable for further analysis.

Results from the pollen, sediment and radiocarbon analysis of cores 1 and 2 are presented in figures 2.2 through 2.5 and Appendices A and B. Both cores represent roughly 10,000 years of vegetation history, reflecting climatic and hydrologic changes. Each core is presented separately to highlight the similarities and differences between the two cores.

2.3.1 Core 1 - Highbush Blueberry

Core 1 was taken from a highbush blueberry swamp. Highbush blueberry (*Vaccinium corymbosum*), pickerelweed (*Pontederia cordata*), and sedge (*Carex* spp.) tussocks dominated the vegetation in this area. This core, extracted in two successive pushes, was 74 cm in length. Plant fibers permeated the upper 60 cm. The bottom 14 cm of the core was dominated by lake mud and fine particles of sand (figure 2.2). Between 15 and 60 cm, the sediment was composed primarily of lake mud and moss peat, although herbaceous peat was found above 24 cm. From 15 cm through the top of the core, the sediment was mainly moss and herbaceous peat with some herbaceous fragments (mostly plant roots).

Correlations of radiocarbon dates with core depth to produce an age-depth model were not possible and indicated uneven sedimentation rates at this site. Consequently, results from this core will be presented by depth rather than age. Despite being unable to ascribe a specific age to a depth, it is possible to employ pollen markers to date certain areas of the core.

Charcoal fragments, presented as a ratio of charcoal to pollen, did not vary greatly through this core. In fact, charcoal levels were low throughout this core, peaking at 62 cm, and showing a rising trend from 7 cm through the core top.

Forty-three distinct palymorphs were identified in this core and zonation in PSIMPOLL created 8 somewhat distinct zones. Pollen abundances varied greatly throughout the core (figure 2.3); to facilitate interpretation, several species are highlighted. *Pinus* abundances are high from the base of the core to 30 cm, peaking at 74 cm. The abundance of *Quercus* increases above 30 cm, peaking at 24 cm, but remains high through the top of the core. *Betula*, however, is present in moderate amounts throughout most of the core, dropping noticeably at 30 cm. *Tsuga* is present at low levels through 15 cm, above which it disappears completely. *Carya* is also present at low levels throughout the length of the core. *Castanea* increases above 12 cm through the top of the core. Below 30 cm, *Alnus* levels are low, but rise after 30 cm to a maximum at 15 cm. Ericaceae are present throughout almost the entire core, rising to a peak at 24 cm and remaining high through the top. *Ilex* is also present throughout the entire core, peaking at 30 cm. *Ambrosia* is consistently present above 60 cm, peaking slightly at 52 and 30 cm and then rising at 24 cm through the top of the core. Several wetland species, *Typha* and *Nympha* are also found at various points in the core.

The bottom three zones, as identified in PSIMPOLL, are fairly similar, differing primarily in the abundances of *Betula*, *Alnus* and Poaceae. Through these three zones, the abundances of these three species declines. The fourth zone is distinguished by a significant decline in *Pinus* coupled with an increase in *Quercus.* At the same time, *Ilex, Ambrosia,* and Poaceae abundances increase. The remaining zones differ primarily in the abundances of *Alnus,* Ericaceae, *Betula, Acer rubrum* and *A. saccharum.*

2.3.2 Core 2 - Red Maple Swamp

Core 2 was taken from a red maple swamp. Vegetation in this community was dominated by red maple (*Acer rubrum*), highbush blueberry (*Vaccinium corymbosum*), sedges (*Carex* spp) and sphagnum covered hummocks. Extracted in three pushes, this core was 140 cm in length. The top 40 cm of this core was loose, fibrous peat; plant fibers permeated the top 63 cm of the core.

Sediment composition fluctuated dramatically in parts of this core (figure 2.4, table 2.7). From the core bottom to 120 cm, the sediment composition was primarily lake mud with small amounts of sand or peat. Sediment from the next 10 cm (120 – 110 cm) was composed of lake mud and moss peat in roughly equal parts. Sand particles and reed fragments were also found. From 110 – 100 cm, the sediment reverts to a composition primarily of lake mud with small amounts of sand particles and peat. Above 100 cm through the top of the core, sediment composition follows a similar pattern to core 1, becoming progressively more composed of peat with herbaceous fragments.

Charcoal levels fluctuated throughout the core, although the variation was not significant. Very low amounts of charcoal were found in the bottom 20 cm of the core. Above 120 cm, the amount of charcoal oscillates, but there are no major peaks. The upper 30 cm of the core does display a trend of increasing charcoal amounts.

A total of fifty-nine palymorphs and ten zones were identified in this core. Pollen abundances varied dramatically throughout the core; to aid in interpretation, selected species have been focused on (figure 2.5). *Pinus*, abundant at the bottom of the core, decreases rapidly beginning at 125 cm and remains low throughout the rest of the core, with the exception of a brief spike at 95 cm. Levels of *Quercus* are initially low, but rapidly increase above 125 cm and remain high. *Betula*, present throughout the core in moderate amounts, drops dramatically at 125 cm and abundances remain low throughout, with the exception of small peaks at 95 cm and the core top. *Acer saccharum* is present throughout the core, in somewhat lower levels above 40 cm; *Acer rubrum* is present in small amounts at various points in the core. *Tsuga* is also present at low levels throughout the core. *Castanea*, present through much of the core, becomes a significant component of the pollen spectra above 35 cm. *Alnus*, present throughout the core, reaches a peak at 35 cm and is a major component of the pollen spectrum. *Ilex*, also present throughout the core, gradually increases at 70 cm to a peak at 55 cm and gradually tapers off above 55 cm. Ericaceae is found at several points in the core. *Ambrosia*, an indicator of open habitat, is present throughout the core. At 50 cm, *Ambrosia* shows a small peak. Beginning at 35 cm, *Ambrosia* levels rise to their peak at the top of the core. Several aquatic species are present in the core, including *Typha, Nuphar* and other members of the Nymphaceae family.

Of the ten zones identified in PSIMPOLL, two are worth highlighting. A large shift in the abundances of *Pinus* and *Quercus* dominate zone 2. *Betula, Alnus* and *Ilex* also decline. Zone 4 is also noteworthy, again, because of the dramatic shift in *Pinus* and *Quercus* abundances. Other zones are dominated by differing abundances of *Acer rubrum* and *A. saccharum*, *Alnus*, *Ilex*, Ericaceae, *Typha*, and *Ambrosia*.

2.4 Discussion

2.4.1 Wetland Development

The pollen spectra as described above are consistent with other studies of vegetation history in the northeast (eg Shuman et al. (2004)) and of local vegetation studies (Niering 1953, Heusser 1963, Meyerson 1970). Swamp sediments have been shown to capture both regional and local pollen (Bunting et al. 1998), and results from these two cores do reflect regional and local dynamics. However, the regional and local signals are not uniform through either core, reflecting the changing community structure.

Sediment and pollen data from the highbush blueberry core (core 1) primarily reflect local vegetation dynamics (table 2.6). Wetland development is clearly recorded by the sediment as it shifts from lake mud at the bottom to moss and herbaceous peat at the top. Pollen data largely supports this trajectory. High levels of Ericaceae and *Ilex* at 24 cm, for example, coincide with a shift in sediment composition that indicates the establishment of a scrub/shrub wetland.

Regional dynamics are also captured by the pollen data, especially in the lower half of the core. Here, a lake receiving primarily regional pollen dominates the landscape. For example, the sharp drop in *Pinus* coupled with an increase in *Quercus* at 30 cm signifies a regional event, a climatic shift to a warmer and wetter climate. This is reinforced by the simultaneous increase in *Alnus,* a moisture restricted species (Thompson et al. 1999). As the wetland developed, the input of the local pollen input increased and the sediment and pollen data begin to strongly reinforce each other.

Although the time period captured by the core from the red maple swamp is roughly the same as for the highbush blueberry core, the length of this core provides a more detailed vegetation history. As before, regional and local dynamics are inconsistently captured by pollen and sediment (table 2.7). Low levels of *Quercus* coupled with high amounts of *Pinus* at the bottom of the core (125 – 140 cm) indicate a cool and dry period some 9670 rycBP (radio carbon years before present). Above 125 cm, *Pinus* levels drop, while *Quercus* levels increase, signifying a shift to a warm and moist climate. *Pinus* abundance spikes at 95 cm and coincides with a dip in *Quercus* abundance. This is a substantial change, again, probably reflecting regional climate changes; in this instance, this may very well reflect the 8.2 ka event. (Although the interpolated date for this event is approximately 7400 rcyBP, it is highly unlikely that this date is correct. This core captures 10 ka of sedimentation; sedimentation rates were certainly not constant. A shift of 800 years between an interpolated date and a 'cultural' date is not significant.) Other taxa change substantially at this time (though not with the same magnitude as *Pinus* and *Quercus*). *Ambrosia* is tolerant of dry condition; its increase at this time may be a response to drier conditions associated with the 8.2 ka event. Moisture loving taxa, including *Tsuga* and *Fagus* decline at this time. Taken together, this data indicates a brief dry period, followed by a return to wetter conditions.

A significant difference between the two cores occurs at 120 cm (roughly 8200 rcyBP). Here, the sediment changes unexpectedly. In addition to lake mud, the sediment includes a small fraction of moss peat with reed fragments, which disappear at 110 cm. The presence of terrestrial peat and herbaceous fragments indicates drier conditions, perhaps a shallow lake or lake margin. This anomaly, which is not seen in the core from the highbush blueberry swamp, could be an artifact of the different core lengths (the highbush blueberry core could be severely compacted and obscure this event) or it could reflect the landscape position of each core. The site of the highbush blueberry core may have been at the center of a postglacial lake. In this location, the core could be insulated from minor environmental changes. Conversely, the site of the red maple core might have been on the edge of the lake and would therefore be more susceptible to hydrologic fluctuations.

Pollen data, however, portray a somewhat different history. At this change in sediment structure, only a few species, notably *Pinus* and *Quercus* change. However, the decline in *Pinus* coupled with an increase in *Quercus* does not indicate drying conditions; rather, it indicates a shift from dry conditions to substantially wetter conditions. The seemingly contradictory nature of the data occurs again between 90 and 100 cm (7700 and 7100 rcyBP). Here, sediment data denote substantially wetter conditions, while *Pinus* and *Quercus* abundances reflect drier conditions. Lake conditions capture primarily regional pollen, reflecting broader landscape dynamics while sediment data document local conditions. Despite appearing contradictory, the pollen and sediment data underscore the complex nature of wetland development and the necessity for multiple lines of evidence when reconstructing wetland history.

The proximate cause for wetland development at Great Swamp is unclear. Elsewhere, wetland development has been linked to both climate change (Winkler 1988, Zoltai and Vitt 1990) and autogenic forces (Foster and Wright Jr. 1990). Without further radiocarbon dating, it is difficult to link the infilling of the lake at Great Swamp with regional climate changes (ie 4.2 ka drought) or local hydrological changes. However, because earlier plant communities do not reemerge, it seems more plausible that succession at this site was driven by local changes in hydrology.

2.4.2 Ambrosia dynamics

Ambrosia is an early successional species, reflecting an open habitat. Frequently, *Ambrosia* is used as a cultural marker to date the timing of settlement. In the two cores from Great Swamp, however, *Ambrosia* peaks earlier, at 52 cm (8590 RYBP) and 30 cm in the highbush blueberry core and at 50 cm (5530 rcyBP) in the red maple core. Climate change could explain these *Ambrosia* peaks, but would be accompanied by a shift in the tree community to an arid, open forest. For example, in the highbush blueberry core, there is no major change in the tree community at 52 cm; while the forest community does shift at 30 cm, it is to a community typical of a warm, moist climate. Climate change, therefore, is unlikely to account for either of these *Ambrosia* peaks. Sediment data indicate wetland succession; that is, the infilling of the lake which could create a suitable open habitat for *Ambrosia* colonization. Peaks of Poaceae and Cyperaceae that coincide with the *Ambrosia* peaks reinforce this hydrologic history. In the red maple core, higher levels of Cyperaceae and Poaceae occur just after the *Ambrosia* peak at 50 cm, which could indicate a small drying event followed by a return to moist conditions.

Intensive land clearance and settlement could still be dated by changes in *Ambrosia*, namely, by the magnitude of an *Ambrosia* peak closer to the top of the core. In the highbush blueberry core, for example, not only is there a distinct rise in *Ambrosia*, but zonation of the core clearly separates the upper 4 cm. This could represent settlement. *Acer rubrum*, an early colonizer following disturbance, also increases slightly at the top of the core. Other indicators of settlement, including an increase of weedy species like *Rumex* and *Plantago*, are, however, absent from the core. If the top 4 cm do represent the time since settlement, it seems that this portion of the core is compacted or truncated, making it difficult to document distinct changes in vegetation over the past 300 years.

The red maple core also fails to conclusively document settlement. As in the first core, the lack of other weedy species near the top of the core indicates the recent sediment record is either severely truncated or missing. Unlike the first core, however, there is no distinct zonation of the upper few centimeters of the core, implying that the recent sediment record has perhaps been lost in this portion of the swamp.

2.4.3 Vegetation Communities

As discussed above, the Great Swamp landscape has changed dramatically in the last 10,000 years. The open lake ecosystem hosted typical aquatic vegetation, including Nymphaceae. As wetland formation began, graminoid communities established and were initially dominated by Poaceae. Rising levels of Cyperaceae in the upper portions of the highbush blueberry cores indicate increasing importance at this site. High levels of *Ilex* and Ericaceae beginning at 35 cm document the development of a scrub/shrub wetland in the highbush blueberry swamp. A short-lived alder thicket is indicated by relatively high levels of *Alnus* at 15 cm.

The development of a scrub/shrub wetland in the red maple swamp begins at 70 cm (6000 rcyBP) with the rise in *Ilex* and continues through 40 cm (3000 rcyBP). *Alnus* spikes at 35 cm (2800 rcyBP), which probably represents a relatively short-lived alder thicket. A brief incursion of an open wetland occurs between 30 and 40 cm, as indicated by a spike in *Typha*. Above 30 cm (2200 rcyBP), *Ilex* and *Typha* decline and *Alnus* rises slightly, indicating the re-establishment of an *Alnus* thicket.

Many of the vegetation communities found at each site are similar, for example, *Ilex* and Ericaceae dominated scrub/shrub wetlands occur in both the highbush blueberry and red maple swamps. However, the relative importance of individual taxa does differ between the two sites. *Ilex*, *Typha*, and *Alnus* are important taxa in the red maple swamp, while other taxa, including Ericaceae and Cyperaceae are important to the highbush blueberry community. While wetland development and vegetation succession at each site follows similar pathways, the differences in dominant vegetation highlight the long-term importance of a diverse array of vegetation communities to Great Swamp.

This study highlights the many complexities associated with reconstructing the vegetation history of a wetland. A major challenge is the changing pollen source area. As the physical template of the landscape changes, so, too, does the area from which pollen is captured. This results in a pollen signature that is, at times, primarily regional, local, or a mix, making interpretation difficult. Using multiple, independent lines of evidence greatly facilitates the interpretation of past dynamics. Sediment analysis is a particularly strong complementary method as it provides evidence of local hydrology and documents wetland succession through peat development. In Great Swamp, sediment data recorded the development of scrub/shrub wetlands from an open lake ecosystem. This knowledge informed the pollen interpretation, providing evidence of local mechanisms shaping vegetation and making it possible to identify specific wetland communities.

A second difficulty in interpreting the pollen spectra is in identifying specific wetland communities. Many wetland plant communities do not produce distinct pollen signatures. For this reason, while we can be fairly confident that the scrub/shrub and open wetland communities interpreted from the pollen data did exist, we can't assume that these were the only plant communities to have existed in Great Swamp.

Finally, this vegetation history of Great Swamp provides several important insights for understanding land-cover change. First, vegetation at Great Swamp has historically been diverse, as shown by changes in vegetation communities over time and by the differences in vegetation between the two cores. Second, this diversity is due, in large part to hydrology. Great Swamp water levels have fluctuated over time and space, creating a mix of habitat suited to different species. This history and these dynamics impacted settlement and land-use in the 18^{th} century and influenced land-use and land-cover change over the past 300 years.

Table 2.1. Summary of pollen transport mechanisms. Based on Tauber (1965) and Moore et al. (1991).

Mechanism	Description	Pollen Source Area
Rain	Pollen carried in rain droplets	Regional
Canopy circulation	Pollen carried by air currents above the canopy	Regional, extra-local
Subcanopy circulation	Pollen carried by subcanopy air movement	Regional, extra-local
Inwashing	Pollen transported by drainage water	Extra-local, local
Gravity	Aquatic or wetland pollen that drops directly from the plant to the surface	Local

Table 2.2. Pollen characteristics of common species at Great Swamp. Based on data from Davis (1984).

Taxa	Pollination Syndrome	Relative Pollen Abundance
Alder	Wind	Overrepresented
Birch	Wind	Overrepresented
Blueberry	Insect	Underrepresented or Rare
Chestnut	Insect	Low
Hemlock	Wind	Moderate
Hickory	Wind	Moderate
Holly	Insect	Underrepresented or Rare
Maple	Wind/Insect	Moderate
Oak	Wind	Overrepresented
Pine	Wind	Very High
Ragweed	Wind	Overrepresented

Table 2.3. Radiocarbon dates from peat samples from Great Swamp.

Core	Depth (cm)	^{14}C Date (radiocarbon years before present $\pm$ 1σ)
Core 1	60	8590 $\pm$ 50
Core 1	140	10950 $\pm$ 50
Core 2	60	5470 $\pm$ 50
Core 2	74	9610 $\pm$ 50

Table 2.4. Physical properties assessed using Troels-Smith sediment description system.

Property	Description
Nigror	Degree of darkness
Stratifacto	Degree of stratification
Elasticitas	Degree of elasticity
Siccitas	Degree of dryness
Other notes	Can include sediment structure, nature of boundary lines, etc

Table 2.5. Composition properties assessed using Troels-Smith sediment description system.

Class	Symbol	Description
Substantua humosa	Sh	Completely disintegrated organic substances
Turfa	Tb	Moss peat
	Tl	Wood peat
	Th	Herbaceous peat
Detritus	Dl	Fragments of wood, bark, etc, >2mm
	Dh	Fragments of herbaceous plants
	Dg	Fragments of woody and herbaceous plants, <2mm
Limus	Ld	Lake mud with plant and animal fragments
	Lso	Lake mud with diatoms
	Lc	Marl
	Lf	Iron oxide
Argilla	As	Clay
	Ag	Silt
Grana	Ga	Fine sand (0.06 – 0.6 mm)
	Gs	Course sand (.6mm – 2mm)
	Gg	Gravel (>2mm)

Table 2.6. Development of the highbush blueberry swamp.

Depth (cm)	Sediment Description	Implied Site Conditions	Pollen Source Area
0 – 15	Moss and herbaceous peat with herbaceous fragments	Vegetated wetland	Mainly local
16-24	Lake mud and moss peat, with limited herbaceous peat	Small, shallow lake	Local with some regional input
25-60	Lake mud and moss peat	Shallow lake	Regional and local
61-74	Lake mud and sand	Open lake	Mainly regional with some local

Table 2.7. Development of the red maple swamp.

Depth (cm)	Sediment Description	Implied Site Conditions	Pollen Source Area
0 - 30	Moss and herbaceous peat with herbaceous plant fragments	Vegetated wetland	Mainly local
30 – 40	Moss and wood peat	Vegetated wetland	Mainly local
40 - 50	Moss and herbaceous peat	Vegetated wetland	Mainly local
50 - 70	Moss peat with herbaceous plant fragments	Vegetated wetland	Mainly local
70 - 80	Moss peat with lake mud	Vegetated wetland near small lake	Mainly local with some regional
80 - 90	Moss peat with lake mud and sand	Small, shallow lake	Mainly regional and local
90 – 110	Lake mud with sand and peat	Shallow lake	Regional
110 - 120	Lake mud and moss peat	Small, shallow lake	Regional and local
120 - 140	Lake mud with sand and peat	Shallow lake	Mainly regional

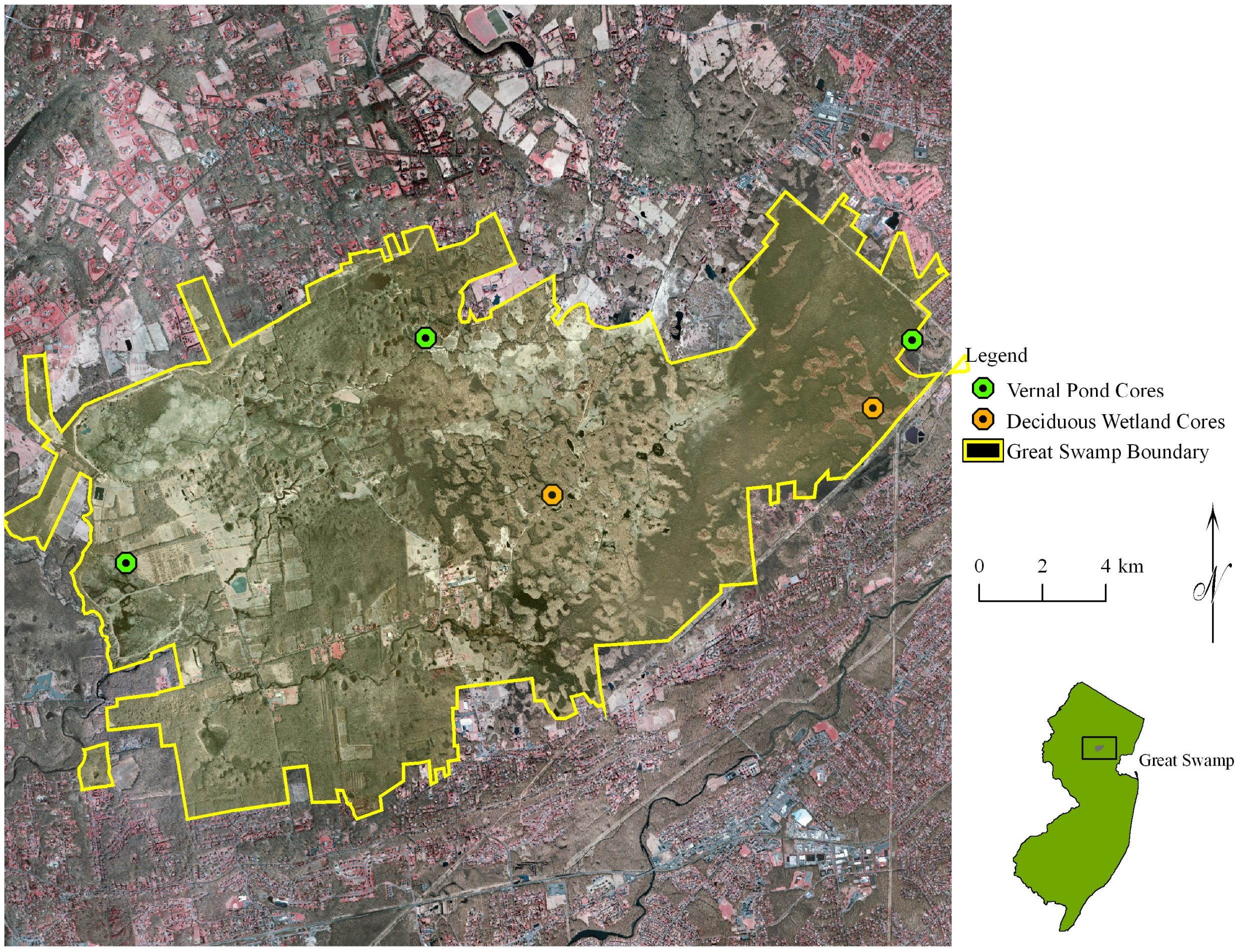


Figure 2.1. Location of coring points in Great Swamp.

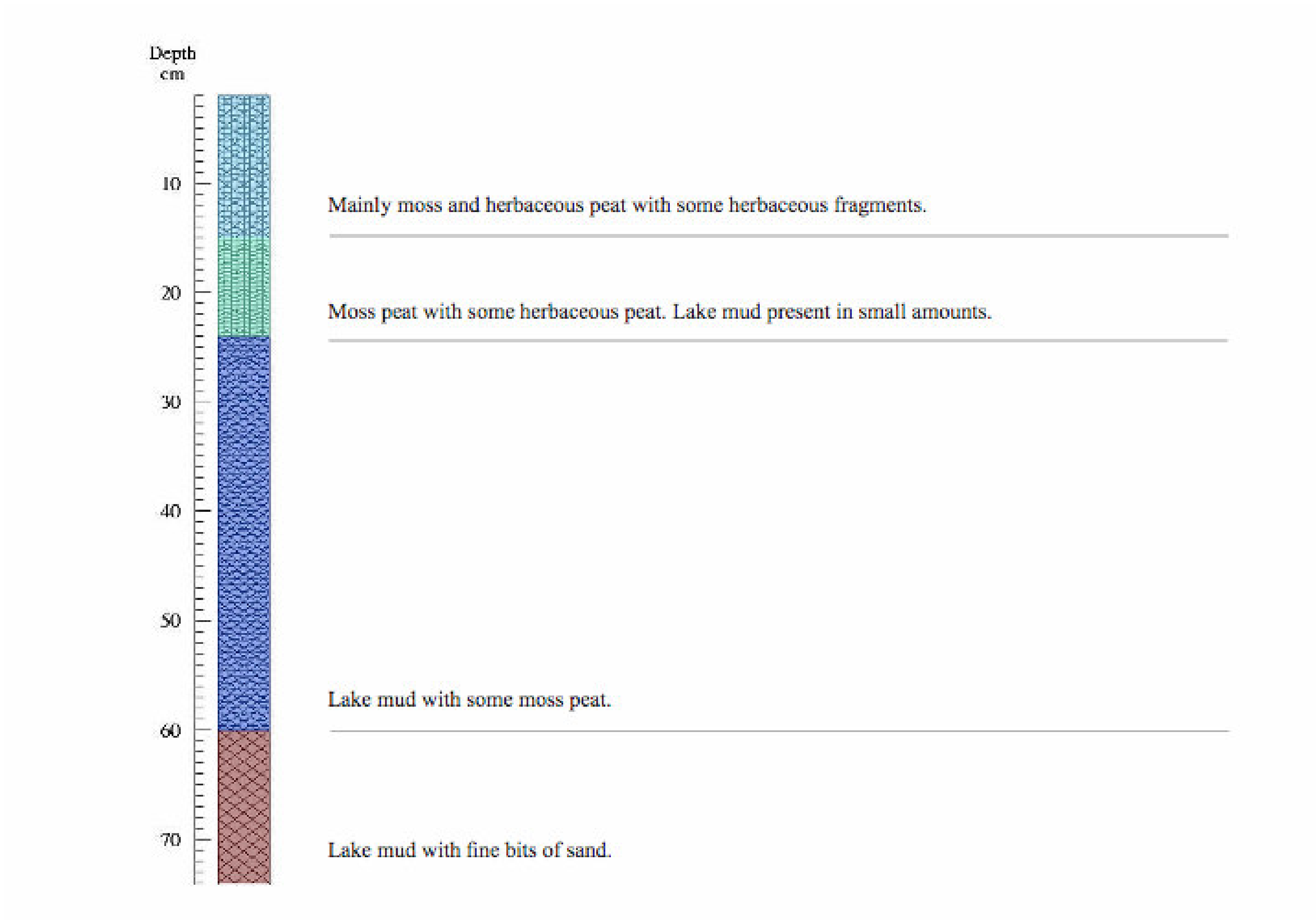


Figure 2.2. Sediment descriptions for Core 1, from the Highbush Blueberry Swamp.

Great Swamp Highbush Blueberry Swamp

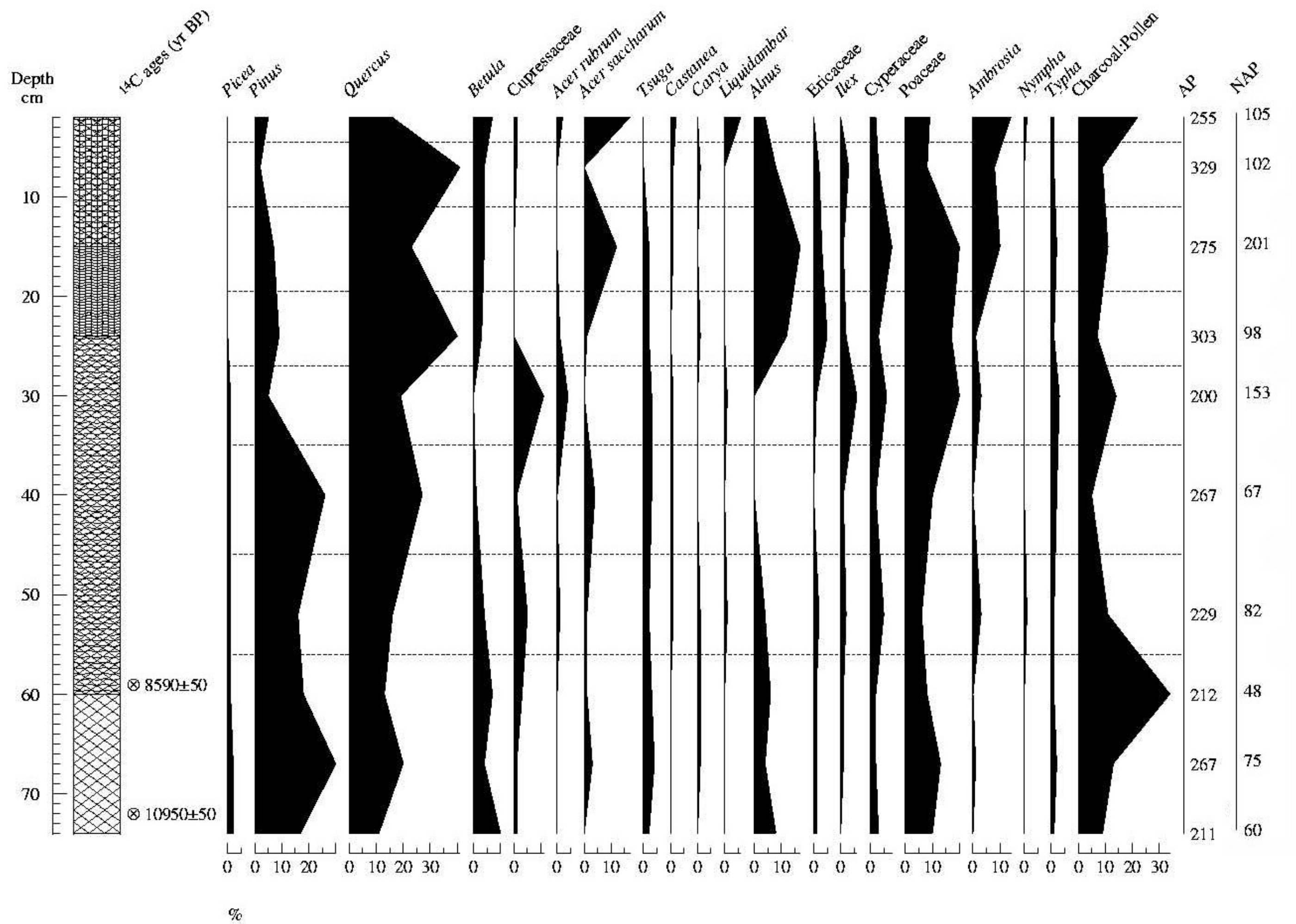


Figure 2.3. Summary of pollen percent diagrams from Core 1, Highbush Blueberry Swamp in Great Swamp.

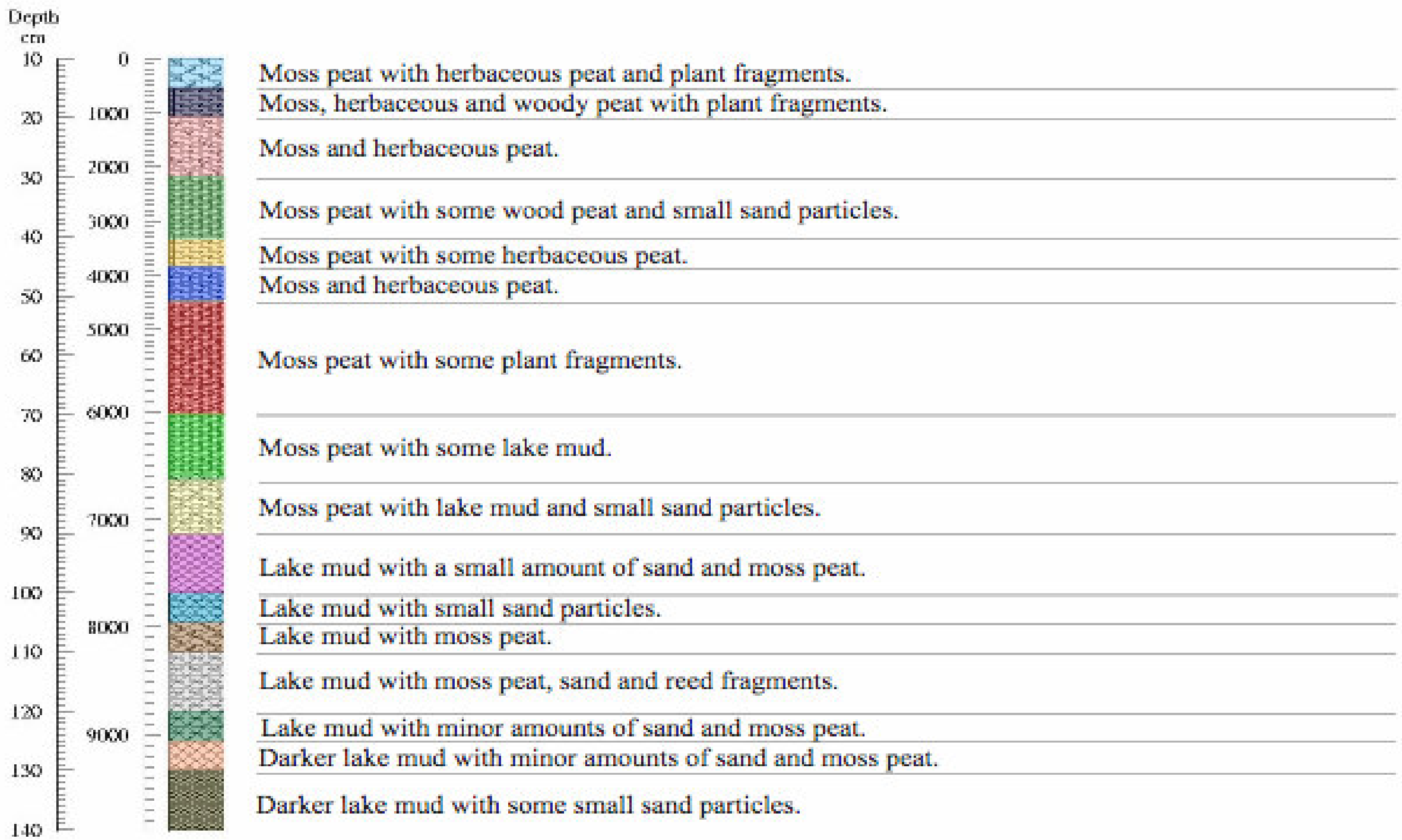


Figure 2.4. Sediment descriptions for Core 2, from the Red Maple Swamp.

Great Swamp Red Maple Swamp

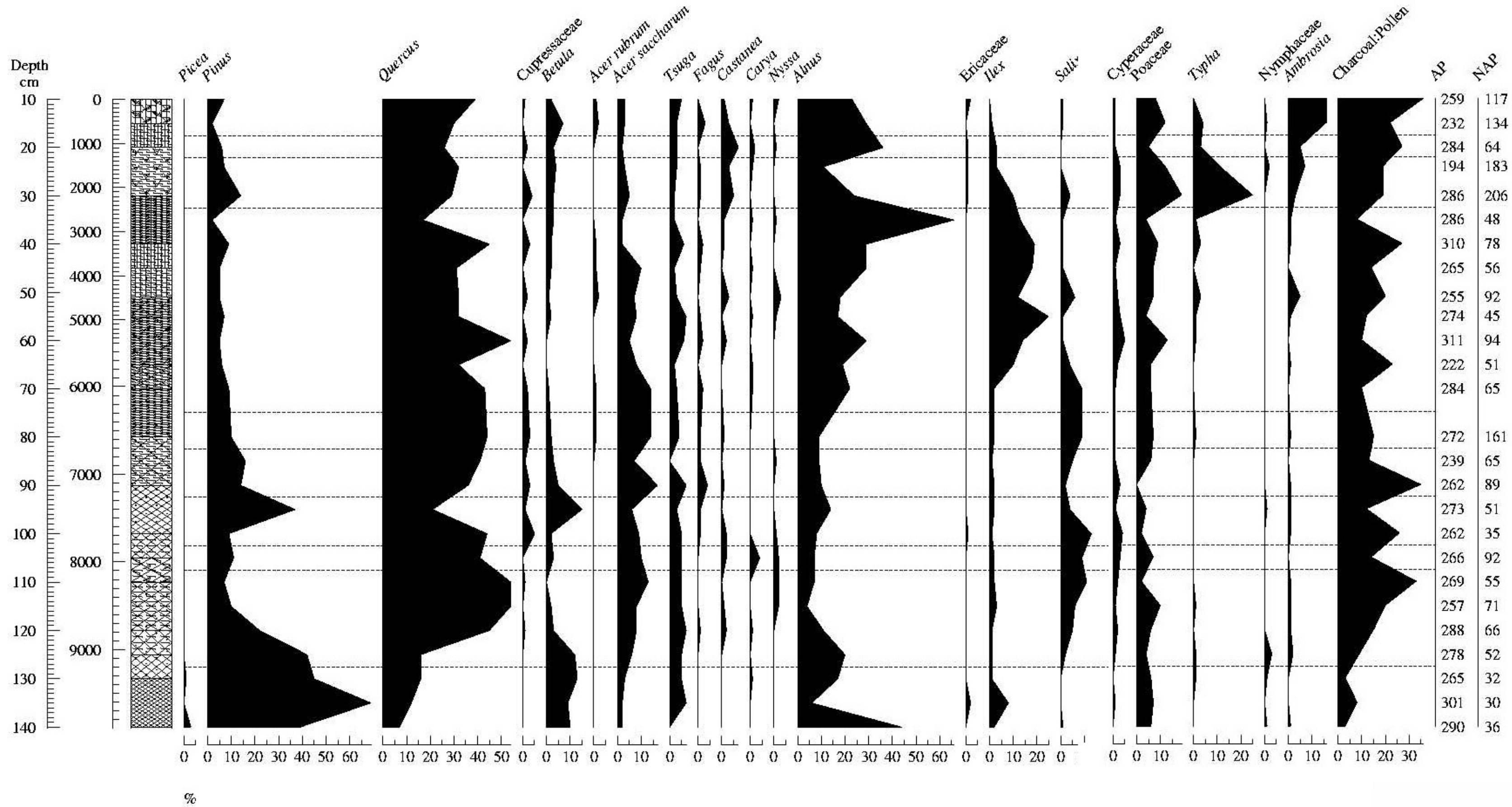


Figure 2.5. Summary of pollen percent diagrams from Core 2, Red Maple Swamp in Great Swamp.

3.0 Land-use and land-cover in the last 300 years: historical document analysis

3.1 Introduction

Is history important in ecology? As ecologists, we are aware of the role history can play in shaping ecosystems. Too frequently, however, we underestimate the significance of past land-use, glibly acknowledging the importance of history without really understanding the complex interactions that can occur between land-use and land-cover over time. Models and predictions of future land-cover change rely on an understanding of the complexities and relationships between land-use and land-cover change.

At the time of European settlement, an estimated 221 million acres of wetlands existed in the Unites Stated (Dahl 1990). Since that time, roughly half of all wetlands have been lost through agriculture, urbanization, and other land-use practices (Dahl and Allord 1996). In New Jersey alone, nearly 39% of wetlands were lost between 1780 and 1980 (Dahl 1990). The net effect of wetland loss and degradation is an increase in flood and drought damage, a loss of biodiversity, and a decreased functional value to humans (Owen 1999, Mitsch and Gosselink 2000).

Early settlers to the northeast had a complex relationship with wetlands. Coastal and freshwater marshes reminded settlers of pastoral landscapes in Europe and were quickly exploited to feed livestock and settlers (Vileisis 1999). Further upstream, settlers encountered a landscape unfamiliar to most – wooded wetlands or swamps – wicked lands that restricted travel, limited agriculture and harbored disease (Dahl and Allord 1996). In fact, many prominent contemporaries of the 17^{th} century expressed negative opinions of swamps, including William Bradford, Increase Mather and John Bunyon (author of The Pilgrim's Progress). While settlers avoided entering the chaotic and muck-filled swamps of the northeast, the negative reputation of swamps did nothing to deter trade with Native Americans for fur and other resources extracted from swamps (Vileisis 1999).

Timber and profit needs eventually forced colonists to reconsider swamps. Despite the perceived 'evil' nature of swamps, an increasing number of settlers understood the agricultural potential of many swamps. Agrarian journals of the early 1800s focused on drainage as a method to convert worthless land into fertile farms. By 1849, with the passage of the Swamp Lands Acts, the United States government set a tone that promoted the drainage and reclamation of wetlands; this attitude would persist well into the 20th century (Dahl and Allord 1996).

Changing technology and increasing population pressures in the first half of the 20th century accelerated wetland drainage and conversion across the United States (Dahl and Allord 1996). Government policies promoting the drainage of wetlands continued through the 1960s. Then, as scientists understood the ecological value of wetlands, they joined with hunters, engineers and lawyers to change both the public and government's perception of wetlands (Mitsch and Gosselink 2000). Their efforts are reflected in the sale of Duck Stamps by the United States FWS and the adoption of Swampbuster policies that removed wetland drainage incentives (Prince 1997). The effects of the Federal government's wetland policy reversal are not yet clear, but there is an indication that the rate of wetland loss is declining while restoration efforts increase (Dahl and Allord 1996).

Current North American wetlands continue to reflect this land-use history. Agriculture, a dominant wetland land-use, accounts for nearly 87% of all wetland losses in the United States (Tiner 1984). Ditch creation and wetland drainage, common methods to dry wetlands, interfere with the hydrology of a wetland (ie standing water and water-logged soils). Ditches and channels are very efficient at drying a wetland and often result in water levels that fluctuate dramatically (Owen 1999, Hayes and Vepraskas 2000, Mitsch and Gosselink 2000). In addition, ditches can result in increased levels of iron in nearby soils (Hayes and Vepraskas 2000).

Following agricultural abandonment in a wetland, invasive species frequently come to dominate the vegetation (Owen 1999). Increasing urbanization can lead to increasing rates of sedimentation (Brenner et al. 2001, Kim et al. 2001) and rates of accumulation of carbon, nitrogen and phosphorous (Brenner et al. 2001). As a result of land-use that alters both hydrology and soil properties, the biodiversity and ecosystem functions of a wetland can be dramatically altered (Cahoon and Reed 1995, Fisher et al. 1996, Owen 1999).

3.1.2 Great Swamp

Local, site-specific studies allow researchers to address landscape complexities through interdisciplinary research. On their own, site-specific studies provide the details needed to better manage and conserve a particular landscape. Collected site-specific studies help in the creation of generalized knowledge regarding the driving forces of land-use change.

Great Swamp has a distinct land-use history. Through 1950, most wetlands in the United States, including Great Swamp, were ditched and drained for agriculture (Dahl 1990, Dahl and Allord 1996). However, unlike the majority of drained wetlands, Great

Swamp did not then transition to an urban center (Thibault and Zipperer 1994). Instead, Great Swamp became a part of the National Wildlife Refuge System and to this day is managed for the protection of a broad array of animal and plant communities (U.S. Fish & Wildlife Service 1999).

Understanding the legacies of land-use on vegetation at Great Swamp first requires the definition of current and historical patterns of land-cover and land-use change. To define these patterns, I used historical documents to document the patterns of land-use and land-cover change over the roughly 300 years since European settlement of Great Swamp. Since historical resources are often scarce and not always available at appropriate temporal and spatial scales, any historical document analysis requires the use of multiple lines of evidence and necessitates a qualitative narrative that is quantitative when possible.

3.2 Methods

Vegetation change from the time of European settlement through the present was documented using a variety of historical sources. State and local archival collections were searched for maps, deeds, surveys, diaries, and any other documents relating to land cover and land-use in Great Swamp (table 3.1).

Land-use was chronicled with state and agricultural censuses, local deeds and diaries. Great Swamp comprises many towns within Morris County. Where possible, land-use specific to Great Swamp was identified; in other instances, it was interpreted from township data. State and local archives (table 3.1) were again searched for documents pertaining to the land-use history of Great Swamp. This information complements the study of land-cover change, and provides an entrance into identifying the human activities important to patterning modern and future vegetation communities. Vegetation and land-use data are presented below as a narrative with a timeline (figure 3.1) chronicling selected events.

Historical documents, while valuable tools for reconstructing land-cover and land-use, provide interesting challenges to the ecologist. Most historical texts lack quantitative information, making statistical analysis of change impossible. The quality of these sources is also widely variable (Russell 1997, Edmonds 2001); historical texts are often riddled with errors, omissions, assumptions and preconceptions. For example, early land descriptions, written by prospectors, were often written to entice settlers; as a result, these writings frequently extolled the virtues of a land while ignoring potential difficulties. Alternatively, noted New Jersey surveyors, including James Dunham and John Reading provide fairly reliable data in their land descriptions. Maps can provide another excellent source of land cover and land-use information. However, accuracy of early maps is generally poor as inexperienced surveyors frequently drew them. In order to discover errors and inconsistencies, texts were compared with one another whenever possible.

3.3 Results

3.3.1 Early land-use and land-cover

The early and rapid settlement of the Piedmont physiographic region of New Jersey was not reflected in Morris County (Wacker 1975). Settlement of the Passaic River Valley began around 1660 on land that was easily accessible and fertile (Wacker and Clemens 1995); however, the difficulty in accessing interior land impeded settlement (Wacker 1975). At the time of European settlement of the Passaic River valley, bands of

Lenape were camping and homesteading in the drier portions of glacial lake Passaic (Kraft 1984). In the mid-1960s, the Shongum Chapter of the New Jersey Archeological Society, undertook several excavations of Native American campsites near and within Great Swamp (Veit 2003, Zaikowski 2003). Unfortunately, no report was ever issued on these excavations and the artifacts were largely lost (Zaikowski 2003). Increasing urbanization pressures have usurped further excavations; as a result, there is minimal information regarding the Native American settlement of the Passaic River Valley (Kraft 1972, 1984).

The New Britain Purchase of 1708, while illegal, represented the first ‘sale’ of Great Swamp land from the Lenape to early land prospectors (Barber and Howe 1844, Vanderpoel 1921, Parrish and Walmsley 1997). This sale transferred approximately 30,000 acres of land, which must have included Great Swamp. Early maps of the area, from 1706 and 1715 do not indicate the presence of Great Swamp or even the Passaic River (Worlidge 1706, Moll 1715). The lack of information points to the limited settlement and importance of the area at this time.

John Reading was the first surveyor to describe portions of Great Swamp (1715). Reading’s survey notes are not clear as to how much land was surveyed, but it was at least 4 lots, which, at the time, were probably fairly large as he was surveying for a group of land prospectors who hoped to purchase portions of the swamp (Barber and Howe 1844). Reading’s survey makes limited use of trees as corner markers for the land within Great Swamp, referring instead to stone piles. Despite this, his notes clearly indicate the presence of white oak, poplar and maple (table 3.2). More notably, Reading notes the wet nature of the land he is surveying. In his notes, he refers to flooding in several passages during his April 17 survey efforts (p 2). This could be due to the Passaic River jumping its banks as a result of spring rains or snowmelts. He also makes note of surveying lands that are adjacent to a Great Swamp on April 17 and 18th (p 1, 2 and 4). One lot is noted as being above a “Bogg meadow” (p 2), indicating the presence of a graminoid-dominated wetland. Together, these notes indicate the general wet nature of the area; clearly, a marsh existed at the time of settlement.

James Dunham’s later survey (1783) adds additional insight into early vegetation communities at Great Swamp. While it is not clear how large the surveyed area was, Dunham does write that several noted local land prospectors, including William Penn and Joseph Budd, hired him. In total, Dunham specifically mentions four distinct lots that he surveyed. It is plausible, then, that these were somewhat larger land tracts.

The area Dunham surveyed was clearly swampy – at least one survey mark occurs “near the swamp” (p 10) and he explicitly references a “great swamp near the headwaters of the Passaic” (p 21). Dunham’s survey methods, like those of his contemporaries, used trees as corner markers for surveyed tracts of lands. Based on his survey notes (table 3.2), white oak was frequently used as a corner marker, indicating the prevalence of white oak at this time. The presence of elm and ash in Dunham’s survey, both uncommon survey species for this region (Southgate, personal communication), suggests the presence of typical Piedmont swamps (Robichaud et al. 1994). Based on Dunham’s survey, it appears that despite at least 60 years of settler interest in this area, Great Swamp remained a notable local wetland.

While the early surveys completed by Reading and Dunham both point to light settlement in and around Great Swamp, they may hint at the diversity of vegetation communities. Reading's survey makes limited use of trees as corner markers, which is not typical of his surveys. It is plausible that there were few trees in the area he surveyed, which could indicate the presence of a more open wetland. This is in contrast to the Dunham survey, which used 17 trees to survey 4 lots. When coupled with the uncommon survey species he used, it seems likely that Dunham was surveying a wooded swamp.

A third set of surveys of Great Swamp land was commissioned by William Alexander, the self-proclaimed Earl of Stirling. Alexander owned several lots in Great Swamp ranging in size from 70 acres to 171 acres (Alexander 1858). While survey notes of these lots are limited, the surveyor clearly states that the lands are part of the Great Swamp. White oak and beech are the dominant corner markers for these surveyed lots (table 3.2).

All three surveyors list white oak, which indicates that it was probably a dominant tree at the time of settlement. Since the surveyors do not appear to be preferentially surveying upland areas, it is peculiar that so much white oak was documented. It seems plausible that white oak was short-hand for swamp white oak. While surveyors were not trained botanists, making misidentification a possibility, they appeared well versed in a variety of tree species. This indicates that their knowledge and identification of trees was sufficient to correctly identify most trees. The problem almost certainly lies in the use of common names. For colonial records, some common names were used imprecisely or have no known Linnean taxonomic equivalent (Ogden III 1961, Whitney 1994). For these reasons, white oak will be interpreted as swamp white oak.

As these early surveys were being conducted, land prospectors were already selling off parcels of land. For example, an early deed from Great Swamp (Morris County

1782) specifically mentions the transfer of woods, meadows and pastures in Great Swamp. This terminology could be what was generally used at the time to denote the transfer of land or it could indicate specific land-cover and land-use activities at the time of sale.

Early settlers were lured from New England to Morris County by the prospect of iron mining (National Iron Bank of Morristown 1943). By 1720, the first settlers were living in Great Swamp, farming clearings and uplands while logging other areas (Smith 1993, Parrish and Walmsley 1997, U.S. Fish & Wildlife Service 1997). Despite excellent peat and timber products (Barber and Howe 1844), the inaccessibility of Great Swamp and the immense amount of work necessary to turn the swamp into arable land continued to impede settlement. A decree by New Jersey's governing body in 1772 enabled owners of meadows and swamps in and near Great Swamp to "clear, deepen and dig the ditches for more effectual drainage" (Anonymous 1880). Settlement within the swamp, however, remained light (Thayer 1975). Nearly 80 years after initial settlement, the vision of Great Swamp as a 'rugged wilderness' in need of taming persisted (Smith 1993).

Limited settlement in Great Swamp did not reflect the population growth of the surrounding towns. As settlers continued to move into New Jersey, land exploration and clearance increased. In the late 18th century, most arable land in what was to become Morris County had been cleared and converted to agriculture (Wacker and Clemens 1995). The timber needs for building, heating, and fences made wooded land increasingly valuable. Regionally, barrels were in great demand and were locally made from white oak drawn from the Great Swamp (Thayer 1975). Timber from Great Swamp supported a local hub and felly (wheel rim) factory (Bailey 1967) and was used as fuel for local forges and furnaces (Alexander 1858) and ship timbers (Bailey 1869, Bailey 1967, Smith 1993). By 1760, Great Swamp was advertised as the last regional place for wood (Anonymous 1880). The abundance of 'chest-nut [sic], black-ash and hickery [sic]' is also noted (Anonymous 1880). Wacker & Clemens (1995) also note that by 1772, the only remaining wooded habitat large enough to support herds of deer was quite probably the "poorly drained Great Swamp" (p 55). Sparse forests coupled with the expense of fuel meant many families owned and exploited woodlots within the Great Swamp (Howell 1868, Thayer 1975, Smith 1993). The diary of Onesimus Whitehead (1790-1814) mentions drawing wood from a local swamp, which in all probability was the Great Swamp (Wacker and Clemens 1995). The value of this land for wood and woodlots almost certainly outweighed the value and effort of converting the swampland to agriculture at this time.

However, early maps (Anonymous 1769, Faden 1777) that clearly demarcate an area labeled Great Swamp, indicate the area that is today Great Swamp was much smaller in the 18th century. The above descriptions of Great Swamp probably refer to the eastern portion of the swamp and indicate that the western portion of the swamp had either not been explored (which seems unlikely) or had already been subjected to some clearing and agriculture.

Deeds from parcels of land within Great Swamp point to agriculture and settlement of the western portion of Great Swamp beginning circa 1780. Several early deeds use roads as property boundaries, and at least one deed mentions a "new road to be laid out through the swamp" (Morris County 1782). In these instances of land sales, surveyors often used tree stumps of various species; an early deed of sale in Great Swamp specifically mentions stumps of walnut and white oak (again, this is could be swamp white oak), as corner markers (Morris County 1780). These stumps were the result of land clearing, either for timber or agriculture. Other early deeds make almost no use of trees as corner markers, relying on fence posts, stone piles and even the middle of roads.

Several early deeds reference ditches, which are a distinct hallmark of agriculture. The most prominent ditch at Great Swamp, the Tichenor Ditch, probably refers to a ditch created by Daniel Tichenor, an early settler of Great Swamp who purchased several land parcels in the 1780s (Morris County 1780, 1782). Tichenor's ditch occurs in the Western portion of the swamp and was undoubtedly created to drain a portion of land to make it more suitable for agriculture.

3.3.2 The 19th Century

The 19th century saw the complete transformation of much of Great Swamp. Agricultural needs soon outstripped the value of wooded lands and the drainage and 'reclamation' of Great Swamp accelerated.

Several deeds indicate the prevalence of agriculture by referring to ditches that ran through or adjacent to the land (Morris County 1813, 1907). Several ditches were dug through Great Swamp, though none figure as prominently as the Tichenor ditch. Mentioned in deeds as late as 1858 (Morris County 1846, 1858b) and on an 1868 map (Howell 1868), it isn't clear when this ditch was established, though it is likely the ditch was dug in the late 18th century (Morris County 1780, 1782).

Other indicators of agriculture in historical documents were difficult to find. A deed from 1858 specifically mentions the Abraham Brittin Swamp farm, but exactly what was being farmed is unclear (Morris County 1858a). Another deed, from 1867, details land bounded by a meadow with a bridge over Tichenor's ditch; as before, the ditch is draining land for agriculture and the land is near a meadow, which was likely supporting livestock.

The drainage of Great Swamp was clearly important. The New Jersey legislature commissioned a study by George Bailey, a hydraulic engineer, on the potential for draining Great Swamp to maximize the amount of arable land. Bailey described the hydrology of local streams and the Passaic river as sluggish, full of irregular crooks that cause wrack build up and "retards river flow" (Bailey 1869). He suggested the removal of the dam on the Passaic River along with widening, deepening and straightening the river. These actions, he felt, would heighten river flow while preventing the build-up of wrack, leaving the Great Swamp drier and more suitable for agriculture. As it was, "much of the land is worthless and getting worse by the year." Despite Bailey's recommendations, no unified action was ever taken by the state (Cavanaugh 1978).

In addition to agriculture, small woodlots continued to be scattered throughout the swamp. An 1867 deed specifically mentions a woodlot containing black ash, maple, white ash, and pin oak (Morris County 1867). Maps and deeds show twenty-seven lots of land, each of either 5 or 10 acres, that were of such uniform shape and size and, in all likelihood, were woodlots (Morris County 1863, Howell 1868).

Many areas that remained uncleared were dominated by chestnut (Barber and Howe 1844). As chestnut is unable to grow in particularly wet areas (Gleason and Cronquist 1991, Thompson et al. 1999), it seems logical to conclude that the uncleared areas dominated by chestnut were upland areas. It isn't clear why these upland sites remained; perhaps the soils were too poor to farm or the chestnuts were maintained for nuts.

Despite the intense exploitation of much of Great Swamp, some areas remained flooded. An 1858 deed included an updated land survey. Pin oaks were used to mark three corners, as was a large black oak stump (Morris County 1858b). This information points to the persistence of some wetlands in Great Swamp through the mid-19th century.

In the late 19th century, CC Vermeule created the first topographic maps of New Jersey (Vermeule 1870). Vermeule did not specifically map land-cover, but he did document the general location of forests, fresh meadows, and wooded swamps. Much of the area of Great Swamp was open, indicating settlement and agriculture. Roads clearly crisscross the western portion of the swamp and many of these roads persist today. In the eastern portion of Great Swamp, Vermeule outlined a large wooded swamp that is ringed by small fresh meadows to the west and roads and development to the east. The large wooded swamp corresponds with one of the largest land-cover categories found on modern maps, an *Acer rubrum-Rhododendron* dominated community. The New Jersey Geological Survey, under the direction of John Smock created a second map in 1900 of the forests of northern New Jersey (Smock and Vermeule 1900). This map generally reinforces Vermeule's topography map, but is more explicit about land-cover (figure 3.2). Most of the eastern portion of Great Swamp is covered with forest and fresh meadow/swamp (Vermeule's key does not distinguish between these two habitats). A small portion of the center of the swamp is purely fresh meadow/swamp, possibly indicating wetter lands. Towards the west, the contiguous cover of Great Swamp ends. The large patches of woods and meadows are broken by bare land, which can be interpreted as settled lands. Small fragments of forests and fresh meadows/swamps are interspersed with the developed land.

Agricultural expansion through Great Swamp coincided with increasing population pressures from the adjacent towns, including Chatham and Passaic Townships. Population growth in Morris County and the townships adjacent to Great Swamp was generally brisk (figure 3.3), not unlike the trends seen nationally. These population pressures of the mid-19th century spilled into Great Swamp, accelerating settlement and land conversion to agriculture. The latter half of the 19th century saw significant population gains in and around Great Swamp. The population drop occurring between 1890 and 1900 is due to the incorporation of Madison from Chatham Township.

A general term, agriculture can refer to the growing of crops, orchards or livestock. One of the best data sources on agriculture is the United States Census. Beginning with the 7th Census of 1850, the United States Census Bureau began to formally collect data on agriculture at the county level. Specifically, the Bureau tracked the output of agricultural and forest products and the area of land in improved and unimproved agriculture. In the 19th century, livestock dominated Morris County agriculture (table 3.3). Orchard and market garden products were also significant. Land devoted to agriculture remained high through 1880 in Morris County. This pattern is similar to national trends, where the movement of farms from the east to the west and mid-west began around 1850 (Maizel et al. 1999). In Morris County, the area in farmland fluctuates through the 19th century and widespread farm abandonment begins in the 1880s, and declines precipitously through 1970 (figure 3.4).

3.3.3 The 20th Century

In the decades following settlement, a large fraction of Great Swamp had been cleared and tilled. By 1901, "every acre of [Great Swamp] *can* be cultivated and all the products of the temperate zone can be grown in its fruitful soil (Whitehead 1901)." Agriculture and settlement had changed Great Swamp to land that was "level as a parlor floor" without "a stone of any considerable size" (Whitehead 1901). Important crops at this time included hay and forage, market garden products, and livestock (table 3.4). Reporting on crop values to the United States Census continued to be inconsistent, which accounts for missing values throughout this time period.

Agriculture abandonment and old-field succession were beginning to again change the landscape of Great Swamp. Vermeule (1900), in a survey of northern forests of New Jersey, described minimal forest regrowth in the northeastern portion of Great Swamp. Large trees were scarce, and the community was dominated by pin-oak, with maple, birch, ash, elm and even red cedar. Few chestnut trees remained, and then, only on high ground. Vermeule generally considered the timber of Great Swamp to be poor due to heavy cutting and agriculture.

Wetlands must also have persisted in Great Swamp. In the 1930s, the Works Projects Administration (WPA) constructed more ditches in Great Swamp (presumably for mosquito control), and straightened and deepened the channel of Black Brook (Cavanaugh 1978). Herbarium specimens, indexed as part of the MetroFlora Project at the Brooklyn Botanical Garden provide a glimpse of Great Swamp vegetation in the 1930s and 1940s (Brooklyn Botanic Garden 2004) as do the notes from a 1946 botanical field trip (Nearing 1946). These short lists are far from inclusive, but do show that several typical wetland species, including *Rhododendron viscosum, Spiraea tomentosa,* and *Vaccinium corymbosum* were found over several years in the first half of the 20^{th} century (table 3.5).

Farm abandonment throughout Great Swamp (see figure 3.4) was followed by ecological succession, though many large farms persisted through the 1950s (Zook 1970, Cavanaugh 1978). Commuters, businessmen and the traits of suburbia began to replace the community of farmers that had settled Great Swamp at the close of the 18th century. As land-use in and around Great Swamp changed, so too did the plant communities.

In 1979, an extensive inventory of plants found at Great Swamp was conducted (Zuck 1979). A field trip of the Torrey Botanic Club supplements this list (Anderson 1996) as does a vegetation survey conducted in 2002 (Southgate 2004). Over that time period, 573 species were found (Appendix A). Several invasive species that are of current concern to Refuge managers, including *Lythrum salicaria* were present in 1979. Others, including *Microstegium vimineum*, were not. Today, Great Swamp is home to 16 distinct plant communities (see chapter 1).

3.3.4 20^{th} Century Management History

Located 26 miles from Manhattan, the 7,500 acres of Great Swamp experienced intense urbanization pressures, especially in the 1960s. Local residents, resisting urbanization, value the land for recreation, hunting, and more. The dichotomy between cultural values and urbanization led to formal management of the Great Swamp.

In response to mounting metropolitan pressures on mass transit, the combined Port Authority of New York and New Jersey proposed in 1959 to locate a new 10,000-

acre jet port on the Great Swamp (Cavanaugh 1978). Situated in one of the most urban environs of the nation, (the New York/Philadelphia metro are) this new jet port was slated to ease the congestion of the three existing airports in the tri-state area. Local outrage at the potential urbanization and subsequent loss of small towns, local businesses, and open space resulted in the formation of several citizen groups that eventually halted the building of a jet port (Luten 1963, Cavanaugh 1978) through the formal creation of the Great Swamp National Wildlife Refuge (GSNWR). Placed under the management of the United States Fish and Wildlife Service in 1964, the GSNWR still faced several battles. A 1966 report of the Port Authority again named the GSNWR as the prime choice for a jet port. Citizens, backed by congressional leaders proposed that the eastern part of the GSNWR be designated a wilderness area, under the guidelines of the Wilderness Act of 1964 (Cavanaugh 1978). Such a designation would ensure a preserved status of Great Swamp and would forever prevent the construction of a jetport on the land of the GSNWR. Despite conflict among local citizens and Washington politicians, the area was eventually designated as a Wilderness Area (Cavanaugh 1978).

Clashes between local citizens and swamp managers began soon after the Wilderness designation. Management of the swamp meant the halt of wetland drainage, which adversely affected area farmers (Cavanaugh 1978). In addition, recreation activities, which had once included horse trails, picnic areas, and hunting, were curtailed to pedestrian nature trails (DePalma 1983).

Today, Great Swamp is managed to conserve, manage and restore landscapes in order to support fish, wildlife and plant resources. As part of that mission, Great Swamp managers continue to acquire land from private and public landowners. These lands are then restored to upland habitats (U.S. Fish & Wildlife Service 1999).

Because the GSNWR is divided into two distinct management zones (the Wilderness and non-wilderness area), managers of Great Swamp employ several management strategies. The western portion of the swamp, or non-wilderness area, is intensively managed to ensure habitat availability for a variety of wildlife. Invasive species, like Purple Loosestrife (*Lythrum salicaria*), are actively controlled, through biological, chemical and even mechanical control. Conversely, the eastern portion of the swamp, or the Wilderness Area, is not actively managed. The only exception is the removal of human created structures from newly acquired land. Permanent structures, motorized vehicles and equipment are banned from the Wilderness Area.

3.4 Discussion

Land-use is related to many factors, including environmental characteristics, culture and settlement patterns and economics (Bennett 1976, Meinig 1995, Black et al. 1998). Changes in land-use can be related to changes in each of those factors. In Great Swamp, initial landscape characteristics, including hydrology, landscape position and land-cover combined to shape early settlement patterns.

Land-cover of the Great Swamp at the time of settlement was mixed, but decidedly wet. That Great Swamp was not important to early settlers is clear from its omission on early maps of New Jersey and Morris County. However, early surveys by Reading and Dunham indicate a diverse landscape with several distinct plant communities, including forested and scrub/shrub wetlands. This information, combined with the few maps that do make note of the Great Swamp imply that the eastern portion of Great Swamp was predominately a forested wetland, while the western portion included scrub/shrub wetlands interspersed with arable land.

Early surveyors and topographers were clearly ‘viewing’ the landscape of Great Swamp differently from modern managers and ecologists. Where modern wetland delineations would label both the eastern and western portion of Great Swamp as wetland, 18th century surveyors saw the western portion as potentially profitable, arable land, not swamp land. The inaccessibility, hydrology and poor soils of the eastern portion may have combined with the value of timber to ensure its status as a swamp. Peat in the west may have been of better quality and it may have been easier to ditch and drain this area of the swamp.

Transformation of Great Swamp did not immediately follow early land speculation. Settlement was initially sparse despite the growth of surrounding towns. Mounting population pressures and economic driving forces influenced subsequent land-use and the resulting plant communities. By the turn of the 18th century, Great Swamp was clearly being transformed for agriculture, although the entirety of Great Swamp was not exploited uniformly. Diverse land cover resulted in distinctly mixed land-use of Great Swamp. The western portion of Great Swamp was settled first and quickly converted to agriculture. This land-use was intensive (forest clearing, earth moving, ditch digging), physically altering the landscape and modifying hydrology. Agriculture would continue in this region of Great Swamp through the early part of the 20th century. The eastern portion of the swamp was clearly valued for its dense timber growth and hunting opportunities. As a result, land-use was initially limited to selective harvesting of timber and hunting. These activities, which undoubtedly impacted contemporary forest composition, were far less destructive and did little to modify the physical template of the swamp.

Mounting population pressures eventually caused agriculture to expand eastward through Great Swamp. It's unclear whether the entire eastern portion of the swamp was logged and converted to agriculture, but it seems unlikely. Writings of Whitehead and CC Vermeule at the turn of the 20th century certainly indicate widespread clearance (Vermeule 1900, Whitehead 1901), with scattered wetlands throughout the landscape. Deeds and aerial photography also indicate the persistence of wetlands in the east. It is likely that agriculture expanded eastward, but never fully dominated the eastern portion of the swamp, perhaps because of hydrology or adverse microtopography.

The development and land-use of Great Swamp initially follows the common trajectory of other United States wetlands (Vileisis 1999). Population growth corresponds with farm activity and as the rate of population growth increased, agriculture expanded. Following the peak in agriculture, around 1890, abandonment of agriculture begins and corresponds to slower rates of population growth. Following WWII, local lifestyles shifted away from the agrarian. As urbanization began, the rate of population growth again increased, as Great Swamp is within commuting distance to NYC. It is common that farmed wetlands, following abandonment, are converted into suburban or urban centers (Tiner 1984, Thibault and Zipperer 1994). Intensive development of Great Swamp, however, did not occur. Instead, later 20th century land-use trended towards more passive uses, including birding and hiking (although several small farms persisted through the 1950s). Widespread development, seen elsewhere in the nation, did not occur in Great Swamp, largely because of the efforts of local citizens.

Great Swamp currently supports a diverse array of habitats, from herbaceous dominated and scrub/shrub wetlands to wooded swamps and sandy uplands. A quantitative comparison with pre-European communities is not possible. However, qualitatively, it appears that Great Swamp is regaining many of the communities that were lost in the 18th and 19th centuries (see chapter 4 for further analysis). The mechanisms behind this recovery are not clear, but underlying geology and hydrology could be important factors.

This research highlights the importance of historical studies to scrutinize inherent biases regarding the impact of land-use on current and future vegetation. As ecologists, we are aware that past disturbance can continue to shape current landscapes (Foster et al. 1998). However, we bias ourselves when we assume that past land-use *always* continues to shape current communities. The history of Great Swamp demonstrates that despite over 200 years of intensive use and management, historical landscapes can re-emerge. This indicates that human land-use, while important, works in concert with other forces to pattern modern vegetation.

Table 3.1. New Jersey and New York archives and repositories searched. In some instances, the specific collection examined is noted.

Brooklyn Botanical Society, Brooklyn, NY
-New York Metropolitan Flora
Longhill Township Public Library, Longhill, NJ
Morris County Clerk, Morristown, NJ
Morris County Historical Society, Morristown, NJ
Morris County Library, Whippany, NJ
Morristown Library, Morristown, NJ
New Jersey Historical Society, Newark, NJ
New Jersey State Archives, Trenton, NJ
-Agriculture Census
New York Historical Society, New York, NY
-William Alexander Papers, 1717 – 1783
Alexander Library, Rutgers University, New Brunswick, NJ
-Special Collections
-Federal and State government documents

Table 3.2. Summary of data from 18th century surveys of Great Swamp. Numbers for species indicate the number of trees of that species marked in that survey. Species richness is the total number of species in that survey.

	James Dunham Survey (1783)	John Reading Survey of Lots (1715)	Survey of Lands in Alexander Family Papers (1754)	Total
Ash	2			2
Beech			2	2
Black Oak	2			2
Chestnut	2			2
Chestnut stand	1			1
Elm	2		1	3
Hickory sapling	3			3
Maple	1	2		3
Poplar		1		1
White Oak	4	1	2	7
Species richness	8	3	3	

Table 3.3. Nineteenth century crop values (in dollars) in Morris County, New Jersey. Source: (University of Virginia. Geospatial and Statistical Data Center 2004).

	1850	1860	1870	1880	1890	1900
Livestock	805,177	1,090,484	1,401,712	989,062	1,009,690	987,558
Orchard Products	25,101	21,243	95,523	n/a	n/a	n/a
Market Garden Products	12,753	8,600	20,847	n/a	n/a	n/a

Table 3.4. Twentieth century crop values (in dollars) in Morris County, New Jersey. Source: (University of Virginia. Geospatial and Statistical Data Center 2004).

	1910	1920	1930	1940	1950
Cereals	408,196	913,643	162,787	117,748	n/a
Fruits and Nuts	125,952	137,977	143,452	93,865	160,052
Hay and Forage	496,226	694,786	413,591	453,846	n/a
Livestock	n/a	1,915,710	n/a	n/a	n/a
Grains & Seeds	7,709	4,931	2,644	754	n/a
Market Garden Products	262,139	511,049	68,321	n/a	754,332

Table 3.5. Species list from field trips and surveys in Great Swamp during the first half of the 20th century.

Species	Year											
	1934	1935	1936	1939	1940	1941	1944	1946	1949	1956	1957	1962
Amelanchier canadensis											X	
Aster umbellatus											X	
Betula alleghanensis				X								
Calla palustris					X							
Cardamine bulbosa				X								
Cephalanthus occidentalis					X							
Chimaphila maculata			X									
Chimaphila umbellata			X									
Clethra alnifolia					X		X					
Comptonia peregrina			X									
Cornus foemina		X	X									
Corylus americana			X									
Crataegus sp							X					
Dryopteris x boottii									X			
Isoetes engelmannii									X			
Juniperus virginiana						X	X					
Kalmia sp												X
Kalmia latifolia	X	X										
Lonicera dioica			X	X								
Lonicera sp			X									
Lyonia ligustrina			X									
Nemopanthus mucronatus					X							
Ophioglossum vulgatum								X				
Potentilla fruticosa			X									
Quercus bicolor							X					
Quercus palustris							X					
Rhododendron sp												X
Rhododendron maximum			X									
Rhododendron periclymenoides			X									
Rhododendron viscosum			X		X							
Rosa palustris					X							

Species	Year											
	1934	1935	1936	1939	1940	1941	1944	1946	1949	1956	1957	1962
Rubus hispidus				X								
Saururus cernuus			X									
Smilax rotundifolia			X									
Solidago nemoralis											X	
Solidago odora											X	
Sparganium americanum										X		
Spiraea alba var. *latifolia*			X									
Spiraea tomentosa			X		X							
Vaccinium corymbosum			X	X								
Viburnum dentatum			X									

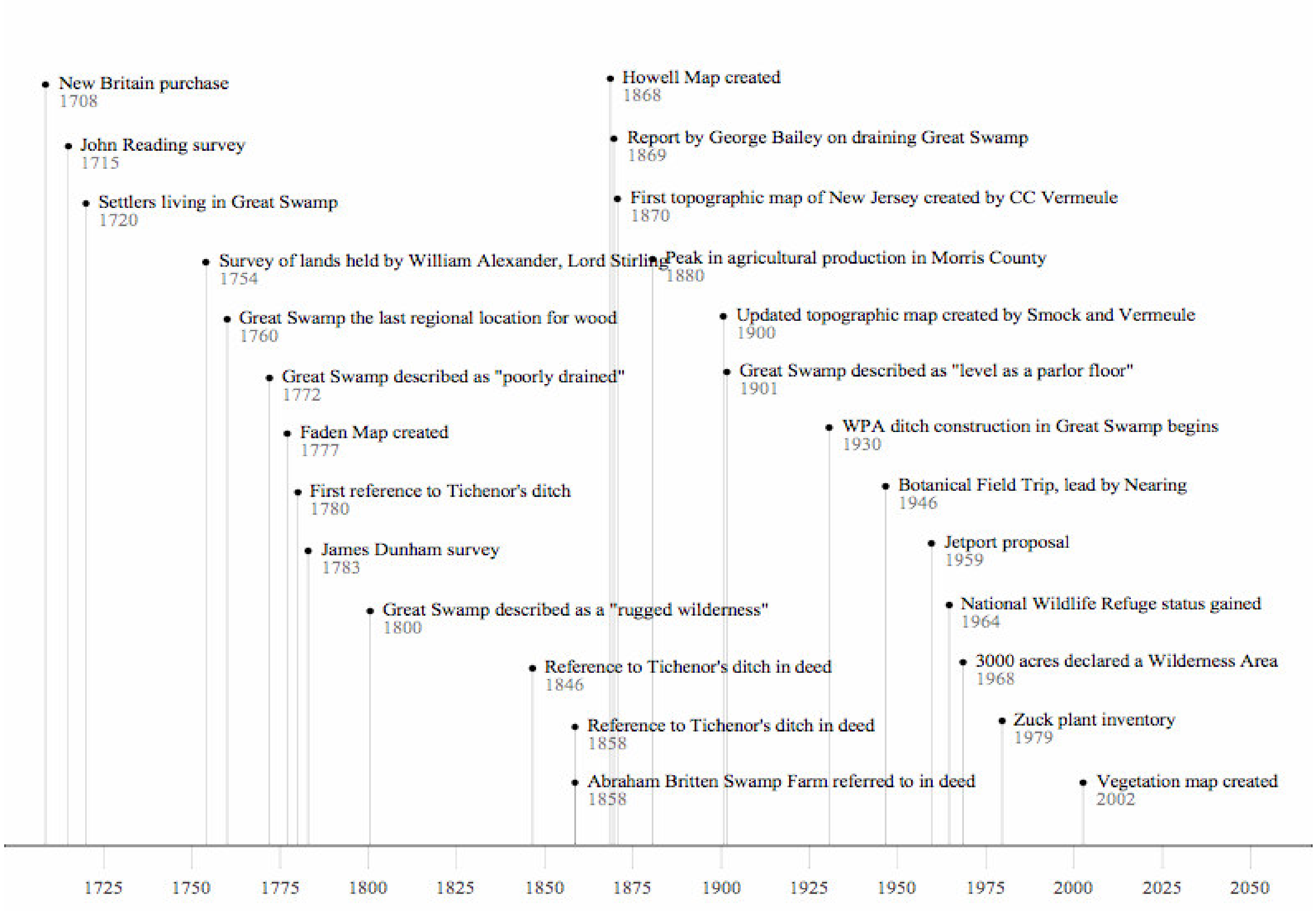


Figure 3.1. Timeline of major events occurring in or associated with Great Swamp.

Figure 3.2. Excerpt of Great Swamp from a 1900 topographic map (Smock and Vermeule 1900). Short dashed lines indicate 'fresh marsh' and long dashed lines indicate wooded swamp.

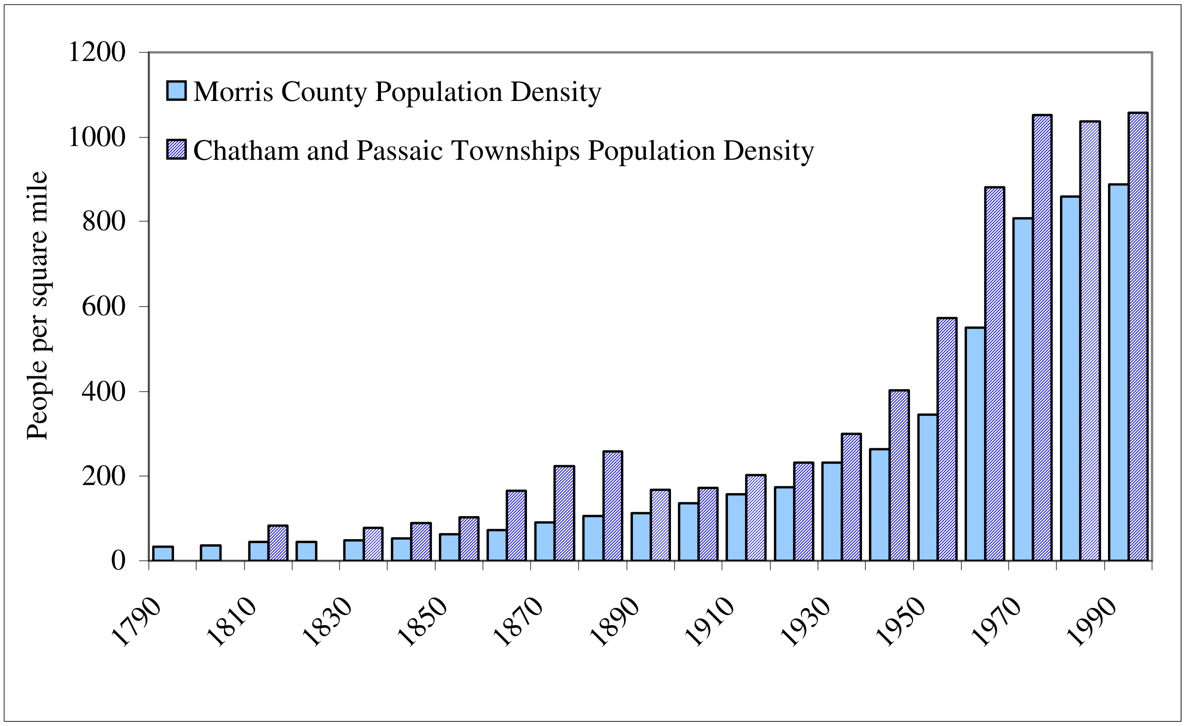


Figure 3.3. Population growth for Morris County, New Jersey and two adjacent townships, Chatham and Passaic (now Long Hill). Data is compiled from state and federal census data. (United States Census Office 1791, 1801, 1811, 1821, 1832, 1840, 1853, 1862, 1870, 1883, 1890, 1900, United States Bureau of the Census 1913, 1923, 1931, 1942, 1952, 1960, 1970, 1980, 1990). Data gaps are apparent before 1810 and again in 1820 due to the loss of records from these time periods.

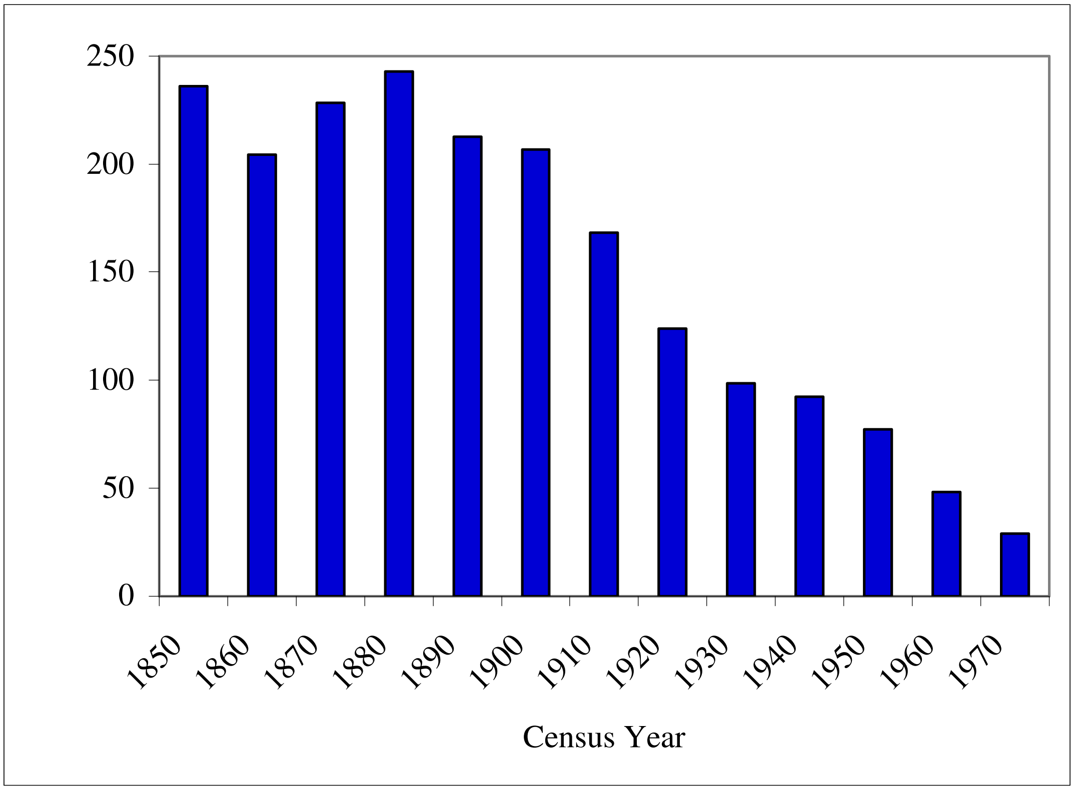


Figure 3.4. Total area in farmland, Morris County, New Jersey. Source: (University of Virginia. Geospatial and Statistical Data Center 2004).

4.0 Great Swamp 20th century landscape patterns

4.1 Introduction

In the northeastern US, the 20th century witnessed significant changes in land-use and land-cover. Agriculture continued to move west, abandoning fields to succession or development. Across much of the region, forest regeneration converted denuded mountains and barren vistas to green landscapes.

Despite appearing ‘natural,’ the forests that developed on old-fields often reflect historic land activities (Foster 1992, Russell 1997, Foster et al. 1998, Bürgi et al. 2000, Bellemare et al. 2002). In general, agriculture has led to the homogenization of forests both at the landscape level (Foster et al. 2003, Loo and Ives 2003b) and regional level (Foster 1992, Foster et al. 1998, Fuller et al. 1998) and in soils (Koerner et al. 1997, Compton et al. 1998, Compton and Boone 2000, Dupouey et al. 2002). Plant establishment is often restricted by historical land-uses (Motzkin et al. 1996) and even microbial communities can be limited by historical land-use (Foster et al. 2003).

Wetlands have also been impacted by land-use. Research has shown that land-use directly and indirectly impacts wetlands by altering sedimentation rates, water quality and community composition (Wilcox 1995, Owen 1999). Despite this knowledge, studies of land-use legacies in wetlands are limited (Mitsch and Gosselink 2000, Girard et al. 2002). Unlike northeastern forests, which are regenerating following decades of exploitation, wetlands, despite varied protective measures continue to be destroyed (Dahl 2000). Since European settlement, well over half of all wetlands have been converted to agriculture, urbanized or otherwise lost to land-use practices (Dahl and Allord 1996). Although it is rare for abandoned agricultural wetlands to escape development (Dahl 2000), those that remain are seldom restored (Mitsch and Gosselink 2000). Wetlands that persist tend to grow in size, succeeding through several community types (Thibault and Zipperer 1994).

At the micro-temporal scale, land-use has the potential to be an important driving force of landscape change. As shown in chapter 3, historical documents can record a great deal of information regarding land-use and land-cover. However, the rate and magnitude of landscape change in the 20th century makes it desirable to have a more finely grained data set, one that quantitatively captures landscape pattern and change. Aerial photography can be used to reconstruct changes in land-cover and land-use at the micro-temporal scale. Simple metrics, including the number and size of land-use and land-cover classes, habitat diversity, dominant community, and patch shape effectively quantify landscape pattern (Turner et al. 2001).

This study uses aerial photography to recreate Great Swamp's land-use and land-cover over the last 100 years. As detailed in chapter 3, land-use in Great Swamp, including 20th century management practices, was divided. This dichotomy makes possible a comparative study that can elucidate a link between land-use and current vegetation patterns. Specifically, I sought to compare the eastern and western regions over time to determine the importance of land-use history to current landscape patterns.

4.2 Methods

4.2.1 Vegetation mapping

A vegetation map was created by NatureServe based on 1999 aerial photography and fieldwork completed in 2002 and 2003 (NatureServe 2004a, Thompson 2004). This map delineated vegetation into 16 vegetation communities and 8 land-use categories (table 4.1).

4.2.2 Aerial photo analysis

Aerial photography for Great Swamp began in the 1930s and images are available as either a hard copy or digitally. In order to best assess land-cover and land-use change, I chose to analyze the earliest available images (from 1932), images from the period when Great Swamp became a National Wildlife Refuge (1962) and the most recently available aerial photos (2002).

Digital images for the Bernardsville and Chatham quadrangles from 1932 were obtained from the Grant F. Walton Center for Remote Sensing and Spatial Analysis (CRSSA) at Rutgers (table 4.2). These images had previously been scanned and georeferenced using the 2002 NJDEP orthophotography.

Hardcopy images of the Bernardsville and Chatham quadrangles from 1962 were digitally photographed using a Nikon Coolpix 990 with a resolution of 3.1 megapixels (table 4.2). The digital images were georeferenced in ArcGIS 9.1 using the 2002 NJDEP orthophotography (these images have an RMSE of approximately 4 ft). Six control points were matched to their corresponding locations on the 2002 photos for the Chatham image and the RMSE was 20.13 ft. Nine control points were used to georeference the Bernardsville image and the RMSE was 15.23 ft. Both images were processed with a second order polynomial nearest neighbor georectification and exported as TIFF files. The error associated with both images is to be expected as a result of the quality of the original images, the digitizing method and the georeferencing processes. Finally, the images were loaded into ERDAS for mosaicing.

4.2.3 Analyzing land cover and land-use change since 1930

In order to maximize consistency and ease interpretation, mapping worked in reverse chronological order, from the field-verified map of 1999 through 1932. The initial vegetation map of 1999 was overlaid on the 1962 image and edited in ArcGIS 9.1 to reflect vegetation change between 1962 and 1999. Interpretation of aerial photos was based on tone, texture and landscape position and was greatly aided by descriptions of aerial signatures of the 2002 vegetation (Thompson 2004). This process was then repeated with the 1932 image, where the 1962 vegetation map was overlaid on the 1932 image.

In creating the historical vegetation maps, I restricted the analysis to the 24 land-cover classes defined in the 2002 vegetation map. The 2002 survey also included extensive descriptions of nearly all of the land-cover classes and often linked specific communities to historical land-use (table 4.3). From these descriptions, I chose to use the land-cover class UO (urban orchard) to more generally refer to agriculture. I also interpret the cover class *Spiraea tomentosa* (CEGL 6571) as an early successional community. In 2002, this community is largely the result of active maintenance (i.e. mowing) and occurs primarily on former agricultural lands. It is likely, however, that without maintenance, this community would largely succeed to a wooded habitat.

Dozens of metrics exist to quantify landscape pattern; however, most metrics are correlated (O'Neill et al. 1988, Riitters et al. 1995). In order to minimize redundancy, I focused on temporal change at the landscape and patch level. I first describe changes in landscape composition using a simple measure of richness and Shannon-Weiner diversity. I then focus on changes in the spatial configuration of the landscape using patch-based metrics, including total number of patches, total area of each cover class, average patch area and perimeter/area measures. Patch-based metrics are a good way to capture landscape change (Dunn et al. 1991, Turner et al. 2001). For example, patch size can influence the composition and richness of the vegetation communities (Dunn et al. 1991) and perimeter/area measures can reflect land-use (Turner et al. 2001). I first describe the patterns for the entire landscape of Great Swamp over time; I then use these metrics to compare the Managed and Wilderness (west and east, respectively) Areas over time.

Finally, I created a change matrix to compare the 1932 and 2002 vegetation. The vegetation maps for each time period were converted to raster files and combined using the spatial analyst tool in ArcMap. Results were converted into a two-dimensional transition matrix and are presented for the entire landscape of Great Swamp and for the Wilderness and Managed Areas separately.

4.3 Results

4.3.1 Land-cover across Great Swamp: landscape composition and structure

Great Swamp has transitioned from an agrarian landscape in 1932 to a mixed wetland in 2002 (figure 4.1). In this time period, landscape diversity and community richness have both increased (table 4.4). Agriculture (CEGL UO) and urban areas represented over 50% of the 1932 landscape, but less than 10% in future years (figure

4.2). *Acer rubrum-Rhododendron* (CEGL 6156) was also a dominant land-cover, occupying nearly 20% of the landscape in all three years. *Spiraea tomentosa* (CEGL 6571) habitat was a minor landscape community in 1932, but occupied nearly 15% of the 2002 landscape. A similar pattern is seen in the wooded wetland community, *Quercus palustris/bicolor-Acer rubrum* (CEGL 6240). *Fagus grandiflora-Betula lenta* (CEGL 6921) increased steadily over time to occupy 15% of the landscape. Of the herbaceous wetlands, only one community type, *Typha* (CEGL 6153) changed significantly and even then, *Typha* never represented more than 8% of the total cover.

The total number of patches in each land-cover class increased over time with the exception of agriculture (table 4.4). The largest gain in number of patches for all cover classes occurs between 1932 and 1962. At the same time, the average patch size decreases. In all three years, the mean patch area for most cover classes is less than 10 ha (table 4.5); in fact, the majority of patches are less than 5 ha. Agriculture is a notable exception, as the average patch size in 1932 is just over 50 ha. The mean patch size for *Acer rubrum-Rhododendron* and urban transition (CEGL UT) was also large in 1932. By 1962, agriculture patches are significantly smaller, averaging just over 10 ha. *Acer rubrum-Rhododendron* patches are much smaller on average in 1962 and 2002 than in 1932. Patch area for all cover classes continued to decline in 2002, with no cover class having an average greater than 20 ha.

The herbaceous and scrub/shrub wetland communities exhibit a great deal of variation in mean patch size (table 4.5). In part, this is because the landscape is composed of hundreds of small (generally less than 5 ha) patches of these communities. Small changes in these communities can occur because of actual fluctuations on the landscape or as a result of error associated with aerial photographs and vegetation maps. Given the scale of the landscape and the size of these patches, it is tempting to dismiss this variation as an artifact of photo interpretation. This seems unlikely to be the only reason for variation, given the trends in landscape composition (figures 4.1 and 4.2). It seems more plausible that these communities are responding to very local habitat fluctuations.

Several land-cover classes changed markedly in a number of metrics between 1932 and 2002 (table 4.5). The change in agriculture represented the largest decrease in area (table 4.5). For this cover class, both the number of patches and average patch size declined significantly by 2002. At the same time, the total area and number of patches of *Spiraea tomentosa* increased. Also notable was the change in *Acer rubrum-Rhododendron*; this land-cover class increased in total area and number of patches, but the mean patch size decreased over time.

The majority of landscape change occurred between 1932 and 1962 (figures 4.1 and 4.2). It is during this time period that significant changes in agriculture and *Spiraea tomentosa* occur. The percentage of land in urban residential (UR) also increased markedly during this time. Based on urbanization trends in the region at this time, we might expect this trend to continue into 2002. However, refuge management from the 1960s on effectively halted the progression of residential land-cover.

4.3.2 Land-cover transitions across Great Swamp

Retention values, which represent the percentage of a land-cover category that remains the same from 1932 to 2002, range from less than 1% to 89% (table 4.6). Several land-cover categories changed substantially over time. Over 50% of the land classified as agriculture in 1932 has transitioned to *Spiraea tomentosa*, *Quercus palustris/bicolor-Acer rubrum* or *Fagus grandiflora-Betula lenta*. Nearly 75% of land categorized as *Spiraea tomentosa* has become *Fraxinus* spp-*Acer rubrum, Quercus palustris-Acer rubrum* or *Acer rubrum-Rhododendron*. Several land-cover categories remain relatively stable through time. For example 89% of the 1932 *Phragmites* land-cover remains in 2002; 66% of *Acer rubrum-Rhododendron* remains in 2002.

Herbaceous wetland retention values range from 7 – 89%. 80% of open water communities transition to *Typha* in 2002. Two communities, *Pontederia* and *Petandra* change substantially over time, transitioning to deciduous wooded wetlands or deciduous forests, respectively.

Three deciduous wooded wetland communities had retention values greater than 50%. In general, land in this classification transitions to other wooded wetlands or to deciduous forest. For example, *Fagus grandiflora-Acer rubrum* communities transition largely to *Quercus palustris/bicolor-Acer rubrum*, a deciduous wooded wetland. Conversely, deciduous forests tend to become deciduous wooded wetlands. For example, although 57% of *Quercus primus/velutina-Fagus grandiflora* remains the same through time, 31% transitions to *Acer rubrum-Rhododendron* by 2002.

Urban categories generally have low retention values, due largely to the creation and management of the National Wildlife Refuge. Most urban areas succeeded either to *Spiraea tomentosa* or a deciduous forest community. Urban residential cover, however, remained fairly static, with a retention value of 52%.

4.3.3 East versus west: land-cover composition and structure in the Managed and Wilderness Areas

Many land-cover patterns persist when the landscape is divided into east and west based on the demarcation of the Wilderness and Managed Areas. Diversity increased since 1932 in both regions although diversity is consistently higher in the Managed Area over all three sampled years (table 4.7). Community richness and the total number of patches in each region also increased over time (table 4.7).

Landscape composition is quite different between the Wilderness and Managed Areas, especially in 2002 (figures 4.1 and 4.3). Agriculture was the dominant land-cover in 1932, representing over 60% of the Managed Area and nearly 40% of the Wilderness. By 2002, agriculture accounts for less than 5% of either landscape. *Spiraea tomentosa* reaches 20% of the total land cover in the Managed Area by 2002; in the Wilderness Area, this cover class spikes in 1962. *Typha* wetlands cover an increasing proportion of both landscapes. *Acer rubrum-Rhododendron* communities represent over 40% of the Wilderness landscape in all three years, but in the Managed Area, covers less than 5%. Two cover classes increased markedly in the Managed Area, *Quercus palustris/bicolor-Acer rubrum*.

As for the landscape as a whole, the total number of patches in each land-cover class increased over time, especially between 1932 and 1962 (table 4.8). The exception, again, is agriculture where the majority of patches are lost between 1932 and 1962 in the Wilderness Area and between 1962 and 2002 in the Managed Area. In both landscapes, there are significant increases in the number of patches of *Typha* and *Acer rubrum-*

Rhododendron. The number of urban residential patches increased significantly in the Managed Area, especially between 1932 and 1962, as did *Spiraea tomentosa*.

Mean patch size also decreased over time, with the exception of *Spiraea tomentosa* (table 4.8). The metric for this land-cover class peaked in 1962 in the Wilderness Area while remaining fairly constant in the Managed Area, especially between 1962 and 2002. Mean patch size of *Acer rubrum-Rhododendron* drops considerably between 1932 and 1962 in the Wilderness Area.

As mean patch size decreased, the total area of several land-cover classes increased (table 4.8). Two land-cover classes, *Typha* and *Fagus grandiflora-Betula lenta*, increased over time in both landscapes. The Wilderness Area experienced mostly minor gains in all land-cover classes, including *Acer rubrum-Rhododendron.* However, total area for two cover classes, *Spiraea tomentosa* and *Quercus palustris/bicolor-Acer rubrum* increased substantially in the Managed Area.

Patch shape shows some patterning on an east/west basis (table 4.9). In the Wilderness Area, complexity generally increases with time, with the exception of *Phragmites* wetlands (CEGL 4141) and *Quercus*-dominated forests (CEGL 6919). The complexity of most cover classes in the Managed Area changes very little over time. Urban areas tend to be the simplest in shape, though in 1932, deciduous wooded wetlands also have a low P/A ratio. No cover class stands out as being consistently the least or most complex over time in either the Managed or Wilderness Area.

There was a net increase in the coverage of most land-cover classes between 1932 and 1962, with the exception of urban covers (figure 4.4). Land-cover gains were not uniform across the landscape. The Wilderness Area had greater gains in forested land while the Managed Area had greater gains in wooded wetlands and scrub/shrub habitats. Although the net loss in urban cover is impressive, it is due to massive losses in agricultural lands (table 4.8). In the Managed Area, for example, all other urban categories show a net gain in coverage. Such skewing does not occur in the other vegetation groups.

4.3.4 East versus west: land-cover transitions in the Managed and Wilderness Areas

Retention values for the Managed and Wilderness Areas range from less than 1% to 80% in the Wilderness Area and 90% in the Managed Area (tables 4.10 and 4.11). In both areas, less than 1% of agriculture remains the same over time. In the Managed Area, nearly 30% of agricultural land becomes *Spiraea tomentosa* and 20% becomes *Quercus palustris/bicolor-Acer rubrum*. In the Wilderness Area, 35% becomes *Fagus grandiflora-Betula lenta*, 20% becomes *Acer rubrum-Rhododendron* and 20% becomes *Typha*.

Spiraea tomentosa dominated communities also change substantially in both the Managed and Wilderness Areas. In the Wilderness Area, 37% of this community transitions to *Acer rubrum-Rhododendron* and 31% become *Nuphar* wetlands. In the Managed Area, 27% of *Spiraea tomentosa* succeeds to *Quercus palustris-Acer rubrum* and 15% to *Acer rubrum-Rhododendron*. Isolated basins in the Wilderness Area also change substantially, with 80% succeeding to *Typha* wetlands.

Several communities remain relatively stable through time, though the identity of these communities varies between the Managed and Wilderness Areas. Six communities have retention values greater than 50% in the Managed Area. Notable communities include *Phragmites* wetlands, with 90% retention and urban residential habitat, with 60%

retention. Only one forested community, the wetland *Quercus palustris/bicolor-Acer rubrum*, had a retention value greater than 50%. The remaining deciduous wooded wetlands and forest communities transition largely to deciduous wooded wetlands; for example, 35% of *Fagus grandiflora-Betula lenta* becomes *Quercus palustris/bicolor-Acer rubrum* by 2002.

Five communities have retention values greater than 50% in the Wilderness Area. The nearly 80% retention value of the deciduous wooded wetland, *Acer rubrum-Rhododendron* stands out. Three of the five deciduous wooded wetlands have retention values greater than 50% as do both deciduous forests. Transitions among these five communities are largely to deciduous wooded wetlands. The two remaining deciduous wetlands, *Quercus palustris-Acer rubrum* and *Quercus palustris/bicolor-Acer rubrum*, with retention values of 32% and 17%, respectively, transition primarily to deciduous forests.

4.4 Discussion

The 20th century was a very dynamic period in the history of Great Swamp, as the agrarian landscape of 1932 gave way to a mosaic of wetland communities in 2002. At a time when many wetlands in the United States were permanently lost to urbanization and agriculture (Dahl 2000), Great Swamp has been an exception. The cultural value of Great Swamp has changed with time and it is largely due to the development of a positive public perception in the 1950s and 1960s that Great Swamp persists as a wetland.

Great Swamp today is a diverse landscape, with habitats representing several phases of wetland succession. Herbaceous wetland communities emerged quickly following the cessation of agriculture, which is surprising, given the system of ditches dug to facilitate drainage. In other landscapes, it has been shown that ditches quickly lose effectiveness without maintenance (Fisher et al. 1996). It is plausible, then, that without maintenance, the integrity of these ditches rapidly eroded returning a more natural, if modified hydrology to Great Swamp. The expansion of *Typha*, a community linked to disturbed hydrology, is certainly a response to such landscape changes. Herbaceous communities in general appear to be very sensitive to local environmental changes, expanding as appropriate habitat becomes available.

The expansion of the early successional scrub/shrub community, *Spiraea tomentosa*, is inversely related to changes in agriculture. This community is generally restricted to former agricultural sites, and, without maintenance would succeed to wooded habitats. In the Wilderness Area, this is what has happened. Much of this community remains in the Managed Area because of regular mowing (NatureServe 2004a).

Landscape homogenization, which is a common trend following agriculture (Foster et al. 2003, Loo and Ives 2003b), does not appear to be occurring at Great Swamp. The increasing number of patches with decreasing patch size represents the development of a diverse landscape mosaic. While metric patterns like this typically indicate landscape fragmentation, this is clearly not occurring at Great Swamp. It seems more likely that other pattern drivers are emerging to influence landscape patterns. For example, many herbaceous land-cover classes appear to be responding to local hydrologic changes, expanding as suitable habitat becomes available. Some communities, like *Typha* are restricted to sites with disturbed hydrology, but many are not. Finally, although many agricultural fields have succeeded to the same wooded wetland, *Quercus palustris-Quercus bicolor-Acer rubrum*, other land-cover classes have emerged in these areas.

A heterogeneous landscape appears to be a hallmark of Great Swamp. Sediment analysis revealed a diverse landscape that was responsive to local environmental conditions (chapter 2). The reemergence of heterogeneity following centuries of manipulation hints at the importance of other, non-human drivers to landscape patterning.

4.4.1 East versus west: community development in the Managed and Wilderness Areas

These results show that the landscape of Great Swamp is patterned on an east/west basis. A large patch of *Acer rubrum-Rhododendron*, with patches of *Quercus primus/velutina-Fagus grandiflora* interspersed throughout, has consistently dominated the Wilderness Area, expanding somewhat with the end of agriculture. The limited agriculture that occurred in the Wilderness Area in 1932 had all but disappeared by 1962 and is reflected by the peak in early successional communities, namely the scrub/shrub community, *Spiraea tomentosa.* By 2002, most of the scrub/shrub communities had succeeded to other land-cover classes. There was little transition to the agriculturally restricted community, *Quercus palustris/bicolor-Acer rubrum*; rather, old fields succeeded to *Acer rubrum-Rhododendron* and *Quercus primus/velutina-Fagus grandiflora*, the seemingly signature communities of the Wilderness Area.

Agriculture was an integral part of the Managed landscape through the 1960s, when Great Swamp came under federal management. At this point, the remaining farmland was abandoned and secondary succession began. Many old-fields continue to be covered by the early successional community *Spiraea tomentosa*, due in large part to continued mowing by Refuge managers. A substantial proportion of old fields have succeeded to *Quercus palustris/bicolor-Acer rubrum*. However, many old fields have transitioned to other deciduous wooded wetlands and deciduous forests, many of which are not typically associated with agriculture. As a result, this area of Great Swamp is more diverse and heterogeneous than what might be expected.

Formal management of Great Swamp has had mixed results. Urbanization and residential creep posed a significant threat to the continued existence of the Managed Area. Management practices begun in the 1960s, including the acquisition of additional lands, effectively curtailed the expansion of housing developments, but many residential areas from 1932 remain in 2002. As noted previously, management has been integral in maintaining early successional habitat, but appears to have had little impact on most other land-cover classes. Although the 2002 landscape is notably different from 1962, the majority of landscape change occurred between 1932 and 1962, prior to formal management.

4.4.2 Land-use legacies

Agriculture, as the dominant land-use throughout much of Great Swamp's history, has had a lasting effect on the landscape of Great Swamp. The impact and prevalence of land-use, however, is distinctly different between the Managed and Wilderness Areas, differentially impacting landscape composition and structure.

At a very basic level, land-use continues to be reflected in patch shape. Although there are more patches found in the west, these patches are typically quite simple in shape, oftentimes rectilinear, reflecting the boundaries of old farmland. In contrast, eastern patches are typically complex in shape.

While communities associated with recent agriculture including *Spiraea tomentosa* and the wooded wetland, *Quercus palustris/bicolor-Acer rubrum* are found in both landscapes, they are a fairly minor component of the Wilderness Area, succeeding to deciduous forests. *Fagus grandiflora-Acer rubrum*, however, a community associated with older agriculture, remains a small but consistent aspect of the Wilderness landscape.

The Managed Area, however, is dominated by *Spiraea tomentosa* and *Quercus palustris/bicolor-Acer rubrum.* The scrub/shrub community is quite dynamic, transitioning to a number of other land-cover categories, especially *Quercus palustris-Acer rubrum* and the urban community, *Fraxinus spp-Acer rubrum*. Conversely, a large proportion of the *Quercus palustris/bicolor-Acer rubrum* community established in 1932 remains in 2002; a small portion succeeds to *Fagus grandiflora-Acer rubrum*.

Other signatures of past land-use occur in both the Wilderness and Managed Areas. Ditches dug to create arable land are, in many instances, still visible on the landscape. Even ditches that have eroded continue to influence landscape patterns. This is evidenced by the expansion and persistence of *Typha*, a signature community of modified hydrology. Although *Typha* communities are more stable in the Managed Area, they continue to expand in both Areas. A second indicator of disturbed hydrology, *Phragmites*, is also found throughout Great Swamp. A very minor component of either the Wilderness or Managed Areas, *Phragmites* communities are, nevertheless, quite persistent in the Managed Area. Clearly, the modifications of hydrology have had a significant impact on current vegetation communities, especially in the Managed Area.

Although active land-use has not occurred in the Wilderness Area since the 1960s, human activity continues to impact this land. This is most apparent in the shape of *Quercus primus/velutina-Fagus grandiflora* communities, a community restricted to sand 'islands' found primarily in the east. Although the number of patches and total area of this habitat increases, the shape of this habitat changes significantly by 2002. The simplification in patch shape is driven by external land-use limiting the boundaries of this community and imposing rather rectilinear shapes, especially in the northeastern region of the Wilderness Area.

Historical documents (see chapter 3) reveal differential exploitation of Great Swamp. The intense agriculture that dominated the west expanded into the east, but logging and hunting were the main activities of the Wilderness Area. Despite roughly 40 years of conservation, the Managed and Wilderness Areas continue to differ in landscape composition and spatial configuration. Land-use has driven many of these patterns, especially in the west where patch shape and composition continue to reflect the agricultural history of Great Swamp.

If land-use were the only significant force patterning the landscape, we might expect to see the eastern and western regions grow more similar over time, especially with respect to landscape composition. This is clearly not the case. From here, we must ask, what other forces could be influencing modern vegetation patterns? Answering this question requires adopting a multi-scalar approach to integrate data across temporal scales.

Table 4.1. Vegetation map codes and description. CEGL code refers to the community element global code, a classification scheme often used by NatureServe.

CEGL Code	Vegetation Description
2386	*Nuphar*
4141	*Phragmites*
6069	*Cephalanthus*
6072	*Fagus grandiflora-Acer rubrum*
6119	*Acer rubrum-Carex*
6153	*Typha*
6156	*Acer rubrum-Rhododendron*
6185	*Quercus palustris-Acer rubrum*
6191	*Pontderia*
6240	*Quercus palustris-Quercus bicolor-Acer rubrum*
6362	Open Water
6412	*Carex* spp
6571	*Spiraea tomentosa*
6919	*Quercus primus-Quercus velutina-Fagus grandiflora*
6921	*Fagus grandiflora-Betula lenta-Quercus*
7696	*Petandra*
PFS	*Fraxinus* spp-*Acer rubrum*
PHI	Isolated Basin
UI	Urban Industrial
UO	Urban Orchard
UR	Urban Residential
US	Commercial & Services
UT	Urban Transition
UU	Urban Upland

Table 4.2. Aerial photography information.

Map Date	Original Scale	Source	Color
2002	1:2400	NJDEP[1]	Color
1962	1:18000	CRSSA[2]	Black & White
1932	1:24000	NJDEP	Black & White

[1]New Jersey Department of Environmental Protection.
[2]Center for Remote Sensing and Spatial Analysis.

Table 4.3. Expanded descriptions of selected vegetation classes of Great Swamp. Based on a 2002 vegetation survey (NatureServe 2004).

Land-cover class	CEGL Code	Expanded vegetation description
Typha	6153	Occurs primarily on sites with historic or contemporary modifications to hydrology.
Spiraea tomentosa	6571	Without maintenance, this community succeeds to scrub/shrub and wooded habitats.
Fagus grandiflora-Acer rubrum	6072	Some evidence of ditches; generally restricted to older agriculture sites.
Quercus palustris-Quercus bicolor-Acer rubrum	6240	Restricted to former agriculture sites.
Quercus primus-Quercus velutina-Fagus grandiflora	6919	Restricted to sandy islands primarily in the east.
Urban Orchard	UO	More generally used to represent agriculture.

Table 4.4. Landscape composition metrics for Great Swamp. Calculations were performed using coverage data (in hectares) for each vegetation class.

	1932	1962	2002
Richness	19	24	24
Diversity	1.59	2.45	2.44
Total Number of Patches	427	1083	1357

Table 4.5. Summary metrics for Great Swamp.

Vegetation Description		CEGL Codes	Total land-cover area (ha)			Mean patch size (ha)			Total number of patches		
			1932	1962	2002	1932	1962	2002	1932	1962	2002
Herbaceous Wetland	*Nuphar*	2386	1.22	21.90	36.20	0.41	0.41	0.55	3	54	66
	Phragmites	4141	1.59	8.46	12.38	1.59	0.77	0.73	1	11	17
	Typha	6153	63.58	150.10	304.60	3.97	2.11	3.11	16	71	98
	Pontderia	6191	5.77	69.19	27.04	0.96	1.98	0.50	6	35	54
	Open Water	6362	0.62	6.64	14.05	0.62	0.35	0.47	1	19	30
	Carex spp	6412	0.00	17.09	16.19	0.00	2.85	2.70	0	6	6
	Petandra	7696	16.34	13.67	14.05	5.45	1.71	1.17	3	8	12
Scrub/Shrub Wetland	*Cephalanthus*	6069	5.56	23.92	29.59	0.51	0.49	0.43	11	49	69
	Spiraea tomentosa	6571	82.41	539.18	546.94	4.58	6.34	4.31	18	85	127
Deciduous Wooded Wetland	*Fagus grandiflora-Acer rubrum*	6072	89.04	165.44	158.45	4.95	3.31	2.78	18	50	57
	Acer rubrum-Carex	6119	4.41	21.21	33.23	0.40	0.33	0.42	11	64	80
	Acer rubrum-Rhododendron	6156	807.21	720.44	795.60	35.10	5.34	5.10	23	135	156
	Quercus palustris-Acer rubrum	6185	156.31	190.73	189.70	4.34	4.65	3.58	36	41	53
	Quercus palustris-Quercus bicolor-Acer rubrum	6240	127.97	636.28	625.58	8.00	12.24	9.20	16	52	68
Deciduous Forest	*Quercus primus-Quercus velutina-Fagus grandiflora*	6919	109.20	192.71	180.50	1.61	1.72	1.63	68	112	111
	Fagus grandiflora-Betula lenta-Quercus	6921	421.61	518.71	640.02	6.91	8.10	6.81	61	64	94
Urban	*Fraxinus* spp-*Acer rubrum*	PFS	0.00	5.32	67.57	0.00	5.32	16.89	0	1	4
	Isolated Basin	PHI	0.09	1.01	4.58	0.09	0.08	0.23	1	13	20
	Urban Industrial	UI	0.00	8.66	11.09	0.00	2.17	2.22	0	4	5
	Urban Orchard	UO	2236.78	440.45	14.18	50.84	13.76	1.29	44	32	11
	Urban Residential	UR	59.51	353.13	339.23	1.32	5.19	4.65	45	68	73
	Commercial & Services	US	0.00	38.85	40.46	0.00	3.24	2.53	0	12	16
	Urban Transition	UT	45.74	73.42	74.50	22.87	24.47	4.14	2	3	18
	Urban Upland	UU	0.00	17.66	59.53	0.00	1.96	3.50	0	9	17

Table 4.6. Transition matrix for Great Swamp.

		2002	Herbaceous Wetlands							Deciduous Scrub/Shrub Wetlands		Deciduous Wooded Wetlands				
			Nuphar	*Phragmites*	*Typha*	*Pontderia*	Open Water	*Carex* spp	*Petandra*	*Cephalanthus*	*Spiraea tomentosa*	*Fagus grandiflora-Acer rubrum*	*Acer rubrum-Carex*	*Acer rubrum-Rhododendron*	*Quercus palustris-Acer rubrum*	*Quercus palustris/ bicolor-Acer rubrum*
	1932		2386	4141	6153	6191	6362	6412	7696	6069	6571	6072	6119	6156	6185	6240
Herbaceous Wetlands	*Nuphar*	2386	57.14													
	Phragmites	4141		89.47												
	Typha	6153	0.60	0.75	53.66	0.60	5.08	1.49		2.99	11.51	1.49	1.94	5.53	7.17	
	Pontderia	6191				18.64			6.78		27.12			16.95	16.95	6.78
	Open Water	6362			80.00											
	Carex spp	6412														
	Petandra	7696	7.95		0.57				6.82		3.41			2.84	14.20	13.64
Deciduous Scrub/Shrub Wetlands	*Cephalanthus*	6069			4.92					42.62	4.92			13.11	1.64	
	Spiraea tomentosa	6571	2.61		3.40	0.68			0.91	0.57	4.20	2.49	0.68	15.87	24.72	5.67
Deciduous Wooded Wetlands	*Fagus grandiflora-Acer rubrum*	6072	0.83		0.52	0.52			0.10	0.10	0.72	36.92	1.03	15.31		31.44
	Acer rubrum-Carex	6119									4.35	6.52	52.17	8.70	8.70	2.17
	Acer rubrum-Rhododendron	6156	1.02	0.09	0.61	0.11		0.05		0.07	0.96	3.97	0.45	65.84	0.32	0.79
	Quercus palustris-Acer rubrum	6185	0.06		6.77	0.59	1.25		1.13	0.83	6.12	9.20	0.77	7.01	29.45	16.81
	Quercus palustris/bicolor-Acer rubrum	6240		0.22	2.18			7.35			0.36	6.11		5.97	0.29	54.66
Deciduous Forests	*Quercus primus/velutina-Fagus grandiflora*	6919	1.46	0.17	0.17	0.09					0.43	3.78		31.36	0.09	
	Fagus grandiflora-Betula lenta	6921	0.27	0.02	2.50	2.65	0.11		0.33	0.71	2.63	2.61	0.60	5.95	3.03	27.94
Urban	*Fraxinus* spp-*Acer rubrum*	PFS														
	Isolated Basin	PHI											100.00			
	Urban Industrial	UI														
	Urban Orchard	UO	0.90	0.37	10.53	0.52	0.39	0.26	0.37	0.84	22.14	2.41	0.90	6.60	4.40	16.57
	Urban Residential	UR	0.47		3.11	0.16					14.60	0.31		2.95	3.26	1.09
	Commercial & Services	US														
	Urban Transition	UT		1.23		0.41				1.64		0.20		9.00		
	Urban Upland	UU														

			Deciduous Forests		Urban							
		2002	*Quercus primus/ velutina-Fagus grandiflora*	*Fagus grandiflora-Betula lenta*	*Fraxinus* spp-*Acer rubrum*	Isolated Basin	Urban Industrial	Urban Orchard	Urban Residential	Commercial & Services	Urban Transition	Urban Upland
	1932		6919	6921	PFS	PHI	UI	UO	UR	US	UT	UU
Herbaceous Wetlands	*Nuphar*	2386		7.14							35.71	
	Phragmites	4141									10.53	
	Typha	6153		7.03								0.15
	Pontderia	6191		3.39					1.69			1.69
	Open Water	6362		20.00								
	Carex spp	6412										
	Petandra	7696			30.11				16.48		1.70	2.27
Deciduous Scrub/Shrub Wetlands	*Cephalanthus*	6069		32.79								
	Spiraea tomentosa	6571	1.81	4.65	24.72				1.81	0.34		4.88
Deciduous Wooded Wetlands	*Fagus grandiflora-Acer rubrum*	6072	4.03	0.10					3.00	3.31		2.07
	Acer rubrum-Carex	6119		17.39								
	Acer rubrum-Rhododendron	6156	9.26	6.37			0.22		5.71	0.26	1.84	2.06
	Quercus palustris-Acer rubrum	6185	0.24	12.11	4.69	0.18			1.96		0.30	0.53
	Quercus palustris/bicolor-Acer rubrum	6240	2.11	12.59				1.46	4.59	0.95	0.44	0.73
Deciduous Forests	*Quercus primus/velutina-Fagus grandiflora*	6919	57.13	1.72					0.17			3.44
	Fagus grandiflora-Betula lenta	6921	0.18	35.74	1.46			0.07	9.31	1.46	1.59	0.86
Urban	*Fraxinus* spp-*Acer rubrum*	PFS										
	Isolated Basin	PHI										
	Urban Industrial	UI										
	Urban Orchard	UO	0.92	16.78	1.29	0.20	0.42	0.52	9.07	0.64	2.23	0.74
	Urban Residential	UR	3.88	14.60			0.16		52.64	1.09	1.55	0.16
	Commercial & Services	US										
	Urban Transition	UT	25.97	4.91					9.00	27.81		19.84
	Urban Upland	UU										

Table 4.7. Landscape composition metrics for the Managed and Wilderness Areas. Calculations were performed using coverage data (in hectares) for each vegetation class.

	1932		1962		2002	
	Managed	Wilderness	Managed	Wilderness	Managed	Wilderness
Richness	18	15	24	22	24	21
Diversity	1.51	1.45	2.43	1.99	2.43	1.83
Number of Patches	232	195	612	471	797	560

Table 4.8. Summary metrics for the Managed (M) and Wilderness (W) Areas of Great Swamp.

Vegetation Description		CEGL Codes	Total land-cover area (ha)						Mean patch size (ha)						Total number of patches					
			1932		1962		2002		1932		1962		2002		1932		1962		2002	
			M	W	M	W	M	W	M	W	M	W	M	W	M	W	M	W	M	W
Herbaceous Wetland	*Nuphar*	2386	1.22	0.00	8.35	13.55	15.25	20.95	0.30	0.00	4.38	0.65	0.34	0.95	4	0	34	21	45	22
	Phragmites	4141	1.56	0.03	3.85	4.61	5.11	7.27	1.56	0.03	0.96	0.46	0.73	0.56	1	1	4	10	7	13
	Typha	6153	34.76	28.82	68.24	81.86	150.10	154.50	6.95	2.22	3.10	1.52	3.75	2.24	5	13	22	54	40	69
	Pontderia	6191	5.77	0.00	66.18	3.01	25.29	1.76	0.96	0.00	2.36	0.30	0.53	0.25	6	0	28	10	48	7
	Open Water	6362	0.00	0.62	0.13	6.51	0.13	13.93	0.00	0.62	0.04	0.41	0.04	0.52	0	1	3	16	3	27
	Carex spp	6412	0.00	0.00	15.10	1.99	11.46	4.73	0.00	0.00	3.78	0.99	3.82	1.58	0	0	4	2	3	3
	Petandra	7696	16.34	0.00	13.48	0.19	13.36	0.69	5.45	0.00	1.93	0.19	1.34	0.23	3	0	7	1	10	3
Scrub/Shrub Wetland	*Cephalanthus*	6069	2.77	2.80	14.59	9.32	12.60	16.98	0.46	0.56	0.63	0.33	0.42	0.40	6	5	23	28	30	42
	Spiraea tomentosa	6571	76.30	6.11	356.46	182.72	524.29	22.65	6.36	0.87	4.88	7.94	4.81	0.84	12	7	73	23	109	27
Deciduous Wooded Wetland	*Fagus grandiflora-Acer rubrum*	6072	77.35	11.69	100.45	64.99	105.08	53.37	5.95	1.46	4.02	2.03	3.62	1.57	13	8	25	32	29	34
	Acer rubrum-Carex	6119	2.09	2.32	13.30	7.91	18.94	14.29	0.30	0.58	0.29	0.40	0.34	0.51	7	4	46	20	56	28
	Acer rubrum-Rhododendron	6156	220.33	586.88	149.20	571.24	138.01	657.22	15.74	48.91	2.04	7.72	1.66	7.73	14	12	73	74	83	85
	Quercus palustris-Acer rubrum	6185	121.80	34.51	147.65	43.08	158.42	31.29	4.68	2.88	5.91	2.39	5.28	1.25	26	12	25	18	30	25
	Quercus palustris-Quercus bicolor-Acer rubrum	6240	116.30	11.68	541.77	94.51	549.34	76.23	11.63	1.67	14.26	5.56	10.99	3.05	10	7	38	17	50	25
Deciduous Forest	*Quercus primus-Quercus velutina-Fagus grandiflora*	6919	17.15	92.06	88.16	104.55	86.60	93.90	1.22	1.53	3.04	1.19	2.89	1.09	14	60	29	88	30	86
	Fagus grandiflora-Betula lenta-Quercus	6921	260.05	161.56	205.21	313.50	281.35	358.67	7.22	4.49	4.77	8.96	4.20	7.97	36	36	43	35	67	45
Urban	*Fraxinus* spp-*Acer rubrum*	PFS	0.00	0.00	5.32	0.00	67.57	0.00	0.00	0.00	5.32	0.00	16.89	0.00	0	0	1	0	4	0
	Isolated Basin	PHI	0.09	0.00	0.81	0.19	4.39	0.19	0.09	0.00	0.07	0.19	0.23	0.19	1	0	12	1	19	1
	Urban Industrial	UI	0.00	0.00	8.66	0.00	11.09	0.00	0.00	0.00	2.17	0.00	2.22	0.00	0	0	4	0	5	0
	Urban Orchard	UO	1633.66	603.12	418.91	21.54	7.24	0.39	51.05	27.41	13.96	3.59	1.03	0.13	32	22	30	6	7	3
	Urban Residential	UR	52.08	7.43	340.20	13.75	335.61	3.61	1.30	1.24	5.32	1.53	4.66	1.20	40	6	64	9	72	3

Vegetation Description	CEGL Codes	Total land-cover area (ha)						Mean patch size (ha)						Total number of patches					
		1932		1962		2002		1932		1962		2002		1932		1962		2002	
		M	W	M	W	M	W	M	W	M	W	M	W	M	W	M	W	M	W
Commercial & Services	US	0.00	0.00	37.95	0.91	40.46	0.00	0.00	0.00	3.16	0.91	2.53	0.00	0	0	12	1	16	0
Urban Transition	UT	43.18	2.55	66.17	7.25	63.95	10.55	21.59	2.55	22.06	7.25	3.76	3.52	2	1	3	1	17	3
Urban Upland	UU	0.00	0.00	12.66	5.00	50.90	8.63	0.00	0.00	1.41	1.25	3.18	1.08	0	0	9	4	16	8

Table 4.9. Mean perimeter/area ratios for each land-cover class in the Managed and Wilderness Areas.

	Vegetation Description	CEGL Code	1932		1962		2002	
			Managed	Wilderness	Managed	Wilderness	Managed	Wilderness
Herbaceous Wetland	**Nuphar**	2386	0.896	0.000	0.045	0.033	0.036	0.037
	Phragmites	4141	0.012	0.163	0.024	0.035	0.023	0.027
	Typha	6153	0.010	0.021	0.053	0.027	0.055	0.030
	Pontderia	6191	0.030	0.000	0.050	0.040	0.044	0.030
	Open Water	6362	0.000	0.022	0.061	0.043	0.061	0.047
	Carex spp	6412	0.000	0.000	0.022	0.015	0.020	0.016
	Petandra	7696	0.011	0.000	0.036	0.044	0.666	0.046
Scrub/Shrub Wetland	*Cephalanthus*	6069	0.024	0.023	0.035	0.035	0.032	0.034
	Spiraea tomentosa	6571	0.011	0.017	0.030	0.030	0.023	0.045
Deciduous Wooded Wetland	*Fagus grandiflora-Acer rubrum*	6072	0.017	0.018	0.017	0.020	0.019	0.023
	Acer rubrum-Carex	6119	0.028	0.020	0.036	0.037	0.042	0.032
	Acer rubrum-Rhododendron	6156	0.018	0.018	0.030	0.033	0.039	0.030
	Quercus palustris-Acer rubrum	6185	0.012	0.014	0.016	0.019	0.017	0.021
	Quercus palustris-Quercus bicolor-Acer rubrum	6240	0.008	0.033	0.015	0.115	0.036	0.090
Deciduous Forest	*Quercus primus-Quercus velutina-Fagus grandiflora*	6919	0.022	0.160	0.416	0.118	0.103	0.029
	Fagus grandiflora-Betula lenta-Quercus	6921	0.936	0.017	0.033	0.041	0.029	0.124
Urban	*Fraxinus* spp-*Acer rubrum*	PFS	0.000	0.000	0.009	0.000	0.005	0.000
	Isolated Basin	PHI	0.038	0.000	0.053	0.034	0.045	0.034
	Urban Industrial	UI	0.000	0.000	0.010	0.000	0.014	0.000
	Urban Orchard	UO	0.011	0.039	0.026	0.013	0.035	0.044
	Urban Residential	UR	0.019	0.022	0.013	0.069	0.015	0.204
	Commercial & Services	US	0.000	0.000	0.012	0.013	0.015	0.000
	Urban Transition	UT	0.009	0.022	0.008	0.007	0.024	0.117
	Urban Upland	UU	0.000	0.000	0.075	0.059	0.055	0.135

Table 4.10. Transition matrix for the Managed Area.

		2002	Herbaceous Wetlands							Deciduous Scrub/Shrub Wetlands		Deciduous Wooded Wetlands				
			Nuphar	*Phragmites*	*Typha*	*Pontderia*	Open Water	*Carex* spp	*Petandra*	*Cephalanthus*	*Spiraea tomentosa*	*Fagus grandiflora-Acer rubrum*	*Acer rubrum-Carex*	*Acer rubrum-Rhododendron*	*Quercus palustris-Acer rubrum*	*Quercus palustris/ bicolor-Acer rubrum*
	1932		2386	4141	6153	6191	6362	6412	7696	6069	6571	6072	6119	6156	6185	6240
Herbaceous Wetlands	*Nuphar*	2386	57.14													
	Phragmites	4141		89.47												
	Typha	6153			63.98	1.08					19.35	0.27			12.37	
	Pontderia	6191				18.64			6.78		27.12			16.95	16.95	6.78
	Open Water	6362														
	Carex spp	6412														
	Petandra	7696	7.95		0.57				6.82		3.41			2.84	14.20	13.64
Deciduous Scrub/Shrub Wetlands	*Cephalanthus*	6069			3.23					54.84	9.68				3.23	
	Spiraea tomentosa	6571	0.37		3.66	0.73			0.98	0.61	4.52	2.69	0.73	14.16	26.62	6.11
Deciduous Wooded Wetlands	*Fagus grandiflora-Acer rubrum*	6072	0.96			0.60			0.12	0.12	0.84	34.61	1.20	11.50		36.41
	Acer rubrum-Carex	6119									10.53	15.79	47.37		21.05	5.26
	Acer rubrum-Rhododendron	6156	0.92	0.34	0.21	0.13				0.04	2.23	2.39	0.88	27.71		1.30
	Quercus palustris-Acer rubrum	6185			6.12	0.76	0.08		1.45	0.69	7.87	11.85	0.92	6.35	28.67	21.64
	Quercus palustris/bicolor-Acer rubrum	6240		0.24				8.12			0.32	6.75		4.34	0.32	58.92
Deciduous Forests	*Quercus primus/velutina-Fagus grandiflora*	6919		1.07		0.53					1.07	5.35		23.53		
	Fagus grandiflora-Betula lenta	6921	0.14	0.04	0.83	4.31			0.50	0.25	4.05		0.90	1.51	4.38	35.20
Urban	*Fraxinus* spp-*Acer rubrum*	PFS														
	Isolated Basin	PHI											100.00			
	Urban Industrial	UI														
	Urban Orchard	UO	0.57	0.12	7.04	0.64		0.14	0.47	0.48	29.23	2.98	0.66	1.92	5.13	19.85
	Urban Residential	UR	0.53			0.18					15.67	0.35		1.94	1.23	1.06
	Commercial & Services	US														
	Urban Transition	UT		1.31		0.44				1.74		0.22		3.92		
	Urban Upland	UU														

Table 4.10, continued

		2002	Deciduous Forests: *Quercus primus/velutina-Fagus grandiflora*	Deciduous Forests: *Fagus grandiflora-Betula lenta*	Urban: *Fraxinus* spp-*Acer rubrum*	Isolated Basin	Urban Industrial	Urban Orchard	Urban Residential	Commercial & Services	Urban Transition	Urban Upland
	1932		6919	6921	PFS	PHI	UI	UO	UR	US	UT	UU
Herbaceous Wetlands	*Nuphar*	2386		7.14							35.71	
	Phragmites	4141									10.53	
	Typha	6153		2.69								0.27
	Pontderia	6191		3.39					1.69			1.69
	Open Water	6362										
	Carex spp	6412										
	Petandra	7696			30.11				16.48		1.70	2.27
Deciduous Scrub/Shrub Wetlands	*Cephalanthus*	6069		29.03								
	Spiraea tomentosa	6571	0.49	4.15	26.62				1.95	0.37		5.25
Deciduous Wooded Wetlands	*Fagus grandiflora-Acer rubrum*	6072	4.19	0.12					3.47	3.83		2.04
	Acer rubrum-Carex	6119										
	Acer rubrum-Rhododendron	6156	18.60	9.91			0.80		20.91	0.97	6.72	5.96
	Quercus palustris-Acer rubrum	6185		3.75	6.04	0.23			2.52		0.38	0.69
	Quercus palustris/bicolor-Acer rubrum	6240	2.33	9.65				1.61	5.06	1.05	0.48	0.80
Deciduous Forests	*Quercus primus/velutina-Fagus grandiflora*	6919	45.45	8.02					1.07			13.90
	Fagus grandiflora-Betula lenta	6921	0.29	24.47	2.37			0.11	15.11	2.37	2.05	1.15
Urban	*Fraxinus* spp-*Acer rubrum*	PFS										
	Isolated Basin	PHI										
	Urban Industrial	UI										
	Urban Orchard	UO	1.05	10.03	1.76	0.26	0.57	0.69	12.19	0.88	2.48	0.85
	Urban Residential	UR	4.40	11.62			0.18		59.68	1.23	1.76	0.18

			Deciduous Forests		Urban							
		2002	*Quercus primus/velutina-Fagus grandiflora*	*Fagus grandiflora-Betula lenta*	*Fraxinus* spp-*Acer rubrum*	Isolated Basin	Urban Industrial	Urban Orchard	Urban Residential	Commercial & Services	Urban Transition	Urban Upland
	1932		6919	6921	PFS	PHI	UI	UO	UR	US	UT	UU
	Commercial & Services	US										
	Urban Transition	UT	27.02	5.23					9.59	29.63		20.92
	Urban Upland	UU										

Table 4.11. Transition matrix for the Wilderness Area.

			Herbaceous Wetlands							Deciduous Scrub/Shrub Wetlands		Deciduous Wooded Wetlands				
		2002	*Nuphar*	*Phragmites*	*Typha*	*Pontderia*	Open Water	*Carex* spp	*Petandra*	*Cephalanthus*	*Spiraea tomentosa*	*Fagus grandiflora-Acer rubrum*	*Acer rubrum-Carex*	*Acer rubrum-Rhododendron*	*Quercus palustris-Acer rubrum*	*Quercus palustris/ bicolor-Acer rubrum*
	1932		2386	4141	6153	6191	6362	6412	7696	6069	6571	6072	6119	6156	6185	6240
Herbaceous Wetlands	*Nuphar*	2386														
	Phragmites	4141														
	Typha	6153	1.33	1.33	41.53		12.29	3.99		5.98	1.33	2.99	4.32	12.29	1.33	
	Pontderia	6191														
	Open Water	6362														
	Carex spp	6412														
	Petandra	7696														
Deciduous Scrub/Shrub Wetlands	*Cephalanthus*	6069			10.00					33.33				23.33		
	Spiraea tomentosa	6571	30.77										3.08	36.92		
Deciduous Wooded Wetlands	*Fagus grandiflora-Acer rubrum*	6072			3.23							54.84		40.32		
	Acer rubrum-Carex	6119											55.56	25.93		
	Acer rubrum-Rhododendron	6156	1.00		0.81	0.13		0.06		0.06	0.57	4.65	0.29	79.65	0.48	0.54
	Quercus palustris-Acer rubrum	6185	0.28		8.84		4.70			1.93			0.28	7.46	32.32	
	Quercus palustris/bicolor-Acer rubrum	6240			23.33						0.83			16.67	0.83	16.67
Deciduous Forests	*Quercus primus/velutina-Fagus grandiflora*	6919	1.90								0.40	3.30		33.57		
	Fagus grandiflora-Betula lenta	6921	0.35		5.42		0.29			1.44	0.46	6.98	0.12	12.51	0.98	15.97
Urban	*Fraxinus* spp-*Acer rubrum*	PFS														
	Isolated Basin	PHI			80.00											
	Urban Industrial	UI														
	Urban Orchard	UO	1.70	1.06	20.01	0.20	1.33	0.55	0.08	1.83	2.82	0.98	1.55	19.44	2.44	7.56
	Urban Residential	UR			26.19						8.33			8.33	17.86	1.19
	Commercial & Services	US														

			Herbaceous Wetlands							Deciduous Scrub/Shrub Wetlands		Deciduous Wooded Wetlands				
		2002	*Nuphar*	*Phragmites*	*Typha*	*Pontderia*	Open Water	*Carex* spp	*Petandra*	*Cephalanthus*	*Spiraea tomentosa*	*Fagus grandiflora-Acer rubrum*	*Acer rubrum-Carex*	*Acer rubrum-Rhododendron*	*Quercus palustris-Acer rubrum*	*Quercus palustris/ bicolor-Acer rubrum*
	1932		2386	4141	6153	6191	6362	6412	7696	6069	6571	6072	6119	6156	6185	6240
	Urban Transition	UT												87.10		
	Urban Upland	UU														

Table 4.11, continued

			Deciduous Forests		Urban							
		2002	*Quercus primus/ velutina-Fagus grandiflora*	*Fagus grandiflora-Betula lenta*	Fraxinus spp-Acer rubrum	Isolated Basin	Urban Industrial	Urban Orchard	Urban Residential	Commercial & Services	Urban Transition	Urban Upland
	1932		6919	6921	PFS	PHI	UI	UO	UR	US	UT	UU
Herbaceous Wetlands	*Nuphar*	2386										
	Phragmites	4141										
	Typha	6153		11.30								
	Pontderia	6191										
	Open Water	6362										
	Carex spp	6412										
	Petandra	7696										
Deciduous Scrub/Shrub Wetlands	*Cephalanthus*	6069		33.33								
	Spiraea tomentosa	6571	18.46	9.23								1.54
Deciduous Wooded Wetlands	*Fagus grandiflora-Acer rubrum*	6072	0.81									0.81
	Acer rubrum-Carex	6119		18.52								
	Acer rubrum-Rhododendron	6156	6.04	5.11								0.62
	Quercus palustris-Acer rubrum	6185	1.38	42.82								
	Quercus palustris/bicolor-Acer rubrum	6240		41.67								
Deciduous Forests	*Quercus primus/velutina-Fagus grandiflora*	6919	58.64	0.50								1.70
	Fagus grandiflora-Betula lenta	6921		54.38							0.75	0.35
Urban	*Fraxinus* spp-*Acer rubrum*	PFS										
	Isolated Basin	PHI		20.00								
	Urban Industrial	UI										
	Urban Orchard	UO	0.58	35.21		0.03		0.08	0.58		1.53	0.43
	Urban Residential	UR		38.10								
	Commercial & Services	US										
	Urban Transition	UT	9.68									3.23
	Urban Upland	UU										

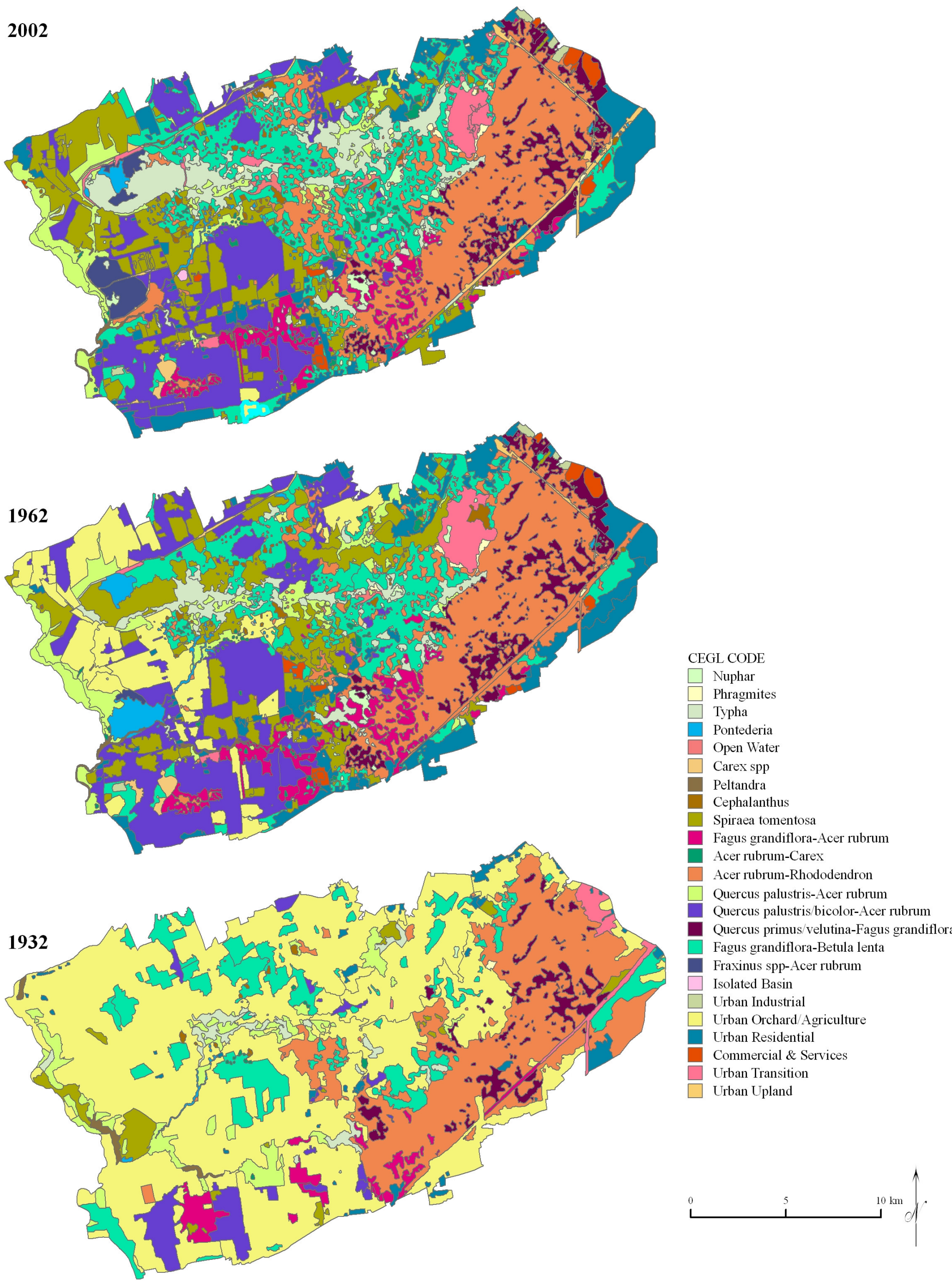
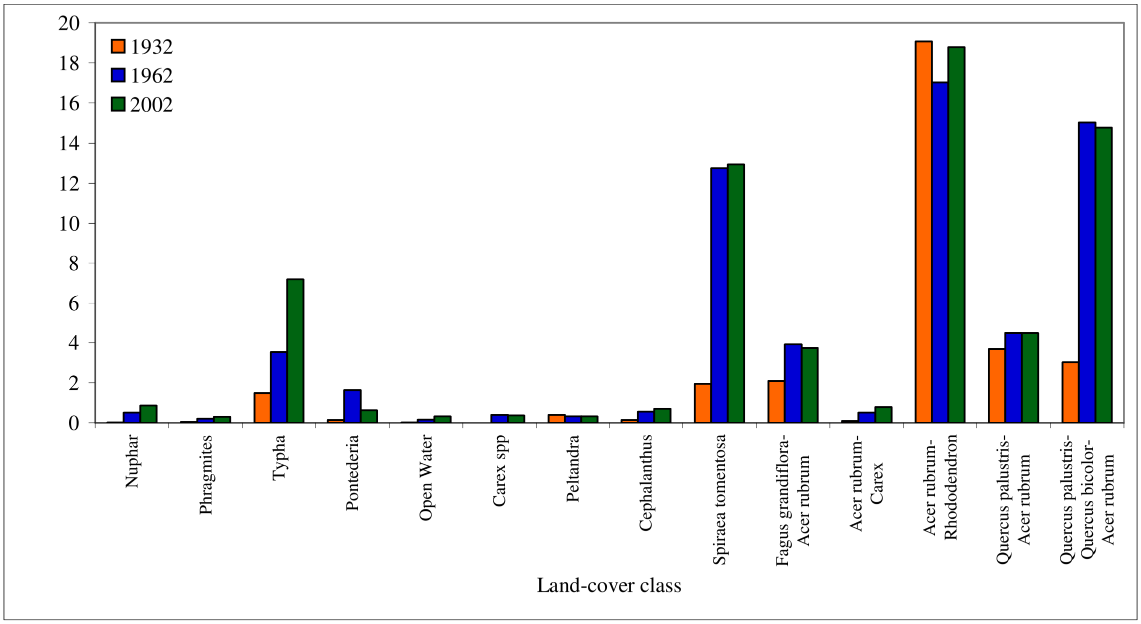


Figure 4.1. Vegetation map of Great Swamp in (a) 1932, (b) 1962, and (c) 2002.

(a)



(b)

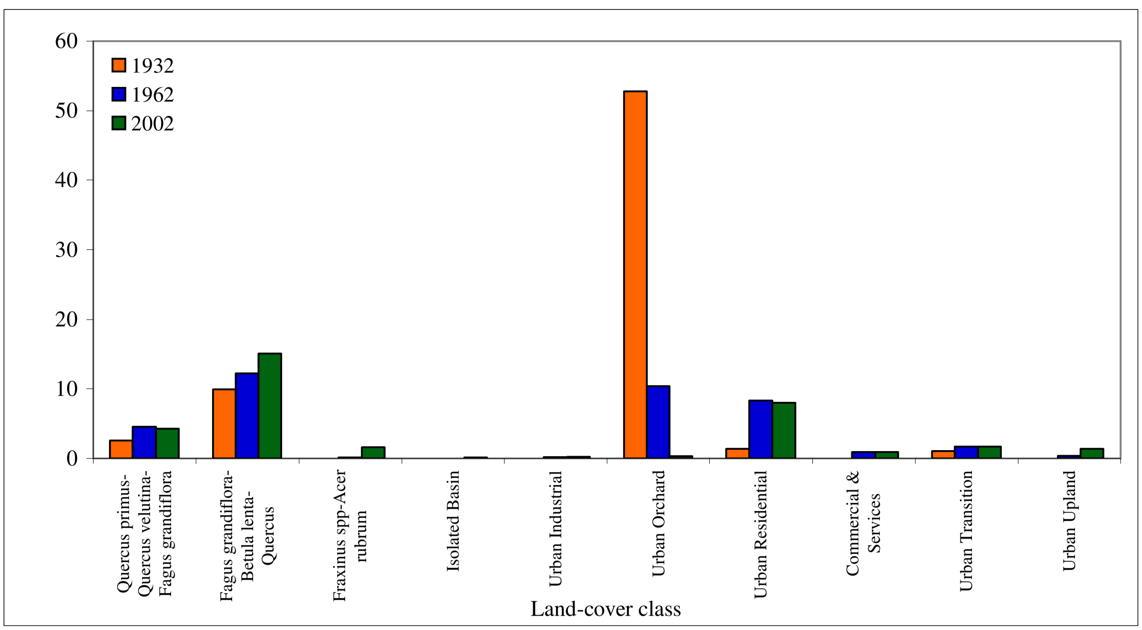
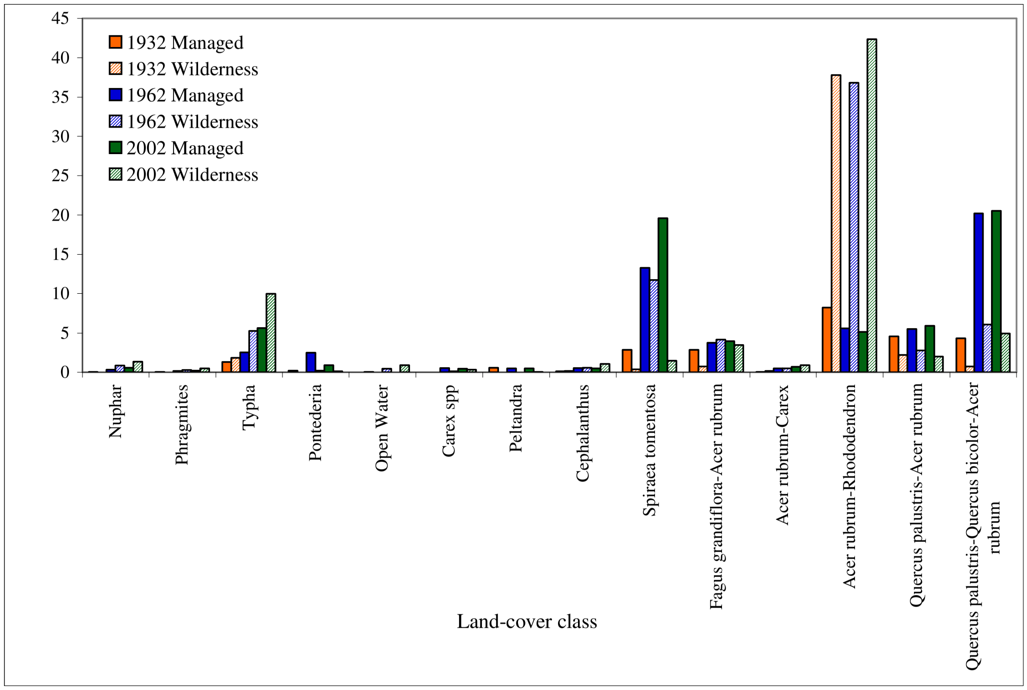
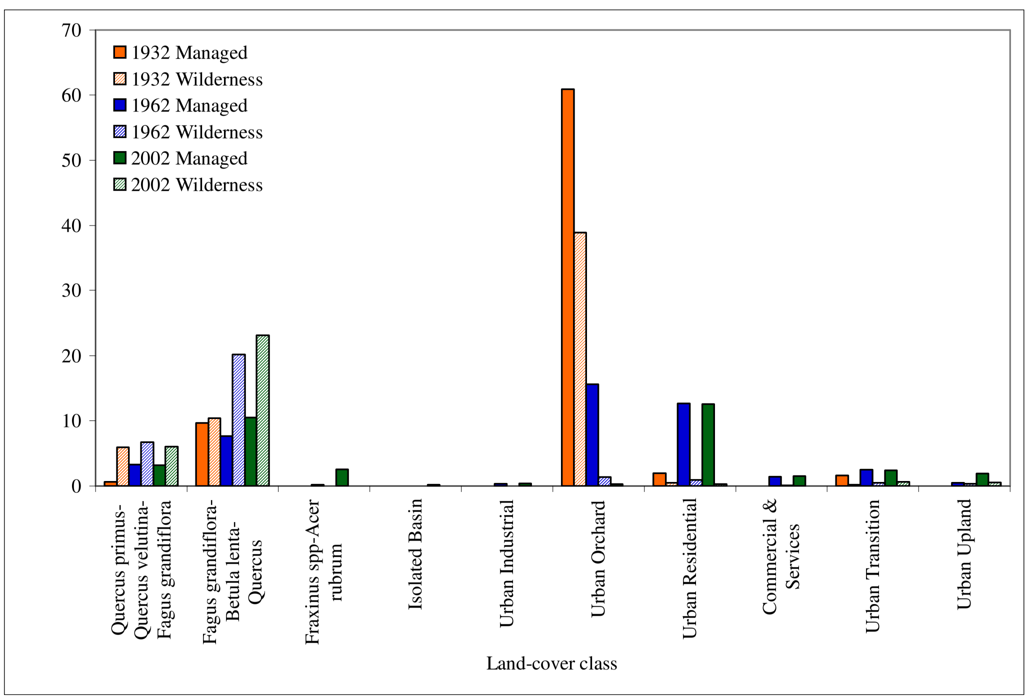


Figure 4.2. Land-cover composition in 1932, 1962 and 2002 for Great Swamp for (a) herbaceous, scrub/shrub and wooded wetlands; and, (b) forests and urban areas.

(a)





(b)

Figure 4.3. Land-cover composition in 1932, 1962 and 2002 for the Managed and Wilderness Areas of Great Swamp for (a) herbaceous, scrub/shrub and wooded wetlands; and, (b) forests and urban areas.

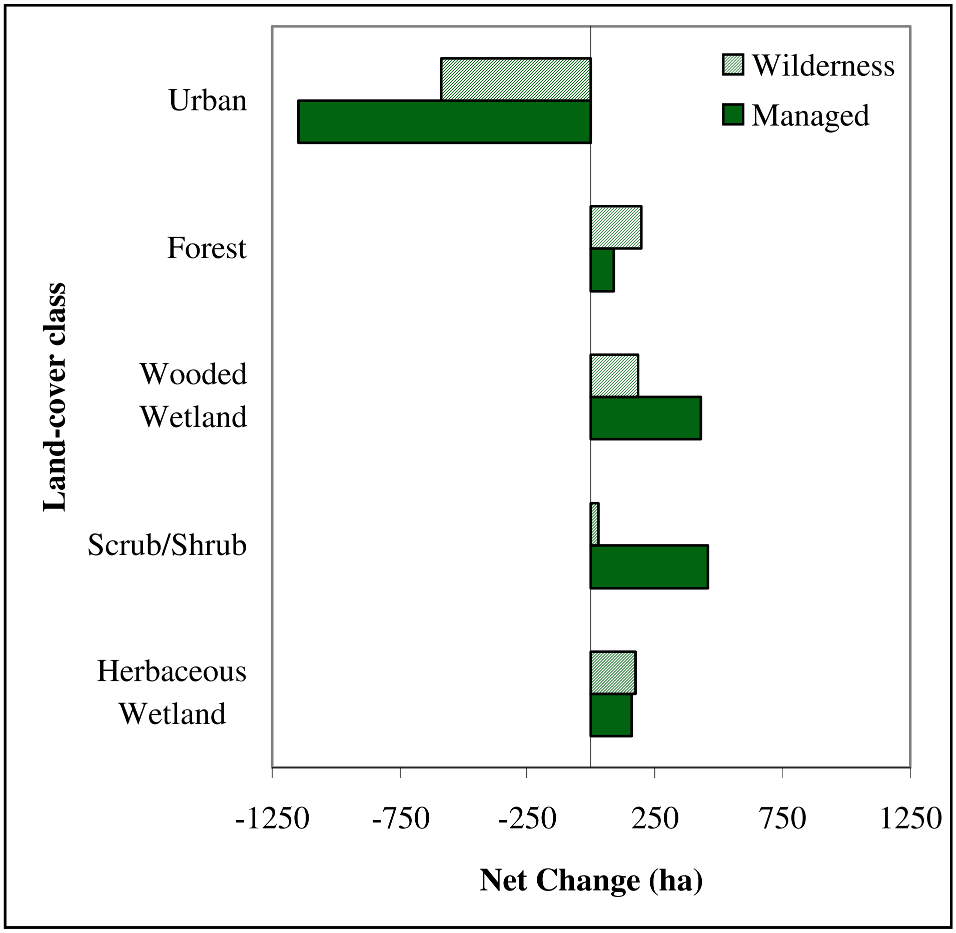


Figure 4.3. Net change in land-cover area between 1932 and 2002 in Great Swamp, as partitioned for the Managed and Wilderness Areas.

5.0 Conclusions

Land-use can be a dominant driving force of landscape pattern. Driving forces acting at broader temporal scales, however, act to constrain and limit land-use and, consequently, indirectly impact current landscape patterns. The space-time hierarchy, as used in this thesis, provides a framework to study landscape change and the dominant forces of change, including land-use. By considering a broader temporal scale, this research recognizes that (1) at the landscape level, multiple drivers, including land-use interact to generate pattern; (2) land-use itself is not a random disturbance; rather, it is inextricably linked to contemporary physical and biological patterns; and, (3) driving forces typically thought of as constant at the micro-scale can impact vegetation patterns at multiple spatial and temporal scales.

5.1 Challenges of reconstructing wetland history

Lakes and ponds have long been used to recreate landscape history. A substantial amount of research has addressed many of the difficulties in interpreting pollen assemblages from open water bodies in forested landscapes such that it is possible to relate pollen percentages to community composition and structure (see Jackson 1994). There is significantly less literature regarding the interpretation of wetland sediment; much of this research focuses on upland communities and not on the wetlands themselves (Tinsley and Smith 1974, Caseldine 1981). However, several studies of surface pollen assemblages have shown that some wetland communities have distinct pollen signatures (Janssen 1973, Bunting et al. 1998).

Wetland development further complicates reconstructing the landscape's history. As a wetland forms, in many instances from an open water body, the pollen source area changes. Large lakes, for example, collect primarily regional pollen while closed-canopy forest hollows collect mostly local pollen. Depending on the trajectory of wetland formation, the pollen source area could shift from regional to local; however, wetland development is rarely linear and the pollen source area can fluctuate between regional and local. Using additional data sources like sediment analysis can help define the wetland state, which then informs the interpretation of the pollen data. For example, sedimentary descriptions may document a terrestrial wetland, perhaps a sedge-dominated peatland. This information focuses the interpretation of pollen data on changes in graminoids and related wetland species.

Finally, nearly 300 years of active wetland destruction in the US have left many states with a fraction of their original wetlands. In the contiguous US, an estimated 53% of wetlands have been destroyed; in New Jersey, 39% of the wetlands that existed in the 1780s have disappeared (Dahl 1990). Although wetland destruction has slowed, remaining wetlands are still threatened by development, hydrological alterations, pollution and adjacent land-use. Even where wetlands persist, they have been substantially altered by human activities over the last few centuries. This intense history has left many wetlands with a compromised stratigraphy, making pollen and macro-fossil analysis unsuitable methods to reconstruct vegetation history. In these instances, alternative methods, including historical document analysis and sediment descriptions can be combined to reconstruct many aspects of a landscape's history.

5.2 Great Swamp landscape patterns

In reconstructing the vegetation and land-use history of Great Swamp, it became apparent that, for a number of physical and biological features, the eastern and western portion of the swamp differed through time (table 5.1). Below, I summarize the physical and biotic patterns and then discuss how this dichotomy informs our understanding of the driving forces shaping the modern vegetation of Great Swamp.

5.2.1 Historical and contemporary spatial patterns

Glacial processes are traditionally thought of as large-scale (both spatially and temporally) and, from the perspective of landscape legacies, are treated as constants. However, glacial and post-glacial events pattern the landscape and, in many instances, leave a legacy that greatly influences subsequent processes and, indirectly, current landscape patterns. In Great Swamp, glacial retreat and the subsequent glacial and post-glacial lakes created a landscape that was not uniform in the accumulation of post-glacial deposits. While post-glacial deposits in Great Swamp are primarily mineral (Qst) and organic (Qs), the distribution of these deposits is clearly patterned on an east/west basis. The eastern swamp is composed primarily of organic deposits with small patches of mineral deposits dotted across the landscape. In the west, several large patches of mineral deposits dominate, while patches of organic deposits are scattered throughout.

It is perhaps not surprising, then, that contemporary soils of Great Swamp display a similar pattern. The eastern swamp is composed primarily of Carlisle Muck (Cm) with scattered patches of Pompton Sandy Loam (PtB). The arrangement of soil patches across the landscape greatly resembles the pattern seen in post-glacial deposition. The western swamp is composed of several large patches of Parsippany Silt Loam (Pk), with small patches of several different soil types. Unlike the eastern swamp, post-glacial deposition patterns do not resemble soil patterns, nor does either feature resemble modern vegetation patterns in the west. In the east, soil and post-glacial deposition generally coincide well with vegetation.

5.2.2 Land-use patterns

At the time of EuroAmerican settlement, it seems likely that vegetation also differed between the east and west. Early maps labeled only the eastern swamp as Great Swamp. Exactly why such a distinction was made is unknown; it seems likely that differences in community structure played a role. Surveyors recorded distinct habitats in Great Swamp. The notes of John Reading clearly referred to a more open habitat, one with fewer trees, while James Dunham's survey described a forested wetland. Mapmakers would have termed a wooded wetland a swamp but might not have given the same designation to a scrub/shrub or open habitat. Because many maps were economically motivated, it follows that the timber-rich land of the east would have been marked, while the western swamp, with scrub/shrub and open communities, would have been better suited to agriculture (and was therefore not considered part of the swamp). (It may also be true that, at the time the maps were drawn, the west had already been settled and widely cleared. However, this is contradicted by local histories that record the settlement timeline). In fact, later maps, deeds and local histories show that settlers cleared and farmed the west, while primarily using the eastern swamp as a source for timber and game. Mounting population pressures through the 19th century caused agriculture from the west to expand into the east, but the widespread clearance and farming of the west never dominated the east.

Management practices in the latter half of the 20^{th} century closely mimic historic land-use. Although the initial US FWS management plan treated the whole of Great Swamp as an actively managed refuge, continued development pressures prompted managers and citizens to seek further protection for the land. The Wilderness Act of 1964 offered a solution: definite and perpetual protection for Great Swamp but with a caveat: people were required to take a passive role in the management of the land. As a result, managers put forth only a portion of the swamp, the eastern area, for protection as a Wilderness Area. The selection of this area was based, in part, on preexisting conditions; this region, also known as the M. Hartley Dodge Area was already a Natural Landmark. In 1968, Congress formally declared the eastern region of Great Swamp a Wilderness Area. Nearly 40 years later, Great Swamp continues to be bifurcated into a Managed and Wilderness Area.

5.2.3 Contemporary landscape patterns

While the landscape of Great Swamp is diverse, the distribution of habitats is neither random nor uniform. Red-maple swamps clearly dominate the eastern landscape and are found primarily on Carlisle muck soils. Vegetation patterns in the east mimic soil and post-glacial deposition patterns. In the west, pin-oak swamps dominate, especially on formerly farmed lands. Vegetation in the west does not mimic the pattern of either post-glacial deposits or soil.

These physical and biotic patterns demonstrate the interconnectedness of humans and the environment through time. The clear dichotomy between the east and west makes it possible to compare the two sides through time and allows the integration of landscape ecology and history (Russell 1997, Bürgi and Russell 2001). In this manner, we can better understand the forces that patterned historic landscapes and we can determine those forces that are still important to today's landscape.

5.3 Great Swamp driving forces

Climate is an important pattern generator at the macro-temporal scale. Pollen data from Great Swamp capture some climatic fluctuation over roughly the last 10,000 years; however, the pollen signature does not clearly and consistently record climate change and subsequent local vegetation shifts. Some regional response to climate change is evident, especially further back in time. This is an artifact of an open community structure that captured regional data. Subsequent changes in community structure, succession from an open lake to a scrub/shrub or wooded wetland with a closed canopy, limited the pollen source area to more local sources, which reflect primarily local vegetation changes. As a result, indicators of climate change are largely missing from the pollen data. Further, it seems likely, given the size of Great Swamp, that the impact of climate on vegetation was uniform across the landscape. At this scale, it is unlikely that climate was a significant driving force of vegetation change.

Wetland development and changing hydrology, as shown by pollen and sediment data, played a major role in the diversity of habitats found in Great Swamp. A comparison of the pollen and sediment data from the two cores documents non-linear wetland development that was not uniform between each of the coring locations. These site-specific histories represent community dynamics that were probably common across Great Swamp; that is, each location responded individually to hydrologic changes and different vegetation communities resulted. Hydrology (more specifically, changes in hydrology) clearly drove community succession at Great Swamp.

The geologic history, especially the sequence of lakes and post-glacial deposition, created a bifurcated template at Great Swamp. This has influenced subsequent environmental patterns, including peat formation, soil development, community structure and composition, and human land-use. In the eastern swamp, post-glacial deposition, soils and vegetation patterns align well (figure 5.1); this is not the case in the west. In fact, patterns in the west appear to be independent of each other, indicating the importance of another driving force.

Land-use was not uniform across Great Swamp. In the west, transformation of the landscape for agriculture through clear cutting, ditching and plowing created a potential for permanently altered soils, hydrology and resulting vegetation. Eastern land-use, primarily logging and hunting, was far less intense. The legacy from each of these land-uses would differ in the impact on landscape patterns. Analysis of 20th century air photos documents the differences in modern vegetation communities of the eastern and western areas of the swamp. Both regions support a number of habitats, but the dominant habitat differs. A permanently flooded forest dominates the east (*Acer rubrum-Rhododendron*) while a seasonally flooded forest that succeeds on abandoned fields dominates the west (*Quercus palustris-Acer rubrum*). A qualitative comparison of the vegetation, soil and geological maps shows that vegetation patterns in the east generally mimic soils and geology; in the west, current vegetation more strongly follows historic land-use patterns.

Land-use in Great Swamp was not random. The contemporary plant communities as well as the quality of peat and soil influenced EuroAmerican activities. Driving forces responsible for those initial patterns, especially geology, are to some extent indirectly responsible for current landscape patterns. In the western swamp, the intense land-use has become an overriding influence on current vegetation; patterns in the east still appear to be linked to driving forces operating at longer temporal scales.

As put forth by Turner (2005), understanding the relative importance of multiple driving forces, and their roles at multiple scales is an important yet challenging task facing landscape ecologists. Many studies focus on a single, dominant driver rather than on the multiple drivers that interact to generate spatial patterns. The approach proposed by Bürgi et al (2004) provides one method to explicitly address and model multiple drivers. Using this approach, it is possible to model the relationships between several driving forces and their collective impact on vegetation change at Great Swamp (figure 5.2). In this model, the hexagon defines the study area, that is, Great Swamp, while the cylinder defines the landscape element of interest, in this case, vegetation. The focus on two distinct temporal scales is reflected in the two thicker arrows emanating from the vegetation cylinder. The remaining shapes each represent driving forces, where arrows reflect a causal relationship. For example, the arrow from geology to hydrology indicates the impact of geology on hydrologic patterns in Great Swamp. Climate sits directly outside of the defined study site. This is because climate is very much an exogenous force, occurring outside the realm of this study but nevertheless having an impact of vegetation patterns.

This model makes clear the importance of multiple driving forces acting at two distinct scales in shaping vegetation patterns. However, it also demonstrates a relationship between the driving forces that could be considered a hierarchy. A nested hierarchy defines any system of interconnections wherein higher levels constrain lower levels to various degrees, depending on the time constraints of the behavior (Allen and Starr 1982, Urban et al. 1987, Turner et al. 2001). Levels are distinguished by differences in the rates or frequencies of their characteristic behaviors. Typically, landscape ecologists focus on the hierarchy of space, but temporal hierarchies also exist. In Great Swamp, a nested hierarchy occurs among the driving forces acting on vegetation patterns (figure 5.3). Geological processes, acting across the meso (and even the macro-temporal scale, though that was beyond the scope of this study) underlie, constrain and interact with forces operating over shorter time scales, including hydrology and soil formation (and even human activity, though this is mediated by hydrology and soils). This is seen in Great Swamp by the patterns of underlying geology and soils, which vary on a distinct east/west basis. Further, in the east, patterns of geology and soils align well (figure 5.1) At the next level in this hierarchy, hydrology and soils interact with each other and together they constrain human activity. Again, this is seen in the distinct settlement patterns that vary on an east/west basis. Ultimately, these three levels of driving forces result in the vegetation patterns seen today.

This integrated approach to reconstructing landscape addresses many of the challenges set forth by Turner (2005). Not only has this study focused on processes rather than patterns through time, but it has also focused on multiple driving forces at multiple temporal scales rather than a single, dominant force. Further, by using a systems approach to model the driving forces it became apparent that the driving forces could be modeled as a nested hierarchy.

5.4 The importance of considering multiple scales

The recognition that current land-use will influence future landscapes has prompted increasing interest in understanding landscape legacies. Because land-use legacies span decades and centuries, researchers must explicitly address the concept of scale (i.e. What spatial area is of interest? What temporal scale is appropriate?). The temporal-spatial hierarchy provides a framework to bound research questions and allows a focus on a select set of pattern drivers.

Land-use is neither a random nor an independent process. Humans act in response to and in concert with their environment. Rigidly limiting a study's temporal scope can overemphasize the role of human activity in landscape patterning. As 21st century ecologists, we are well aware that humans are modifying our environment (Vitousek et al. 1997). However, this realization often biases research to the extent that we ignore driving forces operating at broader temporal scales. Driving forces of change, including land-use, interact across temporal scales to influence landscape patterns (Black et al. 2003, Bürgi et al. 2004). Taking a multi-scalar approach to questions involving land-use enables a more complete understanding of the driving forces patterning current and future landscapes.

Results from Great Swamp demonstrate the importance of considering multiple scales when recreating the ecological history of a landscape. At the micro-temporal scale, land-use is an important driving force of current vegetation patterns in Great Swamp, especially in the west where modern vegetation strongly reflects past land-use. Glacial retreat and the resulting geology and hydrology are clearly dominant driving forces at the meso-temporal scale.

For site-specific research, a focus on individual driving forces of change can be appropriate (Christensen 1989, Bürgi et al. 2004). However, at the landscape or regional scale, research must address multiple driving forces, including human activity, and must understand the connection between those driving forces (Bürgi et al. 2004). This approach is critical to understanding the dynamics of change at Great Swamp where land-use was clearly patterned on the contemporary biotic and abiotic template. After interacting with people for nearly 300 years, the landscape of Great Swamp still exhibits some patterns that are tied to broader forces.

What can this research tell us about the future of Great Swamp? In a word: resilient. Over three hundred years of human activity have not been without consequence on the landscape. Community composition continues to reflect land-use; a similar pattern may also be true for soils and microtopography. However, successional dynamics have resulted in the reestablishment of a landscape of diverse wetlands. Current wetlands may not be exact duplicates of their pre-European counterparts, but they are certainly similar and may provide many of the same ecosystem functions. These dynamics, combined with the cultural and legal value placed on Great Swamp makes it plausible to expect the continuation of Great Swamp as a diverse landscape that supports a myriad of wildlife.

As this study of Great Swamp has shown, landscapes are complex systems of interactions and interdependencies. Such complexity makes it challenging to study and conceptualize landscape patterns and processes; however, carefully and appropriately defining both the temporal and spatial scales can simplify research questions. In this manner, we can integrate research methods to identify the driving forces of change and uncover the links between multiple driving forces and between people and the land in order to understand the forces driving current and future landscape patterns.

Table 5.1. Driving forces and landscape characteristics that exhibit distinct east/west patterning in Great Swamp.

Driving Force	Temporal Scale
Geology	Macro & Meso
Soil	Meso
Peat	Meso
Land-use	Micro

Response Variables
Habitat diversity
Dominant vegetation community

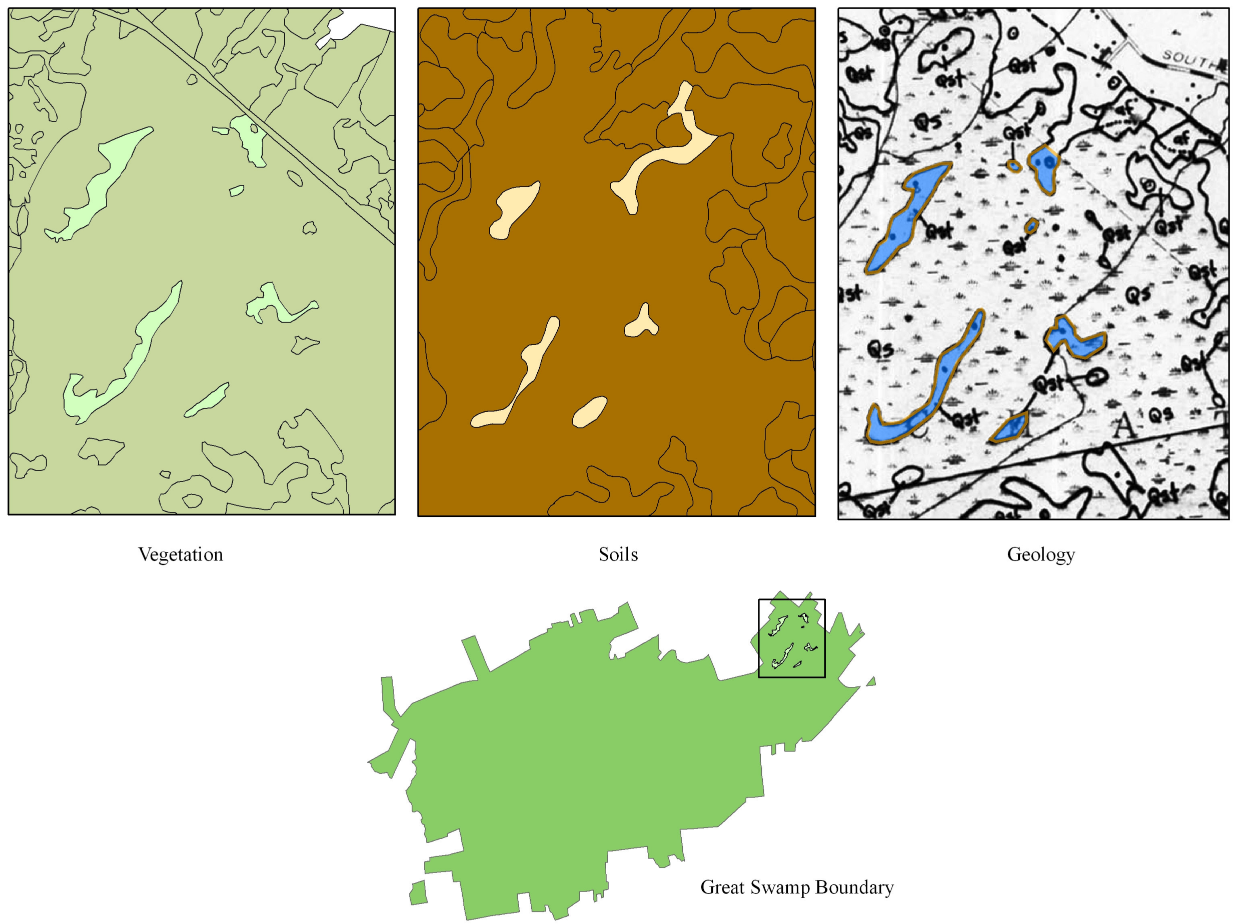


Figure 5.1. Comparison of three landscape characteristics in the Wilderness Area of the Great Swamp National Wildlife Refuge. Note the similarities in patch shape for vegetation, soil and geology.

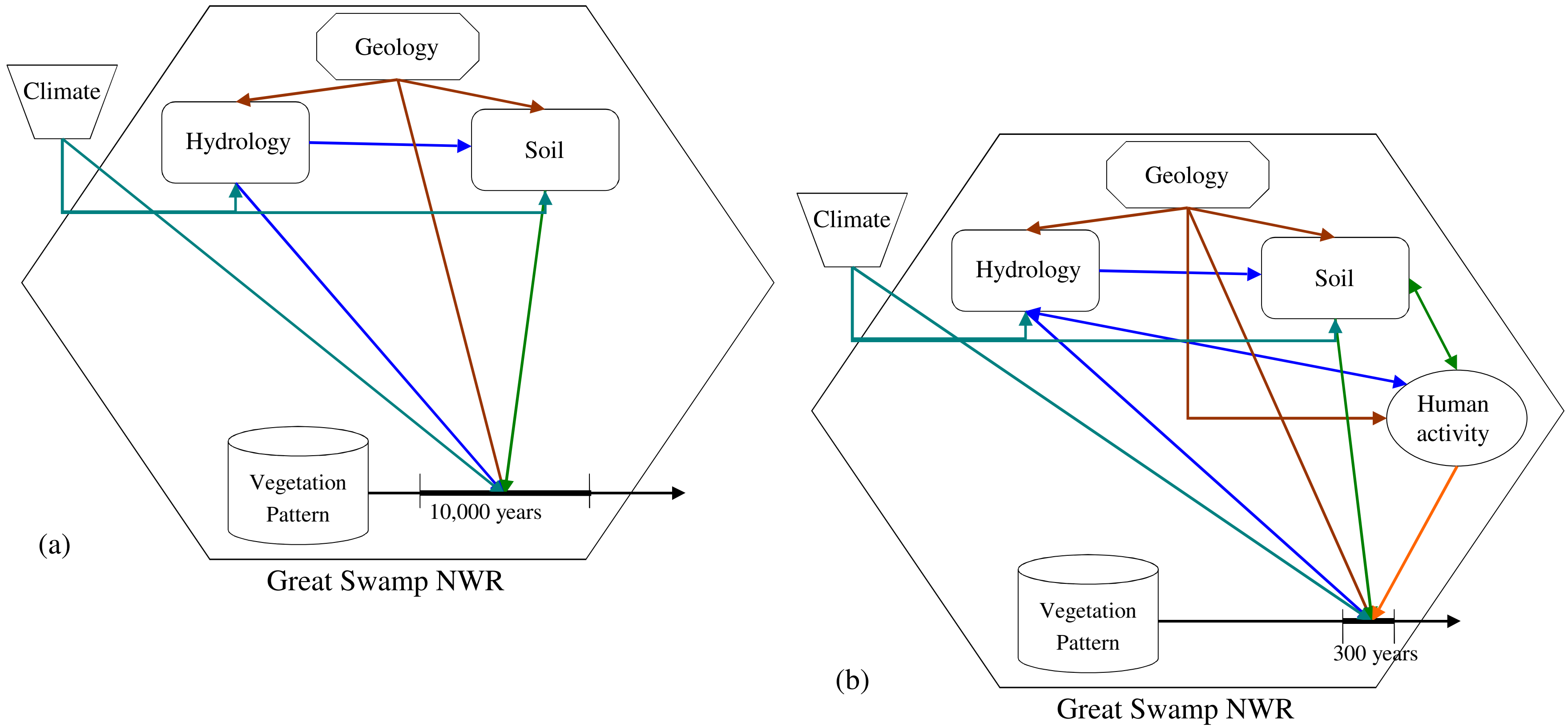


Figure 5.2. Model of driving forces important to Great Swamp vegetation patterns over (a) the last 10,000 years and (b) the last 300 years.

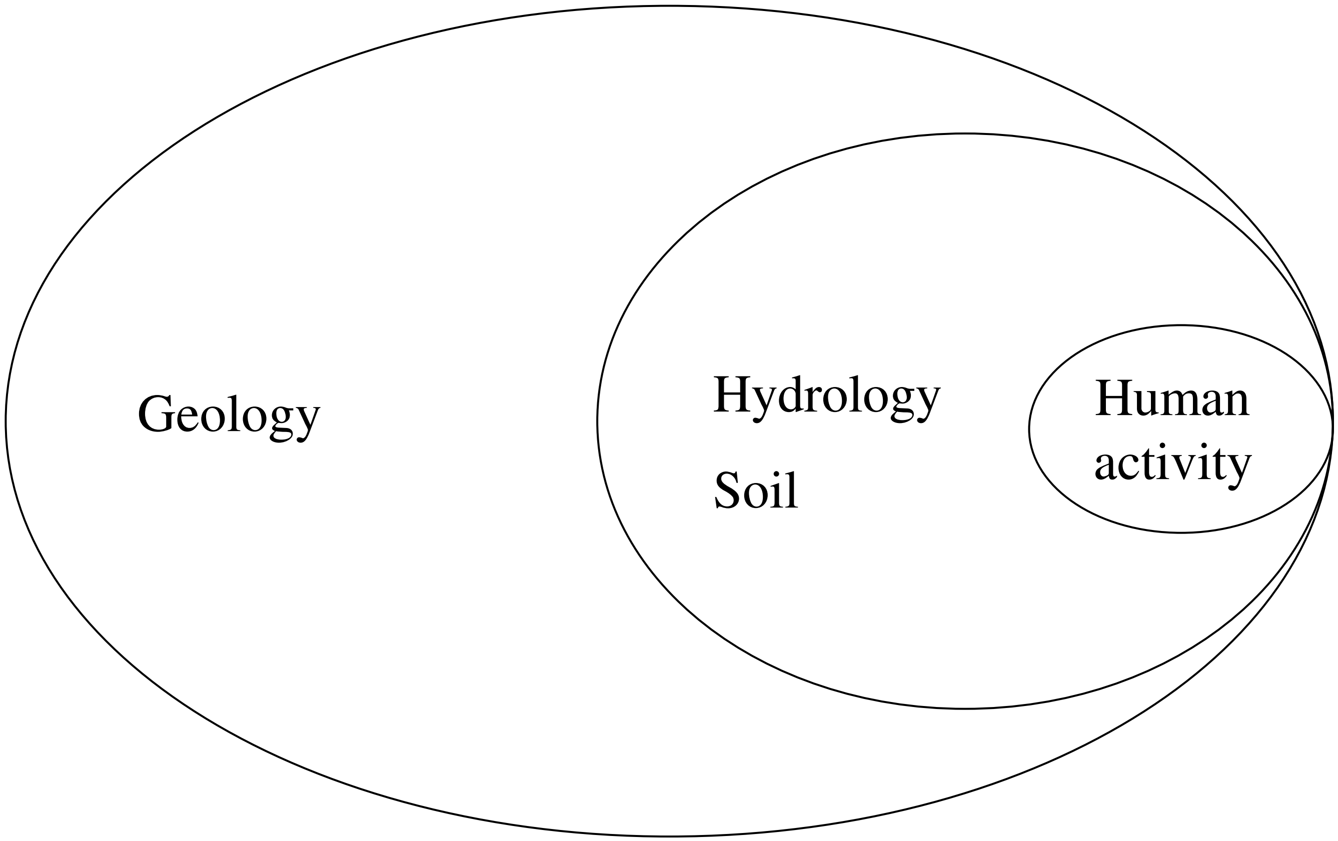


Figure 5.3. Hierarchy of driving forces patterning vegetation at Great Swamp. Larger spheres constrain smaller spheres.

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Appendix A: Raw pollen data for the highbush blueberry and red maple swamps.

Highbush blueberry	Depth (cm)									
Species	**2**	**7**	**15**	**24**	**30**	**40**	**52**	**60**	**67**	**74**
Acer rubrum	6	1	1	2	16		3			
Acer saccharum	65	1	45	5		15	3	2	10	1
Alismataceae					3			1		1
Alnus	17	30	65	47			17	23	14	30
Ambrosia	52	30	37	3	12	1	10	1	2	
Asteraceae	4	14	28	13	13	8	10	4	5	6
Betula	27	15	17	13	1	5	14	25	15	38
Carpinus								3		7
Carya	1	3	1	5		1	3	5	3	
Castanea	9	4	2		2	2	5	1	1	
Chenopodiaceae					1		2			
Cornus					1					
Cupressaceae	2	2			40	5	20	12	2	2
Cyperaceae	7	13	30	12	21	8	20	8	7	11
Ericaceae		9	12	19	2	1	9	2	5	2
Fabaceae			20		6					
Fagus	2						3		1	
Fraxinus	11	2	3		2	1	4	1		
Ilex		13	2	7	23	4	7	3	2	
Juglans		2		3	1					
Larix										4
Liquidambar	22	1	1	1	4		4			
Nympha	2				1		3			
Nyssa						2	1			
Onagraceae										1
Picea					3	4	3	5	7	9
Pinus	19	9	26	35	18	99	61	68	112	63
Poaceae	33	29	77	66	77	37	21	29	49	38
Polygonum				1	1					
Populus							1			
Potamogeton					1					
Quercus	60	156	86	151	73	102	60	49	75	43
Rhamnus		64		5	3	9			2	

Highbush blueberry	Depth (cm)									
Species	**2**	**7**	**15**	**24**	**30**	**40**	**52**	**60**	**67**	**74**
Rhus		2				2	1		3	
Rosaceae		12		1		5		2	2	
Rumex	1				7		13			
Salix	4	5	2			3	2		2	3
Schropulareaceae	1							1		
Tilia		1			1					
Tsuga		1	9	9	10	12	7	13	14	9
Typha	5	2	9	2	10	6	2	2	7	3
Ulmus	10	2	3	1		2	1		2	
Vitis		8					1			
monolete spores	132	91	234	243	403	376	79	119	172	40
trilete spores	77	7	11	12	13	8	11	6	4	6
Unknown 2	4		1					1		
Unknown 4	3		3					1		
Unknown 6	8		5					2		
Unknown 9	2									
Unknown 11	1									
Lycopodium spike	70	33	50	18	17	11	31	33	17	31
Charcoal	83	46	80	46	104	34	46	133	65	29

Red Maple	**Depth (cm)**																									
Species	**10**	**15**	**20**	**24**	**30**	**35**	**40**	**45**	**51**	**55**	**60**	**65**	**70**	**80**	**85**	**90**	**95**	**100**	**105**	**110**	**115**	**120**	**125**	**130**	**135**	**140**
Acer rubrum	3	5	1	1	1		2	2	4				2	2			1	1								
Acer saccharum	8	7	5	9	12	5	4	26	18	22	13	21	35	37	19	43	15	23	25	33	20	22	16	7	4	6
Alnus	60	75	93	29	63	172	74	76	47	45	75	48	58	24	23	25	35	20	18	18	10	28	51	44	15	115
Ambrosia	59	59	19	25	11	2	3		17	4		2		4	1	5	5	2		3	3	2	6		1	2
Asteraceae	5	4	5	2	3	3	6	5	4	3	2	4	4	5	3	2	8	6	4	8	4	3	2	2		4
Betula	6	19	8	10	8	7	6	4	3	4	1		2	5	9	12	38	4	8	1	4	7	30	34	24	27
Caprifoliaceae													5	2	1		1		2		1			2		
Carpinus																										5
Carya	2	1	4	3		3		2		2		2	2	1				1	10		1	2		2		
Castanea	3	7	19	8	12	2	2		7		4			3	1	2	1	4	4		3	5				1
Ceanothus									1																	
Cercis				1	1		1							17							3	10				

Red Maple												**Depth (cm)**														
Species	**10**	**15**	**20**	**24**	**30**	**35**	**40**	**45**	**51**	**55**	**60**	**65**	**70**	**80**	**85**	**90**	**95**	**100**	**105**	**110**	**115**	**120**	**125**	**130**	**135**	**140**
Chenopodiaceae		4									1				1					1						
Cornus													1													
Cupressaceae	2		6		10		9		6	1	5		4	8	2	7	2	13		2		2				
Cyperaceae	4	4	2	11	10	2	11	5	8	11	20	7	5	4	5	12	4	16	11	6	3	7	3	1	4	1
Diospyros						1																				
Elaeagnus									1																	
Ericaceae	4		3	3	3		1		1	1	1	1						2			1	1	1	1	6	1
Fabaceae	0	0	0	5	0	4	0	4	0	3	4	0	0	1	3	0	1	0	4	0	0	0	0	0	0	0
Fagus		7	1	3	3	1	4	2		2	4		4	3	3	11	2	2		1		3	1			
Fraxinus	5	1		2	9	1			3		1	2		3			2				3			1		
Galium		1																								
Gentiana						1																				
Ilex	1	3	8	9	25	34	49	47	30	66	35	27	4	4	2	4	5	3	6	4	7	3	3	3	20	4
Juglans		2		2				1														1				
Liquidambar	1	4		3	2			2	1	1		2		1	2		2	2	1							
Liriodendron	1																									
Lobelia					2						5			7						3						
Malva											2		1			4										
Nymphaceae	1	3	0	7	0	0	0	1	1	0	0	0	0	0	0	1	5	0	0	0	0	0	13	3	0	5
Nyssa	4		2			3		1	7	3		1			2			2	6	5	5					
Physalis														1												
Picea																							1	2	1	9
Pinus	19	6	16	17	35	5	23	14	14	18	12	16	23	25	42	36	96	24	28	17	27	56	110	116	178	101
Plantago	4		5																							
Platanus	21		42		8				1							2										
Poaceae	30	44	19	45	72	14	34	25	25	15	47	24	21	25	24		16	6	25	9	37	21	16	21	25	22
Polygonum				1											1											
Populus									1														1			
Potamogeton			3	45	1				9			1		4									3			1
Quercus	100	77	68	84	76	44	116	79	83	84	139	83	112	115	106	94	54	115	105	139	139	117	41	41	32	17
Ranunculus													1													
Rhamnus		2			1		1		3	3	4	4	2	3	13		1		8	5	4	6	4	1		
Rhus	1							3	1						4		4	1		2	2		1			
Rosaceae	0	0	0	0	1	3	6	0	5	0	4	0	21	84	0	60	0	3	0	2	0	1	5	0	0	0
Rumex	9		1		2		4	1	7	1									3		1	8				
Salix	3	2	1	1	11	3	3	3	15	2	2	10	23	24	14	4	11	33	24	28	15	14	5			2

Red Maple													**Depth (cm)**													
Species	**10**	**15**	**20**	**24**	**30**	**35**	**40**	**45**	**51**	**55**	**60**	**65**	**70**	**80**	**85**	**90**	**95**	**100**	**105**	**110**	**115**	**120**	**125**	**130**	**135**	**140**
Sambucus																			4	4						
Sanicula					1																					
Saxifragaceae														1												
Solanaceae	1																									
Tilia	2								2				1	1		2			1		1					
Tsuga	12	9	7	8	5	4	16	5	8	17	15	5	8	11		18	8	13	13	12	14	19	14	13	18	
Typha	1	15	10	40	94	3	11		12	3	3			5		1	1	1	1	1	3		2	2		
Ulmus	2	5		2	2	2		1	1	3			3	2	1	2			5		3	2			3	2
Verbena	1							1																		
Viola	1				4	13	1	1		2	4	5	3	1	7	2	6		18		14	6				1
Vitis				1	2	2		10		3	2	8	3		15	2			24	9		8	1	1		
monolete spores	33	22	41	52	73	56	143	74	84	97	156	88	100	63	225	202	167	127	137	66	190	131	129	49	99	29
trilete spores	21	1	9	8	11	6	7	5	12	6	6	4	5	16	4	12	11	26	9	12	5	8	4	37	10	11
Ophioglossum																										
Osmunda																										
Unknown 2, 22					2																					
Unknown 1							1																			
Unknown 2, 24									1																	
Unknown 1, 26													1													
Unknown 2, 30																				6						
Unknown 3, 30																				2						
Unknown 4, 30																				3						
Lycopodium	94	59	50	64	104	21	56	40	84	35	26	40	21	24	20	26	14	23	22	25	17	35	25	25	10	5
Charcoal	134	79	95	73	92	27	103	46	70	38	42	64	34	66	38	123	38	78	49	108	67	52	29	10	28	9

Appendix B: Raw sediment data for the highbush blueberry and red maple swamps.

Blueberry	Physical properties[1]				Humification[2]	Composition[3]															
Depth	**Nigror**	**Stratifactio**	**Elasticitas**	**Siccitas**	**---**	**Sh**	**Tbs**	**Tl**	**Th**	**Dl**	**Dh**	**Dg**	**Ld**	**Lso**	**Lc**	**Lf**	**As**	**Ag**	**Ga**	**Gs**	**GG**
2 cm	4				too dry		1		2		1										
7 cm	4				not enough																
15 cm	4				too dry		1		1				2							+	
24 cm	4				too dry		2		1										1	+	
30 cm	4				not enough																
40 cm					not enough																
52 cm					too dry		1						3								
60 cm					too dry		1						3								
67 cm					too dry								2						2		
74 cm					too dry								2						2	+	

Red Maple	Physical properties[1]				Humification[2]	Composition[3]															
Depth	**Nigror**	**Stratifactio**	**Elasticitas**	**Siccitas**	**---**	**Sh**	**Tbs**	**Tl**	**Th**	**Dl**	**Dh**	**Dg**	**Ld**	**Lso**	**Lc**	**Lf**	**As**	**Ag**	**Ga**	**Gs**	**GG**
10cm	4		1	2	1		2		1		1										
15cm	4		1	2	too dry		1	1	1		1										
20cm	4		1	2	1		2		2												
24cm					not enough																
30cm	4				too dry		2	1											1		
35cm			2	2	not enough																
40cm	4		2	2	1		3		1												
45cm	4		2	2	1		2		2												
51cm	4		2	2			2		1										1		
55cm	4		2	2			3				+		1						+		
60cm	4		2	2	2		3				1										
65cm	4		1	2	2		3				1								+		
70cm	4		1	2	3		3						1								
80cm	4		1	2	3		3						+						1		
85cm	4		1	2	3		2						1						1	+	
90cm	4		1	2	3		2						1						1		
95cm	4		1	2	3								3						1		
100cm	4				too dry								3						1		
105cm	4		1	2	3		1						3								
110cm	4		1	2	3		1				1		1						1	+	

Red Maple	Physical properties[1]				Humification[2]	Composition[3]															
Depth	**Nigror**	**Stratifactio**	**Elasticitas**	**Siccitas**	**---**	**Sh**	**Tbs**	**Tl**	**Th**	**Dl**	**Dh**	**Dg**	**Ld**	**Lso**	**Lc**	**Lf**	**As**	**Ag**	**Ga**	**Gs**	**GG**
115cm	4		1	2	3		1						2						1		
120cm	4		1	2	3		1						2						1		
125cm	3		1	2	3		1						3						1		
130cm	3		1	3	3								3						1		
135cm	3		1	3	too dry								4						+		
140cm	3		1	3	3								4						+	+	

[1]Sedimentary analysis was completed some time after the core had been extracted. As a result, it was not possible to measure elasticitas or siccitas.
[2]As above, the condition of the core did not generally lend itself to a thorough or confident measure of humification.
[3]Composition class definitions as follows:

Sh	Substantua humosa	
Tbs	Turfa	Moss peat
Tl	Turfa	Wood peat
Th	Turfa	Herbaceous peat
Dl	Detritus	Fragments of wood, bark, etc, >2 mm
Dh	Detritus	Fragments of herbaceous plants
Dg	Detritus	Fragments of wood and herbaceous plants, <2 mm
Ld	Limus	Lake mud with plant and animal fragments
Lso	Limus	Lake mud with diatoms
Lc	Limus	Marl
Lf	Limus	Iron oxide
As	Argilla	Clay
Ag	Argilla	Silt
Ga	Grana	Fine sand
Gs	Grana	Course sand
GG	Grana	Gravel

Curriculum Vita

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