Mannahatta: An Ecological First Look at the Manhattan Landscape Prior to Henry Hudson

Eric W. Sanderson[1,*] and Marianne Brown[2]

Abstract - The British Headquarters Map, circa 1782, provides a remarkable window onto the natural topography, hydrology, and land cover of Manhattan Island, NY, before extensive urbanization. Manhattan formerly hosted a rugged topography watered by over 108 km of streams and at least 21 ponds, flowing in and out of wetlands that covered nearly 10% of the island in the late 18th century. These features are largely representative of the landscape prior to European settlement. We used ecological features interpreted from the British Headquarters Map, and additional historical, ecological, and archeological information, to hypothesize about the ecosystem composition of the pre-European island. We suggest that 54 different ecological communities may have once been found on the island or in nearby waters, including chestnut-tulip tree forests, Hempstead Plains grasslands, freshwater and tidal marshes, hardwood swamps, peatlands, rocky headwater streams, coastal-plain ponds, eelgrass meadows, and culturally derived ecosystems, such as Native American village sites and fields. This former ecosystem mosaic, consisting of over 99% natural areas, stands in sharp contrast to the 21st-century state of the island in which only 3% of its area is dedicated to ecological management.

Introduction

To students of the natural history of New York City, an interest in the past ecology of the local region is almost inevitable because the modern cityscape is so markedly different from the historical landscape (Hornaday 1909, Kieran 1959, Shorto, 2004). Although striking remnants of tidal wetlands and upland forests remain, these fragments just hint at the remarkably abundant natural environment in which this archetypical city has been constructed (Barlow 1969). Early Dutch and English accounts overflow with fantastic descriptions of the abundant wildlife, magnificent park-like forests, and extensive marshlands of Manhattan Island and neighboring areas (Table 1). Unfortunately, nearly 400 years of development have rendered this earlier abundance as difficult to imagine to us as perhaps our modern roads, skyscrapers, and wealth would be to those first European colonists and their Native American neighbors.

Fortunately, the past natural communities of Manhattan Island are not totally lost, as a combination of historical resources, ecological understanding, and modern geographic tools can be applied to the rich ecological and historical research resources of New York to understand the past natural

[1]Living Landscapes Program, Wildlife Conservation Society, 2300 Southern Boulevard, Bronx, NY 10460. [2]Department of Geography, Hunter College, City University of New York, 696 Park Avenue, New York, NY 10021. [*]Corresponding author - esanderson@wcs.org.

Table 1. Selected 17th-century descriptions of Manhattan Island from Dutch, French, and English sources. Translations are reprinted from Jameson (1909). Notes in brackets are provided by the authors. Year = year described.

Description	Year	Source
"When I came on shore, the swarthy natives all stood and sang in their fashion. Their clothing consists of the skins of foxes and other animals, which they dress and make garments from skins of various sorts. Their food is Turkish wheat [maize], which they cook by baking, and is excellent eating…. It is as pleasant a land as one can tread upon, very abundant in all kinds of timber suitable for ship-building, and for making large casks."	1609	Henry Hudson, quoted by De Laet (1625)
"…and hard by it there was a Cliffe, that looked of the colour of a white greene, as though it were either Copper, or Silver myne: and I thinke it to be one of them, by the Trees that grow upon it. For they be all burned, and the other places are greene as grasse, it is on the side of the River that is called Manna-hata."	1609	Juet (1610)
"On this river there is a great traffick in the skins of beavers, otters, foxes, bears, minks, wild cats, and the like. The land is excellent and agreeable full of noble forest trees and grape vines, and nothing is wanting but the labor and industry of man to render it one of the finest and most fruitful lands in that part of the world."	1624	De Laet (1625)
"The island of Manhatas extends two leagues in length along the Mauritse River [Hudson River], from the point where the Fort "New Amsterdam" is building. It is about seven leagues in circumferance, full of trees, and in the middle rocky to the extent of two leagues in circuit. The north side has good land in two places, where two farmers, each with four horses, would have enough to do without much clearing at first. The grass is good in the forest and valleys, but when made into hay is not so nutritious for cattle as here [in Holland], in consequence of its wild state, but it yearly improves by cultivation. On the east side there rises a large level field, of from 70 to 80 morgens of land [140–160 acres], through which runs a very fine fresh stream; so that land can be ploughed without much clearing. It appears to be good…." (p. 104)	1626	De Rasieres (1628?)
"I began to make a plantation, a league and a half or two leagues above the fort [New Amsterdam, the plantation was probably in Harlem], as there was there a fine location, and full thirty-one morgens [62 acres] of maize-land, where there were no trees to remove; and hay-land lying all together, sufficient for two hundred cattle, which is a great commodity there. I went there to live, half on account of the pleasure of it, as it was all situated along the river."	1640	De Vries (1655)
"The first comers found lands fit for use, deserted by the savages, who formerly had fields here. Those who came later have cleared the woods, which are mostly oak. The soil is good. Deer hunting is abundant in the fall. There are some houses built of stone; lime they make of oyster shells, great heaps of which are found there, made formerly by the savages, who subsist in part by that fishery."	1643	Jogues (1646)

environment. The Mannahatta Project (www.wcs.org/mannahatta) is an effort to document, through historical research and ecological modelling, the Manhattan landscape immediately prior to Henry Hudson's arrival on September 12, 1609. Our hope is that by providing a vivid, ecologically sound, geographically referenced reconstruction of Mannahatta (the Native American name for the island), we can encourage interest in conservation of wild places and wildlife in the city, in the Northeast, and abroad.

This project would not be possible were it not for the existence of the British Headquarters Map from the British occupation of New York during the American Revolution (Fig. 1). Through most of the war, the British worried that George Washington's Continental Army would attempt to re-take the city after its retreat in 1776. Although this attack never materialized, planning for this contingency led to the creation of the British Headquarters Map of approximately 1782 (the date and exact authorship are uncertain), now held in The National Archives in London and recently published for the first time in color (Cohen and Augustyn 1997).

British Army cartographers documented features of military interest at a fine scale: hills and valleys, watercourses, ponds, wetlands, beaches, and the shoreline, as well as an extensive network of roads, fortifications, orchards, and farmlands, and a scattering of buildings north of New York City, which at that time reached just beyond the modern City Hall Park. Many of these same features, particularly the topography, watercourses, wetlands, and shoreline, are also of ecological interest, providing information on landscape drivers of the ecosystem mosaic (Forman 1995). Although created for military reasons, the British Headquarters Map's ultimate value may be found in landscape ecology.

The representation of the natural features of Manhattan at the end of the Revolution is particularly noteworthy because soon after the landscape would be significantly altered. In the years following the Revolution, New York blossomed from a small colonial town into a major city, particularly after the opening of the Erie Canal in 1825, making New York the primary port for goods traveling between the Midwest and Europe (Burrows and Wallace 1999). As the city developed northward, expanding along a rectangular grid according to the Commissioner's Plan of 1811 (Cohen and Augustyn 1997), hills were leveled, valleys filled, and streams diverted into sewers; new buildings, streets, and infrastructure were continually being constructed to support the growing population. Manhattan's population swelled throughout the 19th century, from a little over 33,000 people in 1790 to over 1.4 million by 1890, as new economic wealth created jobs and opportunities for millions of European immigrants (Kantrowitz 1995). This rapid expansion led some New Yorkers to worry about the loss of open space that only 50 years earlier had been available in abundance. William Cullen Bryant and Horace Greeley, among others, led the charge to create Central Park on rocky and swampy lands in the middle of the island (Rosenzweig and Blackmar 1992); other parks were left where the land

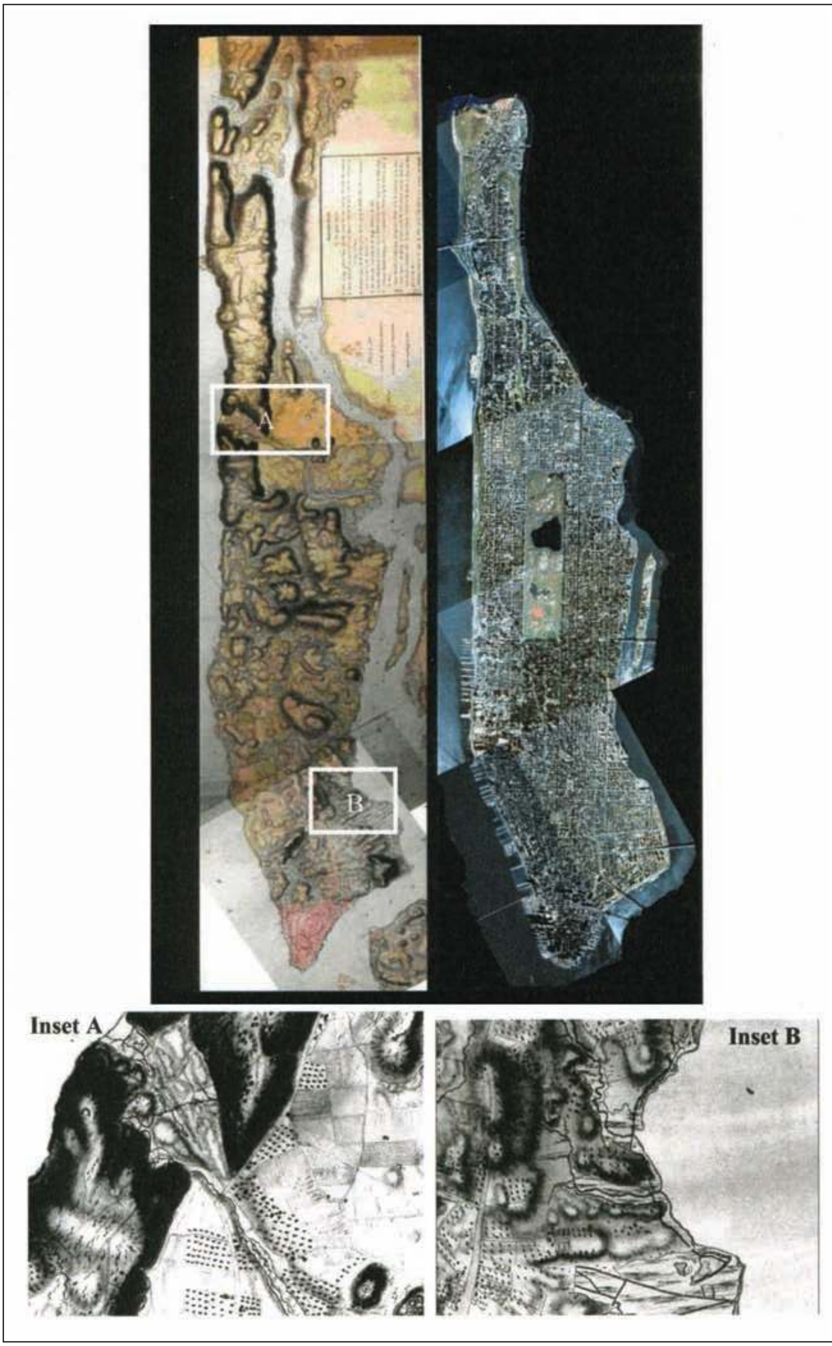

Figure 1. The British Headquarters Map, circa 1782 (left image), in contrast with modern aerial photography of New York City, circa 1998 (right image). Insets A and B show details of the British Headquarters Map.

was too steep to build on (Marcus Garvey Park, Morningside Heights Park, High Bridge Park). By the time the Greater City of New York was formed in 1898, nearly all of Manhattan, save the Inwood neighborhood at the northern end of the island, had been allocated to buildings, streets, factories, rail yards, cemeteries, and other intensive land uses (Burrows and Wallace 1999). The 20^{th} century saw the famous skyscrapers of Manhattan rise above what were once leafy hills, and Robert Moses' expressways wrap the shore over the once sandy beaches. (Fig. 1).

The Mannahatta Project is not the first attempt to map the "primeval" island. Egbert Viele in 1865 and Townsend MacCoun in 1909 created maps of the pre-development landscape, which civil engineers have subsequently praised for their accuracy in charting lost streams (Koeppel 2000). Unfortunately it appears that neither of these early cartographers had access to the British Headquarters Map, which in Robert Augustyn's words "could have suggested schemes of development in greater harmony with the area's natural characteristics than the rigid grid plan that was adopted" (Cohen and Augustyn 1997). It is just such schemes of development in harmony with nature that we hope the city will adopt over its next four hundred years.

The objectives of this paper are to summarize what we currently understand about the ecological community (ecosystem) composition of Manhattan in 1609, based on interpretation of the British Headquarters Map in the context of other ecological (including palynological), archaeological, and historical evidence. Our use of the British Headquarters Map and comparison to modern GIS data for the city also allow us to describe how the ecosystem composition of the island has changed through time and thus, in effect, to do a retrospective land-cover analysis over 400 years of Manhattan's history. Finally we summarize the distributional factors that will allow us in the future to begin mapping the distribution of Manhattan's former ecosystem mosaic and compare it to the modern city.

Methods

The British Headquarters Map, circa 1782

The British Headquarters Map was drawn and colored in pen, ink, and watercolor on paper, 95.25 cm (37.5 inches) wide and 317.5 cm (125 inches) long, resulting in a scale of 6.5 inches for 1 mile (approximately 1:10,000) (Penfold 1974). The original map was drawn on two pieces of paper, which have been attached together, after previously being folded. A limited edition reproduction of the British Headquarters Map was published by B.F. Stevens in 1900, but does not show all the same details as on the manuscript map. An earlier draft of the map is also available (Penfold 1974). There is no documented evidence linking this map to the actual British Headquarters in Manhattan during the American Revolution; Stevens (1900) gave it that name on supposition.

Conversion to geographic information system data

The British Headquarters Map was scanned in color at 600 dpi from three separate plates in Cohen and Augustyn (1997) using a HP ScanJet 5300C scanner (Hewlett-Packard Company, Menlo Park, CA) and then reassembled by matching overlapping features from the three plates. In the process of reassembling the map, we discovered that the map reproduced by Cohen and Augustyn (1997) was itself not assembled correctly from the original two mapsheets. Close examination of the Cohen and Augustyn plate shows that the two sheets should have been matched along a dotted, diagonal line rather than straight across the island. As reproduced in the book, the "E" in the label for the East River appears to be misplaced with respect to the remaining letters. We were able to correct this problem by splitting one of the scanned images and aligning it properly.

The reassembled scanned image was georeferenced to a modern coordinate system (Universal Transverse Mercator, zone 18) by finding a series of points on the map which are still extant in the modern New York City landscape and obtaining their geographic coordinates using a handheld GPS unit (Garmin 12XL, Garmin International Inc., Olathe, KS), with a nominal positional accuracy of approximately 15 m. Rectification was accomplished using the ImageWarp extension (McVay 1998) to Arcview GIS, version 3.2 (Environmental Systems Research Institute, Redlands, CA). To verify the accuracy of this georeferencing, we compared other features visible on the map to their modern locations, based on contemporary geographic data (see below).

We digitized features from the rectified British Headquarters Map by hand at 1:5000 scale. We were able to recognize the following features: shoreline, streams, ponds, wetlands, beaches, and upland areas (Fig. 2). In addition, numerous human modifications of the landscape were visible, including roads, fortifications (both batteries and walls), fields, orchards, manors, bridges, and individual buildings. An urban land-cover classification, indicated in light pink in lower Manhattan, estimated the extent of the built city at that time. Areas of various features were measured to the nearest 10 m^2, and lengths to the nearest 10 m.

Hydrological features represented as polygons with discernable width at the 1:5000 scale were digitized as polygons and identified as either ponds or part of watercourses. All other hydrologic features (e.g., upland streams) were digitized as lines. In combining the land-cover data with the hydrology, we buffered all the linear watercourses with a 1-m buffer as a crude approximation of the riparian area directly influenced by the stream.

Wetlands immediately adjacent to the shoreline were coded as salt or brackish wetlands. Marshes not adjacent to the shoreline were coded as freshwater wetlands. In practice, these estuarine (salt) and palustrine (fresh) ecosystems graded into one another along the line of mean high tide.

The scope of the Mannahatta Project includes the near-shore waters in New York harbor and the Hudson, East, and Harlem rivers, as well as adjacent Governor's Island and Roosevelt Island. We buffered 100 m from the shoreline shown on the British Headquarters Map to create the study extent for this paper.

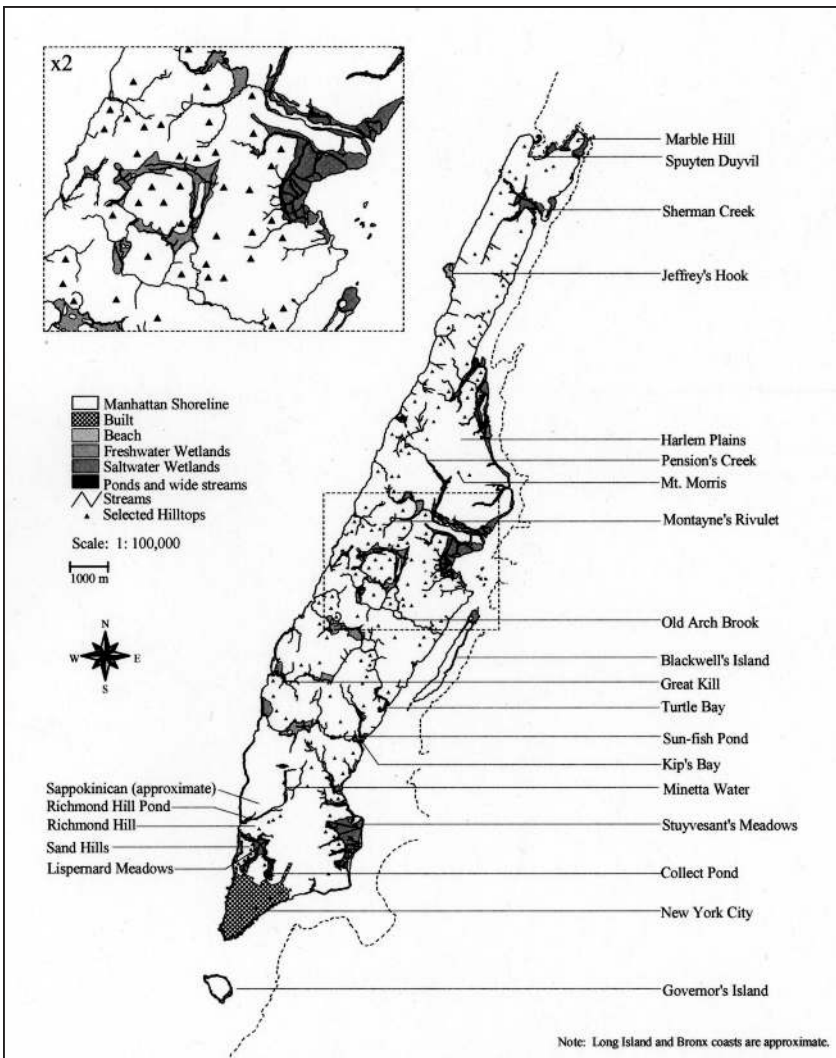

Figure 2. Natural features of Manhattan Island and the extent of New York City interpreted from the British Headquarters Map, circa 1782. Selected features are labeled with their 18th-century names; see text for details. Inset map shows features from central Manhattan at finer resolution. The inset map shows the central part of the island, including parts of the modern day Upper West Side, Upper East Side, Harlem, and northern Central Park.

Ecosystems of pre-European Manahatta

Although the British Headquarters Map does not provide exact information on the ecosystem types that once clothed the island, it does provide some direct and indirect indications relating to the former ecosystem mosaic. The boundary between salt and fresh water, the paths and sizes of hydrological features and topographic relief, and the distribution of wetlands, are all major factors influencing the types and locations of ecosystems that can be read directly from the map. Selected wooded areas on the map are indicated with small trees with either rounded or triangular tops, indicating broadleaf or conifer trees, respectively, although by the time this map was drawn, most of Manhattan had been deforested.

Table 2. Estimated land-cover distribution on Manhattan Island, A. circa 1609, B. circa 1782, and C. circa 2004.

Land-cover type	Area (ha)	% total
A. 1609		
Human-dedicated areas		
Agricultural fields	≈4	<1%
Habitation sites	≈1	<1%
Human-dedicated areas subtotal	5	0.1%
Natural areas		
Forest and shrub	3692	77%
Grasslands	474	10%
Salt and brackish marshes	368	8%
Freshwater marshes, swamps, and bogs	102	2%
Beach and mudflat	65	1%
Old fields and successional shrub	40	1%
Freshwater riparian zones	27	1%
Ponds	7	<1%
Tidal creeks	2	<1%
Natural areas subtotal	4777	99.9%
Island-wide total	4782	100%
B. 1782		
Human-dedicated areas		
Agricultural fields	268	5%
Orchards	210	4%
Roads	194	4%
Built-up area, buildings, and fortifications	124	3%
Gardens	10	<1%
Human-dedicated areas subtotal	806	16%
Natural Areas		
Degraded forest and shrub	3607	73%
Salt and brackish marshes	345	7%
Freshwater marshes, swamps, and bogs	102	2%
Beach and mudflat	52	1%
Ponds and Reservoirs	13	<1%
Freshwater riparian zones	13	<1%
Tidal creeks and ditches	5	<1%
Natural areas subtotal	4138	84%
Island-wide total	4944	100%

We drew on additional information to inform the potential types of ecological communities that might have been found on Mannahatta, including other historical accounts and maps, archaeological evidence, palynological evidence, and modern ecological studies in the Northeast relevant to New York City, as referenced in the text. We followed Reschke's (1990) system of New York State ecological community types, divided into marine, estuarine (salt water wetlands), riverine (streams), lacustrine (lakes), palustrine (freshwater wetlands), and terrestrial (upland) communities or systems, in the discussion below; Edinger et al. (2002) provide a revised version of these communities, which was also consulted. These assignments are all hypothetical, based on the information provided, and should be considered first guesses to be verified through additional investigation. We summarize the environmental factors that would predict where a particular ecosystem would have occurred based on Reschke (1990), Edinger et al. (2002), and Jorgensen (1977) (Table 2). This information will be used in subsequent studies to predict the distribution of ecosystems. For clarity, Reschke's (1990) community type names are shown in quotes in the forthcoming discussion.

We estimated the areas of ecosystem types in 1609 and 1782 based on interpretation of the British Headquarters Map, supplemented by other information. To estimate 1609 features, we needed to remove the effect of development between 1609 and 1782. Pre-1782 features in lower Manhattan were based on interpretation of the Castello Plan (Cortelyou c. 1665), the

Table 2, continued.

Land-cover type	Area (ha)	% total
C. 2004		
Human-dedicated areas		
Buildings	1843	34%
Sidewalks, courtyards, parking lots, gardens, and other open areas	1474	27%
Roads	1303	24%
Recreational open space (over 2 acres)	569	10%
Ball fields, hard courts, skating rinks, swimming pools, and playgrounds	86	2%
Cemeteries	9	<1%
Human-dedicated areas subtotal	5289	97%
Natural areas		
Forests*	111	2%
Reservoirs and lakes	54	1%
Salt marshes*	7	<1%
Freshwater riparian zones	4	<1%
Natural areas subtotal	172	3%
Island-wide total	5460	100%

*Areas designated as "forever wild" by the City of New York Department of Parks and Recreation in Central Park (The Ramble and Hallett Nature Sanctuary) and Inwood Park (Shorakapok Preserve).

Grim Plan c. 1742–1743 (Grim 1813), and the Maerschalck Plan (Maerschalck 1755), as reproduced in Cohen and Augustyn (1997). Other features that were the result of colonial development and land use were also removed from the 1609 calculations. For example, construction roads blocked some streams and created wetlands; in other cases, marshes were ditched to increase drainage. In at least one case, a dam backed up a stream to create a small lake. Riparian areas along streams and tidal creeks were estimated by buffering streams and creeks with a 2-m buffer. We estimated the area of Native American habitation sites by placing a 50-m buffer around six known locations where archaeological evidence indicates prior habitation (Bolton 1934). Active Native American agricultural fields were assumed to cover another 50-m buffer around habitation sites. Old fields and successional shrubs following abandonment of agriculture were assumed to be ten times larger than active fields based on preliminary results from Sarna-Wojcicki (2005). All the figures related to Native American use areas should be considered preliminary. Features from 1782 were interpreted directly from the map in the context of historical descriptions from the late 18^{th} century.

Scientific names and authorities of plants and animals are based on listings in the Integrated Taxonomic Information System (www.itis.usda.gov) (US Department of Agriculture 2006).

Historical features

Where possible, we assigned names to historical features shown on the British Headquarters Map based on an extensive review of the historical literature (Fig. 2). The history of naming on the island is a complicated subject derived from at least three different languages: Munsee, the language of the original inhabitants; Dutch, of the New Amsterdam colonists; and English, of the subsequent British and American occupations. For the purposes of this paper, we provided feature names that appear to have been in use during the American Revolution, though occasionally refer to earlier names where appropriate. Major sources for historical names and the approximate street locations of historical features are Hill and Waring (1897), Riker (1904), Stokes (1915–1928), Grumet (1981), Jackson (1995), and Koeppel (2000) and the maps of Viele (1865), and MacCoun (1909), as well as the British Headquarters Map itself.

Modern datasets

We compared the historical features to modern geographic datasets for Manhattan roads from the New York City "PCPLION" roads dataset (City of New York - Department of City Planning 2005). The positional accuracy of the PCLION dataset is reported as 0.65 mm. Modern land use, including buildings, open space and roads, and shoreline data was derived from the New York City Base Map (Richter and Ostroff 2001). Modern riparian zones were estimated from a map of Central Park and unpublished surveys by E.W. Sanderson on Harlem Heights.

Results and Discussion

The British Headquarters Map provides a remarkable view of the landscape of Manhattan in 1782 and allows us to make inferences about the ecological landscape then, and in earlier times. We review the geometrical accuracy of the map and then summarize the presumed main land-cover types on the island in 1609 in contrast to the island in 2004, before turning to a more speculative discussion about the nature of the ecological communities within each of the major land-cover types. We also identify the geographical highlights (e.g., the longest stream, the largest wetland) and where possible, indicate some of the species that might have been found on Mannahatta. Although the British Headquarters Map is the primary resource, we draw on other historical, archaeological, and ecological lines of evidence as well.

Geometrical accuracy

Using a first-order rectification process, we were able to obtain a root mean square error of approximately 40 m for the British Headquarters Map; in city terms, approximately half an uptown block in midtown Manhattan. The actual geometric accuracy based on comparisons of historical sites to known contemporary locations varied from less than 5 m to more than 150 m, with more variation toward the northern tip of the island. These errors may be due to problems with the map assembly, reproduction of the map, our selection of positions used in the georeferencing, and/or miscalculations in the original surveys. However, these problems should not greatly impact the final results as they extend over only a limited area and we report only summary statistics for the whole island here. Moreover, this geometric accuracy is quite remarkable for a map of this era, comparing favorably with the best county survey maps made in peacetime England in the 18^{th} century (Laxton 1976).

Manhattan and adjacent islands

The shoreline of Manhattan shown on the British Headquarters map was 81.5 km long and varied between 0.5–3.4 km wide, enclosing an area of approximately 4944 ha. This area is approximately 3.3% larger than the area of the island in 1609, but 9.4% smaller than the island in 2004 (Tables 2a–c). These calculations include the numerous marshy islands immediately adjacent to Manhattan uplands (mainly along East and Harlem Rivers), but excludes major East River and Upper Bay islands: Governor's Island and Blackwell's Island (now Roosevelt Island) (Seity and Miller, 1996). Expanding Manhattan by using the near-shore waters as a dump began in Dutch times and continued well into the 20^{th} century (Buttenweiser 1999). At the time of the British Headquarters Map in 1782, two blocks (Pearl to Water Street, and Water to Front Streets) had already been created, with docks and slips extending farther into the East River. The "fill" came from garbage, including sewage, and hills removed in lower Manhattan. (Koeppel 2000). Development of industrial sites, road construction, and promenades enlarged the island to its modern size (Buttenweiser 1999).

The shores of Manhattan used to have numerous sandy beaches, especially along the Hudson shore, covering a total area of 52 ha on the British Headquarters Map. A nearly continuous line of beaches extended from modern day Vesey Street to 33rd Street (4.6 km long), then again from 43rd to 57th Street (1.2 km). Formerly, some of these beaches wrapped around lower Manhattan and up the East River shore. Other beaches filled pocket coves along the Hudson and were found north of Corlear's Hook, in Turtle Bay, and along the Harlem shore on the east side of the island. Gifford Audubon, John James Audubon's son, painted his father sitting on one of the Hudson River beaches near 155th Street in 1845 (Museum of the City of New York 1997), and the Ratzer Map (1767) has an inset image which shows the beach on Governor's Island, facing Manhattan (Cohen and Augustyn 1997).

Watercourses and water bodies

We identified sixty-six separate hydrological networks on the British Headquarters Map, varying in network length and number of channel segments. The total length of all of the watercourses on the island circa 1782 was 108 km (≈67 miles). The largest hydrological network (by length) was Old Arch Brook, or Saw Kill to the Dutch, a 13,710-m long fourth-order stream, which drained the central part of the island in what later became Central Park. Other noteworthy stream courses were: Minetta Water (4370 m), which drained through what has since become Washington Square Park and Greenwich Village; the Great Kill (4640 m), which drained the area from around Times Square to the Hudson River and which was known for its hunting and fishing (Stokes 1915–1927); and Pension's Creek (6750 m), probably the largest stream course by volume, which drained Morningside Heights down through the Harlem Plains.

The majority of the watercourses (60% on an areal basis) flowed through upland areas, forming various riverine and associated palustrine ecosystem types (see below). Twenty-five percent of watercourses flowed through saltwater (estuarine) wetlands and 12% through freshwater (palustrine) wetlands.

Twenty-one ponds or other wide watercourses are shown on the British Headquarters Map. The most important pond was the Collect Pond or Fresh Water (2.2 ha), an important freshwater source for New York City for its first 200 years, but which was later fouled with pollution from a tannery and filled; later this neighborhood became infamous as the Five Points area (see Koeppel 2000 for a detailed history). Richmond Hill Pond, which collected the Minetta Water, was larger in area (3.2 ha) though probably shallower and may have been brackish. This pond was probably created as a defensive measure during the Revolutionary War, as it does not appear on maps from before the war (e.g., Ratzer Map). Other ponds varied in size from 0.01 ha to 1.3 ha. Nine salt ponds are shown within saltwater wetlands, varying in size from 0.03 to 0.5 ha.

Many of the watercourses and wetlands show modification by human beings. Channels in both the Lispernard Meadows and Stuyvesant's Meadows near New York City show signs of channel straightening and ditching. Salt marshes were ditched then, as they still are now, to improve drainage and lower the water table; during the Revolutionary period, such management was an attempt to increase production of salt hay for domestic livestock (Stilgoe 1994). The main stream through Lispernard Meadows, for example, was deepened and straightened into a canal that eventually lent its name to modern day Canal Street. Other watercourses were impacted by roads, which either foreshortened them or caused alterations in their course (e.g., the stream flowing into Sun-fish Pond); however, most of these modifications were limited to the southern half of the island, nearest the city.

The most dramatically modified watercourses are those that cannot be seen on the British Headquarters Map because they had already been lost beneath the 18th century city. These include the small stream the Dutch colonists enlarged to form the "Heere Gracht" along modern Broad Street, and its smaller auxiliary, whose former inhabitants gave their name to Beaver Street (Stokes 1915–1928). Hill and Waring (1897) write of a lovely, pebble-lined brook called the Maagde Paetje (or Virgin's Path) along the line of Maiden Lane, which by 1782 had been buried. Other streams were modified by roads and agricultural areas in the 18th century. In total, there was nearly twice as much area classified as "riparian" in 1609 as in 1782. Nearly all of these streams have been lost from the 21st-century city.

Wetlands

Wetlands of various types covered nearly 10% of Manhattan Island, circa 1782. We identified 25 saltwater wetlands or wetland complexes (totaling 345 ha, inclusive of associated watercourses) and 9 freshwater wetlands on Manhattan Island (totaling 102 ha). Upland riparian areas associated with streams covered another 13 ha.

The largest single wetland on the island was the salty Stuyvesant's Meadows, just north of Corlear's Hook on the East River shore. The largest wetland complex was associated with Pension's Creek in Harlem, also a large salt marsh. Together the wetlands along the East River near Harlem amounted to about 40% of Manhattan's total, nearly 151 ha. Other significant salt marshes were Lispernard Meadows (31 ha), which probably enclosed a gradient from salt water to brackish to fresh water where they drained the Collect Pond; the wetlands around Sherman Creek (33 ha), also probably partially brackish; and the wetlands surrounding Marble Hill at Spuyten Duyvil (21 ha). In general, the topography of the island along the East and Harlem Rivers favored salt marshes more than the Hudson River side because it was more protected from wave action.

A series of freshwater wetlands are shown filling valley depressions in the center part of the island, contributing to streams that drained both east and west. Several were found in the grounds of today's Central Park; one of these (38 ha) nearly surrounded a large hill that provided the headwaters to Old Arch Brook. During the construction of Central Park, large drainage structures and tile fields were installed to remove these waters, and workmen complained of the boggy lands they were converting to a park (Rosenzweig and Blackmar 1992). Other freshwater wetlands were associated with Montayne's Rivulet (12 ha), Minetta Water (5 ha) near Washington Square Park, and many of the unnamed smaller waterways coursing across the island.

Uplands

The remaining 90% of the island was composed of upland ecosystems, largely forests, except on the Harlem Plains, which may have been a grassland, and along the shores, where there were often beaches. Early commentators lavished praise on the forests that once clothed the island (Table 1). Unfortunately, by 1782 these fine woods had experienced extensive deforestation, accelerated by the harsh winters of 1779–1780 and 1780–1781. The large occupying forces, intermittently cut off from access to the surrounding hinterland, were forced to turn on the local resources of Manhattan with dire effect. Burrows and Wallace (1999) quote George Washington's comments a year later, observing the successional shrubland where once trees had stood: "the island is totally stripped of trees; low bushes … appear in places which were covered with wood in the year 1776." These areas of degraded forest and shrub covered 3607 ha (73%) of the island in 1782. In contrast, there would have been approximately 3692 ha of old-growth primary forest, in several different forest types (see below), in 1609.

The main exception to the dominant forest cover of the island may have been the Harlem Plains. In a letter, an early Dutch settler, De Rasieres (1628?), wrote "On the east side (of Manhattan Island) there rises a large level field, of from 70 to 80 morgens of land (140–160 acres), through which runs a very fine fresh stream; so that land can be ploughed without much clearing," (parenthetical comments added by the editor, Jameson). Similarly, Riker (1904), in his *History of Harlem*, imagines standing at McGown's Pass and seeing "a fine level plain" where a Dutchman could find a "future home [on] the rich flats of Muscoota, promising to rival in productiveness the fertile meadows around his native Leyden." Torrey et al. (1817) reports a large number of species from "meadows" on the island, though many of these 19th-century meadows were likely the result of local clear cutting.

De Rasieres (1628?) identified another patch of land where two farmers "would have enough to do without much clearing at first" that may have occurred north of Sherman Creek and south of Marble Hill in an area known as Round Meadow. If both these areas were grasslands, they would have amounted to a significant area, over 450 ha or nearly 10% of the island.

If the Harlem Plains and Round Meadow were grasslands of some sort, they were likely maintained by Native American burning. Bean (2004) showed that a fire frequency of 10 years or less would be sufficient to keep this area open. These factors are discussed further below.

A much smaller area in what is now Tribeca was dominated by sandy soils, extending in some places 110 m from the shore and enclosing two ponds, a total area of 0.6 ha. This area may have contained dunes and may have been part of the same geological formation as the Sand Hills, or Zandtberg in Dutch, that extended to Richmond Hill overlooking Minetta Water, and north into Greenwich Village. These areas, plus the sandy beaches described previously, covered nearly 52 ha in 1782 and 65 ha in 1609 (Table 2). Today these features do not exist.

Human-dedicated areas

The most dramatic change on Manhattan Island over the last 400 years has been the amount of land dedicated to exclusively human uses. In 1609, such areas probably covered less than 1% of the island, in terms of area occupied by habitations and used for active agriculture (Table 2a). Of course, more extensive areas were hunted, fished, and likely influenced by Native American burning. By 1782, the diversity of human uses and the area occupied had increased dramatically, from approximately 5 ha in 1609 to 806 ha by 1782 (Table 2b). Human uses in 1782, apparent on the British Headquarters Map, include urban areas and buildings, agricultural fields and orchards, and gardens. Other natural areas, however, would have been used for hunting and fishing and cutting of firewood. By 2004, the island had again changed dramatically, with approximately 97% of the land area dedicated to human use, including buildings, roads, recreational open spaces, and a complicated intermixture of sidewalks, plazas, gardens, and parking lots (Table 2c). The forest areas managed for ecological value cover only 111 ha (about 2% of the 2004 island). Open-water lakes and reservoirs provide some aquatic habitat (54 ha), and there are a few salt marshes remaining in northern Manhattan as the result of restoration efforts (7 ha).

Marine and estuarine ecosystems

The near-shore waters of Manhattan are reported to have once teemed with marine life, including organisms usually associated with "marine deepwater" communities. In a letter, De Vries (1655) wrote of the many marine fish accessible from New Amsterdam including *Morone saxatilis* Walbaum (Striped Bass), *Pseudopleuronectes americanus* Walbaum (flounder, e.g., Winter Flounder), *Alosa sapidissima* Wilson (herring, e.g., American Shad), *Morone americana* Gmelin (White Perch), and *Anguilla rostrata* Lesueur (American Eel), many of which still frequent the New York Bight (Steinberg et al. 2004, Waldman 1999). Briggs and Waldman (2002) summarize the historical marine fauna in detail, including fish of the New York harbor to the tip of the Battery. One of the reasons Manhattan was selected for the site of New Amsterdam was the deep water just off the tip of the island. Measurements reported on the Debarres Chart, circa 1776 (also reproduced in Cohen and Augustyn [1997]), indicate 5–10 fathom (10–20 m) depths between Manhattan and Governor's islands. The original charter for Trinity Church in lower

Manhattan included rights to whales that stranded themselves on the nearby beach (Stokes 1915–1928).

In shallower water, "marine eelgrass meadows" likely flourished with their distinctive fauna, although no indication is given on the British Headquarters Map. Kieran (1959) noted that *Zosteva* L. (eelgrass) once occurred near the city and may have been returning in the 1950s; Torrey et al. (1817) documented *Zostera marina* L. (seawrack) in their botanical surveys of the vicinity of New York. We speculate that eelgrass meadows may have occurred in shallow protected coves in the lower part of the East River, particularly in Kip's and Turtle bays. Sea turtles as well as freshwater turtles may have frequented these areas, although the name for Turtle Bay may also come from the shape of the bay, like a turtle's curved back (Moscow 1990). Extensive eelgrass beds were known from comparable areas along the Long Island shore (Conrad 1935); however, a wasting disease in the 1930s suddenly decimated the beds (McRoy and Helfferich 1977).

The salt marsh ecosystems that can be seen on the British Headquarters Map were variations of tidal salt marsh, stratified into different communities by small changes in elevation relative to mean sea level (Bertness 1999). At the lowest end, below mean sea level, tidal creeks drained the salt-marsh ecosystems along the shores of the island. Along the margins of the tidal creeks and extending into the marsh at elevations from mean sea level to mean high tide may have been low salt marsh, replaced by high salt marsh from mean high tide up to the highest limit of the spring tidal influence. Salt pannes would form where there was poor drainage from the salt marsh, creating shallow depressions. It is not clear whether the small oblongs in Stuyvesant's Meadows on the British Headquarters Map are salt pannes covered by water or salt pond ecosystems (they are counted in the numbers above as ponds). Along the upland edge of the salt marshes, there would have been borders of "salt scrub" that may have extended some distance inland along the swampy watercourses of lower Manhattan.

Upstream in the many watercourses that drained into salt marshes, there would be a transition from fully salt to brackish communities. The width of this transition would depend on the slope of the channel above mean high tide; in areas of gentle slope, for example, around Sherman Creek, there probably were extensive brackish marshes and the possibility for brackish mudflats or rocky shores. The marshes that were rapidly drained and buried in lower Manhattan (e.g., Beekman's Swamp, near Kip's Bay) may have been brackish marshes, or combinations of brackish marsh and salt scrub. In the watercourse channels, brackish subtidal aquatic beds would have replaced tidal creeks upstream where freshwater flow began to dominate the stream.

Palustrine, riverine, and lacustrine ecosystems

Palustrine ecosystems stretched across a continuum from brackish marshes to fully freshwater ecosystems upstream. In palustrine ecosystems, the depth and frequency of flooding are main drivers of ecosytem type, creating wetlands that varied from herbaceous marshes to wooded swamps. Deep and shallow emergent marshes probably occurred along watercourses and near the margins of many of the eutrophic ponds where there were permanently flooded conditions, with the difference between "deep" and "shallow" water being approximately 15 cm (6 inches). If the Collect Pond had the tidally or seasonally variable water levels of a coastal plain pond (see below), then the surrounding marsh vegetation may have had characteristics more like the coastal-plain pond-shore ecosystem type. Shrub swamps (e.g., shrub carr, alder thickets) would have occurred where slightly drier conditions allowed shrubs to establish, and may have been replaced successionally by red maple hardwood swamps and perhaps floodplain forest (Luttenberg et al. 1993), particularly in the wetlands in the center of the island. Engineers and construction crews complained of the extensive wooded swamps that had to be cleared during the construction of Central Park in the 1850s (Rosenzweig and Blackmar 1992).

Manhattan is near the southern limit of sphagnous peatlands (Johnson 1985), however there are a number of indications that these ecosystems were interlaced among other fresh-water wetlands types. Torrey et al. (1817) reported bog meadows and sphagnous swamps on Manhattan Island in his day, including "wooded, boggy" places in Bloomingdale (now the Upper West Side) and Central Park construction crews found bogs as well as swamps (Rosenzweig and Blackmar 1992). Peatlands typically form in permanently flooded areas where anoxic conditions develop. The open, bog meadows of early Manhattan were probably related to the "coastal plain poor fens" of Long Island and peatlands partially covered by shrub cover were likely "highbush blueberry bog thickets," co-dominated by *Rhododendron viscosum* (L.) Torr. (swamp azealea)—these ecosystems probably existed in the coolest, wettest parts of shallow emergent marshes and shrub/red maple hardwood swamps, respectively. The nutrient character of these bogs may have varied from place to place, depending on the extent to which the local groundwater was enriched by underlying bedrock (e.g., calcareous Inwood marble type). Cedar swamps were known to occur near Manhattan Island in New Jersey and Long Island (Torrey et al. 1817), and a wetland with conifer-type trees is shown on the British Headquarters Map in the vicinity of modern Central Park. Kieran (1959) indicated that *Chamaecyparis thyoides* (L.) B.S.P. (Atlantic white cedar) was once common in swamps and bogs around the city. Thus, if forested peatland was once found on Manhattan, it would have likely been of the "coastal plain Atlantic white cedar swamp" type.

"Rocky headwater stream" probably described most of small streams visible in the uplands on the British Headquarters Map, particularly where there was significant slope. However, there were also other streams, including some of the largest, that arose from springs or groundwater sources associated with freshwater wetlands in the center of the island and were probably of the marsh headwater stream type. These streams are generally shown with the associated wetlands on the British Headquarters Map. Regardless of source, some of the larger streams may have conformed to the more regular "midreach stream" type before reaching salt water, where they would have become increasingly brackish and then saline. Many of these streams may not have flowed year-round, particularly in drought years. Hill and Waring (1897) note that Sun-fish Pond nearly disappeared during times of protracted drought, suggesting that many of the freshwater streams may have been seriously affected by times of low water. These stream courses would have been punctuated by shoreline rocks and outcrops, remnants of the former glaciation of the island; these outcrops supported separate terrestrial communities of plants, mosses, and lichens. The community structure of these outcrops depended on whether the substrate was calcareous in origin or not ("shoreline outcrop" and "calcareous shoreline outcrop"). Calcareous rocks underlay Manhattan in some places (e.g., Inwood marble), although outcrops of calcareous type were probably rare.

Most of the small freshwater ponds on the island were probably "eutrophic ponds," not deep enough to stratify during the summer. These ponds might have supported a characteristic warm-fish biota, although its composition is uncertain since it would have depended on the connectivity of freshwater networks during the post-glacial phase before sea-level rise created Manhattan Island (see discussion in Schmidt 1986). Possibilities include such Northeast regulars as *Lepomis gibbosus* L. (pumpkinseed), *Pomoxis nigromaculatus* Lesueur in Cuvier and Valenciennes (Black Crappie), and *Lepomis auritus* L. (Redbreast Sunfish; there was a Sun-fish Pond on Manhattan). Ponds connected to the marine waters likely were visited by *Alosa pseudoharengus* Wilson (Alewife) and *Anguilla rostrata* Lesueur (American Eel) (Halliwell et al. 2001; Whittier et al. 1999, 2000, 2001).

The one pond that may have been sufficiently deep to stratify twice per year was Collect Pond, which, following Reschke (1990), may have been a "coastal plain pond," formed in a kettle-hole left after the retreating glaciers. Nineteenth-century accounts remark on the depth of this pond, anywhere from 40–70 feet deep (e.g., Hill and Waring 1897, Stokes 1915–1928). We know that Collect Pond received groundwater feeders (Koeppel 2000), but it's less clear whether the water level may have risen tidally; some authors (e.g., Barlow 1969) indicate that it may have once been possible to paddle through the marshes and across Collect Pond, from the Hudson River to the East River, at high tide.

Finally, "vernal pools" most likely filled small, localized depressions in the upland woodlands after significant rains and snowmelt, drying over the course of the summer, but were too small and/or of too little significance to be recorded by military surveyors. These areas did provide an important ephemeral habitat for many woodland-dwelling amphibians, so much so that Peter Kalm, during his 1744 visit to New York City, complained of all the noise. He wrote: "Tree frogs, Dr. Linnaeus's *Rana arborea* (Kalm) [probably means *Hyla cinerea* Schneider, the Green Tree Frog] are so loud it is difficult for a man to make himself heard" (cited in Kieran [1959]).

Terrestrial ecosystems

The British Headquarters Map provides only scattered information about the natural forest cover of Manhattan, largely because it was nearly gone by the time the map was created, but all the evidence points to the island being extensively forested in pre-contact times. Burrows and Wallace (1999) quote anonymous travelers describing forests with towering stands of walnut, cedar, chestnut, maple, and oak. Other early chroniclers, eager to find resources suitable for merchandise focus on the "abundance of blue plums and the finest oaks for height and thickness that one could ever see; together with poplars, Lonen, and various other woods useful in ship-building" (De Laet 1625; also see Table 1). The palynological evidence from Staten Island and Queens also supports a diverse forest including *Quercus*, *Pinus*, *Carya*, *Betula*, and *Tsuga* species (Kleinstein 2003, Sirkin 1967). Data from witness trees and other colonial records confirms these same major tree species in 18th century Queens (Greller 1972, 1975). Nicholls' Map of 1664, drawn shortly after the British captured Manhattan from the Dutch, shows the island extensively forested, especially from Murray Hill north (Cohen and Augustyn 1997), part of the vast mixed deciduous forests that once cloaked the eastern third of North America (Whitney 1994).

The forests of Mannahatta were likely mainly of the "chestnut-oak forest" and "oak-tulip tree forest" types, mixed with occasional patches of "hemlock–northern hardwood forest" in cooler, wetter ravines, an extension of the vast broadleaf deciduous forests that cloaked the Northeast (Kershner 1998, Luttenberg et al. 1993). *Castanea dentata* (Marsh.) Borkh. (American chestnut) was most likely the dominant species of these forests (Paillet 2002), though other hardwoods (e.g., *Quercus rubra* L. [northern red oak], *Quercus alba* L. [white oak], *Liriodendron tulipifera* L. [tulip tree], *Acer rubrum* L. [red maple], and *Fagus grandifolia* Ehrh. [American beech]) were also likely to be important.

There are also records of some softwoods from the island, including *Pinus strobus* L. (white pine) and *Pinus rigida* P. Mill. (pitch pine) (Torrey et al. 1817), which may indicate a community like the "Appalachian oak-pine forest type" as well as "pitch pine-scrub oak barrens," depending on fire frequency and substrate.

The subtle differences in these mixed deciduous forest types would have been due to gradients in edaphic factors such as soil depth and moisture, so that hilltops and areas with sandy soils would have been drier, possibly supporting the more xeric chestnut-oak forest type; hillside slopes and deeper soils may have supported the more mesic oak-tulip forest. Luttenberg et al. (1993), in suggesting native plants for New York City, expanded this description to include "rich mesophytic forests" (on the mesic end) and "oak openings" (on the xeric end), though Reschke (1990) does not describe either of these forest types from the New York City region. These forests types grade into each other so continuously that a classification system like Jorgensen's (1977) description of hilltop, mid-slope, and low-slope oak forest communities may be as useful for describing their inter-relationships as the Reschke (1990) community types. At the wettest end, "red maple hardwood swamps" or "shrub swamps," already discussed, filled the lower-lying depressions. Along the steepest slopes (e.g., along Morningside Heights overlooking Harlem), all of these communities would have been replaced with open-cliff communities, whose species composition varied with substrate ("cliff community" and "calcareous cliff community"), though, as stated earlier, calcareous substrates may have been rare.

Conceptualizing these ancient forests in light of the forests of today is difficult because of the loss of the major overstory dominant tree (American chestnut), the dramatic history of deforestation and then reforestation over most of the Northeast (though not Manhattan), introduction of new species, and changes in disturbance regime. Dunwiddie et al. (1996), White and White (1996), and Whitney (1994) provide quantitative descriptions of representative old-growth stands comparable to Mannahatta's former forests; Brash (2004) summarized much of this data to generate a "type specimen" description that conforms to the ecological communities described here.

These forests were often impacted by fires set by Native Americans; Van der Donck (1650) describes mid-17th-century Native American fire use on Manhattan and in nearby areas, and fire has been documented in southern New England (Cronon 1983) and with many other Native American groups in the 17th century (Day 1953). Native Americans lit fires to clear the underbrush to ease travel and to increase levels of game—practices which are still used by rural peoples today (Putz 2003). These fires likely were a major influence on the terrestrial ecosystems of the island (Foster et al. 2002).

Bean (2004) showed through fire disturbance and succession modeling, that fires occurring more often than once every 10 years would have been sufficient to create the large "meadows" that De Raiseres (1628?) described in his letters. Moreover, it is unlikely that non-anthropogenic ignitions (i.e., lightening strikes) occurred frequently enough in such a small area to create a grassland (e.g., Loope and Anderton 1998). Archaeological evidence, though fragmentary, confirms that there was at least one Lenape settlement in Harlem in early 17th century (Bolton 1934, Grumet 1981). The Nicholls' Map of 1664, mentioned above in the context of forest cover, shows Harlem without forest, though by that time, at least some of the area had been converted for Dutch agriculture (Riker 1904).

There are precedents for grasslands in the New York region. On western Long Island, there was once an extensive grassland ecosystem, the Hempstead Plains grassland, which covered over 24,000 ha and extended into scattered pockets in Brooklyn (Harper 1911). This grassland type was remarkable for its physiognomic similarities to the tallgrass prairies of the Midwest, although there were subtle differences in species composition (Cain et al. 1937, Conrad 1935). The persistence of these grasslands may have been due in part to periodic fires set by the native people, as today national park service personnel seek to restore Brooklyn's Floyd Bennett Field's grasslands using fire (Mittelbach and Crewdson 1997). So if Harlem were once a grassland, it is likely to been of the "Hempstead Plain grassland type", or at least closely related.

It is possible that the Sand Hills (Zandtberge to the Dutch) of lower Manhattan that stretched from Tribeca along the southern edge of Greenwich Village up to Astor Place originally hosted another fire-dependent ecosystem, "pitch pine-scrub oak barrens," akin to the pine barrens of Long Island and New Jersey. Some of these hills on the British Headquarters Map show the same markings as the sandy beaches. Torrey et al. (1817) documented pitch pine in the vicinity of New York, but indicated this species was rare at the beginning of the 19th century when these hills would have already been largely cleared. These forest barren community types depend on a frequent-fire regime (6–15 year repeat cycle) that may have been supplemented by fires set by the nearby Lenape communities near Collect Pond, in Sappokinican (Greenwich Village), and an unnamed habitation site identified in the East Village (Grumet 1981).

Rounding out the list of terrestrial ecological communities, there would have been a number of cultural ecological communities associated with the human inhabitants of Manhattan. Early accounts document that the Lenape people who lived on Manhattan at the beginning of the 17th century were garden horticulturalists (though see discussions in Ceci 1979, 1982), so likely there were actively cultivated fields at several locations on the island ("cropland" types). Grumet (1981) maps several of these, following the suggestions of Bolton (1934), though all of this should be treated skeptically. As these fields were depleted over the course of several growing seasons, the people probably moved to clear new fields, leaving the old fields to become successional ecosystems—"successional old fields," then "succesional shrublands," and eventually forest again, barring further disturbance (Sarna-Wojcicki 2005). These successional communities probably also characterized forest recovery after windthrows associated with hurricanes and other severe storms. Native Americans also populated village sites on the island, building wigwam and longhouse living structures out of natural materials and depositing their wastes in piles or middens ("landfills/dumps"). Apparently, the hill above Collect Pond was the site of a shell midden; several early authors cite the Dutch name of Kalck Hoeck as a corruption of "kalch" meaning lime, probably referring to oyster shells left by Indians (e.g., Hill and Waring 1897, Stokes 1915–1928). "Unpaved paths" connected these community and fields, creating small disturbances in the understory of forests and grasslands. All of the culturally derived ecological communities types need redefinition from the cultural communities offered by Reschke (1990), whose definitions focus on contemporary communities much different from those that once occupied Manhattan Island.

Summary of predictors of ecosystem distribution

Finally, we summarized in the on-line supplemental materials the factors that would have predicted the spatial distribution of ecosystems

(Table S1). The factors across the top of the table can be thought of as the GIS layers necessary to predict the communities listed along the side of the table. We found that 27 factors are necessary to map the potential distribution of ecological communities on Mannahatta; ten of these can be derived directly from the British Headquarters Map, the remainder will require additional information (e.g., derivate soil characteristics) and ecological modeling (e.g., disturbance processes). We also found that these factors fit into five super-categories of predictors: topography, geomorphology, soil, water, and disturbance. Combinations of these five core elements are sufficient to predict the distributions of the 54 communities that once occurred on Manhattan Island.

Conclusions

The British Headquarters Map provides an important, geometrically accurate and extraordinarily detailed window on the past environment of Manhattan. Although all historical sources need to be used with care, this map provides a starting point for understanding the natural landscape of Manhattan, not only in 1782, when the map was created, but farther into the past, including the pre-contact landscape of 1609. We also take advantage of historical accounts, ecological evidence, and archaeological information to supplement information derived directly from the British Headquarters Map and support hypotheses about the ecological community composition of the island. In turn, these comparisons will eventually allow us to create geographically precise descriptions of the natural features extant circa 1609, not only speculating about these communities, but putting them on the map in such a way that they can be compared directly to the block-by-block geography that is home to over 1.5 million people and workplace for another 2.6 million people (US Census Bureau 2006).

Acknowledgments

The authors would like to gratefully acknowledge Han-Yu Hung and Everett W. Sanderson for their assistance in the field, and Jerry Jenkins, Dorothy Peteet, Kent Redford, John Robinson, Amy Vedder, and John Waldman for their advice and support. Robert DeCandido, Sidney Horenstein, and Andrew Greller provided helpful comments on an earlier draft of this manuscript. The guest editor and two anonymous reviewers made additional helpful comments. Gillian Woolmer provided GIS advice and Christina Baranetsky, Timothy Bean, and Daniel Sarna-Wojcicki assisted with the GIS analysis during internships supported by the Center for Environmental Research and Conservation at Columbia University. Markley Boyer made suggestions on the illustrations. Environmental Systems Research Institute's Conservation Program provided GIS software. The Wildlife Conservation Society, the Prospect Hill Foundation and the Sanderson-Hung Family Foundation supported this work financially. The contributions of all are greatly appreciated.

Literature Cited

Barlow, E. 1969. The Forests and Wetlands of New York City. Boston, Little, Brown, New York, NY. 160 pp.

Bean, T. 2004. What made the harlem plains a grassland? Computer modeling for historical ecology of an urban environment. Senior Honors Thesis. Columbia University, New York, NY.

Bertness, M.D. 1999. The Ecology of Atlantic Shorelines. Sinauer Associates, Inc. Sunderland, MA.

Brash, A. 2004. New York City's primeval forest: Depicting the "type specimen." Transactions of the Linnaean Society of New York. Spring 2004.

Briggs, P.T., and J.R. Waldman. 2002. Annotated list of fishes reported from the marine waters of New York. Northeastern Naturalist 9:47–80.

Bolton, R.P. 1934. Indian Life of Long Ago in the City of New York. J. Graham, New York, NY. 167 pp.

Burrows, E.G., and M. Wallace. 1999. Gotham: A History of New York City to 1898. Oxford University Press, New York, NY. 1383 pp.

Buttenweiser, A.L. 1999. Manhattan Water-bound: Manhattan's Waterfront from the Seventeenth Century to the Present. Syracuse University Press, Syracuse, NY. 308 pp.

Cain, S.A., M. Nelson, and W. McLean. 1937. *Andropogonetum hempsteadi:* A Long Island grassland vegetation type. American Midland Naturalist 18:334–350.

Ceci, L. 1979. Maize cultivation in coastal New York: The archeological, agronomical and documentary evidence. North American Archaeologist 1:45–74.

Ceci, L. 1982. Method and theory in coastal New York archaeology: Paradigms of settlement behavior. North American Archaeologist 3:5–36.

City of New York-Department of City Planning. 2005. LION. Vector digital data. Available online at http://www.nyc.gov/html/dcp/html/bytes/applbyte.shtml#geo. Accessed 23 September 2002.

Cohen, P.E., and R.T. Augustyn. 1997. Manhattan in Maps 1527–1995. Rizzoli, New York, NY. 164 pp.

Conrad, H.S. 1935. The plant associations of central Long Island. American Midland Naturalist 16:433–516.

Cronon, W. 1983. Changes in the Land: Indians, Colonists, and the Ecology of New England. Hill and Wang, New York, NY. 241 pp.

Day, G.M. 1953. The Indian as an ecological factor in the northeastern forest. Ecology 34:329–346.

De Laet, J. 1625. New world. Pp. 29–58, *In* J.F. Jameson (Ed.). Narratives of New Netherland, 1609–1664. Barnes and Noble, Inc., New York, NY.

De Rasieres, I. 1628? Letter to Samuel Blommaert. Pp. 97–113, *In* J.F. Jameson (Ed.). Narratives of New Netherland, 1609–1664. Barnes and Noble, Inc., New York, NY.

De Vries, D.P. 1655. Court Historiael Ende Journaels Aenteyckeninge. Pp. 181–234, *In* J.F. Jameson (Ed.). Narratives of New Netherland, 1609–1664. Barnes and Noble, Inc., New York, NY.

Dunwiddie, P., D. Foster, D. Leopold, and R.T. Leverett. 1996. Old-growth forests in southern New England, New York, and Pennsylvania. Pp. 126–143, *In* M.B. Davis (Ed.). Eastern Old-Growth Forests: Prospects for Rediscovery and Recovery. Island Press, Washington, DC. 383 pp.

Edinger, G.J., D.J. Evans, S. Gebauer, T.G. Howard, D.M. Hunt, and A.M. Olivero (Eds.). 2002. Ecological Communities of New York State. Second Edition. A revised and expanded edition of Carol Reschke's Ecological Communities of New York State. (Draft for review). New York Natural Heritage Program, New York State Department of Environmental Conservation, Albany, NY.

Egan, D., and E.A. Howell. 2001. The Historical Ecology Handbook: A Restorationist's Guide to Reference Ecosystems. Island Press, Washington, DC.

Forman, R.T.T. 1995. Land Mosaics: The Ecology of Landscapes and Regions. Cambridge University Press, Cambridge, UK. 632 pp.

Foster, D.R., S. Clayden, D.A. Orwig, B. Hall, and S. Barry. 2002. Oak, chestnut, and fire: Climatic and cultural controls of long-term forest dynamics in New England. Journal of Biogeography 29:1381–1400.

Greller, A.M. 1972. Observations on the forests of northern Queens County, Long Island, from colonial times to the present. Bulletin of the Torrey Botanical Club 99: 202–206.

Greller, A.M. 1975. Persisting natural vegetation in northern Queens County, New York, with proposals for its conservation. Environmental Conservation 2:61–71.

Grumet, R.S. 1981. Native American Place Names in New York City. Museum of the City of New York, New York, NY. 79 pp.

Halliwell, D.B., T.R. Whittier, and N.H. Ringler. 2001. Distribution of Lake Fishes in the Northeast: III Salmonids and associated coldwater species. Northeastern Naturalist 8:189–206.

Harper, R.M. 1911. The Hempstead Plains: A natural prairie on Long Island. Bulletin American Geographical Society 43:351–360.

Hill, G.E., and G.E. Waring, Jr. 1897. Old wells and water-courses on the Isle of Manhattan. Parts I and II. Pp. 191–262, *In* M.W. Goodwin, A.C. Royce, and R. Putnam (Eds.). Historic New York: Being the First Series of the Half Moon Papers. G.P. Putnam's Sons, New York, NY.

Hornaday, W.T. 1909. The Wild Animals of Hudson's Day and the Zoological Park of Our Day. Hudson-Fulton Commission in cooperation with the New York Zoological Society, New York, NY.

Jackson, K.T. 1995. The Encyclopedia of New York City. Yale University Press, New Haven, CT. 1350 pp.

Johnson, C.W. 1985. Bogs of the Northeast. University Press of New England. Hanover, NH. 269 pp.

Jogues, I. 1646. Novum Belgium. Pp. 259–263, In J.F. Jameson (Ed.). Narratives of New Neterland, 1609–1664. Barns and Noble, Inc., New York, NY.

Jorgensen, N. 1977. A Sierra Club Naturalist's Guide to Southern New England. Sierra Club Books, San Francisco, CA. 417 pp.

Kantrowitz, N. 1995. Population. Pp. 920–923, *In* Jackson, K.T. (Ed.). The Encyclopedia of New York City. Yale University Press, New Haven, CT.

Kershner, B. 1998. Guide to Ancient Forests in Vicinity of New York City. New York Old Growth Forest Association, Williamsville, NY.

Kieran, J. 1959. A Natural History of New York City. Houghton Mifflin, Boston, MA. 428 pp.

Koeppel, G.T. 2000. Water for Gotham: A History. Princeton University Press, Princeton, NJ.

Kleinstein, D.S. 2003. Paleoecological change during the past millennium at Saw Mill Creek Salt Marsh, Staten Island, NY. M.Sc. Thesis. Columbia University, New York, NY.

Laxton, P. 1976. The geodetic and topographical evaluation of English county maps, 1740–1840. Cartographic Journal 13:37–54.

Loope, W.L., and J.B. Anderton. 1998. Human vs. lightning ignition of presettlement surface fires in coastal pine forests of the upper Great Lakes. The American Midland Naturalist 140:206–218.

Luttenberg, D., D. Lev, and M. Feller. 1993. Native Species Planting Guide for New York City and Vicinity. Natural Resources Group, City of New York, Department of Parks and Recreation, New York, NY.

MacCoun, T. 1909. The Island of Manhattan (Mannahtin) at the time of its discovery, 1609. Map in the collection of the New York Historical Society, New York, NY.

McRoy, C.P., and C. Helfferich. 1977. Seagrass Ecosystems: A Scientific Perspective. Marcel Dekker, Inc., New York, NY. 314 pp.

McVay, K.R. 1998. ImageWarp ver. 2.0. Available online at http://www.esri.com/arcscripts. Accessed 1 March 2001.

Mittelbach, M., and M. Crewdson. 1997. Wild New York: A Guide to the Wildlife, Wild Places, and Natural Phenomena of New York City. Three Rivers Press, New York, NY. 196 pp.

Moscow, H. 1990. The Street Book: An Encyclopedia of Fordham University Press, Bronx, NY.

Museum of the City of New York. 1977. Our Town: Images and Stories from the Museum of the City of New York. Museum of the City of New York, New York, NY. 222 pp.

Paillet, F. 2002. Chestnut: The history and ecology of a transformed species. Journal of Biogeography 29:1517–1530.

Penfold, P.A. 1974. Maps and Plans in the Public Record Office, Vol. 2: American and West Indies. Public Records Office, London, UK.

Putz, F.E. 2003. Are rednecks the unsung heroes of ecosystem management? WildEarth 13:10–14.

Reschke, C. 1990. Ecological Communities of New York State. New York Natural Heritage Program, Latham, NY. 96 pp.

Richter, V., and Ostroff, G. 2001. New York City's New Base Map: The Holy Grail? ESRI User Conference Proceedings, July 9–13, 2001, San Diego, CA. Available online at http://gis.esri.com/library/userconf/proc01/professional/papers/pap949/p949.htm. See also: http://gis.nyc.gov/doitt/mp/Portal.do. Accessed 26 April 2006.

Riker, J. 1904. Revised History of Harlem (City of New York): Its Origin and Early Annals. New York, NY. 95 pp.

Rosenzweig, R., and E. Blackmar. 1992. The Park and the People: A History of Central Park. Cornell University Press, Ithaca, NY. 623 pp.

Sanderson, E.W. In press. A view of Manhattan Island at the end of the American Revolution: A quantitative analysis of the British Headquarters Map, c. 1782, including comments on its accuracy. Imago Mundi.

Sarna-Wojcicki, D. 2005. Horticulture in Lenape Native American diet and its impact on the landscape ecology of "Manahatta." Senior Honors Thesis. Columbia University, New York, NY. 66 pp.

Schmidt, R.E. 1986. Zoogeography of the northern Appalachians. Pp. 137–159, *In* C.H. Hocutt and E.O. Wiley (Eds.) The Zoogeography of North American Freshwater Fishes. John Wiley and Sons, New York, NY. 866 pp.

Seitz, S., and S. Miller. 1996. The Other Islands of New York City. Countryman Press, Woodstock, VT. 288 pp.

Shorto, R. 2004. The Island at the Center of the World: The Epic Story of Dutch Manhattan and the Forgotten Colony that Shaped America. Doubleday, New York, NY. 385 pp.

Sirkin, L.A. 1967. Late Pleistocene pollen stratigraphy of western Long Island and eastern Staten Island, New York. Pp. 249–274, *In* E.J. Cushing and H.E. Wright, Jr., (Eds.). Quaternary Paleoecology. Yale University Press, New Haven, CT.

Stevens, B.F. 1900. B.F. Stevens' facsimile of the unpublished British headquarters coloured manuscript map of New York and environs, 1782. Reproduced from the original drawing in the War Office, London. Self-published. New York Public Library Map Division, New York, NY.

Steinberg, N., D.J. Suszkowski, L. Clark, and J. Way. 2004. Health of the harbor: The first comprehensive look at the state of the NY/NJ harbor estuary. Hudson River Foundation, New York, NY. 86 pp.

Stilgoe, J.R. 1994. Alongshore. Yale University Press, New Haven, CT. 443 pp.

Stokes, I.N.P. 1915–1928. The Iconography of Manhattan Island, 1498–1909, 6 volumes. R.M. Dodd, New York, NY.

Torrey, J., C.W. Eddy, and D.J.V. Knevels. 1817. Catalogue of Plants, Growing Spontaneously within Thirty Miles of the City of New York. Lyceum of Natural History of New York, NY. 100 pp.

US Census Bureau. 2006. US Census 2000 Gateway. US Department of Commerce, US Census Bureau, Geography Division, Washington, DC. Available online at http://www.census.gov/main/www/cen2000.html. Also see http://www.nyc.gov/html/dcp/pdf/census/demonyc.pdf. Accessed 14 Mrch 2002.

US Department of Agriculture 2006. Integrated Taxonomic Information System (ITIS). Available online at http://www.itis.usda.gov. Accessed on April 12, 2006.

Waldman, J. 1999. Heartbeats in the Muck: A Dramatic Look at the History, Sea Life, and Environment of New York Harbor. The Lyons Press, New York, NY. 178 pp.

White, P.S., and R.D. White. 1996. Old-growth oak and oak-hickory forests. Pp. 178–198, in M.B. Davis (Ed.). Eastern Old-growth Forests: Prospects for Rediscovery and Recovery. Island Press, Washington, DC. 383 pp.

Whitney, G.G. 1994. From Coastal Wilderness to Fruited Plain. Cambridge University Press, New York, NY.

Whittier, T.R., D.B. Halliwell, and R.A. Daniels. 1999. Distribution of lake fishes in the northeast. I. Centrarchidae, Percidae, Esocidae, and Moronidae. Northeastern Naturalist 6:283–304.

Whittier, T.R., D.B. Halliwell, and R.A. Daniels. 2000. Distribution of lake fishes in the northeast. II. The minnows (Cyprindae). Northeastern Naturalist 7:131–156.

Whittier, T.R., D.B. Halliwell, and R.A. Daniels. 2001. Distribution of lake fishes in the northeast. IV. Benthic and small water-column species. Northeastern Naturalist 8:455–482.

Viele, E.L. 1865. Sanitary and topographical map of the city and island of New York. Library of Congress, Washington, DC.