LATE HOLOCENE NATIVE AMERICAN LAND-USE IMPACTS ON THE VEGETATION OF WESTERN AND CENTRAL NEW YORK STATE, USA: AN INTEGRATED HISTORICAL AND PALEOECOLOGICAL ANALYSIS

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ABSTRACT

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This dissertation employed an integrated conceptual model and methodology derived from historical ecology, paleoecology, and archaeology to examine the relationship between evolving prehistoric Native American land-use impacts on vegetation dynamics and their relationship to environmental gradients and coeval paleoclimate change over a ~4400-year period in western and central New York State, USA. The historical ecological component of this study utilized late-18th century CE vegetation data derived from land survey records (LSRs) in conjunction with digital, georeferenced archaeological site location data to evaluate the relationship between agricultural Iroquoian settlement patterns and the distribution of major environmental gradients modulating regional vegetation dynamics prior to widespread Euro-American settlement. Results of non-metric multidimensional scaling (NMS), detrended correspondence analysis (DCA), and agglomerative hierarchical clustering (AHC) indicated the presence of a primary environmental gradient related to fire frequency, which displayed a clear spatial association with the distribution of archaeological sites. Minor gradients associated with soil productivity and canopy density also exhibited spatial correspondences with Native American settlement patterns. Use of combined compositional (bearing tree taxa) and structural (qualitative descriptors of vegetation/landscape form and appearance) data from the LSRs provided greater detail and subtlety in the vegetation ordinations and classifications, clarifying the likely ecological effects and geographic extent of protohistoric and historic Native American populations on the regional landscape.

Paleoecological analysis of a kettle peatland sediment core from the study area revealed a similar primacy of fire frequency through time. The kettle's pollen record documented an initial period (~4400 – 2500 cal. yr BP) of centennial-scale oscillation between fire-tolerant and fire-intolerant pollen taxa, strongly suggesting quasi-cyclic climate modulation. A collapse of this cyclicity becomes evident between ~2500 and 2200 cal. yr BP, with a unidirectional trend toward more numerous fire-tolerant pollen taxa and associated forest community types. The onset of this change is broadly coeval with the earliest appearance of *Zea mays* (maize) in the regional archaeological record. A subsequent exponential increase in non-arboreal pollen indicators of openland habitat is temporally associated with the arrival of fully agricultural Iroquoian populations within a 20-km radius of the kettle after ~800 cal. yr BP. These findings suggest a dual-phase model for the development of anthropogenic land-use impacts on the regional vegetation, which are hypothesized to have been largely modulated by developing human subsistence patterns.

For my family –
Thank you for your love, patience, and resilience.
Adesso e per sempre.

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CHAPTER 1. INTRODUCTION

Sga:d hëdwa:ye:' ögwa'nigöë'
Dëdwanö:nyo:'gahadayë'
Da:h ne'hoh dih nëyögwa'nigo'dë:ök

Now our minds are one
We give thanks to the trees of the forest
And so let it be that way in our minds
– Ganö:nyök (Seneca Thanksgiving Address)

1. Background

1.1. Reconstructing prehistoric human land-use impacts on vegetation: A North American perspective

The reconstruction of past vegetation change resulting from the influence of indigenous human populations in North America has often been hampered by a lack of integration among available proxies, which possess variable taxonomic, temporal, and spatial resolutions. Specifically, historical land survey records (LSRs) typically capture detailed, species-rich "snapshots" of vegetation conditions immediately prior to local Euro-American settlement within the last ~400 years. In contrast, analyses of paleoecological proxies contained within lacustrine/wetland sediments offer generally continuous records of vegetation dynamics over past millennia, but at coarser taxonomic resolution, as most pollen are identified to the genus level (e.g. Mander and Punyasena 2014). Spatial scales also differ strikingly among these archives of plant community composition. LSRs typically capture species-specific details of vegetation covering large areal extents (10^2 – 10^3 km^2; Wang 2005). Whereas paleoecological data represent a more homogenized composite of pollen rain, deposited at a single site, derived from source areas averaged from local, extralocal, and landscape scales, most commonly within a 20 – 30-km radius of the basin (Jacobson and

Bradshaw 1981). Importantly, to date, no studies have integrated both types of vegetation datasets in eastern North America. Therefore, temporal and spatial gaps likely occur in those studies that reconstruct variability in past forest species composition and structure using only LSR or pollen data sets. Consequently, a fuller, more nuanced interpretation of vegetation change requires the integration of both historic and prehistoric datasets.

1.2. The climate-versus-human conundrum

A confounding factor in the reconstruction and interpretation of past vegetation dynamics rests in the common assumption that climate change has been the primary driver of ecosystem variability over time in eastern North America and elsewhere (e.g. Pederson et al. 2014). Although the role of climate is indeed paramount at protracted timescales (centennial and millennial scales) due to the influence of orbital and solar forcing mechanisms – e.g. the transition from glacial to interglacial climate regimes and their associated biotic responses (e.g. Webb and Williams 2003) – anthropogenic influences on ecosystem variability have played an important role at decadal to centennial timescales (e.g. Birks and Birks 1980; Delcourt and Delcourt 2004). The influence of human land-use impacts has long been recognized in the European paleoecological record, where historic and archaeological evidence attests to the presence of large resident agricultural populations impacting forest species composition, structure, and connectivity (fragmentation) beginning ~8000 cal. yr BP (i.e. the “Neolithic Revolution”; Ruddiman 2003; Roberts et al. 2018). This has led some researchers to suggest the onset of the “Anthropocene” had commenced at this time rather than at the start of the Industrial Revolution (Ruddiman 2003).

In North America, paleoecological paradigms have less commonly considered Native Americans as a major modulator of vegetation dynamics, for a variety of reasons. This lack of attention to the potential role of indigenous populations on driving ecosystem change is at odds with an abundant archaeological and ethnohistorical record indicating substantial landscape alteration at local and possibly landscape scales (Day 1953; Denevan 1992; Doolittle 2000). Specifically, archaeological data demonstrate that agricultural activity commenced in eastern North America with the cultivation of *Cucurbita* sp. (gourd) between 7500 and 5000 cal. yr BP, followed the domestication and incorporation of a suite of native seed crops – primarily floodplain ruderal taxa such as *Iva annua* (marshelder/sumpweed), *Helianthus annuus* (sunflower), and *Chenopodium berlandieri* (goosefoot/lambsquarters) – into regional diets by ~4000 cal. yr BP (Asch and Hart 2004). These cultigens, known collectively as the “Eastern Agricultural Complex” (Smith 1989; Mueller et al. 2017), were grafted onto the pre-existing system of cucurbit cultivation, and eventually augmented by the addition of the tropical cultigen *Zea mays* (maize), making its earliest documented archaeological appearance in eastern North America by ~2300 cal. yr BP (Hart et al. 2007). The protracted emergence of this *in situ* horticultural system during the Middle Holocene (~7000 – 4500 cal. yr BP) was superimposed upon a successful, longstanding hunting-gathering subsistence economy which had been in place since the Early Archaic period (~10,000 – 8000 cal. yr BP; Hart and Lovis 2013).

The subsequent geographic expansion and adoption of *Zea mays* into indigenous subsistence economies during the period from ~2000 to 1000 cal. yr BP – a non-linear process occurring discontinuously in space and time (Hart and Mearns 2002) – was followed by the intensification of maize-based horticulture and agriculture across much of eastern North America, although considerable regional variability is evident in its role as a dietary staple

(Hart 2016). Important developments in archaeological analytical techniques, such as phytolith and starch analyses of pottery cooking residues (Albert et al. 2018), and intensive radiocarbon dating efforts of archaeobotanical remains, have forced a reevaluation of the pattern and process of crop domestication in eastern North America. As a result, this has extended the chronology of certain cultigens (e.g. maize) further back in time, while constraining others (e.g. *Phaseolus vulgaris* [common bean]) to more recent introductions (post-700 cal. yr BP) into indigenous diets (Hart and Scarry 1999). These important revisions to the regional archaeobotanical chronology of eastern North America have forced a reconsideration and redefinition of long-accepted anthropological paradigms related to the adoption of intensive maize-based agriculture as the necessary precursor to settled village life during the Late Woodland period (~1000 – 400 cal. yr BP; Hart and Brumbach 2005).

1.3. Time-depth of anthropogenic change

Considering the complex developmental trajectories of prehistoric Native American crop systems, the corresponding impact of horticultural and agricultural land-use activities on local and regional ecosystems was very likely more complex, subtle, and protracted than has previously been recognized. A key question arises: *How far back in time are signals of anthropogenic land-use visible in the paleoecological record*? Answering this question is complicated by the fact that the North American continent has been inhabited continuously since the terminal Pleistocene (~13,000 cal. yr BP, with equivocal evidence of Pre-Clovis colonization ~15,000 – 13,000 cal. yr BP; Waters and Stafford 2014). During this extended pre-agricultural period – encompassing the majority of the continent’s prehistory – human populations occupied several major biomes and practiced a generalized hunting-foraging subsistence economy. As such, indigenous groups doubtlessly interacted with their local environments in ways that altered ecosystem structure and functioning from the moment of their arrival in the Western Hemisphere (e.g. the Pleistocene megafaunal extinction; Robinson et al. 2005), as has been suggested for human colonization events in other parts of the globe (Steadman 1995; Burney et al. 2003; van der Kaars et al. 2017). As a consequence, anthropogenic impacts on North American biota, landscapes, and disturbance regimes have likely been the norm over the entire span of human occupation beginning ~15,000 cal. yr BP.

Ecosystem effects wrought by incipient horticultural and agricultural land-use activities during the latter half of the Holocene would thus represent a distinct phase of a continuous, millennia-long sequence of human-environment interactions, but would not constitute a complete disjunction with past anthropogenic impacts. In fact, it is probable that prior centuries and millennia of human-mediated interactions would have produced feedbacks and legacy effects that encouraged particular ecological changes and cultural developments and selected for changes in successive generations of organisms, and in humans themselves (i.e. niche construction theory [NCT]; Laland et al. 2009). Tracing the development of specifically horticultural or agricultural interactions related to the diffusion of cultigens, however, must be contextualized within a temporal window informed by the archaeological record. Ideally, a paleoecological research paradigm should seek to capture reference-point conditions existing prior to the onset of important cultural developments in order to identify the dominant modulators of ecological variability (e.g. climate) and their primary characteristics (e.g. periodicity and amplitude of natural variation; corresponding ecosystem effects) in order to compare these to post-baseline conditions in areas where horticultural and agricultural impacts on vegetation occurred.

2. Developing a conceptual framework: anthropogenic disturbance indicators (ADIs)

Paleoecolgical analyses designed to evaluate the influence of past millennia of Native American land-use impacts on prehistoric ecosystems should be set within the context of the *anthropogenic disturbance indicator (ADI*; a term coined herein), which I define as a proxy signal of anthropogenic land-use practices visible within the paleoecological record. ADIs result from the application of external changes having an origin in cultural behaviors to one or more environmental systems (e.g. biosphere, geosphere, atmosphere, hydrosphere). If the strength of the applied change is of sufficient intensity and/or duration, and exceeds an innate system threshold, a period of adjustment will result, producing a state change in the system. These changes should be reflected in one or more proxy indicators that can be preserved within the paleoecological record, and, ideally, can be temporally correlated to established archaeological site chronologies or important, well-dated cultural transitions.

ADIs are similar to the "anthropogenic plant functional type class" (APFT) concept developed by Muñoz and Gajewski (2010), which used early-successional, ruderal, non-arboreal pollen taxa (e.g. *Ambrosia* [ragweed] *Artemisia* [mugwort/wormwood], *Rumex* [dock], *Pteridium* [bracken fern]) as indicators of prehistoric agricultural disturbance in the paleoecological record of southern Ontario, Canada. However, my use of the ADI concept is broader and includes these as well as other biotic and abiotic disturbance indicators that have been utilized in prior studies focused on identifying Native American land-use impacts in the paleoecological, geological, and neo-ecological records. These proxies have included pollen (Delcourt et al. 1998; Loeb 1998; McLauchlan 2003; McAndrews and Turton 2007, 2010; Muñoz and Gajewski 2010; Muñoz et al. 2014; Gajewski et al. 2019), stable isotope geochemistry (Springer et al. 2010; Stinchcomb et al. 2011, 2013), lacustrine sediment charcoal (Patterson and Sassaman 1988; Clark and Royall 1995), soil charcoal (Johnson and Abrams 2017), and archaeobotanical remains (Asch Sidell 2008), among others. For the paleoecological component of this dissertation, I used a variety of proxies that were potentially sensitive to prehistoric anthropogenic land-use impacts including pollen (reconstruction of vegetation), macroscopic sediment charcoal (reconstruction of local fire events), loss-on-ignition (LOI; reconstruction of sediment fluxes due to sustained/episodic erosion), and $\delta^{13}C$ values of sediment organic matter (reconstruction of C_3/C_4 vegetation ratios, biological productivity). I also placed particular emphasis on utilizing historical repositories of local- and landscape-scale vegetation conditions immediately prior to widespread Euro-American settlement to inform my definition of the most important ADIs in the pollen record. This was made possible through the use of recent centuries of digital, georeferenced archaeological site location data analyzed in conjunction with geospatial vegetation data derived from late-18th century CE land survey records (LSRs) in an area with a well-documented, continuous archaeological record.

3. Selection of study area

To address these issues related to detecting Native American land-use practices in the historic and paleoecological records of vegetation change, a broad region encompassing western and central New York State, USA (Figure 1.1) was selected as the study area for a number of reasons: (1) a rich, continuous, and well-studied archaeological record extending back beyond the inception of maize-based agriculture (prior to ~2500 cal. yr BP). (2) Indigenous Iroquoian populations (historically comprising the Neutral, Seneca, Cayuga, and Onondaga nations) of the region practiced an intensive form of maize-based agriculture during the Late Woodland and Historic periods. (3) The existence of numerous, spatially extensive, and

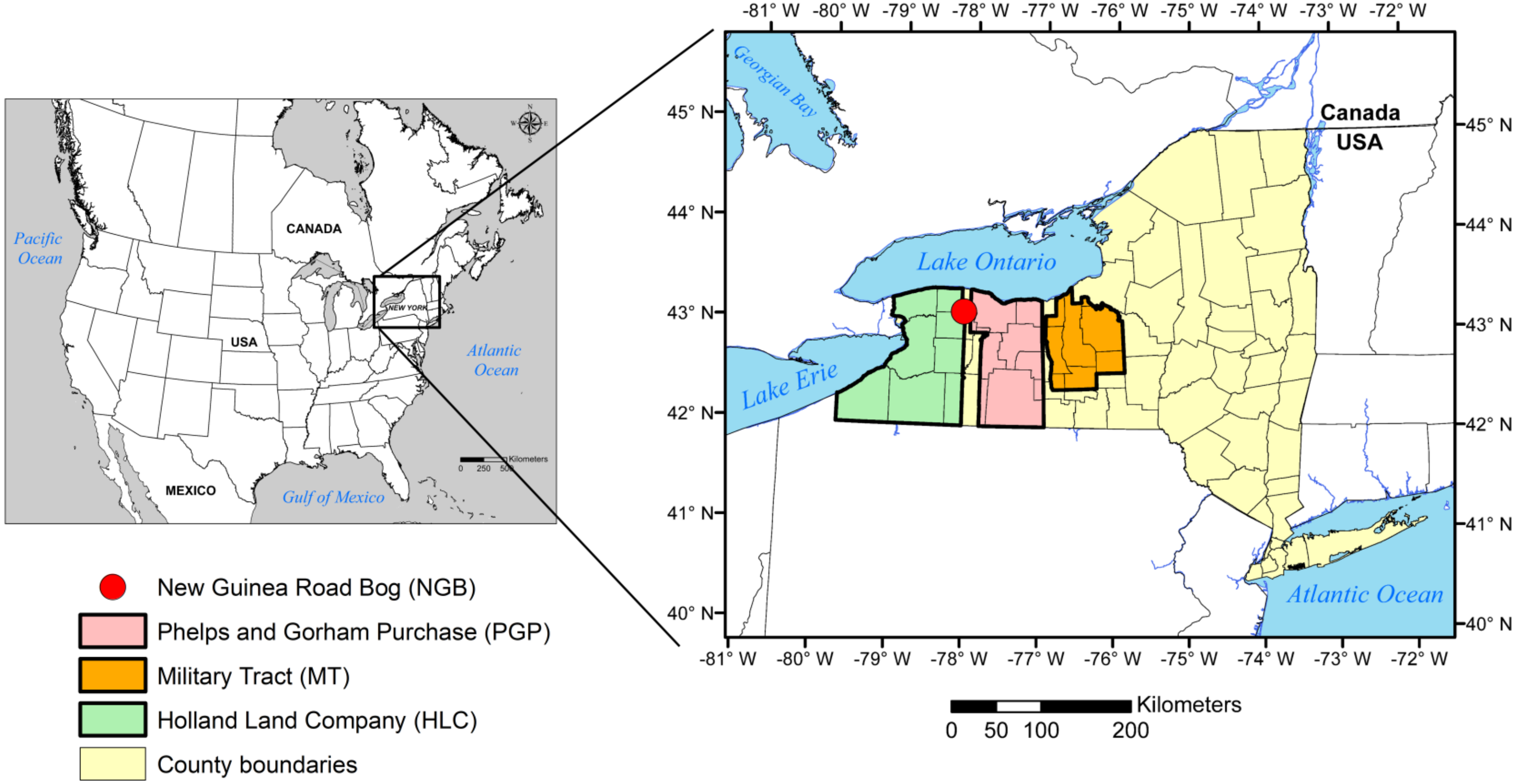

Figure 1.1. Location of the dissertation study area, western and central New York State, USA, showing relative positions of the Phelps and Gorham Purchase (PGP; Chapter 2), Military Tract (MT; Chapter 3), Holland Land Company (HLC), and the New Guinea Road Bog (NGB; Chapter 4) coring site.

detailed late-18th century CE LSRs that capture previously overlooked details of Native American vegetation impacts. (4) Numerous written historical European and Euro-American descriptions of the regional landscape and vegetation as it existed prior to Native American expulsion circa 1779 CE. Many documentary sources (e.g. traveler's accounts, letters, diaries, military journals) also contain detailed accounts of Iroquoian cultural practices, settlement locations, and indigenous subsistence patterns. And, (5) an overall lack of previous research on (pre)historic Native American land-use impacts on the regional vegetation.

Only one lacustrine coring site situated in an area having a history of Iroquoian occupation Crawford Lake, Ontario, Canada has been the subject of intensive paleoecolgical analyses on the effects of Iroquoian agricultural land-use practices (Clark and Royall 1995; Byrne and Finlayson 1998; McAndrews and Turton 2007, 2010). At this site, Iroquoian (Neutral) populations engaged in several phases of forest clearance and cultivation between 1300 and 1670 CE. However, the period prior to Iroquoian settlement was not investigated, resulting in a lack of information on prior land-use by pre-Iroquoian populations. The analyses presented in this dissertation differ from the Crawford Lake studies in that I have deliberately selected a longer period of time in which to trace the development of Native American land-use impacts informed by the recent revisions to the archaeological chronology of cultigen diffusion into the region. This also entailed the selection of a coring site situated at the periphery of known prehistoric (~1000 – 1600 CE) and historic (post-1600 CE) Native American agricultural settlements in order to assess if specific land-use practices could be inferred from this site's paleoecologial record situate in a hinterland. An additional difference between the present analysis and prior research at Crawford Lake lies in the use of historical LSR-derived vegetation data to delineate the spatial and ecological effects of Native American land-use practices within the broader western and central New York State study area, through various multivariate statistical techniques, which served as a conceptual model for the interpretation of down-core variability in proxy indicators (i.e. ADIs).

4. Research goals and questions

This dissertation research had one overarching goal: (1) to quantify and explain the timing, spatial extent and magnitude of prehistoric and historic Native American land-use impacts on the vegetation of central and western New York State over the last 4500 years. This goal was addressed using a comprehensive, innovative approached based upon multivariate statistical analyses of LSR and paleoecological data archives. The multifaceted, multiproxy approach utilized in this research contributes to broader discussions on Native American land-use impacts and provide new avenues of research in future studies. More specifically, this dissertation confronts several important topical questions, including:

(1) *How do ADI signals reflect changes in subsistence and settlement patterns during the transition from hunting-foraging to agricultural subsistence economies during the Woodland period (~3000 – 400 cal. yr BP)?* To answer this question, I utilized an ecological conceptual model developed from multivariate statistical analyses of historic LSR-derived vegetation data to correlate observed down-core changes in paleoecological proxies to inferred periods of anthropogenic disturbance. This was possible through the use of ADIs to track the temporal trajectory of forest compositional turnover (pollen), variability in fire frequency/intensity (macroscopic sediment charcoal), landscape stability (LOI), and landscape openness ($\delta^{13}C$ values on sediment organic matter [OM]).

(2) *Can anthropogenic signals be differentiated from non-cultural (i.e. "natural") indicators in the paleoecological record, most importantly climate*? This question was tested by using the local and regional archaeological chronology – including approximate dates for major cultural transitions – to identify "baseline" conditions prior to the transition from a hunting-foraging subsistence economy to a largely maize-based agricultural one. This entailed selection of a coring site that was likely susceptible to the deposition of an anthropogenic pollen signal from an adjacent or upwind source area. Additionally, dated periods of known regional climate events – e.g. the Medieval Climate Anomaly (MCA; ~1150 – 500 cal. yr BP) and the subsequent Little Ice Age (LIA; ~500 – 100 cal. yr BP; Wanner et al. 2008) – were delineated and comparisons made between proxy indicators during these intervals to test for periods of synchrony and divergence between ADI and other proxies. Initial observations of the paleoecological data were compared to regional paleoclimate and paleopopulation proxies to validate subsequent interpretations and determine if Native American land-use impacts were distinguishable from climate signals in the core's paleoenvironmental record.

(3) *Can data from historical ecology inform the analysis and interpretation of paleoecological data, and vice versa?* Bridging the temporal divide by integrating historical (LSRs) and prehistoric (ADIs) proxy datasets was a major component of this dissertation research. The contrasting taxonomic resolution, temporal scales, and geographic representativeness of each data source made this a challenging task, but one that can be resolved through multivariate statistical analysis of the historic and prehistoric datasets. For example, ordination techniques – including principal component analysis (PCA), detrended correspondence analysis (DCA), and non-

metric multidimensional scaling (NMS) – reduce data complexity to a few, non-correlated, synthetic dimensions encapsulating the major patterns of variance in a vegetation dataset (Kent 2012), regardless of historical (LSRs) or paleoecological (ADIs) origin. The resulting “meta-dimensions” normally are interpreted as the primary underlying environmental modulators (anthropogenic or “natural”) of vegetation dynamics (McCune and Grace 2001). With temporally static LSR data, these modulators can be interpolated from discrete sampling points (i.e. individual witness trees) to a continuous coverage via spatial interpolation to delineate spatial gradients across the landscape. The resulting interpolated maps can then be compared with archaeological site distributions to evaluate spatial trends in environmental modulators with respect to human settlement patterns. In contrast, when using paleoecological data, the synthetic dimensions produced by these ordination techniques can be plotted chronologically to reveal temporal variability in underlying modulators affecting vegetation. Finally, comparison of taxonomic correlations on each meta-dimension between historical and paleoecological datasets can determine if modulators are equivalent, thereby validating their usefulness as indicators of anthropogenic land-use impacts across space and time. This methodological approach represents an innovation that has not been previously applied in any other research on past vegetation change in North America.

5. Summary

This dissertation research is unique in that it used multivariate statistical analyses of historical vegetation data (LSRs) to characterize forest community composition and identify primary modulators of vegetation dynamics, which were applied to both the historical LSR data and the paleoecological record. Using results of the multivariate statistical analyses of the chronologically static LSR data as conceptual models to infer down-core changes in pollen and other proxy indicators of disturbance pathways enabled the tracking of evolving Native American subsistence economies and settlement patterns during the Late Holocene. These changes were validated through analysis of the regional archaeological record. Although regional in focus, this dissertation research has broader applicability, as it demonstrates the complementarity of archaeological, ecological, historical, and paleoecological datasets, which can be used together to help address persistent questions relevant to multidisciplinary research focused on past human-environment interactions. Some of these questions include (1) assessing the timing of the introduction and intensification of incipient horticulture and agriculture in eastern North America, (2) elucidating differences in aboriginal disturbance regimes associated with agricultural and non-agricultural subsistence activities, and (3) tracing the development of regionally rare and threatened ecosystems, such as fire-adapted oak savannas and pine barrens, and their relationship to past human culture change and climatic perturbations. The region's rich archaeological record, wealth of relevant historical and ecological data, and lack of previous studies of this nature make the study area an ideal location in which to test hypotheses of human-environment interactions using such an integrated theoretical and methodological strategy.

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CHAPTER 2. NATIVE AMERICAN LAND-USE IMPACTS ON A TEMPERATE FORESTED ECOSYSTEM, WEST-CENTRAL NEW YORK STATE, USA

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Abstract

Land survey records (LSRs) describing forest species composition prior to extensive Euro-American settlement are critical sources of information on past environmental controls of forest dynamics in eastern North America. Embedded within these historical data sources are evidence of prior Native American land-use. This study expands upon previous LSR-based analyses of Seneca/Iroquoian populations' impacts on the temperate forests of west-central New York state, USA. I utilize an enhanced array of geospatial LSR vegetation data beyond conventional bearing tree data and implement, for the first time, combined indirect ordination of vegetation data along major environmental gradients and numerical classification of discrete upland vegetation communities. Nonmetric multidimensional scaling revealed three main drivers of vegetation dynamics in the study area: (1) fire frequency (53.7% of total variance); (2) soil productivity (22.6% variance); and (3) Native American land-use (15.9% variance). Agglomerative hierarchical clustering reinforced the primacy of these gradients by delineating two major forest types differentiated primarily by fire frequency, and secondarily by soil productivity. Seneca/Iroquoian agricultural villages were preferentially concentrated within fire-tolerant dry upland forests on high-productivity soils within the interior portion of the Lake Ontario Lowland. Fire-tolerant, dry upland forests on low-productivity soils were situated on the adjacent Appalachian Plateau, which was likely utilized by indigenous populations for silvicultural land-use activities. Native American disturbance of temperate forested ecosystems likely varied across the diverse culture areas of eastern North America, with the Seneca/Iroquois representing an extreme end-member within a broad continuum of anthropogenic disturbance. *Key Words: Native Americans, land survey records, vegetation disturbance, land-use history, forest composition.*

1. Introduction

The ecological impact of indigenous populations on prehistoric and early historic landscapes of North America has emerged as an important area of inquiry within physical geography and allied disciplines over recent decades. Native American populations are known to have modified natural vegetation communities over past centuries through a variety of land-use practices including burning, clearing, agriculture, and silviculture (i.e. active/passive management of forest taxa; Muñoz et al. 2014). A range of interdisciplinary perspectives has been employed to investigate the nature, extent, and magnitude of indigenous land-use practices on forested ecosystems prior to European settlement during the 17th – 19th centuries CE (Common Era), including ethnohistory (Day 1953; Denevan 1992; Doolittle 2000), palynology (Delcourt et al. 1998; Muñoz et al. 2015), dendroecology (Ruffner and Abrams 2002), stable isotope geochemistry (Springer et al. 2010), geomorphology (James 2011), geoarchaeology (Stinchcomb et al. 2011), charcoal analysis of lake sediments (Clark and Royall 1996) and soils (Johnson and Abrams 2017), and analysis of historic land survey records (LSRs; Black et al. 2006; Tulowiecki and Larsen 2015). Despite the diversity of approaches utilized, interpretations of Native American land-use impacts upon forested ecosystems remain equivocal, ranging from biome-scale transformations (Abrams and Nowacki 2008) to localized perturbations adjacent to agricultural settlements (Matlack 2013).

Ambiguous and contradictory interpretations of Native American vegetation disturbance can often be attributed to differences in temporal and spatial resolutions between proxies. For example, archaeological data recording prehistoric subsistence practices at specific sites are limited in geographic extent, frequently represent discontinuous intervals of human occupation, and provide limited information on local vegetation conditions in the absence of macrobotanical remains (Asch Sidell 2007). In contrast, paleoecological data (e.g. pollen) derived from lake sediments typically allow for the reconstruction of vegetation and associated climate conditions at finer temporal scales as well as at local- and landscape-level spatial scales during phases of both human occupation and abandonment (McAndrews and Turton 2010). However, differentiating unequivocal paleoecological signals of anthropogenic land-use activities from those related to climatic forcing mechanisms and non-anthropogenic disturbance processes can be problematic. Unequivocal evidence of Native American land-use practices is limited to proxy indicators of agricultural activity such as cultigen pollen grains (McLauchlan 2003), and less conclusively, to the presence of early-successional, herbaceous pollen taxa including grasses (Gramineae spp.) and ragweed (*Ambrosia* spp.; Muñoz and Gajewski 2010).

Signals of Native American land-use activities can often be found in land survey records (LSRs) dating to the 17th – 19th centuries CE, however. These historical documents are the most detailed sources available on the species composition and disturbance regimes of temperate forested ecosystems prior to widespread Euro-American settlement and have been utilized to infer indigenous land-use effects on forest species composition (e.g. Black and Abrams 2001; Foster et al. 2004; Black et al. 2006; Tulowiecki and Larsen 2015) and as indicators of fire (Thomas-Van Gundy and Nowacki 2013). Prior LSR-based research was focused upon analysis of species-level descriptions of bearing (witness) trees blazed and recorded along surveyed bounds. Although bearing trees are important as general indicators of ecological and environmental processes modulating forest dynamics (e.g. Goring et al. 2016; Paciorek et al. 2016), most studies exclusively utilizing bearing trees have identified only a general spatial association between Native American settlement and mast taxa (Foster et al. 2004; Black et al. 2006; Tulowiecki and Larsen 2015). Some concern has been raised over the likelihood of surveyor bias in the selection of particular species used as bearing trees, thereby overrepresenting such taxa relative to their actual importance within forest stands (Wang 2005). However, bearing tree data are only one of several categories of critical environmental indicators commonly found within many LSR data sources that have routinely been ignored in favor of the more numerous bearing trees. By harnessing a wider range of biotic data contained within LSRs, I suggest that vegetation gradients associated with Native American land-use impacts may be more accurately captured than with bearing tree data alone.

To this end, this study utilized an expanded array of LSR-derived vegetation-related variables in addition to conventional bearing tree data, including: (1) inventories of multiple arboreal taxa collected along surveyed bounds; (2) qualitative descriptions of vegetation composition, form, and canopy density; (3) evidence of vegetation disturbance such as fire and windthrows, and (4) indicators of prior Native American land-use activities. By adopting a more inclusive approach that extracts all pertinent environmental indicators from LSR sources, and analyzing these in conjunction with ancillary archaeological site location data using a novel combination of multivariate statistical methods within a geographic information systems (GIS) framework, this study sought to (1) identify clearer signals of Native American land-use impacts associated with maize-based agriculture and silviculture on the species composition of a temperate forested ecosystem through ordination of LSR-derived variables using non-metric multidimensional scaling (NMS); and (2) contextualize anthropogenic disturbance gradients within a landscape-level vegetation community classification scheme using agglomerative hierarchical clustering (AHC). Furthermore, by analyzing chronological shifts in prehistoric and historic human populations across the landscape, the spatial and temporal dynamics of underlying environmental gradients were evaluated more accurately with respect to Native American land-use impacts on regional vegetation communities.

West-central New York State, USA was selected as the study area for several reasons: (1) the existence of a continuous, well-studied archaeological record (Niemczycki 1984); (2) historical occupation by a single indigenous ethnic group practicing one of the most intensive forms of maize-based agriculture in eastern North America; (3) a wealth of detailed 18th century CE LSRs capturing important details of vegetation and environmental conditions; (4) regional late-successional vegetation dominated by mesophytic, fire-intolerant forest taxa sensitive to anthropogenic disturbance; and (5) no prior LSR-based research in the study area specifically evaluating Native American land-use impacts on regional vegetation.

More broadly, this study directly contributes to current debates on the relative intensity, spatial extent, and duration of vegetation disturbance by indigenous Americans (e.g. Crawford et al. 2015; Keeley 2002; Matlack 2013; McAdoo et al. 2013; Muñoz et al. 2015; Klimaszewski-Patterson and Mensing 2016; Klimaszewski-Patterson et al. 2018). This investigation also has relevance for human-environment interactions research emanating from the fields of environmental history, historical ecology, and environmental geography (e.g. Denevan 1992; Doolittle 2000; Lake et al. 2017). Finally, the methodology implemented in this study can serve as a basis for future studies of Native American land-use impacts using LSR data sources.

2. Materials and methods

2.1. Study area

The study area (Figure 2.1; 10,521 km^2) is located in west-central New York State, USA, and is coextensive with the boundaries of the Phelps and Gorham Purchase (PGP), a private land grant established in 1788 CE (Conover 1889). The region is divided into two physiographic sections, the Lake Ontario Lowland to the north and the Appalachian Plateau to the south, with the Portage Escarpment defining the boundary between the two sections. Elevations range from 72 m ASL along the Lake Ontario shoreline to >740 m on the Plateau. Six north-south-trending, elongate lake basins known as the Finger Lakes extend across the Lowland – Plateau boundary; from west to east these include Conesus, Hemlock, Canadice, Honeoye, Canandaigua, and Keuka Lakes (Figure 2.1).

The regional climate is humid continental, with mean January temperatures of -4° to -8°C, mean July temperatures of 16 – 21°C, and average annual precipitation from 825 – 1300 mm, with generally cooler conditions on the Plateau (Garoogian 2010). Although lying outside the main Lake Erie and Lake Ontario snowbelts, the region is characterized by high annual snowfall totals ranging from 1015 – 2500 mm/year. Late-successional vegetation is dominated by mesophytic beech (*Fagus grandifolia*) – sugar maple (*Acer saccharum*) forests on deep, loamy Alfisols over mostly calcareous shale and carbonate bedrock in the Lowland, with hemlock (*Tsuga canadensis*) – northern hardwood forests common on Inceptisols over acidic shale and sandstone on the Plateau (Seischab 1985). Scattered inclusions of oak- (*Quercus* spp.) dominated forest are also found throughout the study area (Shanks 1966).

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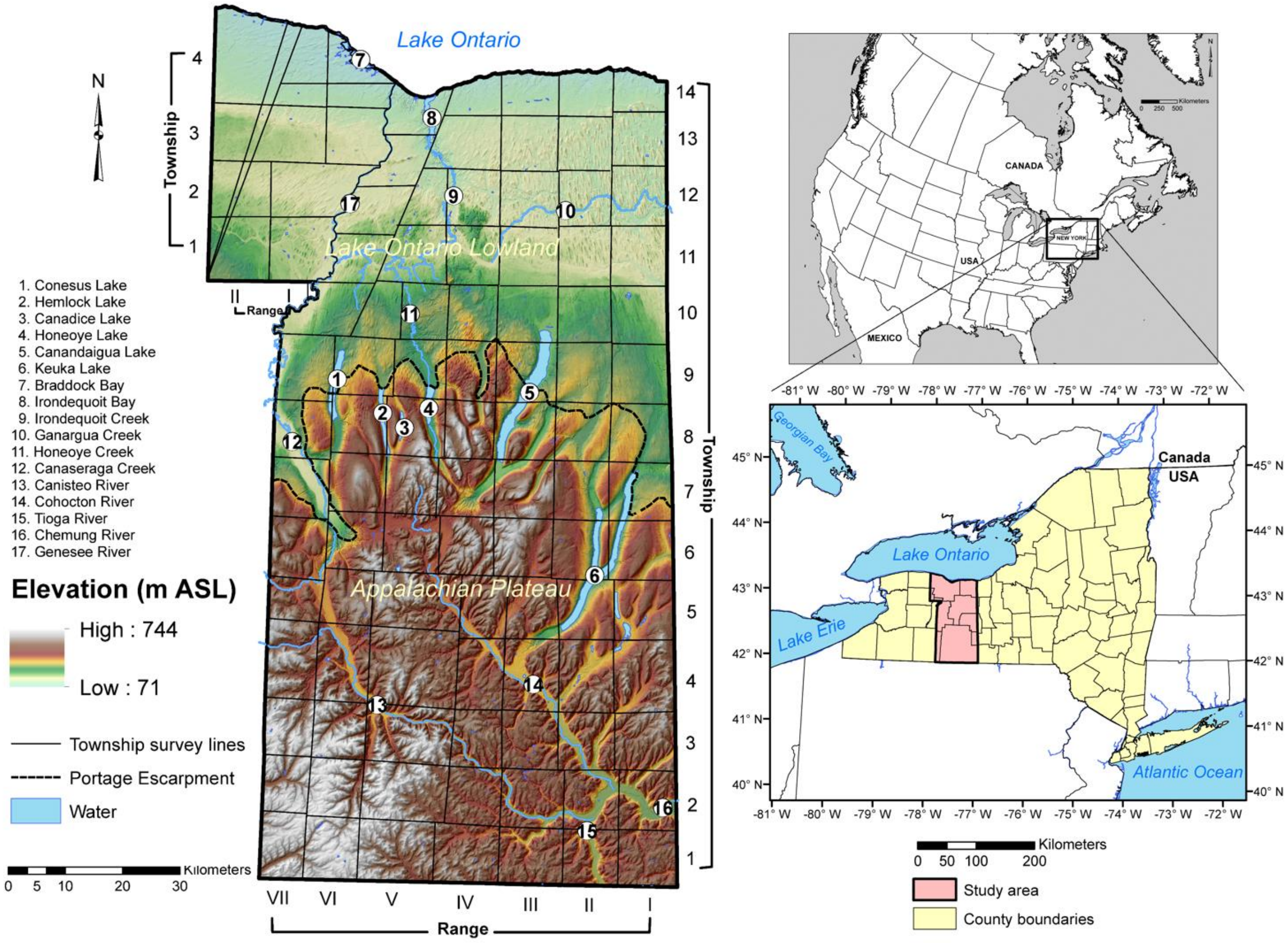

Figure 2.1. Location of Phelps and Gorham Purchase (PGP) study area, west-central New York State, USA Numbers indicate locations of major hydrologic features.

At European contact (~1650 CE), the study area was occupied by the Seneca nation (*Notowa*'*ka*:' or *Onodowahgah*; "People of the Great Hill"; Engelbrecht 2003; Hamilton 2010), an Iroquoian-speaking population comprising the westernmost member of the Hodinöhsö:ni' (Iroquois) Confederacy (Jones 2010). The Seneca and related Northern Iroquoian groups of the lower Great Lakes region practiced intensive forms of maize-based agriculture supplemented by collected wild plant foods and hunted game (Engelbrecht 2003). Early Contact-era Seneca inhabited large, multi-generational longhouses within spatially compact villages occupied for ~10 – 20 years in defensible upland locales (Jordan 2008). Seneca settlements were concentrated along the southern margin of the Lowland (Jones 2010), where loamy, agriculturally-productive Alfisols are concentrated (Cline and Marshall 1976). The Denonville military expedition against the Seneca in 1687 CE (Marshall 1848) resulted in the relocation of most villages to peripheral areas of their historic territory, while the Sullivan-Clinton campaign of 1779 CE destroyed most Seneca settlements in the study area (Cook 1887), with tribal removal to reservations west of the Genesee River (Hauptmannn 2011). However, the Seneca continued to hunt, fish, and forage in the region for several decades after indigenous title had been extinguished (Turner 1850, 1851). Euro-American settlement commenced sporadically in the 1780s CE, intensifying after 1795 CE (Meinig 1966).

2.2. Vegetation data collection, digitization, and georeferencing

The PGP was originally divided into 105 6 x 6-mile (9.66 x 9.66-km) townships based upon a rectilinear grid system of townships and ranges similar to that implemented in 19th century CE Government Land Office surveys in the Midwestern USA (Wang 2005). Township and range bounds (lines) were surveyed from 1788 – 1793 CE. PGP LSRs were obtained from the

Ontario County Historical Museum (Canandaigua, NY), Southeast Steuben Public Library (Corning, NY), Steuben County Clerk's Office (Bath, NY), and Geneva Historical Society (Geneva, NY).

A copy of the original 1794 CE PGP map, reproduced in Conover (1889) and hand-drawn from surveyor field calculations, was digitized in ArcGIS 10.3 (Environmental Research Systems Institute 2014). A georeferenced linear feature class representing township and range bounds was generated from shared boundaries between 1790s townships and modern municipality boundaries and road shapefiles (Cornell University Geospatial Information Repository 2017). Distances recorded along surveyed bounds in perches/rods (1 perch/rod = 5.03 m), chains (1 chain = 20.12 m), and links (1 link = 0.201 m) were converted to metric units (m, km) to aid in georeferencing approximate locations of surveyors' field observations. A derived hillshade raster was generated for the study area from 1-m-resolution digital elevation models (United States Geological Survey 2017). Digital hydrographic data (Cornell University Geospatial Information Repository 2017) were superimposed upon the hillshade raster to aid in locating surveyors' observations, using descriptions of landscape position and terrain features encountered along bounds.

Vegetation data for 1939.2 km (79.7%) of a total possible 2431.8 km of surveyed bounds were transcribed and digitized from the LSRs. The final geospatial database consisted of point observations (n = 10,913; Table 2.1; Figure 2.2A) derived from four types of vegetation data (hereafter "taxon" or "taxa"): (1) bearing (witness) trees blazed and identified to species level at the beginning and end of each surveyed mile; (2) inventories of multiple arboreal taxa recorded at irregular intervals along bounds; (3) qualitative descriptions of vegetation composition or structure; and (4) evidence of disturbance. Line descriptions containing

Table 2.1. Summary of Phelps and Gorham Purchase (PGP) vegetation/disturbance variables (*n* = 49), including binary fire tolerance classification for all arboreal taxa (*n* = 30).

Surveyor/common name	**Scientific name**	**Frequency (*n*)**	**%**	**Tolerance**
Beech	*Fagus grandifolia*	1993	18.26	Intolerant
Sugar maple, hard maple, maple	*Acer saccharum*	1752	16.05	Intolerant
Hemlock	*Tsuga canadensis*	871	7.98	Intolerant
White oak	*Quercus alba*	863	7.91	Tolerant
Basswood, bass, lyn, linden	*Tilia americana*	860	7.88	Intolerant
Ash, white ash	*Fraxinus americana*	647	5.93	Intolerant
Elm, white elm, red elm	*Ulmus* spp.	553	5.07	Intolerant
White pine, pine	*Pinus strobus*	517	4.74	Tolerant
Black oak, red oak	*Quercus rubra, Q. velutina*	463	4.24	Tolerant
Chesnut (American chestnut)	*Castanea dentata*	437	4.00	Tolerant
Hickory, shellbark hickory	*Carya* spp.	327	3.00	Tolerant
Black birch, birch	*Betula nigra*, *B. alleghaniensis*	319	2.92	Intolerant
Oak	*Quercus* spp.	246	2.25	Tolerant
Soft maple	*Acer rubrum/A. saccharinum*	124	1.14	Intolerant
Ironwood	*Carpinus caroliniana; Ostrya virginiana*	121	1.11	Intolerant
Butternut, white walnut	*Juglans cinerea*	87	0.80	Intolerant
Pitch pine, yellow pine	*Pinus rigida*	81	0.74	Tolerant
Sweet cherry, wild cherry, cherry	*Prunus serotina*	79	0.72	Intolerant
Thinly timbered, sparsely timbered	-	68	0.62	n/a
Whitewood (tuliptree, yellow-poplar)	*Liriodendron tulipfera*	63	0.58	Intolerant
Aspen, popple, poplar	*Populus* spp.	58	0.53	Tolerant
Heavily timbered	-	56	0.51	n/a
Windfall, windthrow	-	54	0.49	n/a
Underbrush, scrubby, shrub, bushes	-	45	0.41	n/a
Rock oak, mountain oak, chesnut oak	*Quercus prinus*	42	0.38	Tolerant
Black walnut, walnut	*Juglans nigra*	32	0.29	Tolerant
Norway pine (red pine)	*Pinus resinosa*	19	0.17	Tolerant
Sapling thicket	-	17	0.16	n/a
Scrub oak, shrub oak	*Quercus illicifolia*	15	0.14	Tolerant
Clear land	-	13	0.12	n/a
Open land	-	13	0.12	n/a
Burnt timber, fire	-	12	0.11	n/a
Grassland, grass	Gramineae spp.	11	0.10	n/a
Sassafras	*Sassafas albidum*	8	0.07	Tolerant
Dead timber	-	8	0.07	n/a
Clearing, cleared land, improved land	-	8	0.07	n/a
Hazel	*Corylus* spp.	5	0.05	Tolerant
Savin (Canada yew)	*Taxus canadensis*	5	0.05	Intolerant
No underbrush	-	4	0.04	n/a
Grove, copse	-	2	0.02	n/a
Dogwood (flowering dogwood)	*Cornus florida*	2	0.02	Intolerant
Briers, brambles	*Rubus* spp.	2	0.02	n/a
Laurel	*Kalmia latifolia*	2	0.02	Tolerant
Potato patch	-	2	0.02	n/a
Poor timber	-	2	0.02	n/a
Weeds	-	2	0.02	n/a
Service bush (serviceberry)	*Amelanchier* spp.	1	0.01	Intolerant
Whortleberry (black huckleberry)	*Gaylussacia baccata*	1	0.01	n/a
Corn field	*Zea mays*	1	0.01	n/a
Grand total:		**10,913**	**100.00**	

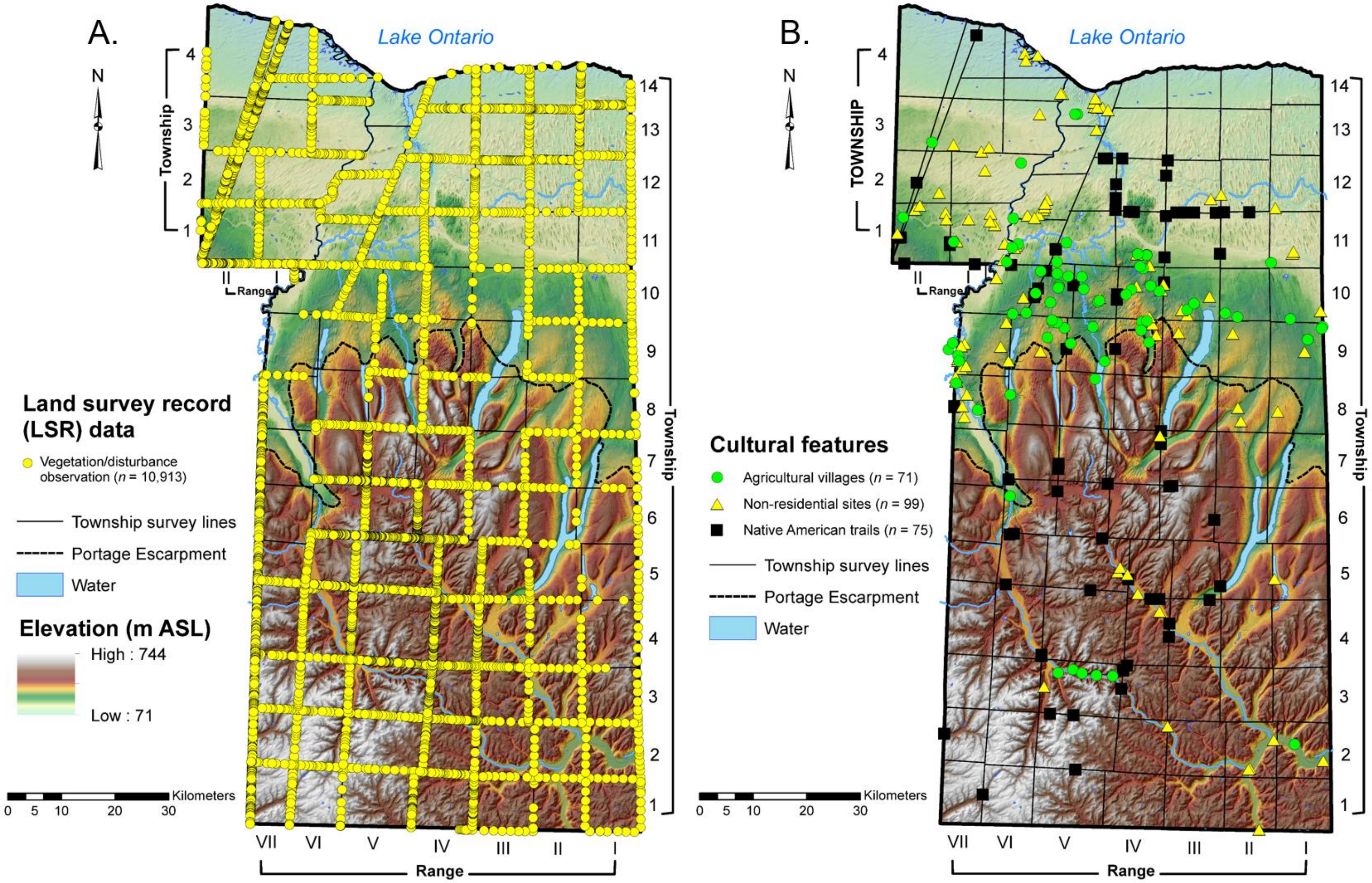

Figure 2.2. A. Location of bearing trees, species inventories, qualitative vegetation descriptions, and disturbance indicators (*n* = 10,913; Table 1) from 1788 – 1793 CE land survey records (LSRs). B. Distribution of Late Woodland (ca. 1000 – 1650 CE) and Historic (1650 – 1779 CE) period Native American agricultural villages (green circles; *n* = 71), non-residential sites (yellow triangles; *n* = 99), and Native American trails (black squares; *n* = 75).

inventories of >2 taxa were disaggregated into multiple overlapping individual point features of a single taxon to render them compatible with bearing tree data. Typical wetland taxa (e.g. black ash [*Fraxinus nigra*]) were excluded from the geospatial database as Tulowiecki and Larsen (2015) found little evidence of Iroquoian disturbance of wetland ecosystems in their analysis of LSR data from southwestern New York.

2.3. Archaeological/cultural data

A geospatial database of Late Woodland (1000 – 1650 CE) and Historic (1650 – 1779 CE) period Native American archaeological sites within the study area (*n* = 172; Figure 2.2B; Appendix A) was compiled from various sources including the New York State Museum (NYSM) Archaeology Laboratory site file, unpublished museum and university field surveys on file at the NYSM, published site reports (Ritchie 1927, 1930), regional syntheses (Niemczycki 1984), highway project surveys (Trubowitz 1983), and ethnohistorical accounts (Cook 1887). The final database comprised agricultural villages (*n* = 71) and non-residential site types (e.g. campsites, burials, workshops, and ceremonial sites; *n* = 99). Additionally, Native American trail point features (*n* = 75) recorded in the PGP LSRs were incorporated into the geospatial archaeological database.

2.4. GIS and statistical analyses

2.4.1. Vegetation data sampling and relativization

The study area was subdivided into 462 5 x 5-km grid cells in ArcGIS 10.3 using the `genvecgrid` command of the Geospatial Modeling Environment (GME) 0.7.3 software package (Beyer 2012), which served as sampling units for statistical analysis. Sums of all taxa (*n* = 49; Table 1) were tallied within each grid cell using the GME `countpntsinpolys` feature. Cells with no vegetation observations (*n* = 137) were deleted, leaving 325 25-km^2 grid cells for analysis. Matrix raw count data were exported to Microsoft Excel 2016 format (Microsoft Corporation 2015) for data relativization using a Hellinger transformation (Legendre and Gallagher 2001) to reduce the biasing effect of commonly-recorded taxa such as beech and sugar maple (Kindt and Coe 2005). Relative frequencies were standardized by sampling unit total to adjust for differences in sums among individual grid cells, which ranged from 1 to 227 ($\bar{x}$ = 35.38; *s* = 35.98).

2.4.2. Non-metric multidimensional scaling (NMS) analysis

Non-metric multidimensional scaling (NMS) is a form of indirect ordination (i.e. ordering of vegetation samples and taxa independently of paired environmental data; Kent 2012) which uses rank order information in a (dis)similarity matrix between sampling units and associated taxa to produce repeated *k*-space ordinations, where *k* typically consists of 1 – 6 synthetic dimensions (McCune and Grace 2002). The NMS algorithm iteratively generates solutions in which rank orders of distances between points in *k*-dimensional species space, as determined by ordination scores, are as near as possible to their rank orders in the original (dis)similarity matrix (McCune and Mefford 2011). A final, stable solution is achieved when the associated rank orders match as closely as possible the target rank orders (i.e. monotonicity; Peck 2010). Goodness-of-fit between the final resolved *k*-space ordination and the original (dis)similarity matrix is determined by an associated stress value, which is equivalent to the residual sum-of-squares from a regression analysis of original rank order distances against *k*-space distances. In a perfect match between a *k*-space NMS ordination and its associated (dis)similarity matrix, stress = 0. Increasing values of stress, up to a maximum value of 100, reflect greater levels of instability between the ordination and (dis)similarity matrix, and consequently, greater "noise" in the underlying data structure (McCune and Grace 2002). Clarke (1993) established general criteria for acceptable stress values based upon reviews of the ecological literature, with values ≤ 15 considered to be optimal. McCune and Grace (2002) emphasized the flexibility and superior performance of NMS over other ordination techniques, particularly: (1) its ability to utilize any ecological distance measure; (2) no assumptions of linearity between species abundance and latent environmental gradients; and (3) extraction of an optimal number of synthetic dimensions in species space by which stress is minimized over multiple iterations of increasing dimensionality.

NMS analysis was conducted on the similarity matrix of Pearson product-moment correlation coefficients of the Hellinger-transformed vegetation data using PC-ORD 6.19 (autopilot mode; 2 – 4 axes; 50 runs on real data, 50 runs on randomized data; stability criterion = 0.00001; solution stability evaluation = 15 iterations out of 250 maximum iterations; random starting coordinates; McCune and Mefford 2011). Once an initial solution was determined, ordination was repeated using starting coordinates derived from the best solution, with a varimax rotation of axes specified for the final NMS solution. NMS analysis was repeated three additional times to verify the consistency and interpretability of outputs across multiple runs. Underlying environmental gradients modulating vegetation composition were subjected to *post hoc* interpretation based upon the relative positioning of taxa along ordination axes. Percent variance explained by each NMS axis was approximated by calculating the coefficient of determination (r^2) for correlations between ordination distances and distances in the original data matrix (Peck 2010).

2.4.3. Agglomerative hierarchical clustering (AHC) analysis

Agglomerative hierarchical clustering (AHC; McCune and Grace 2002) was performed to partition taxa into discrete upland community types, compare the consistency and interpretability of the NMS ordination, and evaluate the relationship between environmental gradients, archaeological site distribution, and vegetation patterns. Inverse analysis – in which individual taxa are allocated into synthetic groups on the basis of their distribution across sampling units (Kent 2012) – was performed in PC-ORD 6.19 (McCune and Mefford 2011) by first transposing the original vegetation data matrix, then calculating the Euclidean distance between NMS taxon scores, and using Ward’s method as a sorting strategy for allocating taxa into discrete groups (McCune and Grace 2002). Ward’s Method evaluates information lost during the fusion of taxa by calculating the sum of squared deviations of each taxon from its group mean, with fusion occurring when the least increase in the error sum-of-squares results (Kent 2012).

2.4.4. Spatial interpolation of NMS scores and AHC class values

NMS taxon scores and AHC class membership values were appended to individual point features in the geospatial vegetation database using a join table in Microsoft Excel 2016, with taxon name as the join field. An ordinary kriging algorithm of the ArcGIS 10.3 Geostatistical Wizard was implemented to interpolate discrete point values to continuous prediction surfaces using a standard neighborhood search type (search radius = 4 [minimum], 10 [maximum] estimation points; radial sectors: [*n* = 8]). Ordinary kriging was chosen for spatial interpolation as exploratory analysis revealed the vegetation data exhibited positive spatial autocorrelation with respect to the distribution of fire-tolerant and disturbance-related taxa

(Moran's I = 0.902851; expected I = -0.0002; s^2 = 0.000042; z = 138.8781; p = 0.00000), thereby violating the assumption of data stationarity (i.e. a universal mean across all estimation points; Fortin and Dale 2005). Geostatistical Wizard prediction surfaces were exported to raster format at 800 x 800-m grid cell resolution for data symbolization and mapping. NMS ordination scores were also appended to all archaeological point features using the `Extract Values to Points` functionality of ArcGIS 10.3, and summary statistics for NMS axis scores were calculated for Native American agricultural villages, non-residential sites, and trails to investigate spatial and temporal trends in environmental modulators of vegetation composition.

2.4.5. Correlation analysis

I explored potential bivariate relationships between NMS ordination scores and selected environmental variables having a presumed association with forest species composition using correlation analysis (Asuero et al. 2006). Regional fire regimes circa 1790 CE were estimated by aggregating all upland arboreal taxa (n = 30) into one of two fire-adaptedness categories based upon eco-physiological adaptations to low-intensity ground fires (Thomas-Van Gundy et al. 2015): (1) fire-tolerant taxa (n = 15) and (2) fire-intolerant taxa (n = 15; Table 1). Percent fire-tolerant taxa was calculated by dividing the total number of fire-tolerant arboreal taxa recorded in each species inventory point feature (prior to disaggregation) by the sum of combined fire-tolerant and fire-intolerant taxa present and multiplying by 100 (Thomas-Van Gundy and Nowacki 2013). Individual bearing trees were assigned a value of zero (fire-intolerant) or 100 (fire-tolerant) based upon a taxon's inferred fire-adaptedness. A continuous prediction surface of percent frequency values was generated via ordinary kriging using the

ArcGIS 10.3 Geostatistical Wizard, and subsequently exported to raster format at 800 x 800-m grid cell resolution.

Digital county-level soil survey polygon shapefiles were obtained for the PGP study area (United States Department of Agriculture 2017). Individual county-level data were mosaiced to a single shapefile using the `Merge` command of ArcGIS 10.3 Data Management toolbox. An ordinally-based soil productivity index value (PI; Schaetzl et al. 2012) representing soil potential for maximal crop growth (range: 0 [least productive] – 19 [most productive]) was assigned to each soil map unit polygon via a spreadsheet join table of PI values (United States Forest Service 2017).

A randomly-generated point feature class (*n* = 5000) created using the `genrandompnts` command of the Geospatial Modeling Environment (GME) 0.7.3 software package (Beyer 2012) was superimposed over the study area, with NMS ordination scores, percent fire-tolerant taxa, and soil PI values appended to each point using the ArcGIS 10.3 `Extract Values to Points` and `Spatial Join` functions. Point attribute data were exported to Microsoft Excel 2016 format for correlation analysis using the XLSTAT 2014 statistical analysis software add-in for Excel (Addinsoft 2014).

3. Results

3.1. Non-metric multidimensional scaling (NMS)

The PC-ORD NMS algorithm arrived at a three-dimensional solution for the PGP vegetation data with a final stress value of 11.96. As stress was below Clarke's (1993) recommended upper threshold of 15, the final solution was regarded as representing an accurate ordination of the vegetation data. Cumulatively, NMS axes 1 – 3 explained 92.2% of the total variance in the vegetation data.

3.1.1. NMS axis 1: fire frequency

NMS axis 1 (Appendix B; Figure 2.3A) explained 53.7% of the total variance in the vegetation data, arranging species along a gradient of fire-adaptedness. Fire-sensitive taxa, including beech (*Fagus grandifolia*; -0.374), sugar maple (*Acer saccharum*; -0.298), hemlock (*Tsuga canadensis*; -0.283), black/yellow birch (*Betula lenta/B. alleghaniensis*; -0.427), cherry (*Prunus* spp.; -0.373), and basswood (*Tilia americana*; -0.231) occupied one end of this axis, with fire-tolerant whortleberry (*GaylUSAccia baccata*; 1.440), hazel (*Corylus* spp.; 0.917), poor timber (1.226), and burnt timber/fire (1.011) at the other end of NMS axis 1. Interpolated, mapped NMS axis 1 scores attained maximum values in a NW – SE-trending band falling across the central portion of the study area (Figure 3A). Minimum NMS axis 1 values occurred in the central and western Plateau and the northern half of the Lowland.

3.1.2. NMS axis 2: soil productivity

NMS axis 2 (Appendix B; Figure 2.3B) accounted for a further 22.6% of the total variance, representing a soil productivity gradient separating indicators of nutrient-limited soils such as red pine (*Pinus resinosa*; -0.861), pitch pine (*Pinus rigida*; -0.689), chestnut oak (*Quercus prinus*; -0.631), and scrub oak (*Quercus illicifolia*; -0.577) from those characteristic of high-nutrient sites associated with Seneca and Euro-American agricultural activity, including grove/copse (1.249), agricultural clearings (0.837), hazel (*Corylus* spp.; 0.726), clear land

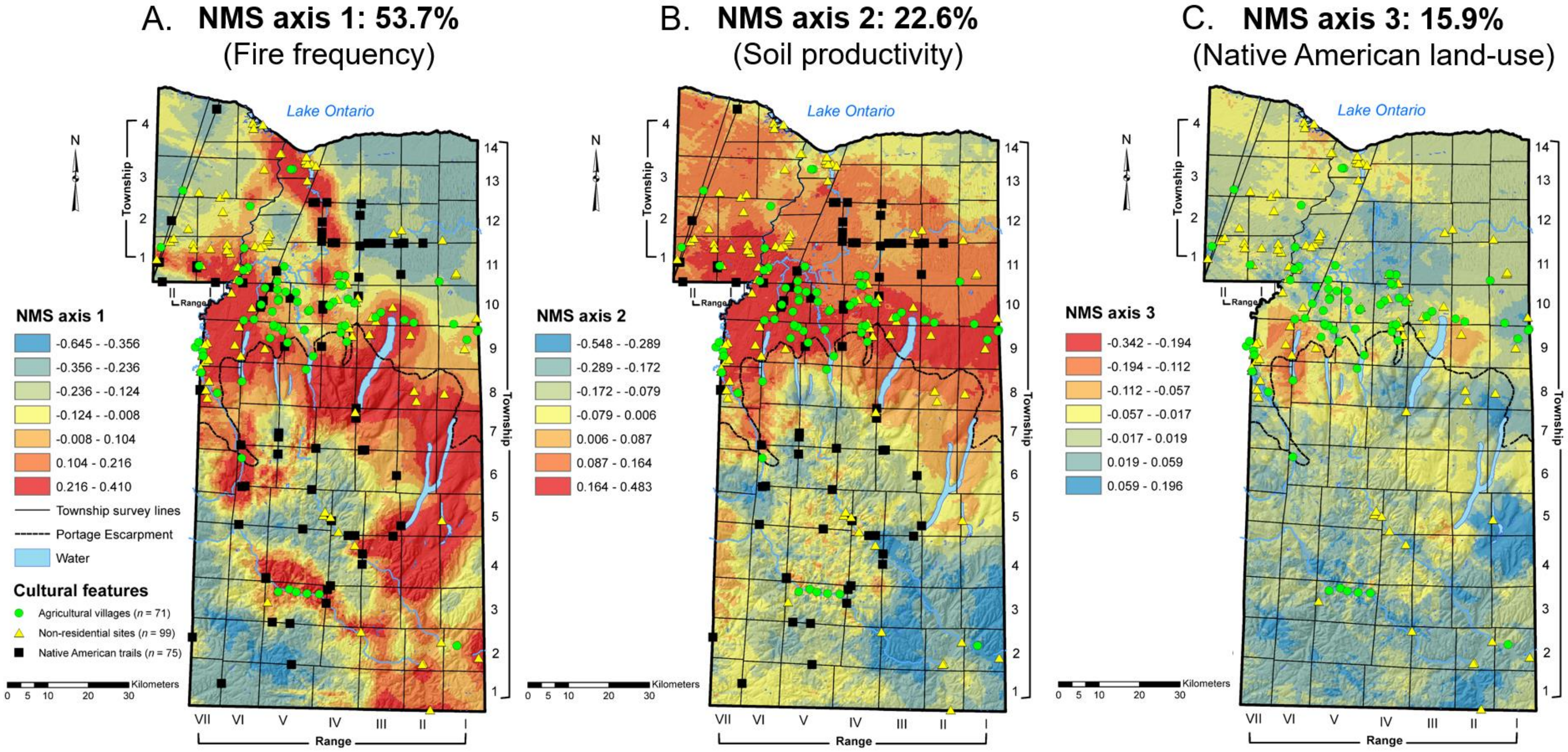

Figure 2.3. Interpolated maps of NMS axis 1 – 3 taxon scores (Appendix B) with respect to Native American cultural features. A. NMS axis 1 (fire frequency). B. NMS axis 2 (soil productivity). C. NMS axis 3 (Native American land-use).

(0.726), and potato patch (0.632). High NMS axis 2 scores were concentrated along the southern margin of the Lowland (Figure 2.3B), generally near former Seneca/Iroquoian agricultural villages, with uniformly low NMS axis 2 values prevalent throughout the Appalachian Plateau.

3.1.3. NMS axis 3: Native American land-use

NMS axis 3 (Appendix B; Figure 2.3C) explained 15.9% of the total variance and defined a minor gradient in forest canopy disturbance separating Seneca and Euro-American agricultural indicators such as cornfield (1.655), potato patch (1.278), weeds (1.197), dead timber (0.999), grove/copse (0.454), and hazel (*Corylus* spp.; 0.407) from taxa characteristic of dry upland forest on high-nutrient soils, including oak (*Quercus* spp.; -0.463), thinly timbered areas (-0.393), open land (-0.303), sassafras (*Sassafras albidum*; -0.274), butternut (*Juglans cinerea*; -0.261), and hickory (*Carya* spp.; -0.249). Peak NMS axis 3 scores were distributed widely throughout both the Lowland and Plateau, with minimum values concentrated in the western Finger Lakes, and in a broad band near the mouth of the Genesee River (Figure 3C).

3.2. Agglomerative hierarchical clustering (AHC)

AHC partitioned the PGP vegetation data into two primary clusters (Figure 2.4) differing in important aspects of species composition, inferred soil characteristics, disturbance regimes, and geographic distribution: (1) *fire-intolerant communities* (moist upland forest; AHC Group 1); and (2) *fire-tolerant communities* (dry upland forest; AHC Group 2). Fire-tolerant communities were secondarily differentiated into those occurring on non-productive (AHC

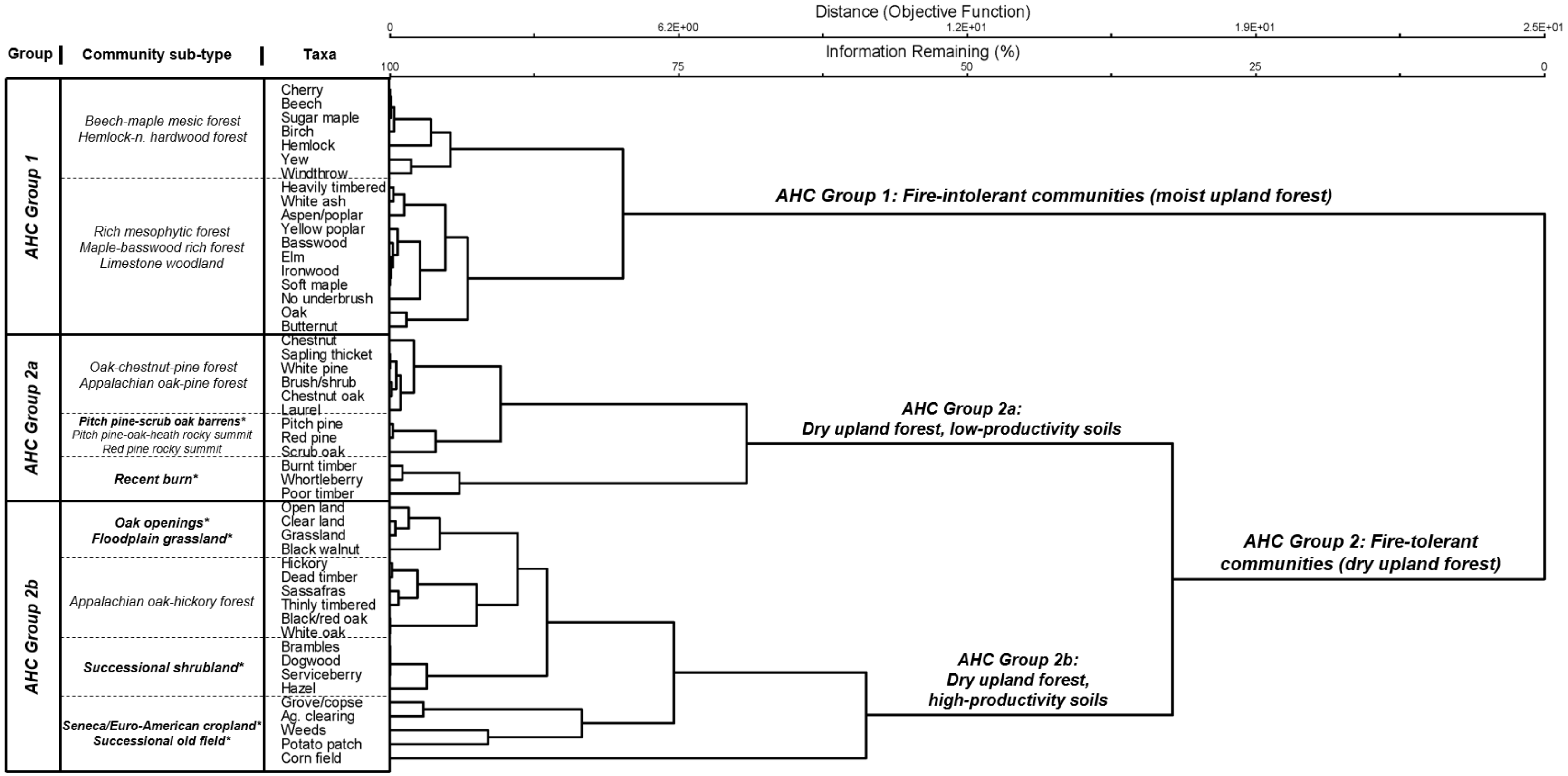

Figure 2.4. Agglomerative hierarchical clustering (AHC) dendrogram of PGP taxa (*n* = 49; Table 1). Names of modern vegetation community types corresponding to secondary AHC clusters are derived from Edinger et al. (2014). Community subtypes associated with Native American land-use activities are indicated by bolded text and asterisks (*).

Group 2a) versus productive soils (AHC Group 2b). Each of the three major community types was further subdivided into several minor clades/subtypes (Figure 4) having modern analogues in the regional vegetation (Edinger et al. 2014).

3.2.1. AHC Group 1: fire-intolerant communities (moist upland forest)

Forests dominated by drought-intolerant, fire-sensitive taxa comprised the most extensive vegetation type within the PGP, occurring in both the Lowland and Plateau (Figure 2.4; 4354.7 km^2 [42.1% of study area]). This cluster was subdivided into two main variants: (1) *beech-maple mesic forest*/*hemlock-northern hardwood forest* comprised chiefly of beech (*Fagus grandifolia*) and sugar maple (*Acer saccharum*) with intermixed hemlock (*Tsuga canadensis*), and yellow/black birch (*Betula alleghaniensis*/*B. lenta*); and (2) *rich mesophytic forest/maple-basswood rich forest/limestone woodland* of butternut (*Juglans cinerea*), elm (*Ulmus* spp.), basswood (*Tilia americana*), white ash (*Fraxinus americana*), and tuliptree (*Liriodendron tulipfera*) mixed with oak (*Quercus* spp.) on lands described by surveyors as "gently sloping" uplands and "bottomland." The major form of disturbance in these forests was windthrow ("windfall"; *n* = 36), which was entirely confined to the steep slopes of the Appalachian Plateau. Additionally, a small number of forest clearings ("thinly timbered"; *n* = 3) were found in moist upland forests in the Lowland, typically in close proximity to Native American trails ("Indian path").

3.2.2. AHC Group 2a: fire-tolerant communities (dry upland forest, low-productivity soils)

This assemblage was dominated by drought- and fire-tolerant vegetation occurring on nutrient-limited Inceptisols (Figure 2.4; 2723.2 km^2 [26.3% of study area]). Major subtypes included: (1) *Oak-chestnut-pine forest/Appalachian oak-pine forest* of chestnut (*Castanea dentata*), white pine (*Pinus strobus*), chestnut oak (*Quercus prinus*), mountain laurel (*Kalmia latifolia*), and brushy/scrubby vegetation; (2) *Pitch pine-scrub oak barrens/pitch pine oak-heath rocky summit/red pine rocky summit* of pitch pine (“yellow pine”; *Pinus rigida*), red pine (“Norway pine”; *P. resinosa*), and scrub oak (*Q. illicifolia*) of both low-elevation floodplain and high-elevation rock outcrop sites; and (3) *Recent burn* showing evidence of catastrophic fire (“timber burnt,” “all destroyed”) with limited post-fire succession (“poor timber,” “whortleberry” [*Gaylussacia baccata*]). Dry upland forest on low-productivity soils extended over a large portion of the central and eastern Appalachian Plateau but was restricted to small, discontinuous areas within the Lowland. This community type was the only one displaying evidence of recent anthropogenic fires ($n = 12$), all adjacent to Native American trails.

3.2.3. AHC Group 2b: fire-tolerant communities (dry upland forest, high-productivity soils)

This forest association occurred primarily in the zone of agriculturally-productive Alfisols (Cline and Marshall 1976) in the southern half of the Lowland (Figure 2.4; 2933.3 km^2 [28.3% of study area]) and was dominated by drought- and fire-tolerant oak (*Quercus* spp.) and possessed relatively open canopy conditions. Major subtypes within AHC Group 2b included: (1) *Oak openings/floodplain grassland* exhibiting open-canopy, savanna-like conditions of scattered mast trees such as black walnut (*Juglans nigra*) and herbaceous ground cover of “very tall grass,” possibly a reference to warm-season prairie grasses including big bluestem (*Andropogon gerardii*) and/or Indian grass (*Sorghastrum nutans*) typical of regional “oak openings” vegetation (Shanks 1966); (2) *Appalachian oak-hickory forest* of black oak (*Q. velutina*), northern red oak (*Q. rubra*), white oak (*Q. alba*), hickory

(*Carya* spp.), sassafras (*Sassafras albidum*), and open-canopy inclusions ("thinly timbered"); (3) post-disturbance *successional shrubland* of briers/brambles (*Rubus* spp.), flowering dogwood (*Cornus florida*), serviceberry ("service bush" [*Amelanchier* spp.]), and hazel (*Corylus* spp.) near former Native American villages; and (4) *Seneca/Euro-American cropland-successional old field-woodlot* communities associated with prior Seneca maize-based agriculture (pre-1779 CE) on floodplains and upland locales, and more recent Euro-American occupation of such sites (post-1779 CE). Evidence of recent agricultural land-use activity included active cropland ("corn field," "potato patch," "patch") abandoned fields in early stages of secondary succession ("weeds"), and isolated stands of timber (grove/copse).

4. Interpretation and discussion

4.1. Interpretation of Native American land-use influences on study area vegetation

The two multivariate statistical methods employed in this study – NMS and AHC – provided complementary lines of evidence for modification of the regional vegetation by Native Americans prior to Euro-American settlement. NMS ordinated compositional, structural, and disturbance-related variables along major environmental gradients underlying the regional vegetation pattern, while AHC clustered these variables into discrete upland community types consistent with the NMS ordination. NMS axis 1 explained over half (53.7%) of the total variance, corresponding to an apparent fire disturbance gradient (Figure 2.3A) separating agricultural ("corn field") and silvicultural ("poor timber," burnt timber/fire, pitch pine) indicators of anthropogenically enhanced fire regimes from those characteristic of infrequent fires (e.g. birch, beech, sugar maple, hemlock) where windthrow was the main form of catastrophic disturbance (Appendix B; Figure 2.4). This interpretation is supported by a very strong, positive correlation between NMS axis 1 scores and percent frequency of fire-tolerant arboreal taxa ($r = 0.962$; $p < 0.0001$), which comprised the major taxa in AHC Groups 2a and 2b. As a whole, Native American agricultural villages ($n = 71$) possessed moderately high values on NMS axis 1 scores ($\bar{x} = 0.133$, $s = 0.150$) and percent frequency fire-tolerant arboreal taxa ($\bar{x} = 47.6\%$, $s = 20.9$), suggesting a pattern of elevated fire frequencies near settlements from deliberate and/or accidental anthropogenic ignitions (Abrams and Nowacki 2008). The correspondence between elevated NMS axis 1 scores (Figure 2.3A), moderate frequencies of fire-tolerant arboreal taxa, anthropogenic land-use indicators (Figures 2.4 and 2.5), and the overlapping geographic distributions of AHC Group 2b (*dry upland forest*, *high-productivity soils*) and Seneca/Iroquoian settlements (Figure 2.6) is thus logical and consistent. Non-residential sites ($n = 99$) have similarly elevated NMS axis 1 scores ($\bar{x} = 0.112$, $s = 0.204$), but their higher standard deviation suggests a wider array of ecological zones with contrasting fire regimes may have been utilized for natural resource extraction, hunting, and related activities than was typical for agricultural village sites. Native American trails ($n = 75$), in contrast, possessed relatively low NMS axis 1 scores ($\bar{x} = 0.040$, $s = 0.248$). While some trails were situated adjacent to recent and older burns and others traversed areas of dry upland forest (AHC Groups 2a and 2b), several were recorded in minimally-disturbed moist upland forest (AHC Group 1). As with non-residential sites, a high standard deviation suggests a relatively broad ecological context for Native American travel routes.

Interestingly, very high NMS axis 1 scores are typical of areas lacking abundant evidence of Late Woodland – Historic period occupation, particularly shoreline-proximal areas of the larger Finger Lakes (Canandaigua, Keuka; Figure 2.3A). Marks and Gardescu (1992) noted a similar pattern in the distribution of fire-tolerant oak in the eastern Finger Lakes region and attributed this to microclimatic conditions. West- and southwest-facing slopes along the

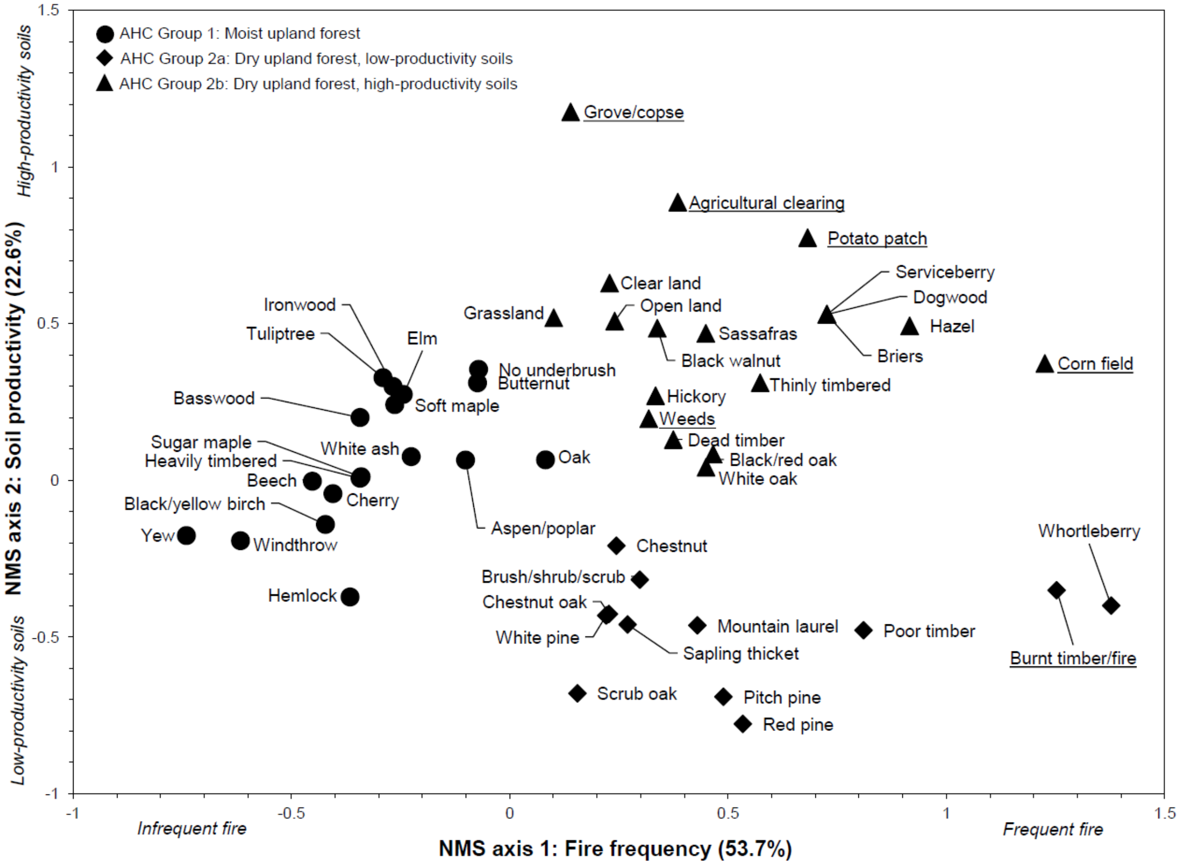

Figure 2.5. Ordination diagram of non-metric multidimensional scaling (NMS) axis 1 and 2 taxon scores for combined compositional/structural variables (*n* = 49; Appendix B). Symbology corresponds to major upland vegetation community types partitioned by agglomerative hierarchical clustering (AHC; circles = AHC Group 1 [*moist upland forest*]; diamonds = AHC Group 2a [*dry upland forest, low-productivity soils*]; triangles = AHC Group 2b [*dry upland forest, high-productivity soils*]). Underlined taxa (*n* = 6) are associated with evidence of Native American land-use practices in the PGP LSRs.

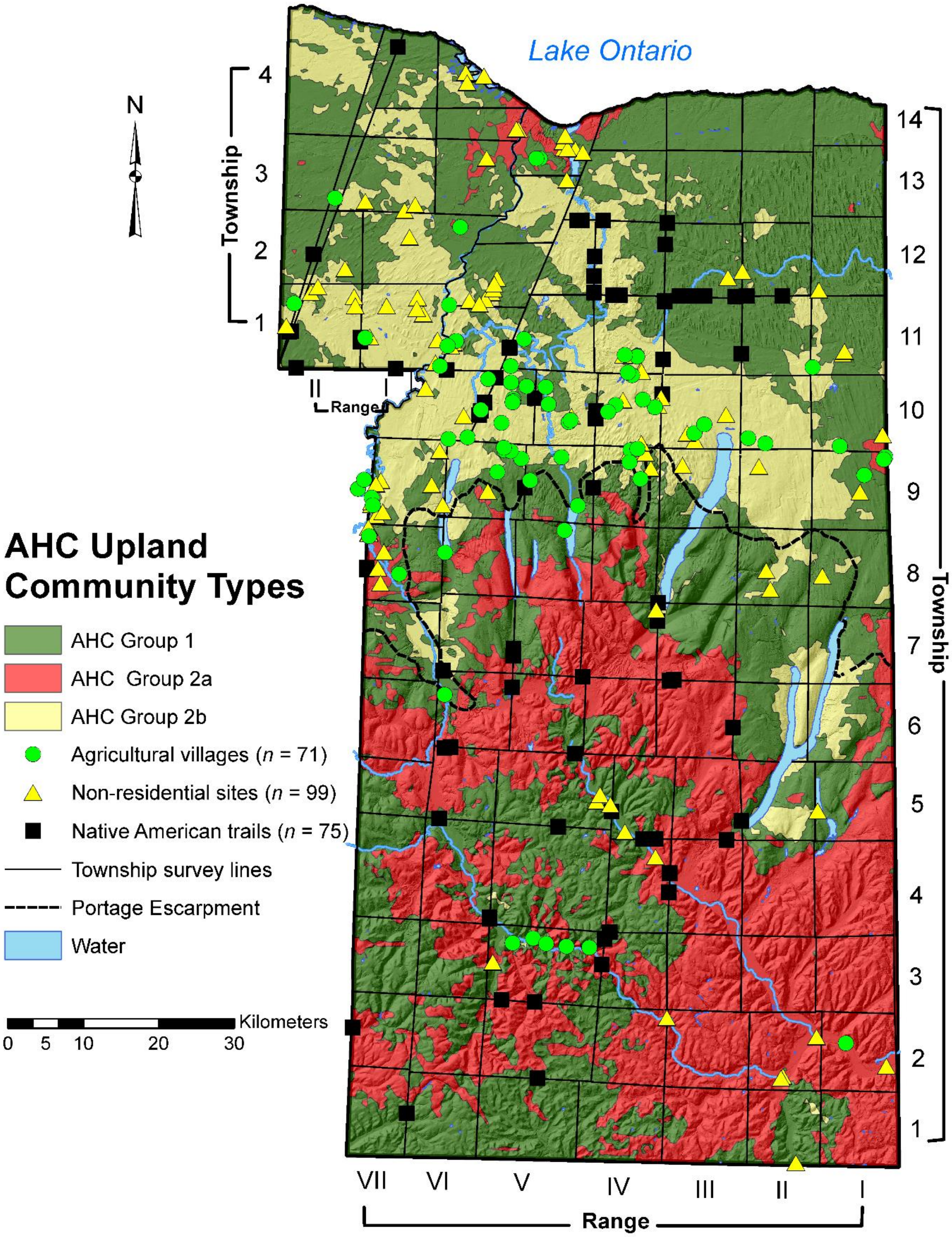

Figure 2.6. Interpolated map of major upland vegetation community types partitioned by agglomerative hierarchical clustering (AHC) of the PGP LSR vegetation data with respect to the distribution of Native American agricultural villages (*n* = 71), non-residential sites (*n* = 99), and trails (*n* = 75).

eastern lakeshores receive greater insolation and are thus warmer and drier than the east-facing slopes along the western shorelines, creating more favorable conditions for the establishment of fire-tolerant taxa (Mohler et al. 2006). However, Thomas-Van Gundy et al. (2015) noted that Seneca and Cayuga Lakes – immediately east of the PGP study area – possessed several Iroquoian villages along their eastern shores. These authors suggested that Native American fires lit near shoreline settlements and campsites would have easily spread up the west-facing slopes and gullies, increasing the total area suitable for fire-tolerant taxa around these lakes. Although there appears to be little archaeological evidence for similar Late Woodland and Historic occupation along the larger Finger Lakes within the PGP, such geographic lacunae may suggest (1) limitations in the existing archaeological record that may not be indicative of the actual extent of Iroquoian occupation or land-use practices; and/or (2) observed vegetation patterns may be related to land-use legacies of populations prior to the development of agricultural Iroquoian societies. Archaeological sites antedating the Late Woodland are common in areas having high NMS axis 1 scores but lacking evidence of more recent occupation (NYSM site file; data not shown). A combination of climate, pre-Iroquoian land-use legacies, and Seneca/Iroquoian settlement and subsistence seems most parsimonious in explaining NMS axis 1 spatial patterns.

Spatial variability in NMS axis 1 scores (Figure 2.3A) is accompanied by temporal variability as well, with scores decreasing progressively with increased site cluster age. 18th century CE agricultural villages ($n = 10$) possess the highest mean NMS axis 1 scores ($\bar{x} = 0.225$, $s = 0.099$) and percent fire-tolerant taxa ($\bar{x} = 66.6\%$, $s = 11.8$), while sites predating the 18th century CE have markedly lower values (17th century CE [*n* = 18], NMS axis 1: x̄ = 0.085, *s* = 0.135; % fire-tolerant: x̄ = 40.6%, *s* = 15.3; 16th century CE [*n* = 10], NMS axis 1: x̄ = 0.105, *s* = 0.113; % fire-tolerant: x̄ = 38.3%, *s* = 14.0; pre-16th century CE [*n* = 11], NMS axis 1: x̄ = 0.020, *s* = 0.122; % fire-tolerant: x̄ = 32.0%, *s* = 16.4). I interpret this temporal trend as being the result of secondary succession and vegetation recovery following site abandonment. Anthropogenic fire ignitions likely decreased in frequency and intensity in the immediate vicinity of villages following desertion, encouraging the establishment of fire-intolerant taxa. This interpretation is supported by surveyor descriptions of mid-successional forests near pre-18th century CE Seneca settlements containing mixed sugar maple (*Acer saccharum*), ironwood (*Ostrya virginiana*/*Carpinus caroliniana*), white ash (*Fraxinus americana*), oak (*Quercus* spp.), and hickory (*Carya* spp.). Temporal variation likely applied to non-residential sites as well, although existing chronological control is generally insufficient for these site types to establish a reliable temporal series (NYSM site file data). Trails were occasionally referenced by surveyors as “old” if there was little evidence of recent use, indicating Seneca travel routes changed through time. Yet, in the absence of definitive evidence for which trails were used at specific chronological intervals, constructing a temporal framework for their effect(s) on vegetation dynamics remains speculative. Although it is impossible to determine the total area disturbed by fires ignited – whether accidentally or intentionally – by Native Americans, the spatial and temporal association between villages, fire-tolerant taxa, and elevated NMS axis 1 scores suggests that many, if not most, fires were of anthropogenic origin, and acted to enhance existing natural fire regimes.

Soil productivity (NMS axis 2; 22.6% of variance explained; Figure 2.3B) was a secondary modulator of forest species composition, providing the basis for the regional differentiation between predominantly broadleaf forests (*beech-maple mesic forest*; *rich mesophytic forest*; *maple-basswood rich forest*; *limestone woodland*; *Appalachian oak-hickory forest*) growing on high-productivity Alfisols in the Lowland and mixed conifer-hardwood forests (*hemlock-northern hardwood*; *oak-chestnut-pine*; *Appalachian oak-pine*; *pitch pine-scrub oak barrens*; *pitch pine-oak-heath rocky summit*; *red pine rocky summit*) occurring on low-productivity Inceptisols primarily on the Plateau (Appendix B; Figure 2.4). NMS axis 2 scores evidenced a moderately strong positive correlation with soil PI ($r = 0.487$; $p < 0.0001$), suggesting a relationship between this dimension and one or more physiochemical measures of soil fertility such as pH. NMS axis 2 scores and soil PI values showed a prominent increase from the oldest site cluster (pre-16th century CE; [$n = 11$], NMS axis 2: $\bar{x} = 0.126$, $s = 0.067$; PI: $\bar{x} = 7.9$, $s = 4.1$) to the subsequent phase (16th century CE [$n = 10$], NMS axis 2: $\bar{x} = 0.238$, $s = 0.088$; PI: $\bar{x} = 10.6$, $s = 0.7$), indicative of the northward migration of sites at this time (Niemczycki 1984) from the lower-productivity soils of the Plateau to the richer soils of the southern Lowland. Thereafter, mean NMS axis 2 scores decrease slightly during the 17th century CE ([$n = 18$], $\bar{x} = 0.184$, $s = 0.048$), but overall soil PI increases marginally ($\bar{x} = 10.9$, $s = 1.1$). Finally, 18th century CE sites ($n = 5$) exhibit a slight decrease in NMS axis 2 scores ($\bar{x} = 0.178$, $s = 0.104$) accompanied by a marked decrease in soil PI ($\bar{x} = 8.4$, $s = 3.0$), likely reflecting disruption of Seneca settlement patterns following Euro-American contact (Jordan 2008). However, maintenance of relatively high NMS axis 2 scores through time suggests that soil productivity was a critical and recurrent factor in the selection of potential village sites among agricultural Iroquoians (Jones 2010). Non-residential sites ([$n = 99$], $\bar{x} = 0.112$, $s = 0.152$) and trails ([$n = 75$], $\bar{x} = 0.040$, $s = 0.146$), in contrast, possessed lower mean NMS axis 2 scores and soil PI values (non-residential sites: $\bar{x} = 8.7$, $s = 4.0$; trails: $\bar{x} = 9.3$, $s = 2.8$) than agricultural villages at any temporal stage, indicating a wider range of soil types was likely used for non-agricultural land-use activities and for the blazing of travel routes.

Finally, NMS axis 3 (15.9% variance explained) revealed variations in anthropogenic land-use impacts on forest structure (Figure 2.3C). This axis differentiated canopy disturbances characteristic of agricultural subsistence practices near former Seneca/Iroquoian villages (corn field, weeds, grove) from those found at greater distances from settlements suggestive of silvicultural land-use activities (e.g. oak, “thinly timbered”, “open land”; Appendix B; Figure 2.4). No specific trends in NMS axis 3 scores were detected between villages (all time periods; [$n = 71$], $\bar{x} = 0.000$, $s = 0.034$), non-residential sites ($n = 99$; $\bar{x} = -0.003$, $s = 0.004$), or trails ($n = 75$; $\bar{x} = 0.009$, $s = 0.026$), nor were trends detectable between dated village site clusters (18th century CE [$n = 10$], $\bar{x} = -0.007$, $s = 0.060$; 17th century CE [$n = 29$], $\bar{x} = -0.001$, $s = 0.044$; 16th century CE [$n = 13$], $\bar{x} = -0.008$, $s = 0.032$; pre-16th century CE [$n = 12$], $\bar{x} = 0.007$, $s = 0.012$).

In sum, AHC confirmed the underlying NMS environmental gradients by classifying the PGP vegetation data into forest community types consistent with the NMS ordination (Figure 2.5), and further reinforced the interpretation of evident Native American land-use signals within the LSR data and revealed by spatial and temporal analysis of the archaeological site data. By integrating AHC and NMS into a synthetic explanatory framework, I propose the following environmental reconstruction of the study area prior to Euro-American settlement.

4.1.1. Lake Ontario Lowland: Native American agriculture and silviculture

Prior to Euro-American incursion during the late 18th century CE, Late Woodland and Historic Seneca/Iroquoian populations established most of their agricultural settlements (*n* = 64; 87.7%) and non-residential sites (*n* = 80; 80.9%) within the southern half of the Lake Ontario Lowland (Figure 2.2B). Native American trails were also somewhat more commonly recorded by PGP surveyors in the Lowland (*n* = 42; 56.0%) than on the Plateau (*n* = 33; 44.0%), reflecting a relatively denser network of travel routes connecting Lowland villages and non-residential sites. This pattern of continuous occupation, village-centered maize cultivation, natural resource extraction/processing, and relatively greater inter-site connectivity suggests that Lowland forests had likely been subjected to the effects of indigenous land-use practices more intensely than the forests of the Plateau. For example, surveyors described sites of abandoned Seneca villages and fields (*n* = 8) as “clearings,” “cleared land,” “old clearing,” “improved land,” and “weeds,” with minor areas of active cropland (most likely of recent Euro-American origin) in the form of “corn field,” and “potato patch.” Sites described as “open land” (*n* = 13), “clear land” (*n* = 13), “grass” (*n* = 11), and “thinly timbered” (*n* = 68) were preferentially concentrated in the Lowland, often near Native American villages and trails. This suggests the presence of fire-dependent, open-canopy savanna and prairie habitat that may have benefitted from anthropogenic ignitions and vegetation clearing (Bean and Sanderson 2007). Together, these sparsely-vegetated habitats represent the clearest indicators of prior decades and centuries of Seneca/Iroquoian land-use impacts within the study area, with agricultural villages serving as foci of such disturbances.

This explanation is reinforced by the results of this study's NMS (Figure 2.3) and AHC (Figure 2.5) analyses. Lowland agricultural villages possessed relatively high mean scores on NMS axes 1 (fire frequency) and 2 (soil productivity), reflecting a clear association of villages with fire- and disturbance tolerant vegetation (Figure 2.3A) growing on soils maximally suited to maize-based agriculture (Figure 2.3B). Fire-tolerant taxa commonly associated with village sites included black walnut (*Juglans nigra*), sassafras (*Sassafras albidum*), hazel (*Corylus* spp.), and briers (*Rubus* spp.). Historical documentation indicates fire was used by Iroquoian populations for a variety of purposes, including the preparation of agricultural land (Halsey [1769] 1906), clearing trails (Maude 1826), harvesting nuts (Parr [1804] 2013), and maintaining browse for game animals (Dwight [1804] 1823).

Anthropogenic fires combined with active management of forest taxa on agriculturally productive soils may explain the observed association between oak-dominated forests and loamy, high-nutrient Alfisols (AHC Group 2b; Figure 2.4). This pattern was also noted by Marks and Gardescu (1992) in the eastern Finger Lakes region, where oaks were often recorded growing on agriculturally-productive sites in the late 18th century CE. This anomaly suggests soil texture was not a primary factor modulating the distribution of at least some fire-tolerant taxa in the Finger Lakes region. This stands in contrast to other parts of the temperate Northeast and Great Lakes regions, where oaks are commonly associated with coarse-textured, droughty soils (Harman 2009). Furthermore, oak frequently occurs on nutrient-rich soils in the modern forests of the Finger Lakes region, particularly on sites with a history of Euro-American disturbance (Mohler et al. 2006). Prior centuries of Iroquoian land-use activities may, therefore, account for the prevalence of fire-tolerant oak on richer sites at the time of the land surveys. Tulowiecki and

Larsen (2015) postulated a scenario of active management of forest resources to explain locally elevated frequencies of mast taxa in the forests of Chautauqua County, New York, an area otherwise typified by extensive stands of fire-resistant moist upland forest. Population movements (i.e. village relocation) likely altered the spatial configuration of fire-altered vegetation in the PGP through time, and the extent of fire-tolerant vegetation may have been more extensive in the decades immediately prior to Seneca removal.

4.1.2. Appalachian Plateau: Native American silviculture and hunting

In contrast to the Lowland, the Appalachian Plateau was sparsely populated, although agricultural Iroquoian groups inhabited the Plateau in other parts of upstate New York (e.g. Tulowiecki and Larsen 2015). Historically, major agricultural villages (Figure 2.2A) were confined to the valleys of the Canisteo ($n = 4$) and Cohocton ($n = 1$) Rivers (Figure 2.1) and were inhabited by a small refugee group of Algonkian-speaking Lenape resettled by the Seneca during the 18th century CE (Grumet 1999). These agricultural settlements likely had an impact on the immediate vegetation. For example, Lenape villages possessed elevated NMS axis 1 scores ($\bar{x} = 0.230$; $s = 0.126$), as did much of the adjacent uplands near the villages (<5 km radius), where oak (*Quercus* spp.) and hickory (*Carya* spp.) occurred in far higher frequencies than in the surrounding hinterland (Figure 2.3A). This isolated cluster of high NMS axis 1 scores suggests that the Lenape had engaged in localized agricultural and silvicultural land-use practices to increase the frequency of mast taxa beyond their normal levels on this part of the Plateau. Significantly, this wedge of high NMS axis 1 scores extending up the Canisteo River valley was the site of several pre-Late Woodland villages and campsites (NYSM site file data).

Notably, the Plateau contained a relatively high frequency of trails observed by surveyors (*n* = 33; 44.0%; Figures 2.2B, 2.6), indicating that parts of the Plateau had been subjected to at least some form of disturbance by Native Americans prior to the land surveys. Many of these trails (*n* = 15; 45.5%) were located within areas classified within AHC Group 2a (*dry upland forest, low-productivity soils*) characterized by fire-tolerant white pine (*Pinus strobus*), pitch pine (*P. rigida*), chestnut (*Castanea dentata*), and “scrubby” or “brushy” early-successional vegetation. It is reasonable to hypothesize that Native American-set fires may have contributed to the expansion of this fire-adapted community type on the Plateau, which was otherwise dominated by moist upland forests. Trails, aside from serving as routes of overland travel, would have also acted as convenient locales for the setting of fires, either to facilitate propagation of economically desirable forest taxa or for the creation of browse for important game animals such as white-tailed deer (*Odocoileus virginianus*; Loskiel 1794). Significantly, the only evidence of recent forest fires (*n* = 12) recorded in the PGP LSRs was on the Plateau, adjacent to Seneca trails, suggesting that at least some fires were set in transit between travel destinations. Supporting this interpretation, Seneca fire-ring hunts were observed by Euro-Americans on the Plateau during the 1790s CE near Conesus Lake (Turner [1795] 1850), an area described by PGP surveyors as “thinly timbered” with oak and chestnut.

4.2. Native American land-use practices: a regional context

Late-18th century CE forests of the PGP study area clearly showed evidence of the legacies of both agricultural and silvicultural land-use practices by Seneca/Iroquoian populations, despite the study area having been largely abandoned for a decade prior to the surveys. Indigenous groups established population centers within a particularly favorable environmental milieu in the interior Lowland, owing to (1) a slightly warmer, drier microclimate; (2) the existence of highly productive soils amenable to maize-based agriculture; and (3) higher frequencies of fire-tolerant mast taxa. Forests within this prime ecological zone showed clear evidence of systematic canopy thinning, vegetation clearing, current and prior maize cultivation, and elevated frequencies of fire-tolerant nut-bearing taxa including oak, hickory, chestnut, and black walnut, as supported by the archaeological and ethnohistorical records (Wykoff 1991). This area also possessed the majority of the PGP's savannas and prairies, many of which were likely of anthropogenic origin (Dwight [1804] 1823).

The strong imprint of Seneca/Iroquoian land-use activities on the PGP landscape are likely atypical compared to other areas of northeastern North America. Iroquoian populations of the lower Great Lakes region were more sedentary than many of their Algonquian-speaking neighbors (Chilton 2010) and inhabited aggregated settlements with high population densities (Engelbrecht 2003) that were occupied for a generation or longer (Jordan 2008). Together, these cultural characteristics suggest that Iroquoians likely left a more visible and enduring imprint on the landscape than other indigenous groups with more dispersed, mobile settlement systems, whose ecological impacts would have been more ephemeral. Iroquoian landscape impacts were likely comparable to those of sedentary Mississippian (~800 – 1600 CE) groups of the Midcontinent (e.g. McLauchlan, 2003; Delcourt and Delcourt 2004; Muñoz et al. 2014) having large, aggregated settlements, high population densities, and practicing intensive forms of maize-based agriculture.

5. Conclusions

The goal of this research was to assess the magnitude and spatial patterning of Native American land-use activities on the temperate forested ecosystems of west-central New York State. This research (1) used an expanded array of vegetation-related environmental indicators derived from historic land survey records (LSRs), rather than only conventional bearing tree data; and (2) introduced the first application of an integrated NMS-AHC statistical methodology to this type of analysis. Combined with spatial and temporal analysis of NMS ordination scores, these enhancements demonstrated an even clearer and stronger relationship between protohistoric and historic Native American settlement and subsistence on the regional vegetation than previous interpretations. The combined contributions of NMS axis 1 (fire frequency) and NMS axis 3 (Native American land-use), which collectively explained 70% of the total variance in the vegetation data, provide compelling evidence linking Seneca/Iroquoian settlement and subsistence to more active fire regimes and other forms of vegetation disturbance. Results of AHC analysis corroborated the NMS ordination by grouping taxa into vegetation communities modulated by disturbance (NMS axes 1 and 3) and secondarily soil fertility (NMS axis 2). Areas at greater distances from settlements, non-residential sites, and trails were less affected by anthropogenic disturbance, where fire-sensitive moist upland forests (AHC Group 1) predominated.

The pronounced transformation of the landscape by Seneca/Iroquoian land-use activities within the study area, however, should not be automatically extrapolated to other portions of eastern

North America, where a diversity of subsistence practices, settlement patterns, and population densities was the norm. This insight has important ramifications for understanding and delineating spatial gradients of land-use intensity by prehistoric and historic Native American societies, with Seneca/Iroquoian populations representing an extreme end-member of a continuum of disturbance compared to more mobile groups whose land-use impacts may have been of shorter duration, smaller spatial extent, and lesser magnitude. Future LSR-based analyses of Native American land-use impacts should therefore consider the cultural context of indigenous populations as an important modulator of disturbance regimes within temperate forested ecosystems.

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APPENDICES

Appendix A. Late Woodland (900 – 1650 CE) and Historic (1650 – 1779 CE) Native American archaeological sites within the Phelps and Gorham Purchase (PGP) study area. The list represents all known villages, earthworks, palisades, burials, cemeteries, ossuaries, campsites, cabins, and middens identified as of December 2015 (*n* = 172). Cultural phases are used where sufficient chronological or cultural context exist for a determination and follow a simplified version of Niemczycki's (1984) terminology for Iroquoian and Seneca-Cayuga tribal evolution in the Genesee Valley and Finger Lakes regions. Phases include Owasco (900 – 1250 CE), Transitional Iroquois (1250 – 1350 CE), Early Iroquois (1350 – 1450 CE), Late Prehistoric Iroquois (1450 – 1550 CE), Protohistoric Iroquois (1550 – 1650 CE), and Historic Seneca (1650 – 1779 CE).

Site name	**Dates occupied**	**Cultural phase/affiliation**	**Site type**	**Reference**
A&R Gravel Pit	Unknown	Unknown	Burial	NYSM site file
ACP GNSE 20	Unknown	Iroquoian	Burial	NYSM site file
ACP LSTN-65	Unknown	Unknown	Village	NYSM site file
ACP LSTN-71	Unknown	Unknown	Unknown	NYSM site file
ACP MNRO 55 A	Unknown	Iroquoian, Algonkian	Village	NYSM site file
ACP MNRO 56 A	Unknown	Unknown	Village, burials	NYSM site file
ACP ONTO 3	Unknown	Unknown	Burial, village	NYSM site file
ACP ONTO 9	Unknown	Unknown	Village, burial	NYSM site file
Adams	1550 - 1575	Protohistoric Iroquois	Village	Jones (2010)
Alhart	1440 - 1510	Late Prehistoric Iroquois (Neutral)	Village, burials	Ritchie (1930)
Alva-Reed	1570 - 1585	Protohistoric Iroquois	Village	Jones (2010)
Andrews	1300 - 1500	Early Iroquois	Village	NYSM site file
Armstrong	Unknown	Unknown	Burial	NYSM site file
Assinisink	1700s	Historic Seneca (Lenape)	Village	NYSM site file
Avery	Unknown	Unknown	Unknown	NYSM site file
Avon Bridge	Unknown	Historic Seneca	Burial	NYSM site file
Batzing	Unknown	Unknown	Unknown	Trubowitz (1983)
Beal, Cherry Street	1675 - 1687	Historic Seneca	Village	Jones (2010)
Belcher	1540 - 1560	Late Prehistoric Iroquois	Village	Jones (2010)
Big Massaug	Unknown	Iroquoian	Campsite	NYSM site file
Blakesley	900 - 1250	Owasco	Campsite, burial	NYSM site file
Bosley Mills/Fort Hill/Gahnyuhsas	1615 - 1630	Protohistoric Iroquois	Village	Jones (2010)
Boughton Hill/Gandagora	1670 - 1687	Historic Seneca	Village, fort, mission	NYSM site file
Gannagaro/Ganondagan	1670 - 1687	Historic Seneca	Village, mission	Jones (2010)

Appendix A (continued).

Site name	Dates occupied	Cultural phase/affiliation	Site type	Reference
Brady 3	Unknown	Unknown	Unknown	Trubowitz (1983)
Brady-Caton 2	Unknown	Unknown	Unknown	Trubowitz (1983)
Bristol	1300 - 1500	Early Iroquois	Village	NYSM site file
Bunce	Unknown	Historic Seneca	Burial	NYSM site file
Burning Springs	900 - ?	Owasco - Iroquoian	Village	NYSM site file
Bushman	Unknown	Iroquoian	Burials	NYSM site file
Buyck 2	Unknown	Iroquoian	Camp, stray find	NYSM site file
California Ranch	1540 - 1560	Late Prehistoric Iroquois	Village	Jones (2010)
Cameron	1575 - 1590	Protohistoric Iroquois	Village	Jones (2010)
Canandaigua Fort Hill	1550 - 1650	Protohistoric Iroquois	Earthwork	Niemczycki (1984)
Canisteo River	900 - 1250	Owasco	Unknown	NYSM site file
Cecelia Terrace	Unknown	Iroquoian	Campsite	NYSM site file
Clifton Springs	ca. 1450	Early Iroquois	Village	NYSM site file
Conn B/Conn	1590 - 1615	Protohistoric Iroquois	Campsite, burial	NYSM site file
Conn A/Conn	1590 - 1615	Protohistoric Iroquois	Campsite, burial	NYSM site file
Cornish	ca. 1600	Protohistoric Iroquois	Village, fort, cemetery	Niemczycki (1984)
Cow Tooth	Unknown	Unknown	Unknown	NYSM site file
Cranberry Pond/Schultz	Unknown	Historic Seneca?	Campsite	Ritchie (1927)
Crye 1	Unknown	Unknown	Campsite (?)	Trubowitz (1983)
Culbertson	1570 - 1585	Protohistoric Iroquois	Village	Jones (2010)
Cullinan B	Unknown	Iroquoian	Burial	NYSM site file
Dann/Gandachioragou	1655 - 1675	Historic Seneca	Village	Jones (2010)
Dansville Fort/William Mitchell	1450 - 1550	Late Prehistoric Iroquois	Village, fort, earthwork	Niemczycki (1984)
Davis Site A	Unknown	Iroquoian	Burial	NYSM site file
Deer Farm	Unknown	Iroquoian	Village	NYSM site file
Dutch Hollow	1590 - 1615	Protohistoric Iroquois	Village	Jones (2010)
Dyunegano	Historic	Historic Seneca	Village, burinals	NYSM site file
Ely	Unknown	Iroquoian (?), Historic Seneca (?)	Campsite	Ritchie (1927)
Factory Hollow	1590 - 1615	Protohistoric Iroquois	Village, camp	Jones (2010)
Fagan 1	Late Woodland	Unknown	Unknown	NYSM site file
Fall Brook/Wadsworth Ossuary	900 - ?	Owasco - Iroquoian	Camp, burial, ossuaries	NYSM site file

Appendix A (continued).

Site name	**Dates occupied**	**Cultural phase/affiliation**	**Site type**	**Reference**
Fall Creek #1	Late Woodland	Unknown	Unknown	NYSM site file
Farrell	Late Woodland	Iroquoian	Campsite	NYSM site file
Feugle	1590 - 1615	Protohistoric Iroquois	Village	Jones (2010)
Fletcher/Simmons	1300 - 1500	Early Iroquois	Village	NYSM site file
Footer	1350 - 1400	Early Iroquois	Village, palisaded fort	NYSM site file
CAN 4-1/NYSM 4287/Fort Hill	1675 - 1687	Historic Seneca	Earthwork	NYSM site file
/NYSM 1383/Fort Hill	1675 - 1687	Historic Seneca	Village, fort, earthwork	NYSM site file
Fort Hill LeRoy	1450 - 1550	Late Prehistoric Iroquois	Village	NYSM site file
Fox/BTH 7-1/UB 610	Late Woodland	Unknown	Unknown	NYSM site file
CAN 11-1/Fox	Historic	Historic Seneca	Village	NYSM site file
Fuierer	Late Woodland	Unknown	Cemetery (?)	NYSM site file
Gannounta	1600s	Historic Seneca (Huron)	Village, burials	Jones (2010)
Garden/Garden Flats	Late Woodland	Unknown	Unknown	NYSM site file
Garner Farm	Late Woodland	Iroquoian	Unknown	NYSM site file
Gathsegwarohare	Destroyed 1779	Historic Seneca	Village	Cook (1887)
Gaw-she-gweh-oh 1	Historic	Iroquoian	Village	NYSM site file
Gaw-she-gweh-oh 2	Historic	Iroquoian	Cemetery	NYSM site file
Genesee 2	Late Woodland	Unknown	Campsite	Trubowitz (1983)
Genesee 5	Late Woodland	Unknown	Campsite	Trubowitz (1983)
Goschkoshing	1700s	Historic Seneca (Lenape)	Village	NYSM site file
Graff	Late Woodland	Unknown	Unknown	NYSM site file
Gruschow	Late Woodland	Unknown	Burial	NYSM site file
Hammond Gravel Pit	Late Woodland	Iroquoian	Burial	NYSM site file
Harscher	1450 - 1550	Late Prehistoric Iroquois	Village, burials	NYSM site file
Haslit	Historic	Unknown	Unknown	NYSM site file
Heck	Late Woodland (?)	Iroquoian (?)	Burial	NYSM site file
Held's Cove	Late Woodland	Unknown	Campsite	Ritchie (1927)
Hickling	Late Woodland	Unknown	Unknown	Kankus (1983)
Hilliard	1450 - 1550	Late Prehistoric Iroquois	Village, hamlet	NYSM site file
Hooker	Late Woodland - Historic	Iroquoian, Seneca	Village, palisade, fort	NYSM site file
Hubbard #7/Hubbard #8	Late Woodland	Iroquoian	Unknown	NYSM site file

Appendix A (continued).

Site name	Dates occupied	Cultural phase/affiliation	Site type	Reference
Hummel	1300 - 1500	Early Iroquois	Campsite	NYSM site file
Johnston	1575 - 1590	Protohistoric Iroquois	Village	Jones (2010)
Jones Chemical	Late Woodland	Iroquoian	Burials	NYSM site file
Jordan	Late Woodland	Iroquoian	Unknown	NYSM site file
Kanadesaga Mound/Geneva Mound	Historic	Historic Seneca	Burial	Jones (2010)
Kanaghsaws/Adjutsa/Conesus/Flannigan	Destroyed 1779	Historic Seneca	Village	Cook (1887)
Kirkwood/Crouse	1675 - 1687	Historic Seneca	Village	Jones (2010)
Klink	Late Woodland	Unknown	Campsite	NYSM site file
Labach Peter's Town	1700s	Historic Seneca (Lenape)	Village	NYSM site file
Leatherstitch/Wadsworth/Street Farm	Late Woodland	Iroquoian	Unknown	NYSM site file
Lee	1300 - 1350	Early Iroquois	Burials	Niemczycki (1984)
Lewis Point	900 - 1250	Owasco	Campsite	NYSM site file
Lima/Ska-hase-ga-oh	1615 - 1630	Protohistoric Iroquois	Village	Jones (2010)
Long Point/Conesus Lake	Late Woodland	Historic Seneca	Campsite	NYSM site file
Long Pond/Kuhn	Late Woodland	Iroquoian	Campsite	Ritchie (1927)
Lower Delta	Late Woodland	Iroquoian	Campsite	NYSM site file
Lower Fall Brook	Historic	Historic Seneca	Village	NYSM site file
Mac Ann	Late Woodland (?)	Iroquoian	Burial	NYSM site file
Macauley 73-3	Late Woodland	Unknown	Unknown	Trubowitz (1983)
Magee/Bill Farm/Onaghee/Huntoon	1700 - 1730	Unknown	Village, burial	NYSM site file
Maplewood Station	1450 -1550	Neutral, Ontario Iroquoian	Village	Ritchie (1930)
Markham/Selden/Big Tree Farm	Late Woodland, Historic (?)	Iroquoian, Seneca (?)	Village, cemeteries	NYSM site file
Marsh/Marsh A/Gandougarae	Historic	Historic Seneca	Campsite	Jones (2010)
Martin Farm	Late Woodland	Unknown	Burial	NYSM site file
Martin Road Gravel Pit	Late Woodland	Iroquoian	Burials	NYSM site file
Menonkowack	1700s	Historic Seneca (Lenape)	Village	NYSM site file
Menzis	1630 - 1655	Protohistoric Iroquois	Village	Jones (2010)
Morrow/Honeoye	900 - ?	Owasco - Iroquoian	Village, burial	NYSM site file
Murawski	900 - 1250 (?)	Owasco (?)	Burial (?)	NYSM site file
NDA 25:30LVTN50	Late Woodland - Historic	Iroquoian, Seneca	Cabin	NYSM site file

Appendix A (continued).

Site name	Dates occupied	Cultural affiliation	Site type	Reference
Newport House/Newport	Late Woodland	Iroquoian	Campsite	Ritchie (1927)
No information	Historic	Historic Seneca	Village, cabins	NYSM site file
Nutimus Town	1700s	Historic Seneca (Lenape)	Village	NYSM site file
Ohagi 6	1350 -1450	Early Iroquois	Village, cemetery	NYSM site file
Palmer A	Late Woodland	Unknown	Burial	NYSM site file
Patry/Wadsworth	Late Woodland - Historic	Iroquoian, Seneca	Undefined	NYSM site file
Pfuntner 2	Late Woodland	Iroquoian	Unknown	Trubowitz (1983)
Phelps	ca. 1525	Late Prehistoric Iroquois	Village, fort, burial	Niemczycki (1984)
Pierce-McMahon	Late Woodland	Unknown	Unknown	NYSM site file
Powerhouse/Keint-he	1630 - 1655	Protohistoric Iroquois	Village, cemetery	Jones (2010)
Putnam	Late Woodland	Iroquoian	Burial	NYSM site file
Read/Townley-Read	Historic	Historic Seneca	Village	NYSM site file
Reed's Corners	Late Woodland	Iroquoian (?)	Cemetery	NYSM site file
Richmond Mills/Alva Reed	1540 - 1560	Protohistoric Iroquois	Village	Jones (2010)
Roberts Wesleyan College	Late Woodland	Iroquoian	Burials	NYSM site file
Rockefeller Farm	Late Woodland	Iroquoian	Campsite	NYSM site file
Rogers	1300 - 1500	Early Iroquois	Camp (?), village (?)	NYSM site file
Royce Kilmer	Late Woodland	Iroquoian	Village, campsites (?)	NYSM site file
Sackett	Late Woodland	Late Woodland	Village	NYSM site file
Sanders	Historic	Historic Seneca	Burial	NYSM site file
Saxton	900 - 1250	Owasco	Unknown	NYSM site file
Schantz	Late Woodland (?)	Iroquoian (Huron/Neutral)	Burial	NYSM site file
Schillinger	Historic	Iroquoian	Village, burials	NYSM site file
Scudder	Middle Late Woodland	Iroquoian	Unknown	NYSM site file
Shakeshaft Gravel Pit	Late Woodland (?)	Iroquoian	Burial	NYSM site file
Snyder-McClure	Historic	Historic Seneca	Village	NYSM site file
Snyder's Point	Late Woodland	Iroquoian	Campsite, midden	NYSM site file
Squash Patch	Late Woodland	Iroquoian	Campsite	Trubowitz (1983)

Appendix A (continued).

Site name	Dates occupied	Cultural phase/affiliation	Site type	Reference
Stewart 4	Middle Late Woodland	Iroquoian	Unknown	NYSM site file
Steele	1630 - 1650	Historic Seneca	Village	Jones (2010)
Stull	Late Woodland	Unknown	Campsite	NYSM site file
Stull/Farley	Late Woodland	Unknown	Village	NYSM site file
SUBI 0845	Late Woodland	Iroquoian	Unknown	NYSM site file
Sutton	Late Woodland - Historic	Iroquoian, Seneca	Village, campsite	NYSM site file
Taft	Historic	Iroquoian	Village	NYSM site file
Techanowunnadaneo	Historic	Historic Seneca	Campsite	NYSM site file
Tirabassi 1	900 - ?	Owasco - Iroquoian	Unknown	NYSM site file
Tirabassi 3	Late Woodland - Historic	Iroquoian, Seneca	Camp, stray find	NYSM site file
Totiakton/Roch. Junction/Kirkpatrick	1675 - 1687	Historic Seneca	Village	Jones (2010)
Tram	1550 - 1575	Protohistoric Iroquois	Village	Jones (2010)
Tram/Adams/General Farm	Historic	Historic Seneca	Village, fort, cemetery	NYSM site file
Unknown	Late Woodland - Historic	Iroquoian, Seneca	Unknown	NYSM site file
Unknown	Late Woodland	Iroquoian (Seneca?)	Unknown	NYSM site file
Upper Delta	900 - 1250	Owasco	Campsite	NYSM site file
Vanzandt/Frank Locus A	900 - 1250	Owasco	Burials	NYSM site file
Volmer	Late Woodland	Iroquoian	Burials	NYSM site file
Wadsworth-Barrows/Wadsworth Fort	900 - 1250	Owasco	Unknown	Niemczycki (1984)
Wallace Area 10	Historic (?)	Historic Seneca (?)	Unknown	NYSM site file
Walton 1	Middle Late Woodland	Iroquoian	Unknown	NYSM site file
Waneta Lake	Late Woodland	Iroquoian	Campsite, midden, burial	NYSM site file
Warren	1615 - 1630	Protohistoric Iroquois	Village	Jones (2010)
Webb	Late Woodland	Unknown	Campsite	NYSM site file
Wheeler	1660 - 1680	Historic Seneca	Campsite	Jones (2010)
White Springs	Historic	Historic Seneca	Village, mission	Jordan (2008)
White Springs Farm	1730s	Historic Seneca	Village	Jordan (2008)
Woolhouse Road	Late Woodland (?)	Late Woodland	Unknown	NYSM site file

Appendix B. Non-metric multidimensional scaling (NMS) taxon scores. Taxa are listed in descending order for each NMS axis.

Species	Axis 1 score
Whortleberry	1.43992
Corn field	1.29313
Poor timber	1.22629
Burnt timber/fire	1.01074
Potato patch	0.94561
Hazel	0.91699
Weeds	0.86194
Pitch pine	0.66849
Thinly timbered	0.58914
Serviceberry	0.58176
Briers/thorn	0.58176
Black/red oak	0.56829
White oak	0.53398
Sassafras	0.52399
Scrub oak	0.52118
Ag. clearing	0.4816
Red pine	0.46909
Hickory	0.46831
Brush/shrub/scrub	0.42487
Sapling thicket	0.42171
Black walnut	0.40688
Dead timber	0.34831
Open land	0.32528
Chestnut	0.32096
Chestnut oak	0.29776
White pine	0.29306
Clear land	0.26883
Oak spp.	0.20274
Mountain laurel	0.1928
Grove/copse	0.186
Grassland	0.1354
Aspen/poplar	0.03238
Butternut	0.02066
White ash	-0.08396
Tuliptree	-0.13319
Elm	-0.14026
No underbrush	-0.17574
Ironwood	-0.20296
Basswood	-0.23134
Hemlock	-0.28359
Sugar maple	-0.29763
Cherry	-0.37262
Beech	-0.37455
Birch	-0.42709
Windthrow	-0.64041

Species	Axis 2 score
Grove/copse	1.24913
Ag. clearing	0.83736
Hazel	0.72568
Clear land	0.70422
Potato patch	0.6325
Serviceberry	0.62577
Briers/thorn	0.62577
Sassafras	0.61596
Grassland	0.58915
Open land	0.53235
Black walnut	0.48797
Butternut	0.43245
Tuliptree	0.43075
Ironwood	0.35892
Thinly timbered	0.35178
Corn field	0.3504
Elm	0.33798
No underbrush	0.32933
Hickory	0.28008
Weeds	0.26466
Basswood	0.25077
Aspen/poplar	0.22225
Black/red oak	0.1443
White ash	0.14395
White oak	0.0724
Oak spp.	0.04925
Sugar maple	0.0308
Beech	0.01245
Dead timber	0.00135
Cherry	-0.07802
Birch	-0.19368
Poor timber	-0.24583
Brush/shrub/scrub	-0.26319
Chestnut	-0.29792
Sapling thicket	-0.31409
Windthrow	-0.3217
Whortleberry	-0.38902
Hemlock	-0.47315
White pine	-0.50135
Mountain laurel	-0.57111
Scrub oak	-0.57679
Burnt timber/fire	-0.60634
Chestnut oak	-0.63076
Pitch pine	-0.68931
Red pine	-0.86063

Species	Axis 3 score
Corn field	1.65532
Potato patch	1.27836
Weeds	1.19677
Dead timber	0.99947
Grove/copse	0.45439
Hazel	0.407
Ag. clearing	0.40171
Mountain laurel	0.29822
Black walnut	0.29443
Windthrow	0.2295
Scrub oak	0.21009
Grassland	0.20056
Red pine	0.19065
White oak	0.17698
Pitch pine	0.15808
Clear land	0.15482
Black/red oak	0.14743
Burnt timber/fire	0.14339
No underbrush	0.11099
Ironwood	0.10605
Whortleberry	0.05836
Birch	0.05446
Sugar maple	0.05152
Beech	0.02272
Poor timber	0.01312
Hemlock	0.01211
Cherry	0.01091
Brush/shrub/scrub	-0.01934
Elm	-0.02828
Aspen/poplar	-0.03041
White pine	-0.03168
Chestnut oak	-0.03687
Basswood	-0.06077
White ash	-0.11815
Serviceberry	-0.15811
Briers/thorn	-0.15811
Sapling thicket	-0.16624
Chestnut	-0.18032
Tuliptree	-0.18382
Hickory	-0.24955
Butternut	-0.26128
Sassafras	-0.27377
Open land	-0.3035
Thinly timbered	-0.39316
Oak spp.	-0.46295

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CHAPTER 3. CHARACTERIZATION OF NATIVE AMERICAN VEGETATION DISTURBANCE IN THE FORESTS OF CENTRAL NEW YORK STATE, USA DURING THE LATE 18th CENTURY CE

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Abstract

Historic land survey records (LSRs) offer important details on local- and landscape-scale vegetation patterns related to Native American land-use practices prior to widespread Euro-American settlement. This study's use of an expanded range of vegetation-related variables derived from LSR sources, combined with archaeological site distribution data, and analyzed using complementary multivariate statistical methods, has provided new insights on the spatial and compositional dynamics of the vegetation of central New York State, USA, an area historically occupied by the Cayuga and Onondaga nations. The upland vegetation of the study area was modulated primarily by fire, followed by soil fertility, and canopy disturbance. Clear signals of Native American agriculture and silviculture were associated with a number of fire-tolerant vegetation communities that were geographically concentrated within an area most conducive to maize cultivation. Numerical classification partitioned the LSR vegetation data into distinct community types: mesophytic upland forest and xerophytic upland forest. This latter type was secondarily differentiated into an unequivocally anthropogenic landscape (*Iroquoian agricultural mosaic*) and a series of fire-tolerant forest and savanna communities with possible connections to silvicultural land-use practices. Distance analysis of ordination scores indicated statistically-significant spatial trends associated with the distribution of archaeological sites, with disturbance most heavily concentrated within 6 km of most sites. Given the success of this methodology, I recommend that this integrated approach become the standard for LSR-based research of Native American vegetation disturbance. *Key Words: detrended correspondence analysis, agglomerative hierarchical clustering, Native Americans, land survey records, vegetation disturbance, historical ecology.*

1. Introduction

Land survey records (LSRs) have emerged as important sources of information on historical vegetation conditions in eastern North America prior to widespread Euro-American occupation ("presettlement") during the 17th – 19th centuries CE (Wang 2005). Consisting of bearing (witness) trees recorded at township and lot corners and associated inventories of multiple woody taxa observed along survey lines, LSRs have been used to determine environmental influences on the distribution of presettlement forest taxa (e.g. Abrams and Ruffner 1995; Whitney and DeCant 2003); evaluate historic changes in species composition resulting from Euro-American forest clearance, agriculture, and fire suppression (e.g. Thompson et al. 2013); reconstruct presettlement vegetation communities (e.g. Cogbill et al. 2002; Wang 2007; Dupuis et al. 2011; Larsen et al. 2015; Goring et al. 2016; Paciorek et al. 2016); and characterize disturbance regimes (e.g. Predmore et al. 2007; Thomas-Van Gundy and Nowacki 2013). LSRs have also been used in recent years as sources of information on Native American land-use impacts on temperate forested ecosystems (e.g. Black and Abrams 2001; Foster et al. 2004; Black et al. 2006; Tulowiecki and Larsen 2015). Analysis of the interactions between prehistoric and historic indigenous societies and native vegetation communities has relevance for a variety of disciplines including archaeology (environmental contextualization of prehistoric culture systems; Gajewski et al. 2019), biogeography (reconstruction of Holocene species' dispersals; MacDougall 2003), climate change studies (estimation of biomass burning and prehistoric carbon storage; Power et al. 2012; Koch et al. 2019), fire ecology (reconstruction of fire regimes prior to Euro-American settlement; Thomas-Van Gundy and Nowacki 2013; Abrams and Nowacki 2019), conservation and restoration ecology (reintroduction of extirpated taxa and recovery of degraded/destroyed ecosystems; Alagona et al. 2012), and historical geography (indigenous land-use legacies on Euro-American settlement geography; Coughlan and Nelson 2018). Unfortunately, studies focused on Native American land-use impacts using high-resolution (spatially and taxonomically) LSR datasets have been relatively few in number and are frequently of limited spatial coverage, typically encompassing county-level-sized or slightly larger (~10^3 km^2; Black and Abrams 2001; Black et al. 2006; Tulowiecki and Larsen 2015) geographic extents. During this time, developments in prehistoric North American archaeology (e.g. pottery residue analysis, flotation of archaeobotanical remains) have revised preexisting interpretations regarding the chronology of indigenous cultigen use and other details on the emergence of early agricultural complex (EAC) horticulture and later maize-based agriculture (e.g. Hart and Brumbach 2005; Asch Sidell 2008; Hart et al. 2007; Hart and Lovis 2013), suggesting a longer duration for major anthropogenic land-use impacts.

Despite these recent advancements in archaeology, linkages between Native American land-use practices and historical vegetation patterns have been hampered by assumptions that only indigenous agricultural villages could have served as foci of vegetation disturbance discernable in the LSRs, and that such disturbances may have affected only a limited extent of the surrounding landscape (e.g. Russell 1983; Matlack 2013). However, Native American settlement systems were complex, consisting of multiple site types devoted to various economic activities beyond maize-based agriculture, such as silviculture (i.e. management of nut- and berry-producing forest taxa; Abrams and Nowacki 2008; Muñoz et al. 2014), hunting, resource extraction and processing, ritual activities, and other uses (Williams 2000). By limiting the scope of potential sources of anthropogenic disturbance to merely agricultural village sites, the full range of Native American land-use impacts has likely been underestimated in previous LSR-based research.

In this paper, I present a LSR-based study of Native American land-use impacts on the upland vegetation of central New York State, USA prior to widespread Euro-American settlement, that offers a major improvement upon previous studies by (1) utilizing a broader selection of archaeological site types (n = 118; e.g. villages, campsites, burials, cemeteries, workshops, quarries); (2) use of a more inclusive set of LSR-derived vegetation variables (n = 9892) comprising witness (bearing) trees, qualitative descriptions of vegetation structure and composition, and evidence of vegetation disturbance (e.g. fire); (3) examining Native American land-use impacts over a larger spatial extent than several prior LSR-based studies; and (4) employing complementary multivariate statistical methods including detrended correspondence analysis (DCA; Hill and Gauch 1980) and agglomerative hierarchical clustering (AHC; Kent 2012) in conjunction with distance analysis of DCA taxon scores to infer the geographic extent and configuration of Native American land-use impacts. In particular, the novel incorporation of structural vegetation data (e.g. descriptions of timber density, habitat appearance, evidence of prior disturbance) extends the interpretative power of traditional LSR-based analyses focusing primarily upon forest compositional change through the exclusive analysis of witness tree data. Although Native American populations doubtlessly affected forest species composition through a variety of land-use practices, most notably the use of fire (Williams 2000; Abrams and Nowacki 2008), abundant ethnohistorical evidence indicates that open-canopy habitats – in the form of savannas, barrens, prairies, and successional old fields – were a commonly-noted feature of the forested landscapes of much of eastern North America prior to Euro-American settlement, and that these were often associated with Native American settlement and/or subsistence activities (Day 1953). Hence, the use of structural data derived from LSRs has the potential to reveal more nuanced approximations of the likely impacts of indigenous land-use activities than forest compositional data alone. Moreover, the incorporation of a wider array of archaeological site types for modeling the spatial dynamics of Native American settlement patterns offers a more realistic conceptual model of Native American land-use impacts than one centered entirely upon agricultural settlements. These methodological innovations were used to identify the primary environmental modulators underlying observed early historic vegetation patterns, delineate major upland vegetation community types, infer the likely relationship between indigenous land-use practices and vegetation communities, and explore spatial gradients in the distribution of environmental modulators with respect to Native American settlement and subsistence. Additionally, this research represents the first LSR-based analysis of Native American land-use impacts on the vegetation of the historical territory of the Cayuga and Onondaga nations, groups belonging to the Haudenosaunee (Iroquois) Confederacy and subsumed within the larger Northern Iroquoian culture group (Engelbrecht 2003).

The broader relevance of this research lies in its attempt to define the spatial parameters of inferred Native American vegetation disturbance through the ordination and classification of LSR-derived vegetation data, and to compare the alignment of these patterns to the spatial distribution of regional archaeological sites. I examined the congruence of Late Woodland (ca. 1000 – 1650 CE) and Historic (1650 – 1779 CE) archaeological site locations and mapped clusters of high values for fire frequency, soil nutrient status, and forest canopy disturbance, and found a high degree of correlation. These results indicate that Native American land-use practices were still detectable within the forests of central New York over a decade following forced contraction of their territories following Euro-American military intervention.

2. Materials and methods

2.1. Environmental and cultural context

The study area is situated in the central portion of New York State between Lake Ontario and the eastern Finger Lakes (Figure 3.1) and is divided into three primary physiographic regions separated by two bedrock escarpments. The Lake Ontario Lowland extends from the Lake Ontario shoreline to the Onondaga Escarpment, and is characterized by sediments and landforms of Late Wisconsinan glacial origin including drumlins, inter-drumlin wetlands, relict beach ridges, wave-eroded drumlins, and till plains overlying non-calcareous shale and sandstone bedrock (Isachsen et al. 1991). The Finger Lakes Hills physiographic region occupies the area between the Onondaga and Portage Escarpments and is comprised of gently rolling till plains underlain primarily by calcareous limestone, dolostone, and shale (Isachsen et al. 1991). Finally, the Appalachian Plateau comprises the generally rugged, heavily dissected terrain south of the Portage Escarpment, and is characterized by non-calcareous shale and siltstone (Isachsen et al. 1991).

Climax forests within the study area are composed predominantly of mesophytic beech (*Fagus grandifolia*) – sugar maple (*Acer saccharum*) forests on high-nutrient Alfisols and hemlock (*Tsuga canadensis*) – northern hardwood forests on low-nutrient Inceptisols (Mohler et al. 2006). Some xerophytic oak-dominated forests are concentrated in the western portion of the study area near Seneca and Cayuga Lakes (Marks and Gardescu 1992). The regional

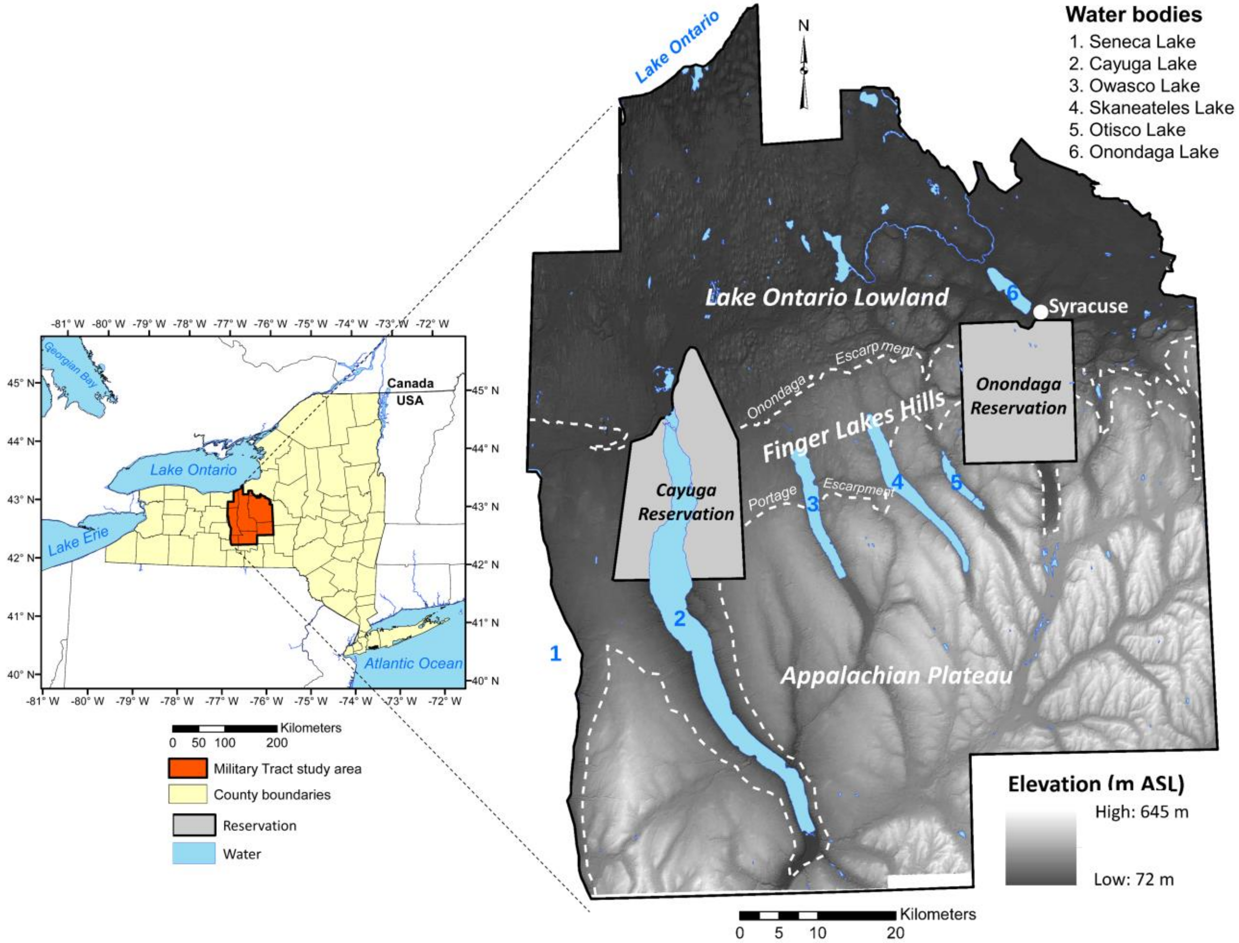

Figure 3.1. Location of the Military Tract study area, central New York State, USA.

climate is humid continental, with mean January temperatures ranging from -6.7° to -3.5°C, mean July temperatures from 19.0 – 22.5°C, and mean annual precipitation from 800 – 1170 mm, with cooler temperatures and higher precipitation prevailing on the Appalachian Plateau (Garoogian 2010). The region is characterized by heavy lake-effect snowfall, with annual totals of 1225 to 3550 mm, with totals increasing southwest to northeast across the study area (Hartnett et al. 2014).

By the time of initial European contact between 1600 and 1650 CE, the eastern Finger Lakes region was home to two (Cayuga and Onondaga nations) of the five culture groups comprising the historical Iroquois (Haudenosaunee) Confederacy (Snow 1996). These Northern Iroquoian populations engaged in a village-centered subsistence economy primarily based on maize-bean-squash intercropping supplemented by hunted game and gathered plant foods. Iroquoian populations inhabited large, multi-generational longhouses within spatially compact villages situated in defensible upland positions that were occupied for several decades (Englebrecht 2003; Jordan 2008). Agricultural Iroquoian populations tended to establish villages in locales having loamy, agriculturally-productive Alfisols (Jones 2010). The Sullivan-Clinton military expedition of 1779 CE destroyed the majority of Cayuga and Onondaga villages in the study area, although reservations for both groups were subsequently established by the Treaty of Canandaigua in 1794, including the 25,900-ha Cayuga Reservation at the northern end of Cayuga Lake and the 27,400-ha Onondaga Reservation south of the modern city of Syracuse (Oberg 2015; Figure 1). During the early 19th century, the Cayuga Reservation was subsequently abolished by New York State and the Onondaga Reservation was reduced in size. Euro-Americans began settling the area sparsely beginning in the 1770s, with settlement intensifying after 1790 CE (Meinig 1966).

2.2. Data collection from LSRs

The study area is centered on a 6800-km^2 land grant known as the Military Tract, established by Congress in 1789 CE (Sherwood 1926). Consisting of 28 townships of approximately 264 km^2 each, land surveys were conducted during the 1790s along township boundary lines, with townships further subdivided into 100 lots of 1.6-km length along each lot bounds. LSR data were obtained for the Military Tract from the New York State Archives, Albany, New York. The LSR notes contain information recorded by surveyors on the species of bearing (witness) trees observed at township and lot corners, as well as inventories of two or more woody (and occasionally non-woody) taxa noted at various points along each surveyed bounds. Species inventory data are normally distance weighted along survey line segments, under the assumption that taxa recorded by surveyors along a mile-long line segment were arranged in descending order of abundance (Seischab 1990). Although this practice was utilized in subsequent 19th century Government Land Office (GLO) surveys (White 1984), in the absence of corroborating evidence for the Military Tract surveys, we made no assumptions on the relative abundance of taxa listed in the inventories. This had the effect of (1) equalizing all taxa, whether recorded as individual bearing trees or as components of species inventories, (2) facilitating the representation of species contained in the inventories as “disaggregated,” discrete point features representing a single taxon, and (3) rendering all vegetation data amenable to subsequent statistical analyses. Consequently, our utilization of combined witness tree and point-transformed inventory data provided a frequency-based (rather than distance-weighted) approach to the analysis of spatial vegetation dynamics and their relationship to Native American land-use impacts. Also present in the LSRs, and rendered as discrete point features, were numerous qualitative descriptions of vegetation structure (e.g. “thinly timbered”), composition (e.g. “oak plains,” “clear land”), disturbance (e.g. burnt timber, windthrows) and recent Native American and Euro-American land-use activity (e.g. old agricultural clearings, cornfields) that provided important information on ecological and environmental conditions relevant to reconstruction of potential anthropogenic disturbance.

Georeferencing the LSR vegetation data was accomplished by digitizing a copy of Simeon De Witt's 1792 map of the Military Tract (Anonymous 1983) which included spatial information on both township and lot perimeters. Township and lot corners were found to coincide with several modern municipality boundaries and roadways, which facilitated georeferencing of the base map. Township and lot bounds were digitized as line feature classes in ArcGIS 10.3 (Environmental Systems Research Institute 2014). Locational data for surveyors' field observations along township and lot bounds were recorded the LSRs in perches/rods (1 perch/rod = 5.03 m), chains (1 chain = 20.12 m), and links (1 link = 0.201 m), and were normally measured as a cumulative distance from the origin (corner bearing tree or post) of each survey bounds, or alternatively, as the distance between successive observation points. Surveying units were converted to metric units (meters) and measured as a linear distance along each digitized township and lot bounds using the ArcMap 10.3 `Measure` tool to more accurately georeference the location of surveyors' field observations. We omitted typical wetland taxa such as black ash (*Fraxinus nigra*) and willow (*Salix* spp.) from inclusion within the geospatial vegetation database as our analysis was focused on upland vegetation dynamics. Tulowiecki and Larsen (2015) found little evidence of Iroquoian land-use impacts on species composition of wetlands in southwestern New York State, and I reasoned that anthropogenic impacts would likely be concentrated within upland locales. Species taxonomic data and qualitative vegetation descriptions were transcribed as a point feature class (*n* = 9892 observations) within an ArcGIS 10.3 geodatabase (Figure 3.2). A total of 31 upland vegetation variables, including species- and genus-level taxa, qualitative

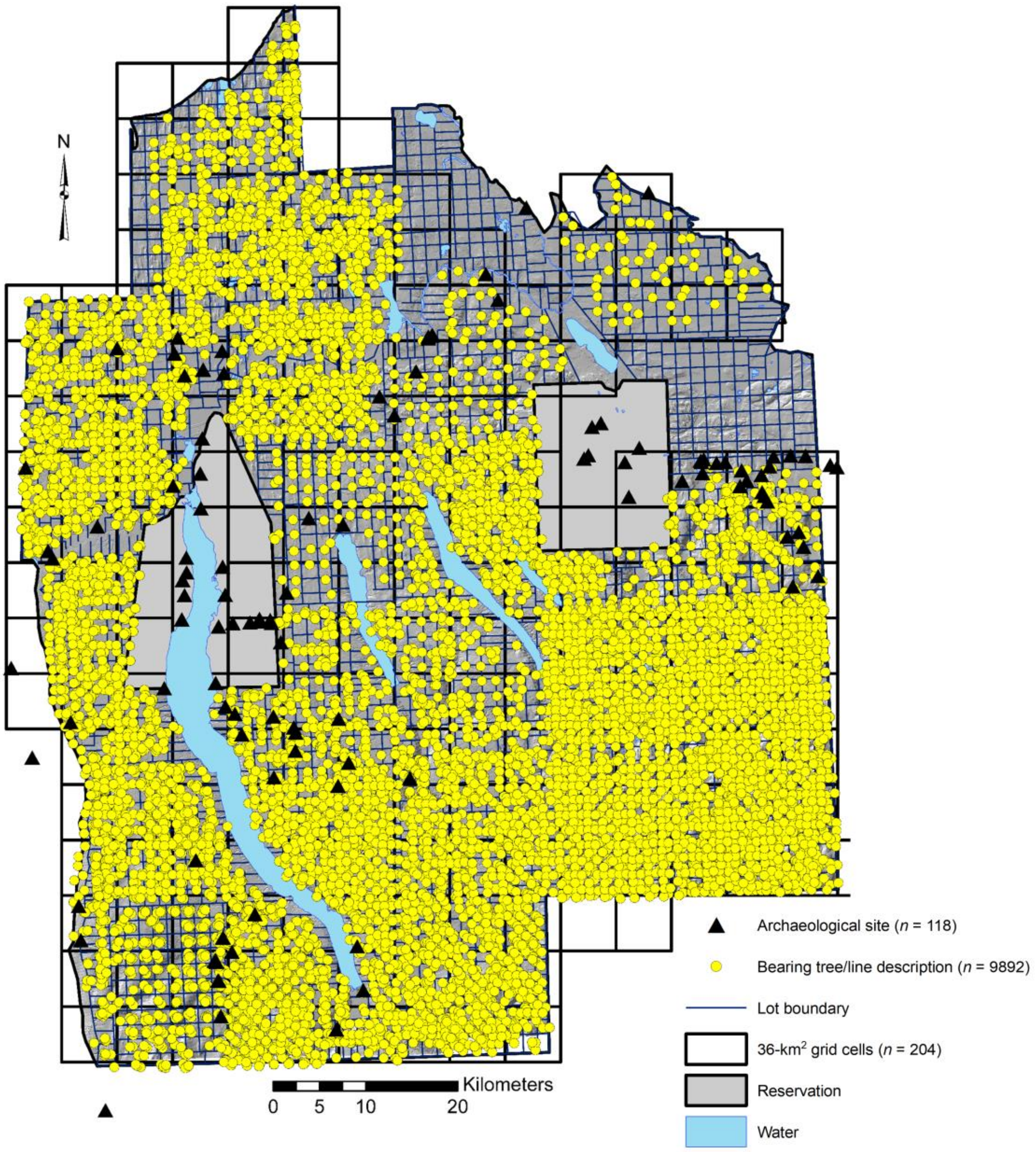

Figure 3.2. Distribution of bearing trees, species inventories, qualitative vegetation descriptions, and disturbance indicators (yellow circles; *n* = 9892) derived from late-18th century CE Military Tract land survey records (LSRs). Black triangles represent Late Woodland (1000 – 1650 CE) and Historic (1650 – 1779 CE) Period Iroquoian archaeological sites (*n* = 118). Lot boundaries (blue lines) and 36-km^2 grid cell sampling units (*n* = 204) are also shown.

vegetation descriptors, and evidence of past and recent disturbance (Table 3.1), were compiled for subsequent statistical and geospatial analysis.

2.3. GIS archaeological database

In order to analyze the potential influence of Iroquoian settlement patterns and land-use practices on regional vegetation gradients, a digital, georeferenced database was created consisting of all known Late Woodland (1000 – 1650 CE) and Historic (1650 – 1779 CE) Period Native American agricultural villages (n = 98) and non-residential site types (n = 20). Among the latter category are single- and recurrent-use campsites (n = 14), burials/cemeteries (n = 3), workshops (n = 1), ceremonial sites (n = 1), and other site types (n = 1; Figure 2; see *Supplementary Materials* Figure S1; Table S1). Archaeological site location data were provided by the New York State Museum (NYSM) Archaeology Laboratory, Albany, New York, with supplemental site data derived from the historical and archaeological literatures (Cook 1887; Tuck 1971; Niemczycki 1984; Bradley 1987).

2.4. LSR data sampling, extraction, and relativization

The study area was subdivided into 260 6-km x 6-km (36 km^2) grid cells using the `genvecgrid` tool of the Geospatial Modeling Environment (GME) 0.7.3.0 software package (Beyer 2012), which served as sampling units in the statistical analyses (Figure 3.2). A 36 km^2 grid cell size was selected as it tended to minimize the likelihood of (1) grouping ecologically unrelated taxa within a larger grid size, potentially homogenizing vegetation-environment relationships; and (2) utilizing too small a sampling area that would likely

Table 3.1. Summary of arboreal and non-arboreal taxa, qualitative vegetation descriptions, and evidence of vegetation disturbance (*n* = 9892) used in detrended correspondence analysis (DCA) and agglomerative hierarchical clustering (AHC) of the Military Tract land survey record (LSR) vegetation data.

Name(s) used by surveyors	**Scientific name**	**Frequency (*n*)**	**Percent (%)**
Beech	*Fagus grandifolia*	2867	28.98
Sugar maple, maple, sugar	*Acer saccharum*	2221	22.45
Basswood, bass, linden, lyn	*Tilia americana*	1369	13.84
Hemlock	*Tsuga canadensis*	593	5.99
Black oak, red oak	*Quercus velutina, Q. rubra*	493	4.98
White ash	*Fraxinus americana*	407	4.11
Elm	*Ulmus* spp.	399	4.03
White oak	*Quercus alba*	279	2.82
White pine, pine	*Pinus strobus*	274	2.77
Hickory, walnut	*Carya* spp.	221	2.23
Chestnut, chesnut	*Castanea dentata*	156	1.58
Birch	*Betula lenta, B. papyrifera, B. alleghaniensis*	138	1.39
Cherry	*Prunus serotina, P. virginiana*	121	1.22
Butternut	*Juglans cinerea*	58	0.59
Shrub, scrub, scrubby	n/a	50	0.51
Ironwood	*Carpinus carolina, Ostrya virginiana*	46	0.46
Aspen, poplar	*Populus* spp.	33	0.33
Black walnut	*Juglans nigra*	27	0.27
Pitch pine, yellow pine	*Pinus rigida*	22	0.22
Whitewood, tuliptree	*Liriodendron tulipfera*	18	0.18
Underbrush, brush	n/a	17	0.17
Thinly timbered	n/a	16	0.16
Old clearing, Indian clearing	n/a	12	0.12
Timber burnt, burn	n/a	9	0.09
Windfall	n/a	9	0.09
Briers, thorn bush	*Rubus* spp.	8	0.08
Scrub oak	*Quercus illicifolia*	7	0.07
Oak plains, plains	n/a	7	0.07
Sapling thicket	n/a	6	0.06
Corn field	*Zea mays* ssp. *mays*	6	0.06
Chesnut oak, chestnut oak	*Quercus prinus*	5	0.05
	Grand total:	**9892**	**100.00**

isolate ecologically related taxa, and was furthermore not commensurate with the likely positional error of vegetation point features. This hypothesis was tested using smaller (2-km) and larger (10-km) grid sampling sizes, and these were found to produce inferior ordination results (data not shown). Tallies of point features representing each vegetation variable (hereafter "taxon") within a grid cell were computed using the GME `countpntsinpolys` tool. Taxon count data for individual grid cells were exported to Microsoft Excel 2016 format (Microsoft Corporation 2015) for further preparation prior to statistical analysis. Frequency sums were originally calculated for a total of 37 upland taxa within 260 grid cells. However, since some grid cells contained no vegetation data points resulting from incomplete spatial coverage (e.g. unsurveyed Native American reservations), cells with <1 observation ($n = 48$) were deleted from the data matrix, resulting in a final count of 204 grid cells (Figure 2). Similarly, taxa having fewer than 5 total occurrences such as red mulberry (*Morus rubra*), serviceberry (*Amelanchier* spp.), plum (*Prunus* spp.), and hazel (*Corylus* spp.), although of potential significance to subsequent ecological interpretations, were excluded to reduce the biasing effect of rare taxa, resulting in a final count of 31 upland taxa retained.

Raw matrix count data were square-root transformed (Hellinger transformation; Legendre and Gallagher 2001) as a means of downweighting the overwhelming influence of certain commonly-recorded taxa such as beech (*Fagus grandifolia*; $n = 2867$) and sugar maple (*Acer saccharum*; $n = 2221$) and upweighting less common taxa (Kindt and Coe 2005). Data relativization was performed on grid cell, rather than taxon, totals to make allowances for large differences between sampling unit taxon counts (Kent 2012), which ranged from 2 to 139 ($\bar{x} = 47.0$; $s = 32.4$).

2.5. Detrended correspondence analysis

Detrended correspondence analysis (DCA; Hill and Gauch 1980) is an indirect ordination method (i.e. requires no supplementary quantitative biotic or environmental data to order vegetation samples; Kent, 2012) that has been used in several LSR-based analyses of historical vegetation (Seischab 1990; Cogbill et al. 2002; Black et al. 2006). Despite earlier criticisms of the technique (McCune and Grace 2002), recent reevaluations of DCA have shown it to be as robust an ordination technique as other, more popular methods such as non-metric multidimensional scaling (NMS; Wildi 2018). One advantage of DCA over other indirect ordination methods such as principal component analysis (PCA) lies in its lack of underlying assumptions of linearity in species-environment response, as most organisms possess a non-linear, unimodal Gaussian model of species abundance along environmental/biotic gradients (McCune and Grace 2002). DCA also provides an improvement upon the related ordination method of correspondence analysis (CA) as it (1) eliminates compression of points at the edges of the first CA axis and (2) removes distortion ("arch effect") resulting from the quadratic relationship between the first and second CA axes (Hill and Gauch 1980). Elimination of the arch effect in DCA is accomplished by "detrending" – division of the first axis into multiple segments within which second axis scores are recalculated to have a mean of zero (Gauch 1982). Decompression (rescaling) of axis 1 edges in DCA is achieved by a similar process of axis segmentation and expansion of the compressed areas so that the appearance and disappearance of taxa (species turnover) along axis 1 is uniform. A byproduct of the axis rescaling process in DCA is that species turnover is measured in units of average standard deviation (SD; Gauch 1982), with a taxon appearing, rising to its mode, and then disappearing in ~4 SD (Kent, 2012). Since DCA requires only a n x p data matrix comprised of n rows of vegetation samples and p columns of taxon abundance data, the method is ideally suited to the ordination of data-rich LSRs for the purpose of identifying environmental gradients associated with anthropogenic disturbance.

DCA was performed on the Hellinger-transformed vegetation data matrix of 31 taxa using PC-ORD 6.19 (McCune and Mefford 2011), with a default value of 26 segments specified for the detrending process and no downweighting of rare taxa, as this was accounted for through prior data screening and relativization of the original data matrix. Since DCA eigenvalues cannot be used to interpret the proportion of variance explained by each axis because of the rescaling and detrending processes inherent to the technique, the robustness of the final DCA ordination was evaluated through *post hoc* calculation of coefficients of determination (r^2) for each DCA axis ($n = 3$) between the Relative Euclidean distance in the original, unreduced species space and Euclidean distance in the ordination space (Peck 2010). This procedure enabled the determination of the proportion of the total variance distributed among the three primary DCA axes. The resulting ordination was visually inspected to qualitatively estimate and explain the likely ecological meaning of the DCA axes (Table 2). DCA axis scores were exported to Microsoft Excel spreadsheet format and arranged in descending order for each axis to more closely examine taxon trends, particularly evidence of species continua, and to refine initial interpretations of underlying ecological and environmental gradients.

2.6. Spatial interpolation and distance analysis of DCA taxon scores

A join table consisting of exported DCA taxon scores and their associated taxa for each of the three main DCA axes was created in Microsoft Excel and appended to the geospatial vegetation point feature class in ArcGIS 10.3, using the taxon name as the join field. The ArcGIS Geostatistical Wizard was used to execute an ordinary kriging interpolation algorithm to generate gridded rasters summarizing the spatial distribution of taxon scores for each of the three DCA axes across the Military Tract study area. A standard neighborhood search type with a minimum of four and maximum of ten neighbors with eight radial sectors for binning the empirical semivariogram was specified during the kriging process. Kriging was performed in order to create continuous, easily-interpretable raster surfaces from the numerous, discrete vegetation point data.

To assess the relationship between Late Woodland and Historic Period Native American settlement patterns and the spatial dynamics of DCA taxon scores, 5000 random points were generated within the spatial extent of the Military Tract grid cell polygon layer using the `genrandompnts` tool of the Geospatial Modeling Environment (GME) 0.7.3.0 software package (Beyer 2012). The random points shapefile was then overlaid upon each interpolated DCA axis score raster surface, and DCA score values for each raster cell were extracted to all overlying point features using the `Extract Values to Points` tool of ArcGIS 10.3 Spatial Analyst. Additionally, the shortest straight-line distance in kilometers from each random point feature to the nearest Native American archaeological site was calculated using the `Near` tool of ArcGIS 10.3, resulting in a proximity range of 0.1 – 42.2 km (n = 5000; $\bar{x}$ = 9.8 km; s = 7.7 km). Appended DCA taxon scores and associated proximity values were subsequently exported from the point feature class' attribute table to Microsoft Excel format. Mean species score values were calculated for successive 1-km binned increments from Native American archaeological sites up to a final distance of 20 km (n = 4443 data points). The resulting mean values were plotted with DCA species score as the dependent variable and distance to the nearest archaeological site as the predictor variable. Linear regression equations were generated for each of the three DCA axes and coefficients of determination

(r^2) were computed to evaluate the strength and direction of relationship between mean ordination scores and Native American settlement patterns.

2.7. Agglomerative hierarchical clustering (AHC) analysis

Inverse agglomerative hierarchical clustering (AHC; McCune and Grace 2002) was performed on the Military Tract LSR data using the PC-ORD 6.19 statistical software package (McCune and Mefford 2011) to classify taxa into discrete upland vegetation communities and to compare the resulting dendrogram to the DCA ordination. Agglomerative classification methods such as AHC proceed by grouping individual sampling units (e.g. grid cells) or variables (e.g. taxa extracted to grid cells) into successively larger groups based upon their degree of similarity, as determined by coefficients contained within a p x p (dis)similarity matrix, until all individual sampling units or variables have been allocated into a single group. Inverse AHC analysis, consisting of transposing the Hellinger-transformed n x p data matrix of n rows of sampling units and p columns of taxa, was performed in order to aggregate taxa, rather than sampling units, into hierarchical groupings. McCune and Mefford (2011) recommended relativization of species data prior to inverse analysis to counter the effects of abundant taxa separating into distinct groups from less common ones. AHC was conducted using a similarity matrix of Pearson's product-moment correlation coefficient (r) values for the 31 taxa as a distance measure, with a Ward's linkage method used as a sorting strategy to allocate taxa into discrete clusters. Ward's method minimizes the total within-cluster error sum of squares (variance) during each iteration by identifying the cluster pair producing the least increase in total post-fusion, within-cluster variance, as determined by the weighted squared distance between cluster means (McCune and Grace 2002; Kent 2012). The final AHC dendrogram was visually inspected for consistency and intelligibility of taxon assignments as well as the partitioning of disturbance indicators across major clades (clusters). Groupings at multiple dendrogram levels were assigned community type descriptions as outlined in the regional ecological literature (Mohler et al. 2006; Edinger et al. 2014) and overlaid onto AHC dendrogram branches to facilitate interpretation and highlight nested relationships among the identified community types.

3. Results

3.1. Detrended correspondence analysis (DCA) ordination of vegetation data

DCA axis 1 (Table 3.2; Figure 3.3A) explained 51.5% of the total variance in the Military Tract vegetation dataset, and arranged taxa along a fire frequency gradient ranging from the most fire-prone vegetation indicators (high, positive DCA axis 1 scores) dominated by thinly timbered areas (DCA axis 1 score = 554.5), bear oak (*Quercus illicifolia*; DCA axis 1 score = 552.8), chestnut oak (*Q. prinus*; DCA axis 1 score = 541.8), pitch pine (*Pinus rigida*; DCA axis 1 score = 481.6), and evidence of burnt timber (DCA axis 1 score = 479.8) to the most fire-sensitive taxa (low, positive DCA axis 1 scores) including black/yellow birch (*Betula lenta*/*B. alleghaniensis*; DCA axis 1 score = 0), hemlock (*Tsuga canadensis*; DCA axis 1 score = 48.4), and beech (*Fagus grandifolia*; DCA axis 1 score = 128.8).

DCA axis 2 (Table 3.2; Figure 3.3B) explained an additional 3.6% of the total variance in the Military Tract vegetation data and arranged vegetation variables indicative of recent Euro-American and past Iroquoian agricultural land-use activities on rich, high-nutrient sites (high, positive DCA axis 2 scores) including sapling thicket (DCA axis 2 score = 382.1), briers (DCA axis 2 score = 373.4), old clearings (DCA axis 2 score = 363.7), and cornfield (DCA

Table 3.2. Detrended correspondence analysis (DCA) taxon scores and percent variance explained for DCA axes 1 – 3 of 18th century CE Military Tract land survey record (LSR) vegetation data, arranged in descending order for each axis. DCA axis 1 explained 51.5% of the total variance in the vegetation dataset and was associated with a fire frequency gradient. DCA axis 2 explained a further 3.6% of the variance and corresponded to a soil fertility gradient. DCA axis 3 explained an additional 6.5% of the variance, and delineated natural versus anthropogenic canopy disturbances.

Taxon	**DCA axis 1 (51.5%)**	**Taxon**	**DCA axis 2 (3.6%)**	**Taxon**	**DCA axis 3 (6.5%)**
Thinly timbered	554.52	Sapling thicket	382.07	Windthrow	437.84
Bear oak	552.81	Briers	373.43	Underbrush	382.29
Chestnut oak	541.48	Old clearing	363.70	Briers	326.69
Pitch pine	481.62	Corn field	340.39	White pine	292.90
Burnt timber/fire	479.81	Aspen/poplar	323.92	Chestnut	291.47
Oak plains	456.41	Cherry	315.58	Black/yellow birch	291.18
Sapling thicket	453.63	Ironwood	298.93	Cherry	290.77
Briers	441.24	Thinly timbered	294.24	Chestnut oak	256.03
Shrub/scrub	431.99	Underbrush	287.02	Pitch pine	254.78
Corn field	416.82	Windthrow	286.63	Shrub/scrub	239.29
Old clearing	408.49	Butternut	280.46	Hemlock	236.83
White oak	405.61	Oak plains	278.63	Butternut	233.94
Aspen/poplar	385.08	Black walnut	248.71	Ironwood	231.96
Black/red oak	382.33	Basswood	156.54	Burnt timber/fire	224.76
Black walnut	372.48	Elm	140.57	Thinly timbered	219.82
Hickory	372.20	Black/yellow birch	135.84	Tuliptree	215.60
White pine	364.12	Sugar maple	117.04	White ash	208.85
Chestnut	360.71	Beech	103.98	Black walnut	161.45
Tuliptree	334.74	White ash	81.99	Elm	154.68
Ironwood	315.87	Hemlock	81.30	White oak	107.24
White ash	293.71	Black/red oak	69.65	Basswood	107.12
Cherry	259.79	White oak	19.18	Black/red oak	84.87
Basswood	256.91	Hickory	-23.07	Sugar maple	68.08
Elm	256.75	Tuliptree	-31.54	Aspen/poplar	39.73
Windthrow	256.32	White pine	-48.32	Beech	39.66
Sugar maple	223.25	Chestnut	-62.81	Hickory	30.20
Butternut	163.20	Shrub/scrub	-119.67	Corn field	24.76
Underbrush	135.51	Pitch pine	-129.34	Old clearing	0.18
Beech	128.86	Burnt timber/fire	-172.26	Bear oak	-95.87
Hemlock	48.43	Chestnut oak	-189.74	Sapling thicket	-297.12
Black/yellow birch	0.00	Bear oak	-304.26	Oak plains	-483.78

axis 2 score = 340.4) against those typical of nutrient-limited soils (low, negative DCA axis 2 scores) including by bear oak (DCA axis 2 score = -304.2), chestnut oak (DCA axis 2 score = -189.7), burnt timber/fire (DCA axis 2 score = -172.2), pitch pine (DCA axis 2 score = -129.3), and shrub/scrub vegetation (DCA axis 2 score = -119.7).

Finally, DCA axis 3 (Table 3.2; Figure 3.3C) accounted for 6.5% of the variance in the Military Tract vegetation dataset. This axis grouped variables associated with fire and/or Iroquoian land-use activities (low, negative DCA axis 3 scores) on the Lake Ontario Lowland and Finger Lakes Hills including oak plains (DCA axis 3 score = -483.8), sapling thicket (DCA axis 3 score = -297.1), bear oak (*Quercus illicifolia*; DCA axis 3 score = -95.9), and old clearing (DCA axis 3 score = 0.2), with natural forest perturbations characteristic of the Appalachian Plateau (high, positive DCA axis 3 scores), including windthrow (DCA axis 3 score = 437.8), underbrush (DCA axis 3 score = 382.3), and briers (DCA axis 3 score = 326.7) at one end of the ordination grouped at the other end of the ordination axis.

3.2. Spatial dynamics of DCA taxon scores in relation to Iroquoian settlement patterns

Mean DCA taxon scores for axes 1 – 3 (Table 3) display statistically significant spatial gradients associated with proximity to Late Woodland (1000 – 1650 CE) and Historic (1650 – 1779 CE) Period Native American archaeological sites. Mean DCA axis 1 scores (Figure 3.4A), interpreted as a regional fire-frequency gradient, decrease progressively over a 20-km linear distance from archaeological sites ($r = -0.8933$; $p < 0.0001$). Peak DCA axis 1 scores (Table 2), associated with fire-adapted taxa and evidence of fire-related disturbance, including thinly timbered areas, bear oak, chestnut oak, pitch pine, and burnt timber, are

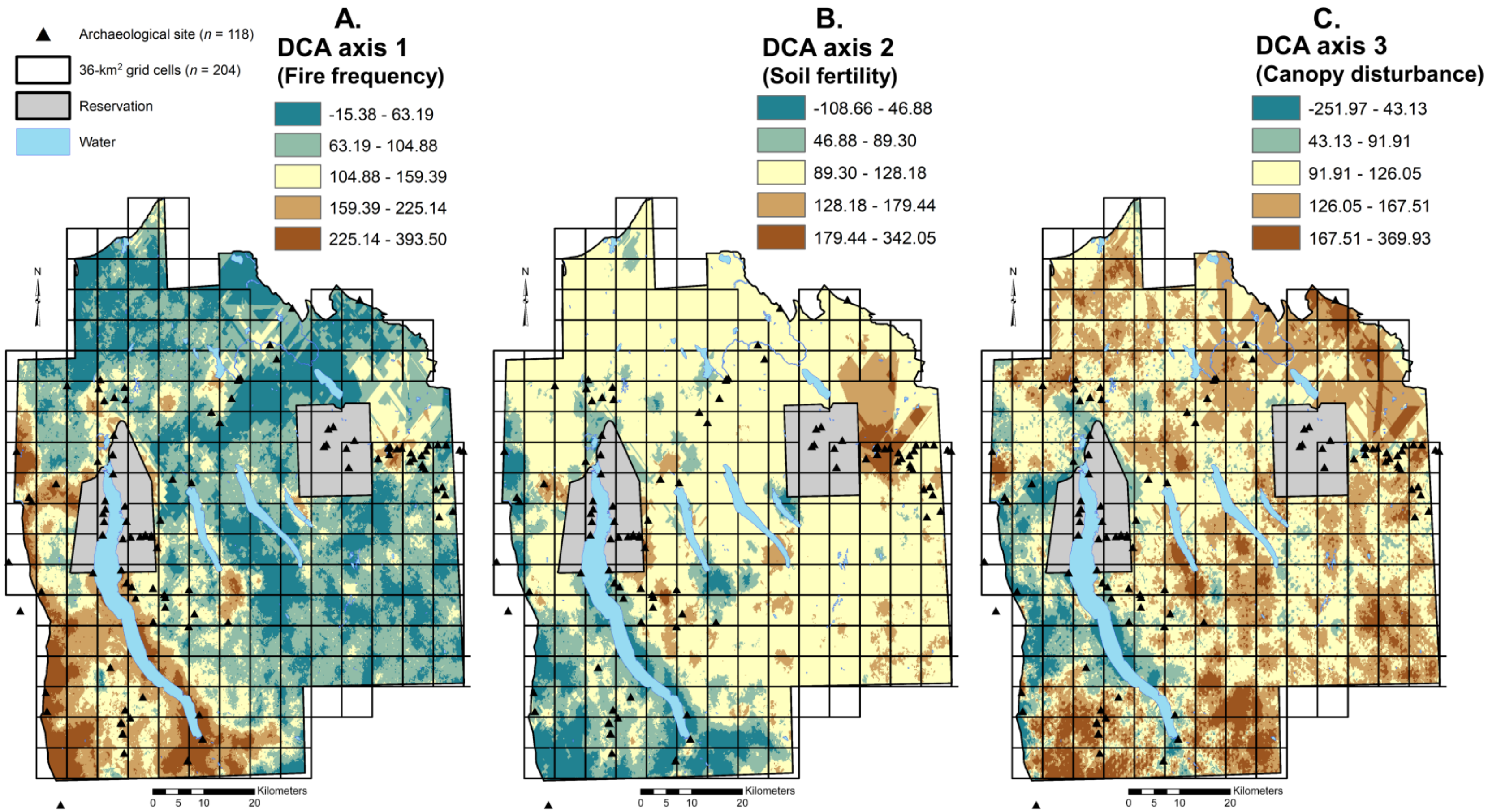

Figure 3.3. Interpolated maps of detrended correspondence analysis (DCA) taxon scores (see Table 3) in relation to the geographic distribution of archaeological sites (black triangles; *n* = 118). A. DCA axis 1 taxon scores (fire frequency). B. DCA axis 2 taxon scores (soil nutrients). C. DCA axis 3 taxon scores (canopy disturbance).

Table 3.3. Summary statistics of spatial trends in detrended correspondence analysis (DCA) taxon scores for DCA axes 1 – 3 of 18th century CE Military Tract land survey record (LSR) vegetation data. Grid cell values from interpolated raster surfaces of DCA taxon scores (Figure 3) were extracted to random data points (*n* = 4443) within a 20-km radius of Late Woodland (1000 – 1650 CE) and Historic (1650 – 1779 CE) Period Native American archaeological sites (*n* = 118; Figure 3.2).

		DCA axis 1 (fire frequency)				**DCA axis 2 (soil nutrients)**				**DCA axis 3 (canopy disturbance)**			
Distance (km)	***n***	**Minimum**	**Mean**	**Maximum**	***s***	**Minimum**	**Mean**	**Maximum**	***s***	**Minimum**	**Mean**	**Maximum**	***s***
1	132	2.03	110.50	330.10	68.65	-10.69	107.52	253.75	39.70	-44.38	116.07	234.97	46.99
2	349	2.03	115.23	346.23	73.58	-8.96	101.85	306.41	39.82	1.00	107.81	262.91	47.24
3	405	0.90	122.71	369.74	77.64	-44.61	94.86	222.03	40.49	2.01	106.31	276.57	50.72
4	403	2.03	112.66	345.55	71.38	-43.59	94.78	200.29	35.98	-61.24	116.55	257.79	44.10
5	374	5.42	116.21	374.60	72.13	-15.35	93.21	233.18	37.27	-223.10	114.64	253.47	50.10
6	362	5.42	113.98	374.60	73.57	-61.06	91.93	215.87	37.32	-54.69	119.17	267.02	44.17
7	303	2.03	104.82	360.03	67.90	-20.97	96.99	209.27	33.14	-88.12	115.96	233.92	43.55
8	309	2.03	110.75	374.60	70.79	-67.17	99.19	199.48	33.25	-61.24	115.97	260.74	39.17
9	251	0.90	104.24	324.66	69.72	-66.93	103.52	184.21	30.27	-223.10	115.70	248.75	44.65
10	202	-4.75	103.05	344.58	74.23	-31.98	98.04	206.56	31.89	-226.04	114.75	217.72	48.85
11	162	0.00	88.95	300.28	55.64	-21.11	102.22	174.54	27.16	-10.82	122.02	280.83	39.11
12	141	0.00	90.72	320.71	62.48	6.79	106.43	195.69	28.11	-60.32	121.16	246.12	45.30
13	167	5.42	83.78	324.66	59.04	-40.10	107.12	174.54	24.87	-158.49	125.71	260.70	45.29
14	175	-4.75	82.98	305.75	49.36	20.90	107.50	179.32	19.83	-49.98	116.81	251.60	42.23
15	147	0.00	86.01	319.07	59.43	6.69	107.26	174.54	23.41	-36.95	116.72	206.12	37.43
16	119	5.42	90.42	369.74	68.97	-14.29	107.45	169.49	21.96	5.78	119.89	231.21	36.17
17	115	5.42	89.18	318.46	58.04	15.11	108.46	181.91	22.28	6.48	123.33	204.80	28.76
18	100	5.42	89.70	346.83	62.40	42.24	109.82	227.78	22.34	-4.62	119.59	207.56	36.53
19	120	5.42	81.55	267.86	51.12	-11.50	109.20	156.52	19.12	-88.12	119.34	217.53	37.48
20	107	5.42	87.67	374.58	63.03	-4.29	108.89	156.50	18.17	-42.41	122.94	260.68	35.60

highest within 2 – 3 km of archaeological sites (n = 405; $\bar{x}$ = 110.5; min. = 2.0; max. = 330.1; s = 68.6).

A more complex, polynomial response is evidenced in the spatial distribution of mean DCA axis 2 taxon scores (Figure 3.4B), interpreted as variability in soil nutrient status. Mean DCA axis 2 scores are highest (n = 132; $\bar{x}$ = 107.5; min. = -10.7; max. = 253.7; s = 39.7) within 1 km of archaeological sites (r = -0.9184; p = 0.0097), decreasing rapidly to a global minimum at 6 km distance (n = 362; $\bar{x}$ = 91.9; min. = -61.1; max. = 215.9; s = 37.3), then increasing steadily beyond 7 km, and attaining a second peak at 17 km (n = 115; $\bar{x}$ = 108.5; min. = 15.1; max. = 181.9; s = 22.3; r = 0.8916; $p < 0.0001$). Mean DCA axis 3 taxon scores (Figure 3.4C) are lowest within 3 km of Native American archaeological sites (n = 405; $\bar{x}$ = 106.3; min. = 2.0; max. = 276.6; s = 50.7), rising steadily with increasing distance (r = 0.6822; p = 0.0009).

3.3. Agglomerative hierarchical clustering (AHC) of vegetation community types

AHC partitioned the Military Tract LSR vegetation data into two main groups differing in fundamental aspects of fire-adaptedness, drought tolerance, soil nutrient requirements, and disturbance regime (Figure 3.5), with several nested sub-groups apparent in the dendrogram.

3.3.1. AHC cluster 1: Mesophytic upland forest

This cluster was comprised of multiple moisture-dependent, fire-intolerant taxa, including beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), and hemlock (*Tsuga canadensis*), collectively forming 71.2% (n = 7050) of the total observations within the Military Tract LSR database. These taxa were further partitioned into three separate sub-groups. A *hemlock-*

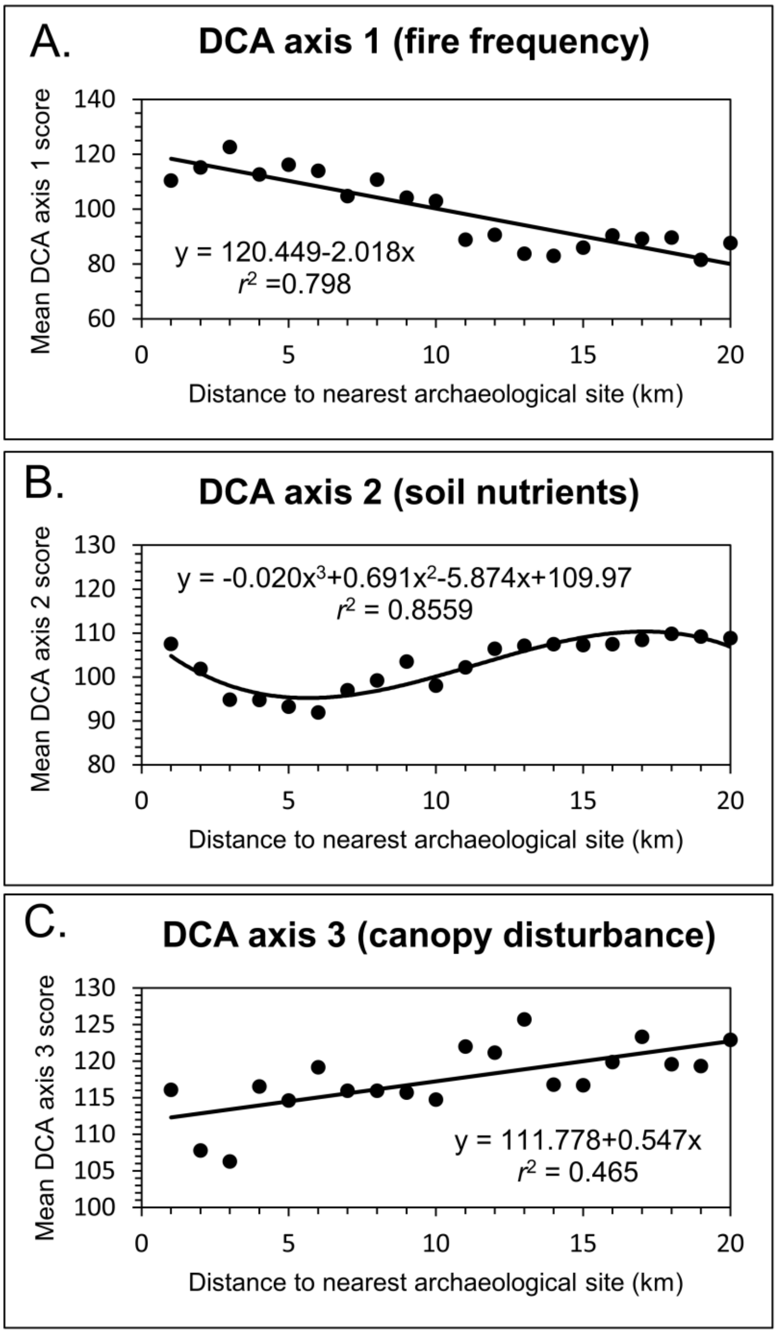

Figure 3.4. Bivariate scatterplots of mean detrended correspondence analysis (DCA) taxon scores versus proximity to Native American archaeological sites. Scores represent mean values calculated within successive 1-km radii of archaeological sites. A. DCA axis 1 (fire frequency gradient). B. DCA axis 2 (soil nutrients gradient). C. DCA axis 3 (canopy disturbance).

northern hardwood forest assemblage dominated by hemlock and beech was confined to higher elevations on the Appalachian Plateau and in areas proximal (<10 km) to Lake Ontario. A *maple-basswood rich mesic forest* assemblage consisting of sugar maple, basswood, elm (*Ulmus* spp.), and tuliptree (*Liriodendron tulipfera*) was typically found on richer upland sites and on moist alluvial soils. Finally, a third sub-group, *post-disturbance successional vegetation*, consisted of taxa suggesting secondary succession and gap-phase dynamics, such as birch (*Betula* spp.), cherry (*Prunus* spp.), butternut (*Juglans cinerea*), white ash (*Fraxinus americana*), and ironwood (*Carpinus caroliniana*/*Ostrya virginiana*). These mid-successional taxa normally occurred as scattered individuals within stands otherwise dominated by late-successional taxa, particularly sugar maple and beech. Included within this group were indicators of more recent catastrophic canopy disturbances, specifically underbrush and windthrows (described as “windfalls” in the survey notes). Windthrows (n = 9) were entirely confined to steep slopes on the Appalachian Plateau and occurred on sites with both hemlock-northern hardwood and maple-basswood rich mesic forest types. No evidence of recent fires was observed within the windthrows.

3.3.2. AHC cluster 2: Xerophytic upland forest

This cluster included a range of drought- and fire-tolerant taxa suggestive of deficient soil moisture conditions and disturbance by fire, as well as evidence of Iroquoian agricultural activity. Closed-canopy forests dominated by oak (*Quercus* spp.), hickory (*Carya* spp.), chestnut (*Castanea dentata*), and white pine (*Pinus strobus*) were the most prevalent vegetation type. Additionally, fire-dependent communities were present in AHC cluster 2, including dry-mesic savanna, xeric oak and pitch pine (*Pinus rigida*) barrens, and evidence of

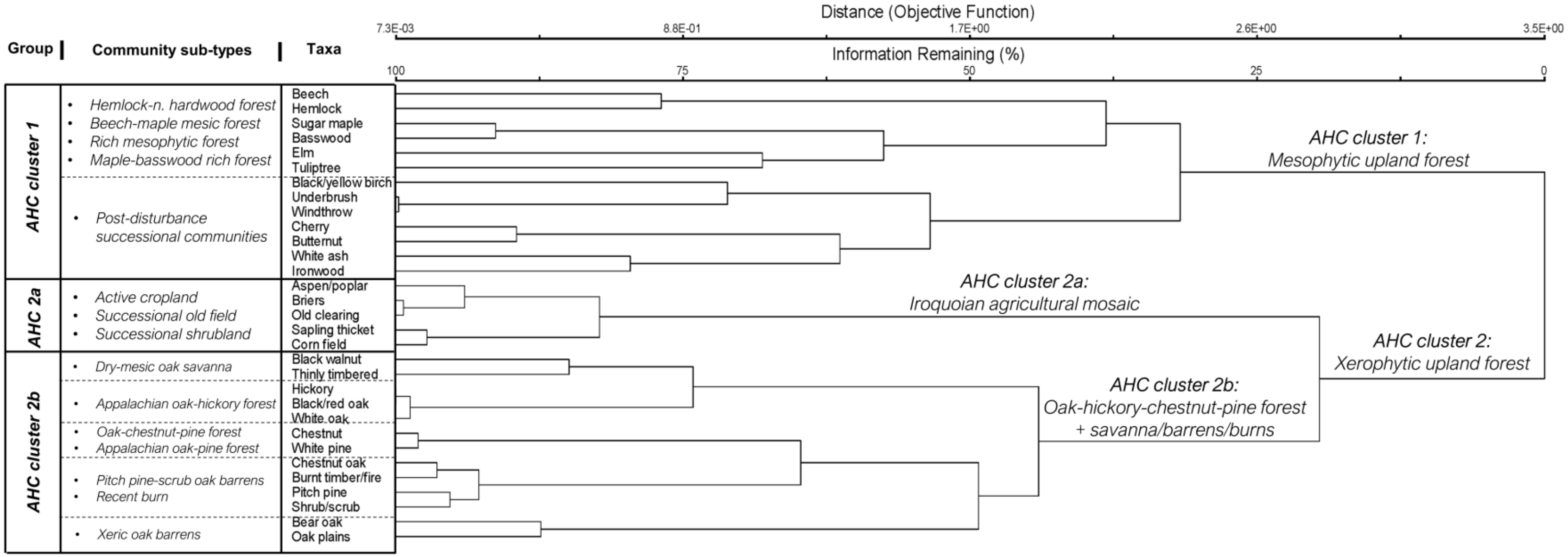

Figure 3.5. Agglomerative hierarchical clustering (AHC) dendrogram of Pearson product-moment correlation coefficient (*r*) distances between vegetation variables (*n* = 31) recorded in the Military Tract land survey records (LSRs). Vegetation community type names are inferred from modern regional equivalents described in Mohler et al. (2006) and Edinger et al. (2014).

recent fires in the form of burnt timber. Finally, indicators of Iroquoian agricultural activity were also associated with this community type.

AHC cluster 2 was differentiated into two major sub-groups differing in canopy density, inferred soil nutrient/textural properties, and predominant disturbance type (Figure 3). AHC cluster 2a (*Iroquoian agricultural mosaic vegetation*) was a largely deforested anthropogenic landscape situated near former sites of Historic Period (1650 – 1779 CE) Onondaga and Cayuga village sites. AHC cluster 2a typically occurred as discontinuous patches of active ("corn field"; *Zea mays*) and abandoned ("old clearing") cropland, early-successional vegetation including sapling thickets, aspen/poplar (*Populus* spp.), and briers (*Rubus* spp.), and open-canopy wooded areas ("open woods," "thinly timbered") within an otherwise densely forested landscape.

AHC cluster 2b (*oak-hickory-chestnut-pine forest + savanna/barrens/burns*) represented a constellation of fire-adapted taxa and associated vegetation communities having no clear connection to Iroquoian agricultural land-use activities. The most common closed-canopy forest community within AHC cluster 2a was *Appalachian oak-hickory forest* of white oak (*Quercus alba*), black oak (*Q. velutina*), northern red oak *(Q. rubra*), and hickory (*Carya* spp.), most commonly found in the Lake Ontario Lowland and Finger Lakes Hills physiographic regions. On the Appalachian Plateau, oaks were often accompanied by American chestnut (*Castanea dentata*) and eastern white pine (*Pinus strobus*), constituting a distinct *chestnut-white pine forest* community type.

The fire-tolerant forests of AHC cluster 2b contained frequent inclusions of open-canopy oak savanna and oak/pine barrens. *Dry-mesic savanna* (known historically as "oak openings";

Shanks 1966) were referred to variously as “open oak woods,” “open oak plain,” “lightly timbered,” “thinly timbered,” and “grass.” Black walnut (*Juglans nigra*) was frequently associated with dry-mesic savannas, although oaks were numerically the most common taxa observed on such sites. Signs of recent fire (*n* = 10) were confined to AHC cluster 2b, as evidenced by surveyor observations of burned vegetation (“timber destroyed by fire,” “burned over with fire,” “woods formerly burnt by firing the woods”), often noted in close spatial proximity to Native American trails recorded in the LSRs. Vegetation types associated with recent burns included *pitch pine barrens* (*Pinus rigida*; “pine plaine” [sic]), *xeric oak barrens* of bear oak (*Quercus illicifolia*; “scrub oak”) or chestnut oak (*Q. prinus*; “rock oak,” “scrubby oak ridge,” “scrub oak land”), and dry-mesic savanna.

4. Interpretation and discussion

The results of this integrated analysis of LSR-derived compositional and structural vegetation data indicate the presence of two major vegetation communities – one largely unaffected by human disturbance (AHC cluster 1; *mesophytic upland forest*) – and another with distinct evidence of Native American land-use impacts (AHC cluster 2 – *xerophytic upland forest*; Figure 3.4). Although evidence of disturbance was found in both communities, the major form of perturbation in the region’s mesophytic upland forests was limited to windthrow, as attested by surveyor observations of discontinuous canopy gaps and toppled trees within otherwise undisturbed late-successional forests. While fire can be an additional disturbance factor inside windthrow canopy gaps (Lorimer and White 2003), no such evidence of fire was recorded by surveyors within the study area. All direct and indirect evidence of fire was confined to areas of xerophytic upland forests in close geographic proximity to Cayuga and Onondaga settlements (Figure 3A).

Correspondence between the DCA ordination and AHC dendrogram was generally close (Figure 3.6). A small number of vegetation variables assigned to AHC cluster 2b, notably black walnut, oak plains, and thinly timbered areas, were more closely associated with AHC cluster 2a (*Iroquoian agricultural mosaic vegetation*) in the DCA species ordination space. However, the remaining 28 vegetation variables demonstrated a strong association between AHC-derived clusters and the two-dimensional arrangement of DCA axes 1 and 2 taxon scores, thereby validating the use of complementary ordination and numerical classification techniques in LSR-based analyses of temperate forested ecosystems. Notably, AHC clusters 2a and 2b shared equally high DCA axis 1 scores (Figure 3.5) suggesting repeated disturbance by fire. The fact that DCA axis 1 accounted for 51.5% of the total variance in the Military Tract LSR data clearly implicates fire as the most important modulator of forest species composition in the study area prior to Euro-American settlement. Moreover, the evident spatial trend of decreasing axis 1 score values with increasing distance from Native American archaeological sites strongly supports the hypothesis of Iroquoian settlement and subsistence patterns contributing to this gradient. Disturbances related to village-centered, maize-based agriculture on high-nutrient soils (high DCA axis 1 + high DCA axis 2 scores; Figure 3.6) were juxtaposed with disturbances associated with possible silvicultural land-use activities (e.g. deliberate burning of vegetation; management of economically desirable forest taxa) on marginal soils (high DCA axis 1 scores + low DCA axis 2 scores; Figure 6). This pattern is consistent with a deliberate partitioning of the central New York landscape into agricultural and silvicultural land-use patches by resident Iroquoian populations. The ecological distinctiveness of both AHC cluster 2 subtypes, combining high-frequency and/or high-intensity fires with extremes in soil productivity, stands in stark contrast to AHC cluster 1 (*mesophytic upland forest*), which was typified by very low fire frequencies on moderately fertile soils (low DCA axis 1 scores + mid-range DCA axis 2 scores; Figure 3.5).

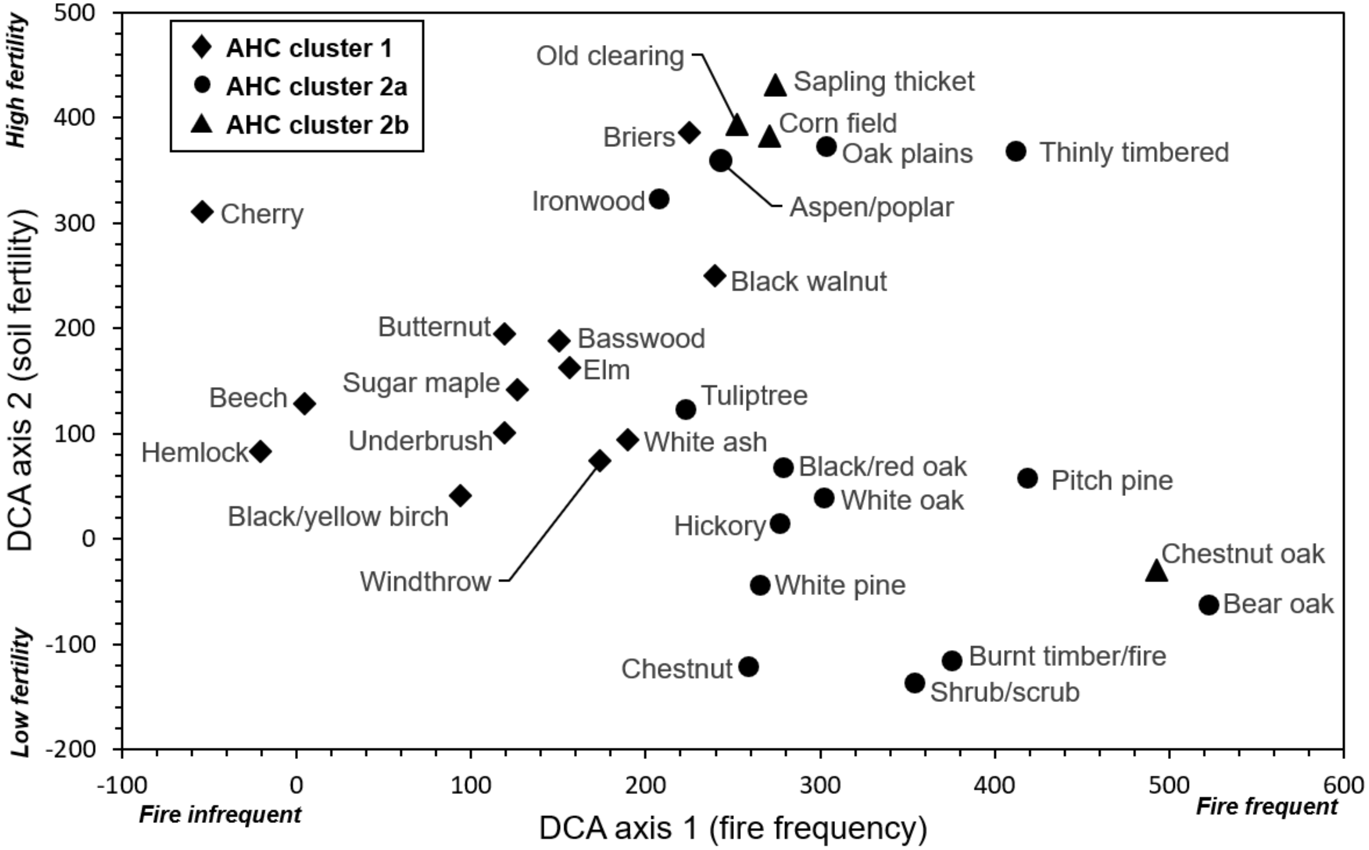

Figure 3.6. Plot of detrended correspondence analysis (DCA) axis 1 (51.5% of variance explained; fire frequency gradient) and DCA axis 2 (3.6% of variance explained; soil fertility gradient) taxon scores. Upland vegetation community types partitioned by agglomerative hierarchical clustering (AHC) are shown as contrasting symbols: AHC cluster 1 (*mesophytic upland forest*) = diamonds; AHC cluster 2a (*Iroquoian agricultural mosaic*) = triangles; AHC cluster 2b (*xerophytic upland forest + savanna/barrens/burns*) = circles.

The relative importance of fire within regional forests is supported by other analyses of late-18th century CE LSR-derived vegetation data. Black et al. (2006) employed DCA to isolate environmental modulators of forest species composition using bearing tree data from northwestern Pennsylvania, an area inhabited historically by the Seneca nation, a tribal group closely related to the Cayuga and Onondaga of the Military Tract (Engelbrecht 2003). Black et al. (2006) interpreted DCA axis 1 – which explained ~50.9% of the variance in the vegetation data – as a fire frequency gradient, although their ordination diagram, unlike the one in the present study (Figure 3.6), was relatively sparse, as it contained no ancillary structural data derived from the LSR sources. Similarly, Fulton and Yansa (2019), in their integrated non-metric multidimensional scaling (NMS) – AHC analysis of compositional and structural vegetation data from the Phelps and Gorham Purchase (PGP) immediately to the west of the Military Tract, interpreted NMS axis 1 as a fire-frequency gradient accounting for 53.7% of the total variance in the PGP vegetation data. That DCA and NMS ordination techniques explained similar proportions of variability in the LSR-derived vegetation data highlights (1) the relative robustness of DCA with respect to other ordination techniques and (2) similarities in the ecological and cultural context of the respective study areas, which possessed comparable vegetation community types and were inhabited by agricultural Northern Iroquoian populations.

In the present study, the spatial distribution of DCA axis 1 taxon scores strongly coincided with the location of archaeological sites, both villages and non-residential sites (Figure 3.3A). Distance analysis confirmed this association, with taxon scores displaying a very strong correlation ($r = -0.8933$; $p < 0.0001$) and distinct linear trend of decreasing values with increasing distance from Native American settlements. This observation strongly suggests that Iroquoian (Cayuga and Onondaga) agricultural villages, campsites, and other site types acted as foci of disturbance, extending outward into the surrounding landscape, with progressively diminishing impacts at greater distances from sites. As the dominant site type was represented by agricultural villages (*n* = 98; 83.1%), it is likely that residential sites served as the primary source for human population pressure on the local environment, in the form of deliberate fire ignitions, forest clearance, and canopy thinning. However, non-residential site types may have also served as convenient locales from which fires may have been set and other land-use practices occurred. This was suggested by Fulton and Yansa's (2019) analysis of Native American impacts on the vegetation in west-central New York State, where roughly equal numbers of residential and non-residential Late Woodland sites were present within the study area, and campsites often occurred within areas of abundant fire-tolerant forest taxa. The relatively low numbers of non-residential site types in the Military Tract may be an artefact of a more incomplete archaeological record, site formation biases, or cultural differences between neighboring Iroquoian populations. Further research will be required in order to resolve this issue. Nevertheless, both studies demonstrate the relative importance of agricultural villages to the spatial patterning of fire regimes in areas occupied by Northern Iroquoian populations. This is particularly important given that much of the lower Great Lakes region is characterized by heavy lake-effect snowfall (1225 to 3550 mm^{-1} yr^{-1}; Garoogian 2010), inhibiting the frequency of natural fire ignitions (Lorimer and White 2003; Henne et al. 2007).

The results of this study are congruent with the archaeological and ethnohistorical literatures regarding the pervasive use of fire as a landscape maintenance tool by Native American populations throughout North America (Abrams and Nowacki 2008). In central New York, Iroquoian populations likely used fire as a means of vegetation removal for the construction of villages (Engelbrecht 2003), the establishment of cropland (Doolittle 2000), active and passive management of forest taxa important to native subsistence economies (Abrams and Nowacki 2008; Muñoz et al. 2014) such as oak (*Quercus* spp.), hickory (*Carya* spp.), and chestnut (*Castanea dentata*), and numerous other reasons (see summaries in Williams 2000 and Anderson 2017). I identified several fire-tolerant and fire-adapted vegetation community sub-types within AHC cluster 2b (Figure 3.5) including *dry-mesic oak savanna*, *Appalachian oak-hickory forest*, *oak-chestnut-pine forest*/*Appalachian oak-pine forest*, *pitch pine-scrub oak barrens*/*recent burn*, and *xeric oak barrens*. Many of these communities were in close geographic proximity to Cayuga settlements within the western portion of the study area bordering the larger Finger Lakes (Figure 3A). Large expanses of savanna and grassland vegetation were described by European visitors to the region during the 18th century CE (e.g. Zeisberger [1750] in Beauchamp 1916), and anthropogenically modified forests containing sugar maple orchards and nut-tree groves were noted by the botanist John Bartram (1966) near the main Onondaga village in 1743 CE. These fire-adapted vegetation types generally possessed high DCA axis 1 scores (Figure 3.6), supporting ethnohistorial accounts linking Native American populations to the deliberate use of fire (Day 1953). Additionally, species compositional analyses of wood charcoal preserved in regional archaeological sites indicate that periods of human occupation were associated with higher frequencies of fire-tolerant oak, hickory, and chestnut charcoal (Asch Sidell 2008), consistent with the results of this study.

Evidence for maize-based Iroquoian agricultural activity is suggested most strongly by DCA axis 2, inferred as a soil fertility gradient, although the relatively low proportion of the total variance explained by this axis (3.6%) renders this interpretation less robust than for DCA axis 1. High DCA axis 2 taxon scores are associated with vegetation suggestive of old-field succession on sites previously farmed by Cayuga and Onondaga populations (Table 3.2).

Such taxa include sapling thicket, briers, old clearing, corn field, and other disturbance-related variables. The spatial configuration of DCA axis 2 scores supports this hypothesis, with the highest scores occurring in areas proximal to historic (post-1650 CE) village clusters (Figure 3.33B). Distance analysis of DCA axis 2 scores (Figure 3.4B) also confirms this inference, with the highest scores within 1 km of archaeological sites, decreasing sharply within 6 km to a global minimum, then rising steadily to a distance of 20 km. I propose that the visible break at 6 km coincides with the likely outer limit of vegetation disturbance related to agricultural land-use practices. This result compares favorably with other estimates of Iroquoian impacts on local vegetation, which hypothesized disturbance radii of 5 – 15 km from agricultural village sites (Black et al. 2006; Tulowiecki and Larsen, 2015). I further hypothesize that the progressive increase in mean DCA axis 2 scores from 6 – 20 km may be a vestige of Cayuga and Onondaga site selection criteria, with preference given to potential village sites exhibiting a combination of (1) high soil productivity amenable to maximal maize yields and (2) proximity to sub-optimal habitat (e.g. AHC clusters 1 and 2b) unsuited to agricultural production. Village sites meeting these dual criteria would have been better situated to maximize crop yields as well as ensure access to a greater range of economically critical natural resources (e.g. wild plant foods, game, timber; see Jones and Wood 2012) due to their location at the interface of multiple vegetation community types, contrasting soilscapes, and ecotones.

More equivocal evidence of likely Iroquoian agricultural land-use activity is suggested by DCA axis 3, which partitioned canopy disturbances between natural (e.g. windthrow) and anthropogenic (e.g. agricultural and silvicultural indicators such as oak plains and sapling thickets) disturbance regimes (Table 3.2; Figure 3.3C). As DCA axis 3 explained only 6.5% of the total variance, this synthetic dimension, like DCA axis 2, is less reliably interpretable than DCA axis 1. The geographic distribution of anthropogenic disturbances (low, negative DCA axis 3 scores) is closely related to the pattern visible for high DCA axis 1 scores (enhanced fire frequency) associated with proximity to Native American archaeological sites (Figure 3a).

A major contribution of the present study to LSR-based analyses of historic vegetation rests in its use of ample structural data to complement and augment the compositional data contained within the LSRs. The exclusive use of bearing tree data in most prior analyses of Native American vegetation disturbance severely limits their ability to accurately reconstruct a fuller range of indigenous land-use practices, particularly those related to agriculture and modification of forest canopy density. For instance, Black et al.'s (2006) DCA analysis of historic LSR-derived bearing tree data from northwestern Pennsylvania revealed indirect evidence of Seneca Iroquoian land-use activities, with higher frequencies of mast taxa such as oak, hickory, and chestnut found in the vicinity of Seneca agricultural villages. In the absence of non-arboreal vegetation indicators, these authors were unable to differentiate agricultural from silvicultural disturbance; such structural data may have been present in the original LSR sources and could have been extracted for inclusion with the bearing tree data. Similarly, Tulowiecki and Larsen's (2015) application of species distribution modeling (SDM) of bearing tree data did not provide evidence distinguishing agricultural from silvicultural forms of disturbance in the forests of nearby southwestern New York. In short, the use of traditional (e.g. DCA) and novel (e.g. SDM) techniques is ultimately limited by the types of vegetation data gathered and analyzed from LSR sources. Future studies aimed at achieving a more complete approximation of Native American land-use impacts on the forested ecosystems of eastern North America would be well served to include a full array of vegetation-related variables embedded within LSR data sources, if these can be identified.

The use of numerical classification to group combined compositional and structural vegetation data represented an additional refinement to existing techniques of LSR-based analyses that complemented and supported our interpretation of the DCA ordination and highlighted the role of ordination and classification as necessary components for cross-validating their respective results. Delineation of discrete community types and nested sub-types within the Military Tract vegetation data facilitated comparison of hierarchical groupings and their relationship to inferred environmental gradients and Native American land-use impacts, emphasizing the close ecological relationship between fire-tolerant and fire-adapted community types (AHC cluster 2), and their possible shared origin in Native American settlement and subsistence practices. Although overt anthropogenic disturbance was confined to the *Iroquoian agricultural mosaic* vegetation community type (AHC cluster 2a), the aggregation of this type with other fire-adapted vegetation types lacking clear evidence of Native American presence (AHC cluster 2b) suggests a close ecological relationship between these disturbance- and fire-prone communities, and a potentially shared origin for both vegetation sub-types in Iroquoian subsistence activities. This agrees with archaeological evidence indicating the use of fire to propagate plant species of importance to traditional subsistence economies (Asch Sidell, 2008) and paleoecological data from eastern North America attesting to the existence of similar fire- and disturbance-adapted vegetation associated with Native American settlement (Clark and Royall, 1995; Delcourt and Delcourt, 1998, 2004; McLauchlan, 2003; McAndrews and Turton, 2010; Muñoz and Gajewski, 2010). Further detailed analyses utilizing both historical and paleoecological perspectives will be required to elucidate the spatial extent and chronological trajectory of this inferred agriculture-silviculture dichotomy.

5. Conclusions

This paper provides an improved methodological framework for analyzing land survey records (LSRs) of vegetation recorded prior to widespread Euro-American settlement in the eastern United States. Elements of this framework included: (1) utilizing an expanded database of vegetation-related variables – bearing trees, qualitative descriptions of vegetation composition and form, and evidence of disturbance; (2) analyzing these data using detrended correspondence analysis (DCA) in conjunction with agglomerative hierarchical clustering (AHC); and (3) performing distance analysis of DCA taxon scores with respect to archaeological site distribution data. Although DCA and distance analysis have been independently used in previous LSR-based analyses of Native American land-use impacts on vegetation, our study represents the first of its kind to integrate all three methods. AHC possess the added benefit of delineating major and minor vegetation community types that can be correlated to extant vegetation types and be used to infer Native American impacts on, and uses of, these communities. I recommend that future LSR-based analyses focusing on indigenous land-use activities employ an integrated methodology combining ordination (DCA), clustering (AHC), and distance analysis.

Archaeological data indicate that agricultural Iroquoian villages generally formed tight spatial clusters within discrete tribal territories (Birch 2015); this distinct landscape patterning has been variously attributed to warfare (Hasenstab 1996), the presence of agriculturally productive soils (Jones 2010), and other factors. The present analysis provides new evidence on the broader environmental and ecological contexts of Iroquoian populations. The Cayuga and Onondaga (and their immediate Iroquoian predecessors) strategically utilized their respective territories in ways that were beneficial to a subsistence economy focused on maize-based agriculture. For example, areas possessing rugged terrain (Appalachian Plateau), agriculturally infertile soils, relatively cooler temperatures and/or excessive soil moisture in lake-effect snowbelt zones (Lake Ontario Lowland) were actively avoided for settlement. The distribution of archaeological sites was concentrated in the Finger Lakes Hills physiographic region, which combined fertile soils with a generally warmer and drier microclimate conducive to maximizing maize yields. This area also likely possessed naturally higher frequencies of nut-bearing trees, adding to its attractiveness for settlement. The spatial distribution of environmental modulators (DCA taxon scores) and forest community types (AHC clusters) indicate the most favorable conditions for agricultural Iroquoian populations was in the central Finger Lakes Hills. The interpolated maps of DCA taxon scores generated in this study can be used by archaeologists as means of identifying possible undiscovered archaeological sites and subsistence patches, as well as by paleoecologists for the selection of lake/wetland coring sites to investigate prehistoric human impacts on local and regional ecosystems. This approach, I reason, can be applied in a variety of ecological and cultural settings possessing adequate historic LSR and prehistoric archaeological data.

Acknowledgements

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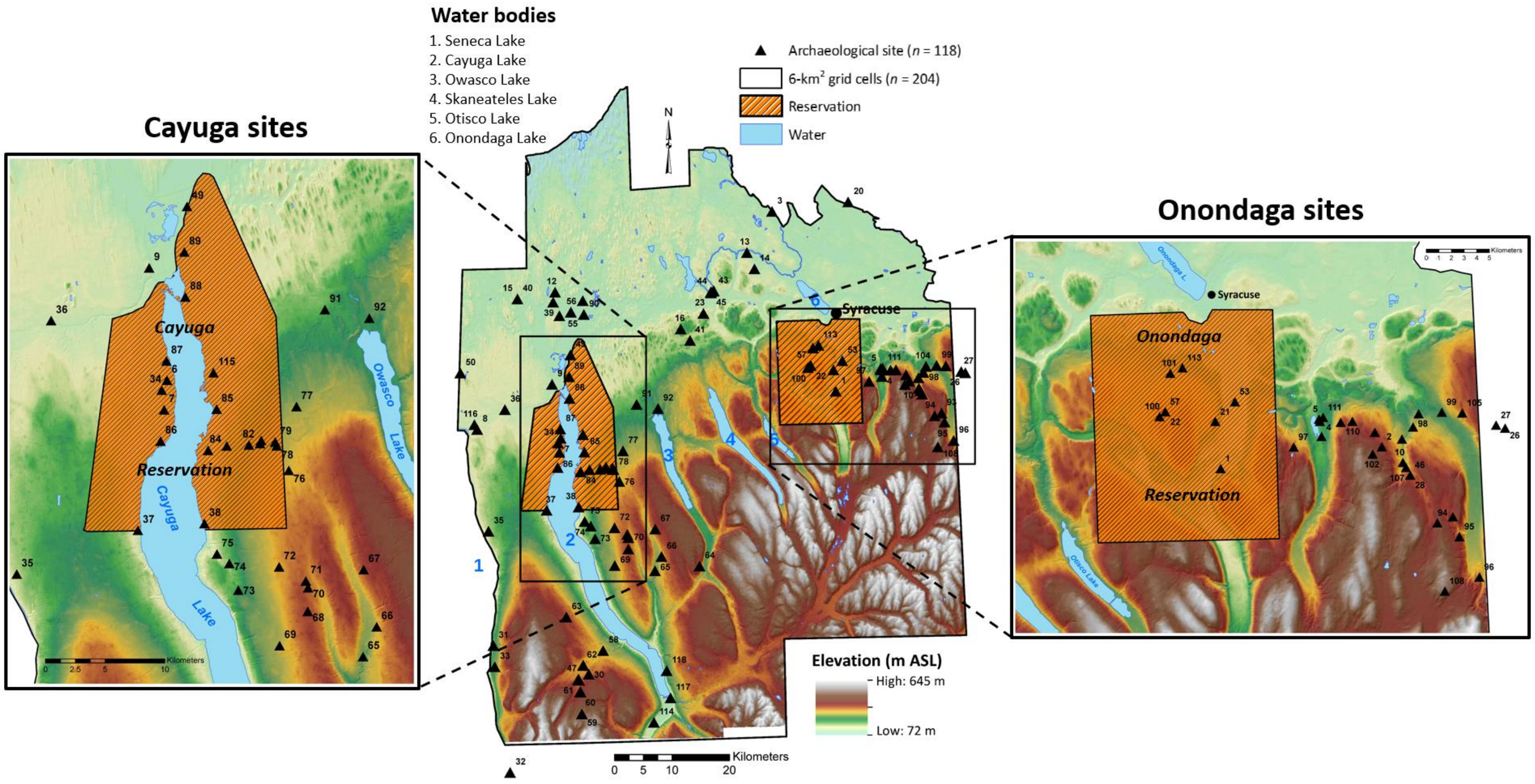
APPENDICES

Appendix A. Location of Late Woodland (ca. 1000 – 1650 CE) and Historic (ca. 1650 – 1779 CE) Period Native American agricultural settlements, campsites, burials, cemeteries, workshops, ceremonial sites, and other site types (black triangles; *n* = 118) located within the Military Tract study area. Numbers correspond to site numbers ("site no.") listed in Table S1. Insets show details of sites within Historic Period Cayuga (left) and Onondaga (right) tribal territories.



Appendix B. List of Late Woodland (ca. 1000 – 1650 CE) and Historic (ca. 1650 – 1779 CE) Native American agricultural settlements, campsites, burials, cemeteries, workshops, ceremonial sites, and other site types (*n* = 118) located within the Military Tract study area. Culture periods are based upon major cultural-chronological divisions of the regional archaeological record (e.g. Funk 1993). Phase/Tradition assignments for each site correspond to Iroquoian developmental stages established for upstate New York (see Bradley 1987).

Site no.	Site name	Culture Period	Phase/Tradition	Site Type	Reference
1	Unknown	Historic Native	Colonial Period	Village	Parker (1922)
2	LOT 18	Historic Native	Onondaga	Village	NYSM Site File
3	Unknown	Historic Native	Colonial Period	Village	Parker (1922)
4	Jamesville Lake	Historic Native	Onondaga	Cemetery	Parker (1922)
5	Jamesville Pen	Historic Native	Onondaga	Village	Tuck (1971)
6	Skannayutenate	Historic Native	Seneca	Village	Cook (1887)
7	New Town	Historic Native	Seneca	Village	Parker (1922)
8	Unknown	Historic Native	Colonial Period	Village	Parker (1922)
9	Unknown	Historic Native	Onondaga	Salt spring	Parker (1922)
10	Unknown	Historic Native	Colonial Period	Village, cemeteries	Parker (1922)
11	Skutt	Late Archaic - Late Woodland	Laurentian - Iroquoian	Campsite	NYSM Site File
12	Crusoe Creek, Crusoe Lake	Late Archaic - Late Woodland	Laurentian - Iroquoian	Campsite, burials, midden	NYSM Site File
13	Crego	Late Woodland	Chance Phase	Village	NYSM Site File
14	Crooked Brook	Late Woodland	Iroquoian	Village	NYSM Site File
15	Unknown	Late Woodland	Owasco	Campsite	NYSM Site File
16	Chamberlain B	Late Woodland	Castle Creek	Village	Tuck (1971)
17	Unknown	Late Woodland	Cayuga	Burial	NYSM Site File
18	Unknown	Late Woodland	Cayuga	Village	NYSM Site File
19	Unknown	Late Woodland	Cayuga	Village	NYSM Site File
20	Smith's Island, Baldwin's Island	Late Woodland	Iroquoian	Campsite	NYSM Site File
21	Cabin	Late Woodland	Owasco	Village	Tuck (1971)
22	Unknown	Late Woodland	Chance Phase	Village	NYSM Site File
23	Maxon-Derby, Merriman B	Late Woodland	Carpenter's Brook	Village	NYSM Site File
24	Jack's Reef No. 1	Middle Woodland - Late Woodland	Jack's Reef - Carpenter's Brook	Village, midden, burial	NYSM Site File
25	Jack's Reef No. 2	Middle Woodland - Late Woodland	Point Peninsula - Owasco	Midden, campsite	NYSM Site File
26	Allen Farm	Late Woodland	Owasco	Campsite	NYSM Site File
27	Owahgen	Late Woodland	Unknown	Campsite	NYSM Site File
28	Unknown	Late Woodland	Iroquoian	Village	Parker (1922)

Appendix B (continued).

Site no.	**Site name**	**Culture Period**	**Phase/Tradition**	**Site Type**	**Reference**
29	Unknown	Late Woodland	Unknown	Earthwork, village	NYSM Site File
30	Welch	Late Woodland	Cayuga	Workshop	NYSM Site File
32	French Catharines Town (Sheoquaga)	Historic Native	Seneca	Village	Cook (1887)
33	Ga-Di-Odji-Ya-Da	Historic Native	Seneca	Village	Cook (1887)
34	Ga-No-Geh	Historic Native	Cayuga	Village	Cook (1887)
35	Ken-dai-a (Appletown)	Historic Native	Seneca	Village	Cook (1887)
36	Scawyace	Historic Native	Cayuga	Village	Cook (1887)
37	Swah-ya-wa-nah	Historic Native	Cayuga	Village	Cook (1887)
38	Chonodote (Peach Town)	Historic Native	Cayuga	Village	Cook (1887)
39	Fort Hill	Late Woodland	Owasco	Earthwork, village	NYSM Site File
40	Unknown	Late Woodland	Owasco	Campsite	NYSM Site File
41	Kelso	Late Woodland	Oak Hill	Village	Tuck (1971)
42	Felix	Middle Woodland - Late Woodland	Jack's Reef - Owasco	Village, campsite, (shell) midden, burials	NYSM Site File
43	Jack's Reef	Middle Woodland - Late Woodland	Jack's Reef - Carpenter's Brook	Village, midden, stone cist burial, cremation	NYSM Site File
44	Jack's Reef	Middle Woodland - Late Woodland	Point Peninsula - Owasco	Midden, campsite	NYSM Site File
45	Carpenter Brook	Late Woodland	Carpenter's Brook	Ceremonial site	NYSM Site File
46	Unknown	Early Late Woodland	Iroquoian	Village	Parker (1922)
47	Unknown	Late Woodland	Cayuga	Burial	NYSM Site File
48	Unknown	Late Woodland	Cayuga	Village	NYSM Site File
49	Kipp Island 4	Middle Woodland - Late Woodland	Hunters Home - Owasco	Village, cemetery	NYSM Site File
50	Hartnagel	Early Archaic - Late Woodland	Bifurcate base - Iroquoian	Campsite	NYSM Site File
51	Unknown	Late Woodland	Unknown	Earthwork, village	NYSM Site File
52	Unknown	Late Woodland	Cayuga	Village	NYSM Site File
53	Valley Oaks	Late Woodland	Unknown	Campsite	Tuck (1971)

Appendix B (continued).

Site no.	Site name	Culture Period	Phase/Tradition	Site Type	Reference
54	Hunters Home	Middle Late Woodland	Unknown	Campsite	NYSM Site File
55	A.B. Dhondt	Archaic - Late Woodland	Laurentian - Iroquoian	Campsite, burial	NYSM Site File
56	Dhondt	Late Archaic - Late Woodland	Lamoka Lake - Owasco	Campsite, burial	NYSM Site File
57	Unknown	Late Woodland	Chance Phase	Village	Niemczycki (1984)
58	Payne	Late Woodland	Iroquoian	Village	Niemczycki (1984)
59	Culver	Late Woodland	Iroquoian	Village	Niemczycki (1984)
60	Carman	Late Woodland	Iroquoian	Village	Niemczycki (1984)
61	Parker Farm	Late Woodland	Iroquoian	Village	Niemczycki (1984)
62	Indian Fort Road	Late Woodland	Iroquoian	Village	Niemczycki (1984)
63	Klinko	Late Woodland	Iroquoian	Village	Niemczycki (1984)
64	East Genoa/Locke Fort	Late Woodland	Iroquoian	Village	Niemczycki (1984)
65	Genoa Fort	Late Woodland	Iroquoian	Village	Niemczycki (1984)
66	Myers Station	Late Woodland	Iroquoian	Village	Niemczycki (1984)
67	Garrett	Late Woodland	Iroquoian	Village	Niemczycki (1984)
68	Landon	Late Woodland	Iroquoian	Village	Niemczycki (1984)
69	Underwood	Late Woodland	Iroquoian	Village	Niemczycki (1984)
70	Mahaney/Colgan	Late Woodland	Iroquoian	Village	Niemczycki (1984)
71	Colgan	Late Woodland	Iroquoian	Village	Niemczycki (1984)
72	Nolan	Late Woodland	Iroquoian	Village	Niemczycki (1984)
73	Corey	Late Woodland	Iroquoian	Village	Niemczycki (1984)
74	Weir	Late Woodland	Iroquoian	Village	Niemczycki (1984)
75	Tschoch-ni-ees	Historic Native	Cayuga	Village	Niemczycki (1984)
76	Paddington	Late Woodland	Iroquoian	Village	Niemczycki (1984)
77	St. Joseph	Late Woodland	Cayuga	Village	Niemczycki (1984)
78	Great Gully Fort	Late Woodland	Iroquoian	Village	Niemczycki (1984)
79	Young Farm	Late Woodland	Iroquoian	Village	Niemczycki (1984)
80	Ga-ya-ga-aw-ha	Historic Native	Cayuga	Village	Niemczycki (1984)
81	Upper Cayuga Town	Historic Native	Cayuga	Village	Niemczycki (1984)
82	Cayuga Castle	Historic Native	Cayuga	Village	Niemczycki (1984)
83	Levanna	Late Woodland	Iroquoian	Village	Niemczycki (1984)
84	Goi-O-Gouen	Historic Native	Cayuga	Village	Niemczycki (1984)
85	Ge-Wa-Ga	Historic Native	Cayuga	Village	Niemczycki (1984)
86	Burrough's Point	Late Woodland	Iroquoian	Village	Niemczycki (1984)
87	Gar-Non-De-Yo	Historic Native	Cayuga	Village	Niemczycki (1984)
88	San-ni-o	Historic Native	Cayuga	Village	Niemczycki (1984)
89	St. Stephen	Historic Native	Cayuga	Village	Niemczycki (1984)

Appendix B (continued).

Site no.	Site name	Culture Period	Phase/Tradition	Site Type	Reference
90	St. Rene	Historic Native	Cayuga	Village	Niemczycki (1984)
91	Fort Hill Auburn	Late Woodland	Iroquoian	Village	Niemczycki (1984)
92	Lakeside Park	Late Woodland	Iroquoian	Village	Niemczycki (1984)
93	Quirk	Late Woodland	Onondaga	Village	Tuck (1971)
94	Pompey Center	Late Woodland	Onondaga	Village	Tuck (1971)
95	Sheldon	Late Woodland	Onondaga	Village	Tuck (1971)
96	Chase	Late Woodland	Onondaga	Village	Tuck (1971)
97	Coye (Toyadasso), Coye II	Late Woodland	Onondaga	Village	Tuck (1971)
98	Indian Hill	Late Woodland	Onondaga	Village	Tuck (1971)
99	Nursery	Late Woodland	Onondaga	Village	Tuck (1971)
100	Schoff	Late Woodland	Onondaga	Village	Tuck (1971)
101	Howlett Hill	Late Woodland	Onondaga	Village	Tuck (1971)
102	Burke	Late Woodland	Onondaga	Village	Tuck (1971)
103	Christopher	Late Woodland	Onondaga	Village	Tuck (1971)
104	Cemetery	Late Woodland	Onondaga	Village	Tuck (1971)
105	Barnes	Late Woodland	Onondaga	Village	Tuck (1971)
106	Indian Castle	Late Woodland	Onondaga	Village	Tuck (1971)
107	Carley	Late Woodland	Onondaga	Village	Tuck (1971)
108	Dwyer	Late Woodland	Onondaga	Village	Tuck (1971);
109	Weston	Late Woodland	Onondaga	Village	Tuck (1971)
110	Bloody Hill	Late Woodland	Onondaga	Village	Tuck (1971)
111	Jamesville Pen	Late Woodland	Onondaga	Village	Tuck (1971)
112	Keough	Late Woodland	Onondaga	Village	Tuck (1971)
113	Furnace Brook	Late Woodland	Onondaga	Village	Tuck (1971)
114	Coreorgonel	Historic Native	Saponi	Village	Cook (1887)
115	Ganiatarage	Historic Native	Iroquoian	Village	Cook (1887)
116	Nu-qui-age	Historic Native	Cayuga	Village	Cook (1887)
117	To-ti-e-ron-no	Historic Native	Cayuga	Village	Cook (1887)
118	Unidentified Village	Historic Native	Iroquoian	Village	Cook (1887)

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CHAPTER 4. PALEOCOLOGICAL INDICATORS OF AGRICULTURAL AND PRE-AGRICULTURAL NATIVE AMERICAN LAND-USE IMPACTS ON THE LATE HOLOCENE FORESTS OF WESTERN NEW YORK STATE, USA

(Manuscript to be submitted to *Quaternary Research*, 5/2019)

Abstract

Pollen and additional paleoecological proxies were analyzed from a sediment core recovered from New Guinea Road Bog (NGB), a kettle peatland in western New York State, USA. Although the coring site was situated in an area peripheral to main foci of human settlement during much of the Late Holocene, the bog was well-positioned to capture an extra-local pollen signal deriving from an upwind source area of intense Native American land-use impacts. The NGB paleoecological record revealed a distinct division into three stages prior to Euro-American settlement: (1) an initial period (~4400 – 2500 cal. yr BP) of quasi-cyclic climate modulation expressed as centennial-scale alternating dominance between fire-tolerant and fire-intolerant pollen taxa; (2) an extended period of emerging anthropogenic influence (~2500 – 800 cal. yr BP) characterized by steadily increasing frequencies of fire-tolerant arboreal pollen taxa; and (3) a final period (~800 – 210 cal. yr BP) of exponentially increasing herbaceous pollen taxa, accelerated charcoal influx, and landscape instability (high sediment flux) temporally associated with the appearance of agricultural Iroquoian groups in western New York State. Native American land-use impacts are best explained by a dual-phase model in which Early Woodland (~3000 – 2000 cal. yr BP) and Middle Woodland (~2000 – 1000 cal. yr BP) societies initiated a progressive, landscape-scale turnover in forest species composition toward increasing frequencies of fire-tolerant taxa as a result of increasing sedentism, greater demand on forest resources, and incipient maize-based horticulture. Subsequent Late Woodland (~1000 – 400 cal. yr BP) and Historic Period (~400 – 210 cal. yr BP) Iroquoian populations acted to drastically modify forest structure by facilitating the expansion of openland habitats, including oak savanna, grassland, and successional old fields, most likely through thinning of stands, wholesale forest clearance, and use of fire as landscape maintenance tool. The results of this study highlight the importance of (1) close examination of local and regional archaeological chronologies, (2) selection of sites based upon spatial criteria including position of basins with respect to prevailing winds, known archaeological site distributions, and reconstructed subsistence catchments, and (3) independent assessment of the extent of Native American land-use impacts, which were likely variable through time and constrained by cultural factors. *Key words*: pollen, charcoal, stable carbon isotopes, Native Americans, wetland, Holocene

1. Introduction

A common assumption in paleoecological reconstructions of past environmental conditions is that climate has been the primary driver of vegetation dynamics and landscape change in temperate North America during the Holocene (e.g. Booth et al. 2012; Viau et al. 2012; Clifford and Booth 2015; Shuman and Marsicek 2016; Gao et al. 2017; Commerford et al. 2018; Shuman et al. 2018). Although climate is a critical modulator of biotic and abiotic environmental processes (Pederson et al. 2014), the assumption of climate dominance has been questioned both for the prehistoric period (Abrams and Nowacki 2015) and historically (Nowacki and Abrams 2015; Abrams and Nowacki 2019) – a period of overwhelming anthropogenic perturbation

("Anthropocene"; Lewis and Maslin 2015). Beyond the readily discernible effects of industrial and post-industrial human societies on modern ecosystems, anthropogenic land-use practices associated with settlement and subsistence patterns of pre-industrial indigenous human populations were also capable of influencing vegetation and landscape dynamics. This has been demonstrated in a small number of paleoecological studies conducted in eastern North America utilizing a variety of proxy datasets including pollen (Delcourt et al. 1998; Muñoz, Schroeder, Fike, and Williams 2014), stable isotope geochemistry (Springer et al. 2010), fluvial geoarchaeology (Stinchcomb et al. 2011), and charcoal analysis (Clark and Royall 1996).

Lacustrine and peatland sediment archives, in particular, have provided important evidence of distinct signals of prehistoric Native American land-use practices, most notably maize (*Zea mays*)-based agriculture (McLauchlan 2003; McAndrews and Turton 2007, 2010). While unequivocal evidence of agricultural activity is limited to the recovery of cultigen pollen grains within a sedimentary sequence, ancillary evidence supporting anthropogenic activity is also normally present in the form of palynomorphs of herbaceous, non-arboreal pollen (NAP) taxa including *Ambrosia* (ragweed), *Artemisia* (mugwort/wormwood), and Poaceae (grasses). These are typically accompanied by indicators of post-disturbance secondary forest succession such as *Quercus* (oak), *Pinus* (pine), and *Populus* (aspen/poplar). That all of the aforementioned arboreal taxa are also tolerant of low-intensity ground fires (Thomas-Van Gundy and Nowacki 2013) provides supplementary support for the interpretation of anthropogenic enhancement of preexisting fire regimes, and by extension, silvicultural activity (i.e. active management of forest resources; Delcourt et al. 1998; Abrams and Nowacki 2008). Pollen and other proxies – minerogenic sediment fluxes (accelerated erosion), stable carbon isotope ratios (C_3 versus C_4

vegetation), and charcoal influx (fire frequency/intensity) – collectively comprise a suite of biotic and abiotic anthropogenic disturbance indicators (*ADIs*; term coined herein) that can provide evidence of human-mediated environmental change in the paleoecological record.

However, due to the limited chronological and cultural focus of prior studies, the most compelling evidence for prehistoric Native American land-use impacts is associated with Late Woodland (~1000 – 400 cal. yr BP [1000 – 1600 CE]) societies known to have practiced maize-based agriculture to varying degrees (Delcourt and Delcourt 2004). As a result, the potential impacts of earlier, pre-agricultural groups are largely unknown, even in those areas where paleoecological evidence for Late Woodland agriculture is documented. For instance, analysis of the sediments of Crawford Lake, southern Ontario, Canada provided evidence of cultigen pollen (*Zea mays*, *Helianthus* [sunflower], and *Cucurbita* [squash]), in addition to cultigen pathogen spores and assorted ADIs associated with occupation by Iroquoian agriculturalists during the 14th – 16th centuries CE (McAndrews and Turton 2010). Yet there is no further information available on pre-Late Woodland indigenous occupation near the lake, or its possible effects on earlier vegetation communities, as the pre-Iroquoian period was not investigated by these researchers.

This situation is particularly unfortunate, as important methodological developments within the discipline of archaeology have recently prompted a revision of existing paradigms surrounding the adoption of maize as a dietary component during the Late Woodland in eastern North America. For example, pytholith analysis of cooking residues from archaeological ceramics (Hart and Matson 2009) has revealed the presence of maize in the Northeast and Great Lakes regions by ~2500 cal. yr BP (Thompson et al. 2004; Hart et al. 2007; Gates St.-Pierre and

Thompson 2015). Intensive radiocarbon dating of archaeobotanical remains have better constrained the spatial and chronological dynamics of maize and other tropical cultigens in the temperate Northeast (Hart and Means 2002), while stable carbon isotope analysis (SCIA; Hart et al. 2012) has helped elucidate the stochasticity and non-linearities surrounding the incorporation of maize into the diets of indigenous populations (Hart and Lovis 2013; Hart 2016). Radiocarbon dating efforts have also forced a reevaluation of the timing of key cultural transitions, such as the first appearance of multi-lineage dwellings (Hart 2000), village aggregation (Birch 2012, 2015), and the strengthening of social networks (Hart et al. 2016). These innovations emerging from the archaeological sciences should therefore serve as an impetus among paleoecologists to provide independent verification of these hypotheses by examining the paleoecological record in greater detail over a longer geologic timeframe. Such an approach would serve to refine and/or re-evaluate the nature, extent, and chronology of land-use impacts associated with revised archaeological conceptual models and broaden the scope of human-vegetation-landscape analyses.

To this end, the present study utilized a synthetic framework informed by recent archaeological developments to link these findings to evidence of anthropogenic disturbance in the paleoecological record using ADIs. By utilizing a well-chosen set of proxy indicators from lacustrine/wetland sediment cores having robust radiocarbon chronologies, the timing of important cultural transitions (e.g. earliest introduction of maize; subsequent diffusion and expansion of cultigens; agricultural/silvicultural land-use intensification) can be evaluated with respect to ADI variability in the paleoecological record. Innovative uses of proxy data can further aid in this task. For example, grouping pollen taxa into higher-level categories based upon shared ecological characteristics allows for the reconstruction of past environmental conditions, such as fire regimes. Aggregating pollen taxa into discrete vegetation community types identified through numerical classification extends the power of paleoecological interpretation by enabling the assessment of time-transgressive community-level patterns rather than taxon-specific ones alone. Approximation of human paleopoulation through frequency analysis of archaeological radiocarbon dates permits the comparison of paleoenvironmental trajectories with inferred trends in anthropogenic disturbance and resource demand. The ultimate synthesis of these archaeological and paleoecological datasets would provide a more comprehensive, subtle, and revealing representation of the prehistoric environment and its inter-relationship with recent millennia of human culture change.

2. Materials and methods

2.1. Study area

2.1.1. Coring site description

The unnamed bog selected for study (hereafter termed New Guinea Road Bog [NGB]) is a small (0.61 ha) kettle peatland lying at an elevation of 196 m ASL located in the Town of Clarendon, Orleans County, New York, USA (43.15°N, 78.09°W; Figure 4.1). The bog is situated in an ice-stagnation landscape of pitted outwash sand and gravel at the eastern edge of Oak Orchard Swamp, a remnant of Late Pleistocene-age proglacial Lake Tonawanda (Natel 2004). The site is characterized by an uneven, rolling landscape of kettle-and-kame topography with locally steep

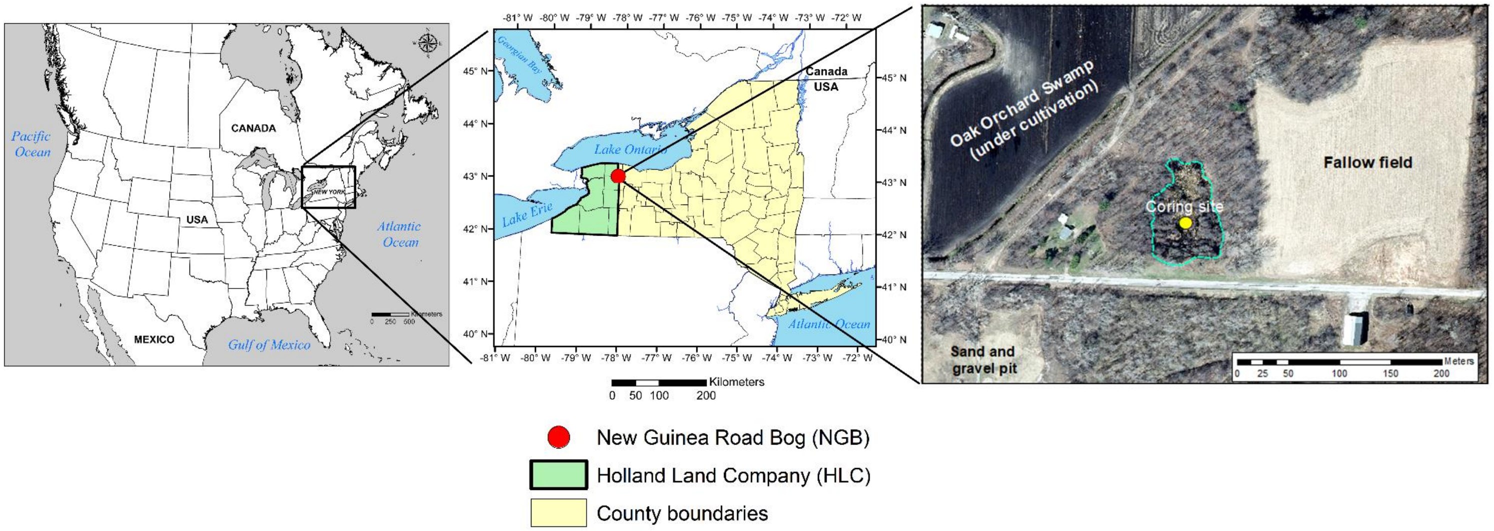

Figure 4.1. Map of New Guinea Road Bog (NGB), showing location of coring site, late-18th century CE Holland Land Company (HLC) survey area, and detail of the coring site vicinity. Yellow circle indicates site of core extraction.

(25 – 60%) slopes underlain by sand and gravel deposits. Local upland soils are dominantly coarse-textured Alfisols and Inceptisols, with organic Histosols in lowland sites (Higgins et al. 1977). The area surrounding the site has been subjected to intense Euro-American disturbance since the late 19th century CE, with muck farming in the Oak Orchard Swamp and maize agriculture and sand and gravel extraction on the uplands representing the dominant historical land uses (D. Harrington, personal communication 2017).

The peatland site was selected for its relative isolation from known archaeological sites within a region otherwise densely populated by pre-agricultural and agricultural Native American groups over the last 4500 years, as indicated by the regional archaeological record. The study site, located in an area dominated by fire-intolerant late-successional forest taxa, should reflect long-term vegetation stability and show little evidence of major paleoenvironmental perturbation, particularly given its close proximity to the Great Lakes, which buffers the area from drought and/or fire due to abundant lake-enhanced precipitation. Therefore, indicators of vegetation turnover (i.e. increased fire-tolerant taxa) or enhanced fire regimes (e.g. sediment charcoal peaks) should provide evidence of prehistoric anthropogenic disturbance affecting the landscape beyond the confines of agricultural fields, provided these data align with the local archaeological chronology, and the magnitude of the disturbance exceeds those associated with climate change (MCA, LIA) alone.

2.1.2. Historic and modern vegetation and climate

Vegetation data from Connecticut Tract land survey records (LSRs) dating from the year 1811

CE provide information on forest species composition and structure for the NGB study area, as do LSRs existing for neighboring surveyed areas within ~2 – 5 km of the site. These historical data indicate the presence of extensive tracts of upland forest dominated by fire-sensitive, late-successional taxa. These mesic-adapted communities were comprised primarily of *Tsuga canadensis* (eastern hemlock), *Fagus grandifolia* (American beech), *Acer saccharum* (sugar maple), *Tilia americana* (American basswood), *Ulmus americana* (American elm), and *Fraxinus* spp. (ash). Fire-tolerant arboreal taxa, such as *Quercus* spp. (oak), *Carya* spp. (hickory), *Castanea dentata* (American chestnut), and *Pinus strobus* (eastern white pine), were found in scattered locales across the region during the late 18th century CE, particularly on sites with shallow soils overlying limestone bedrock or on sandy kame and esker landforms (Shanks 1966).

Point-quarter surveys of upland forests near the bog during the summer of 2017 (A. Fulton, unpublished data) indicate the present vegetation reflects the effects of prior decades of Euro-American land-use practices, with disturbance-related taxa prevalent, including *Prunus serotina* (black cherry), *Fraxinus americana* (white ash), *Pinus strobus* (white pine), *Populus grandidentata* (bigtooth aspen), *Populus deltoides* (eastern cottonwood), and *Acer rubrum* (red maple). Slopes too steep for cultivation preserve much of the late-successional vegetation described in the LSRs, with *Acer saccharum*, *Fagus grandifolia*, *Tsuga canadensis*, and *Betula alleghaniensis* (yellow birch) being the most common arboreal taxa, with the regionally rare *Taxus canadensis* (Canada yew) a notable understory associate.

The modern climate of the study area is humid-continental, with a mean January temperature of -3.7°C and a mean July temperature of 22.2°C (Albion 2 NE station data, 1980 – 2009 climate normals; Garoogian 2010). Mean annual precipitation is ~903 mm^{-1} yr^{-1}. Despite being situated outside the main Lake Erie and Lake Ontario snowbelts, the NGB site is subject to moderate lake-enhancement of winter precipitation, with a mean annual snowfall total of ~1686 mm^{-1} yr^{-1}.

2.2. Core extraction and sampling

Prior coring of the NGB site revealed ~870 cm of peat and gyttja overlying inferred Late Pleistocene-age cross-bedded deltaic sands deposited into proglacial Lake Tonawanda. For the present study, a 320-cm-long core of peat and gyttja was extracted from the center of New Guinea Road Bog during September 2015 using a Russian peat borer, with the core refrigerated prior to laboratory analysis. Core lithostratigraphy was described prior to subsampling for multiple proxies. Wood macrofossils were abundant in the core, and a subset of these ($n = 6$) was AMS radiocarbon dated (Table 4.1).

2.3. Radiocarbon dating and age-depth modeling

Site chronology was established by six terrestrial plant macrofossils (wood) extracted from the core for accelerator mass spectrometry (AMS) radiocarbon dating (Table 4.1). Wood samples were rinsed in deionized water and dried at 60°C for 24 hours before submission to the Center for Applied Isotope Studies at the University of Georgia (Athens, GA, USA), and the Center for Accelerator Mass Spectrometry at Lawrence Livermore National Laboratory (Livermore, CA, USA). All radiocarbon age estimates were calibrated using the INTCAL13 calibration curve

Table 4.1. Accelerator mass spectrometer (AMS) radiocarbon age estimates from New Guinea Road Bog (NGB) core. Radiocarbon ages were calibrated using Calib 7.0.4 software, based on the Intcal13 calibration curve (Reimer et al. 2013).

Laboratory #	**Material dated**	**Depth (cm)**	**^{14}C age**	**Calibrated age BP (2σ range)**	**Median probability BP**	**δ^{13}C (‰)**	**pMC**	**±**
UGAMS-40063	Wood fragment	16 – 18	370±20	499 – 321	447	-22.5	0.9544	0.0023
CAMS-175422	Wood fragment	28 – 30	855±30	899 – 692	795	-23.9	0.8990	0.0032
UGAMS-40064	Wood fragment	48 – 50	2140±20	2297 – 2045	2130	-27.3	0.7661	0.0019
CAMS-175423	Wood fragment	79 – 81	2415±30	2693 – 2501	2597	-27.9	0.7404	0.0027
CAMS-175424	Wood fragment	129 – 131	3040±35	3358 – 3157	3257	-29.4	0.6848	0.0030
CAMS-175425	Tree bark	167 – 168	3935±30	4511 – 4271	4391	-31.2	0.6126	0.0020

(Reimer et al. 2013), and an age-depth model was developed using the Bacon v2.3.3 software package (Blaauw and Christen 2011; Figure 4.2). Bacon uses a Bayesian statistical approach to partition each core into numerous vertical subsections (default = 5 cm thickness), employing millions of Markov Chain Monte Carlo iterations to estimate the accumulation rate for each subsection, which subsequently form the core's integrated age-depth model. A surface age of -65 cal. yr BP (2015 CE) was assigned to the uppermost portion of the core. All calibrated dates were subsequently readjusted so as to reflect years before 2015 CE (0 cal. yr BP).

2.4. Pollen analysis

Sediment samples for pollen analysis (*n* = 168) were sampled at 1-cm resolution and processed according to standard laboratory procedures, including potassium hydroxide (KOH), hydrochloric acid (HCl), hydrofluoric acid (HF), and acetolysis treatment (Faegri and Iversen 1989). Addition steps included sieving (120-μm and 8-μm screens) to reduce the amount of inorganic material. Pollen concentrates were suspended in 3000-cst silicone oil prior to mounting on microscope slides and were examined at 400x magnification using a binocular microscope. A minimum of 400 pollen grains was counted and identified to the greatest taxonomic resolution using published keys (McAndrews et al. 1973; Bassett et al. 1978) and the modern pollen reference collection in the Department of Geography, Environment, and Spatial Sciences, Michigan State University. Percent arboreal (AP) and non-arboreal (NAP) pollen was calculated using the sum of all terrestrial arboreal and non-arboreal pollen grains. A total of 26 pollen taxa was identified from the NGB core and the most common and ecologically significant taxa were plotted using Tilia 1.7.16 (Grimm 2011).

2.5. Macroscopic charcoal analysis

Macroscopic sediment charcoal was analyzed at continuous 1-cm resolution using 1.5 cm^3 volumetric subsamples according to a modified method of Mooney and Tinner (2011). Sediments were first soaked in a 3% hydrogen peroxide (H_2O_2) solution for 24 hours at 20°C, rinsed, and subsequently immersed in a 6% sodium hypochlorite (NaOCl) solution for an additional 24 hours to bleach organic matter. Samples were wet sieved through a 174-µm mesh screen with warm tap water to remove inorganic and organic residues and placed into a gridded petri dish for counting under a dissecting microscope. Wood charcoal counts were relativized to 1 cm^3 volume prior to calculation of charcoal concentration (pieces cm^{-3}) and influx (pieces cm^{-2} yr^{-1}). Charcoal influx was calculated using sediment accumulation times (yr^{-1} cm^{-1}) at each depth interval derived from the core's age-depth model.

2.6. Loss-on-ignition and stable carbon isotope analyses

Loss-on-ignition (LOI) analyses were conducted at 1-cm resolution following standard procedures for estimation of weight percent organic matter, carbonate, terrigenous material, and coarse sand (Heiri et al. 2001; Gale and Hoare 1992). Specifically, sediment subsamples of 3 cm^3 were dried at 80°C for 12 hours, homogenized with a ceramic mortar and pestle, and combusted in a muffle furnace at 550°C and 950°C to determine weight percent organic matter (OM), carbonate, and terrigenous components. Weight percent coarse sand was determined using mechanical sieving of the terrigenous component and is expressed as a percentage of the total terrigenous fraction. Isotopic samples were extracted from the NGB core at 2-cm increments, dried, ground to a fine powder in a porcelain mortar and pestle and decalcified via fumigation with 12M HCl. Samples were analyzed in duplicate on a Costech 4010 elemental analyzer interfaced with a Thermo Delta V stable isotope mass spectrometer at the University of North Carolina Wilmington Center for Marine Science by Dr. Chad Lane.

Sediment $\delta^{13}C_{OM}$ values from the NGB core were compared to those from a cave speleothem record (McFails Cave; van Beynen et al. 2004) located in east-central New York State to correlate regional paleoenvironmental trends. The McFails Cave $\delta^{13}C_{calcite}$ chronology provides a continuous, 7600-year-long record of dripwater-mediated calcite deposition in a closed-canopy, humid-temperate forested environment similar to that of the NGB study area. I used temporal variations in the McFails Cave $\delta^{13}C_{calcite}$ record to infer changes in terrestrial biomass, aquatic productivity, and the relative abundance of C_3 (e.g. broadleaf deciduous forest taxa) versus C_4 plants (e.g. warm-season grasses, maize [*Zea mays*]; Street-Perrott et al. 2004) in the NGB core. Enriched values of sediment and calcite $\delta^{13}C$ (>-20‰) likely reflect forest contraction, reduced vegetation density, and greater C_4 plant biomass; conversely, depleted $\delta^{13}C$ values (<-20‰) suggest greater canopy density, forest expansion, and increased C_3 biomass (Ehleringer and Cerling 2002).

2.7. Principal component analysis (PCA) of pollen data

Principal component analysis (PCA; Kent 2012) was performed on the full NGB pollen spectrum in order to ordinate pollen taxa along the most important environmental gradients and examine paleoecological trends through time. Raw pollen count data were square-root transformed

(Hellinger transformation; Legendre and Gallagher 2001) prior to analysis. PCA was conducted using a matrix of Pearson's product-moment correlation coefficients between pollen taxa and conducted using the PC-ORD 6.19 software package (McCune and Mefford 2011). A varimax rotation was applied to the original unrotated PCA solution to facilitate paleoecological interpretation of the resulting principal components and factor loadings.

2.8. Time series analysis

Determination of cyclical temporal patterns in the NGB pollen data was accomplished via time series analysis of principal component factor scores generated in the PCA analysis (section 3.6), using the PAST 3.22 statistical software package (Hammer et al. 2001). A simple Lomb periodogram algorithm for unevenly sampled data was used (Press et al. 1992), with automatic detrending of the factor score data prior to analysis.

2.9. Prehistoric vegetation community type classification of pollen data

Reconstruction of Late Holocene vegetation community type dynamics represented in the NGB pollen record was based on results of agglomerative hierarchical clustering (AHC) analysis of late 18th century CE land survey records (LSRs) from the broader study area encompassing west-central and central New York State, USA (see Chapters 2 and 3). Through the identification of primary and secondary regional vegetation community types immediately prior to widespread Euro-American settlement circa 1795 CE, I used indicator pollen taxa associated with these community types (Table 4.2) to track chronological changes in and infer modulators of forest community dynamics during the Late Holocene.

2.10. Reconstruction of vegetation-inferred fire regimes

In order to evaluate the influence of climate transitions and Native American land-use practices on local vegetation and disturbance regimes, I aggregated each arboreal pollen taxon identified in the NGB sediment core into one of two fire-adaptedness classes: (1) *fire-tolerant*, including oak (*Quercus* spp.), hickory (*Carya* spp.), chestnut (*Castanea dentata*) and pine (*Pinus* spp.); and (2) *fire-intolerant*, such as maple (*Acer* spp.), beech (*Fagus grandifolia*), hemlock (*Tsuga canadensis*), and basswood (*Tilia americana*; Table 4.3). Fire-adaptedness was determined for major taxa using information on ecophysiological adaptations to moderate-intensity ground fires contained in the Fire Effects Information System (FEIS) online database (United States Department of Agriculture 2018) and summarized in Thomas-Van Gundy and Nowacki (2013) and Van Gundy et al. (2015). Percentages of fire-tolerant and fire-intolerant arboreal taxa for each dated sample in the core were calculated from the total upland arboreal pollen sum.

2.11. Fire-tolerance analysis using land survey records (LSRs)

To assess the influence of fire on the landscape immediately prior to Euro-American settlement, fire-tolerance analysis was conducted on vegetation data derived from late-18th century CE land survey record data within a 30-km buffer surrounding the NGB coring site. Data were taken from Phelps and Gorham Purchase (PGP) LSRs located to the east of the site (Chapter 2) and from Holland Land Company (HLC) LSRs recorded to the west. Major upland forest taxa were

Table 4.2. Binary fire-adaptedness classification for fire-tolerant (*n* = 7) and fire-intolerant (*n* = 13) upland arboreal pollen taxa identified from the New Guinea Road Bog (NGB) sediment core. Classifications are based on ecophysiological adaptations of major forest tree taxa to low-intensity ground fires summarized by Thomas-Van Gundy and Nowacki (2013) and Nowacki and Abrams (2015).

Pollen taxon	**Common name**	**Fire tolerance**
Acer rubrum	Red maple	Fire-intolerant
Acer saccharum	Sugar maple	Fire-intolerant
Betula	Birch	Fire-intolerant
Carya	Hickory	Fire-tolerant
Castanea	Chestnut	Fire-tolerant
Fagus	Beech	Fire-intolerant
Fraxinus	Ash	Fire-intolerant
Juglans cinerea	Butternut	Fire-intolerant
Juglans nigra	Black walnut	Fire-intolerant
Morus	Mulberry	Fire-intolerant
Ostrya/Carpinus	Ironwood/Hornbeam	Fire-intolerant
Pinus diploxylon	Hard pine	Fire-tolerant
Pinus haploxylon	Soft pine	Fire-tolerant
Pinus undifferentiated	Pine	Fire-tolerant
Platanus	Sycamore	Fire-intolerant
Populus	Aspen/poplar	Fire-tolerant
Quercus	Oak	Fire-tolerant
Tilia	Basswood	Fire-intolerant
Tsuga	Hemlock	Fire-intolerant
Ulmus	Elm	Fire-intolerant

Table 4.3. Summary of upland vegetation community types identified by agglomerative hierarchical clustering (AHC) of late-18th century CE land survey vegetation data from west-central New York State, USA (Chapter 2), with names of modern equivalents (Edinger et al. 2014), and pollen taxa used as indicators for each AHC-derived group in the New Guinea Road Bog (NGB) core.

AHC Group	**Vegetation Community Types**	**Indicator Pollen Taxa**
AHC Group 1	Beech-maple mesic forest; hemlock-northern hardwood forest	• Beech (*Fagus grandifolia*) • Sugar maple (*Acer saccharum*) • Hemlock (*Tsuga canadensis*)
AHC Group 1	Rich mesophytic forest; maple-basswood forest	• Ash (*Fraxinus* spp.) • Basswood (*Tilia* spp.) • Elm (*Ulmus* spp.)
AHC Group 2a	Appalachian oak-pine forest; oak-chestnut-pine forest; pitch pine-scrub oak barrens; pitch pine-oak-heath rocky summit; red pine rocky summit	• Chestnut (*Castanea dentata*) • *Pinus* haploxylon-type • *Pinus* diploxylon-type • *Pinus* undifferentiated
AHC Group 2b	Appalachian oak-hickory forest	• Oak (*Quercus* spp.) • Hickory (*Carya* spp.)
AHC Group 2b	Oak openings; floodplain grassland; successional old field	• *Ambrosia*-type • Asteraceae • Cyperaceae • *Plantago* spp. • Poaceae • *Rumex* spp.

grouped according to the fire-tolerance classification scheme outlined in Chapter 2, and an interpolated raster surface of percent fire-tolerant forest taxa was generated in ArcGIS 10.3 (Environmental Research Systems Institute 2014).

2.12. Local archaeological chronology, paleopopulation estimation, and cultigen dates

A geospatial database of Late Woodland (1000 – 1650 CE) and Historic (1650 – 1779 CE) period Native American archaeological sites within a 30-km radius of the NGB coring site (n = 32; Figure 4.2) was extracted from the New York State Museum (NYSM) Archaeology Laboratory site file. This sample comprised sites identified as agricultural Iroquoian villages (n = 8) and non-residential site types (e.g. campsites, burials, workshops, and ceremonial sites; n = 24). Archaeological sites representing all time periods (Paleoindian – Historic; ~13,000 – 150 cal. yr BP; n = 178) within the 30-km buffer were also extracted for spatial comparisons with the 18th century CE LSR data.

Regional human paleopopulation for the duration of the NGB core chronology was inferred by downloading archaeological radiocarbon dates for New York State as of December 2017 (n = 471) from the Canadian Archaeological Radiocarbon Database (CARD; Martindale et al. 2016; https://www.canadianarchaeology.ca). Uncalibrated ^{14}C dates were calibrated using Calib 7.0.4 software, based on the Intcal13 calibration curve (Reimer et al. 2013), and the resulting weighted mean age estimates were grouped into 100-year bins, tallied, and plotted. Selected cultigen (e.g. *Zea mays*) ^{14}C dates for the Northeast and Great Lakes regions were compiled from published sources (e.g. Hart and Lovis 2013; Gates St.-Pierre and Thompson 2015) for comparison with the NGB proxies and other regional datasets.

3. Results

3.1. Age-depth model, lithostratigraphy, and pollen zonation

The NGB core contains a continuous record of sediment deposition extending back to ~4400 cal. yr BP, with some chronological variability in sedimentation rates evident in the core's age-depth model (Figure 4.2). The core was divided into discrete lithostratigraphic (*n* = 6; Figure 4.3) and pollen zones (*n* = 8; Figure 4.4) based upon visual and textural sediment properties and objective zonation (CONISS clustering) of the core's complete pollen spectrum, respectively. Regional archaeological phases are based on Funk (1993).

3.1.1. Zone NGB-1 (4400 – 4020 cal. yr BP; 168 – 158 cm; Late Archaic)

The lowermost unit in the NGB core (Figure 4.4) is characterized by a general decrease in fire- and disturbance pollen indicator taxa, suggesting that a previous zone – not analyzed in the present study – was typified by higher values of similar taxa. Combined fire-tolerant pollen taxa exhibit an initial rise from ~30% at the bottom of the zone to ~40% near the middle of zone NGB-1. This is followed by a progressive decline toward the top of the core to ~25% of the pollen sum. *Quercus* pollen forms the predominant component of the fire-tolerant group, rising from ~22% at the bottom of the zone to 30% near the middle, and declining toward the top to ~13%. Non-arboreal pollen (NAP) taxa – including *Ambrosia*-type, Asteraceae, and Poaceae – display relatively low and steadily decreasing values during this time, falling from ~3 – 2%.

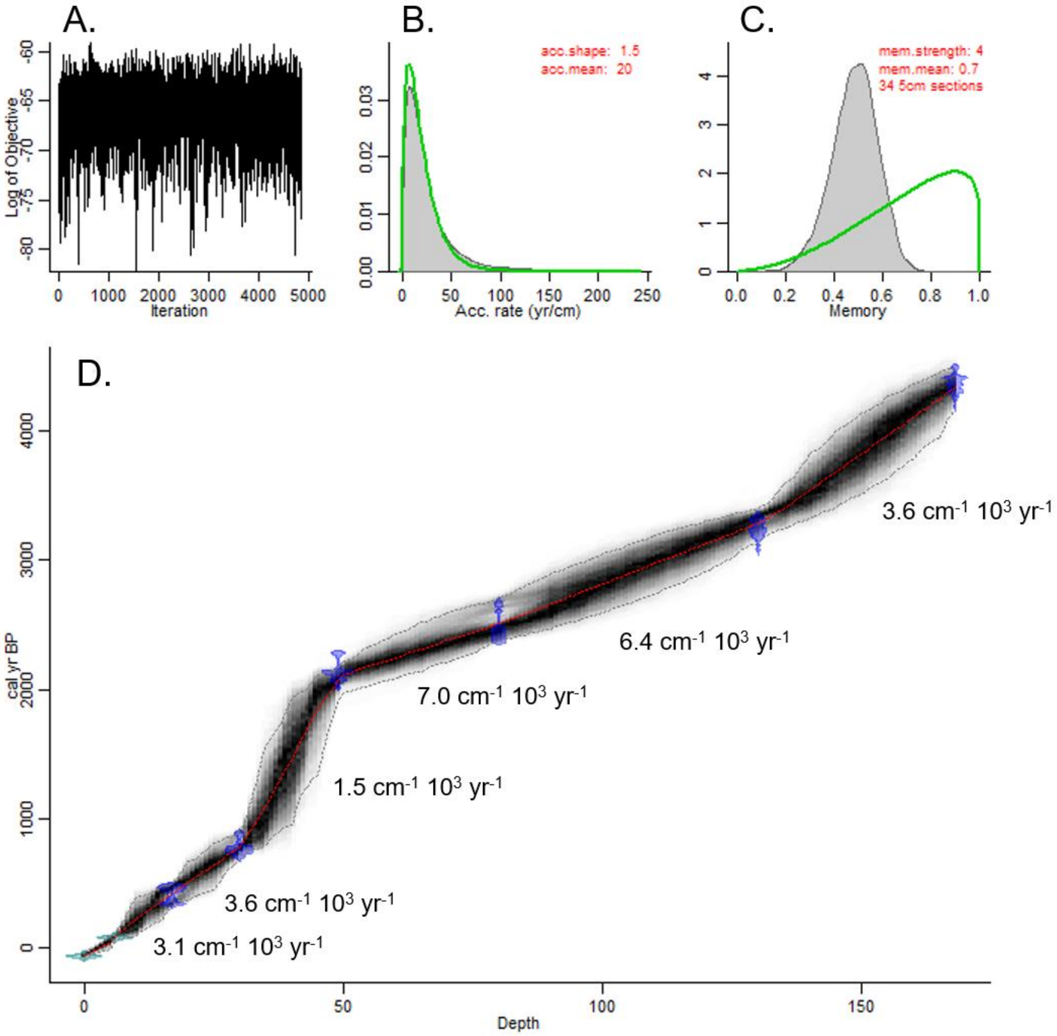

Figure 4.2. Bacon v2.3.3 (Blaauw and Christen 2011) age-depth model for the NGB core. A. Markov Chain Monte Carlo (MCMC) iterations. B. Accumulation rate. C. Memory (autocorrelation strength). Green curves indicate prior distributions, with gray histograms indicating posterior distributions. D. NGB age-depth model (gray-black shading) represented as probability distributions for individual age estimates (purple icons). Light-blue icons near top of core indicate user-input ages for (1) a prominent $\delta^{13}C_{OM}$ anomaly (see Figure 4.4; ~100 cal. yr BP [~1850 CE]) and (2) core-top date (-65 cal. yr BP [2015 CE]). Darker gray colors indicate more robust age estimates. Stippling along edge of age-depth model indicates 95% confidence interval. Best-fit line (red) based on weighted mean age for each depth in core. Estimated sedimentation rates between ^{14}C dates are based upon weighted mean calibrated values taken from the Bacon age-depth model.

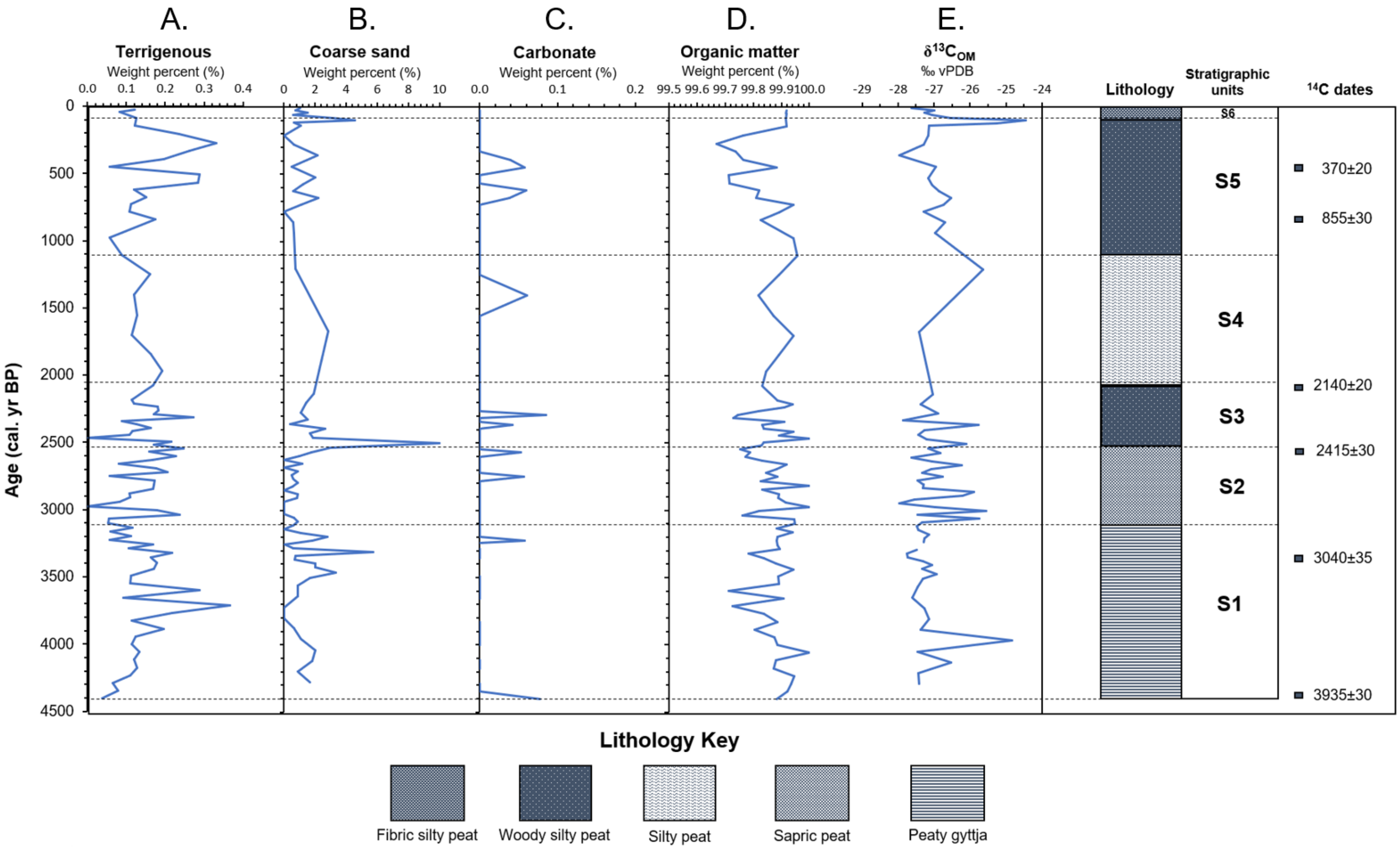

Figure 4.3. Comparison of loss-on-ignition data for the NGB core. A. Weight percent terrigenous matter. B. Weight percent coarse sand measured as percentage of the terrigenous fraction. C. Weight percent carbonate. D. Weight percent organic matter (OM). E. $\delta^{13}C_{OM}$ values of sediment organic matter. Core lithology, lithostratigraphic units, and uncalibrated radiocarbon dates are shown on right. Calibrated timescale (shown on left) is based on Bacon v2.3.3 (Blaauw and Christen 2011) age-depth model.

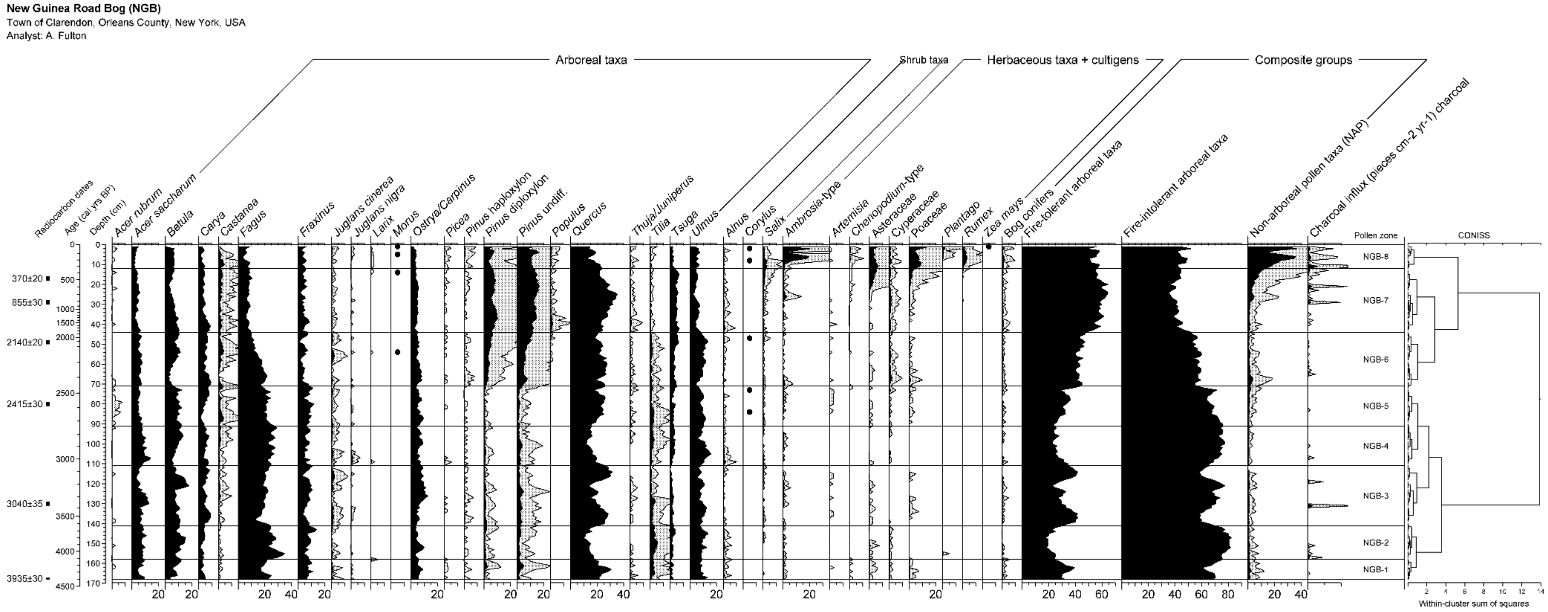

Figure 4.4. NGB pollen diagram showing, from left, individual radiocarbon dates (uncalibrated), calibrated timescale based on Bacon v2.3.3 (Blaauw and Christen 2011) age-depth model, core depth (cm), and percentages for major arboreal, shrub, herbaceous, and cultigen taxa. Composite pollen groups include bog conifers, fire-tolerant and fire-intolerant arboreal taxa (see Table 2), and non-arboreal pollen (NAP) taxa. Macroscopic sediment charcoal influx, pollen zonation, and constrained incremental sum of squares (CONISS) cluster analysis dendrogram are shown at right.

Charcoal is largely absent from zone NGB-1 aside from a few fragments in the lower part of the zone.

Accompanying the overall decrease in fire- and disturbance-related pollen indicators (ADIs), fire-intolerant taxa display an opposite trend after initial fluctuation, with an overall increase from the middle of the zone (~60%) toward the top (~76%). This trend is driven largely by *Fagus* pollen, which rises from ~17% to 23% by the end of Zone NGB-1. LOI values are variable (Figure 4.3), with the most evident trend being a gradual decline in the coarse sand fraction of the terrigenous component. Weight percent OM rises slightly from 99.85 – 99.90%, while percent carbonate declines rapidly from the base of the zone (0.05%) to a total absence for most of the remaining period. Sediment $\delta^{13}C_{OM}$ values increase slightly during this zone from -27.4‰ to -26.5‰.

3.1.2. Zone NGB-2 (4020 – 3630 cal. yr BP; 158 – 140 cm; Late Archaic)

Pollen of fire-intolerant upland pollen taxa show a prominent increase during this time (Figure 4.4), attaining maxima near the middle of the zone (~80%), notably *Fagus*, increasing from ~23% to 35%, *Acer saccharum* generally constant at ~8%, *Betula* rising from 7% to 15% by the middle of the zone, *Fraxinus* rising steadily from ~7% to 12%, and *Tilia* increasing slightly from ~3% to 6%. In response, fire-tolerant pollen taxa continue to fall continuously through the NGB-1 – NGB-2 transition to a low of ~17% by the middle of the zone and rising steadily thereafter toward the top of the zone (~34%). *Quercus* leads this decline, decreasing steadily from ~20 – 11%, with a subsequent rise toward the end of the zone to 20%. NAP taxa continue to decline to below 1% through the zone. Charcoal influx suddenly rises from the base of Zone NGB-2, and minor amounts of charcoal fragments are present in the lower half of the zone, followed by a period of no charcoal deposition to the top of the zone. Percent OM tends to decline during the zone (Figure 4.3), as does coarse sand, although total terrigenous matter exhibits a sustained increase, followed by a slight decline at the end of Zone NGB-2. $\delta^{13}C_{OM}$ values experience a prominent positive excursion near the base of the zone, rising sharply from -27‰ to -25‰, followed by relative stability.

3.1.3. Zone NGB-3 (3630 – 3050 cal. yr BP; 140 – 110 cm; Late Archaic – Terminal Archaic)

Although representing a unitary cluster in the CONISS dendrogram (Figure 4.4), this zone is comprised of three distinct phases. Fire-tolerant pollen taxa exhibit two separate periods of increase during zone NGB-3, one at the bottom (phase 1), which is followed by a prominent decline (phase 2) and succeeded by a second rise in fire-tolerant taxa (phase 3) toward the top of the zone. Phase 1 occurs from 140 cm to 130 cm (3630 to 3350 cal. yr BP), with total fire-tolerant pollen taxa rising from ~22% to 41% of the arboreal pollen sum. *Quercus* pollen increases from ~15% to 28% during phase 1, as do *Carya* (~4% to 9%) and *Castanea* (~0.2% to 0.9%). Fire-intolerant pollen taxa decline from ~72% to 58% of the arboreal pollen sum, including *Fagus* (24% to 12%), *Acer saccharum* (8% to 5%), *Tilia* (3.5% to 1%), and *Betula* (11% to 8%). NAP taxa are still relatively low during phase 1, but a slight rise from ~0.2 to 0.7% is evident. Charcoal is entirely absent from sediments deposited during phase 1. Charcoal influx values rise near the end of phase 1 (~3380 cal. yr BP), with a prominent, but short-lived peak (1.4 pieces cm^{-2} yr^{-1}; 40 pieces cm^{-3}). This phase is also characterized by moderately high, though gradually declining frequencies of terrigenous matter (Figure 4.3); nevertheless, a notable increase in the coarse sand fraction accompanies this downward trend (0.5% to 2%).

Phase 2 occurs from 130 – 120 cm (3350 – 3200 cal. yr BP), with total fire-tolerant pollen taxa decreasing slightly from ~35% to 26%, rising briefly to ~32%, then falling again to ~23%. Conversely, fire-intolerant pollen taxa increase from ~70% to 74%, decline slightly to ~65%, then rise again to~80%. Combined bog conifers increase slightly during phase 2 from <1% to ~1.5%. NAP pollen decreases from 1% to 0.5%. Percent terrigenous material continues its overall decline from ~0.25% to 0.1%. Conversely, coarse sand continues its previous rise during phase 1 (Figure 4.3), with a minor peak of ~5.8% during this period. $\delta^{13}C_{OM}$ values hold constant near -27.5‰.

The final phase 3 extends from 120 – 110 cm (3200 – 3050 cal. yr BP) and exhibits a prominent increase in fire-tolerant pollen taxa (~30% to 42%) most notably *Quercus* (~15% – 30%) and *Carya* (~5% – 8%). Undifferentiated *Pinus* pollen experiences a slight decline during phase 3 (4% – 2%), as does diploxylon *Pinus* (2% – 1%). A decline in fire-intolerant taxa (~75% – 58%) entails a prominent decrease in *Acer saccharum* (10% – 3%), a minor *Fagus* decline (22% – 19%), and a decline in *Tsuga* pollen (~2.5% – 1%). However, fire-intolerant taxa begin to rise near the top of the zone to ~65% as fire-tolerant taxa begin a coeval decline from 42% to 35%. An initial rise in NAP values from ~0.2 – 1.5% is followed by a subsequent decline to <0.5% by the end of the zone. Percent OM declines rapidly to 99.5% at the beginning of phase 3 (Figure 4.3), but quickly rebounds to ~99.9%. Percent terrigenous material registers an increase at ~3130 cal. yr BP from ~0.1 – 0.5%, and percent coarse sand decreases gradually from a previous high of ~5.8% to ~0.5%. $\delta^{13}C_{OM}$ exhibits a slight increase from -27.5‰ to -27‰ at the end of the zone.

3.1.4. Zone NGB-4 (3050 – 2740 cal. yr BP; 110 – 90 cm; Early Woodland)

Fire-intolerant pollen taxa experience a strong recovery during this zone (Figure 4.4), increasing to ~77% by the middle of the zone, and holding constant between 73 and 76% for the remainder of Zone NGB-4. *Fagus* pollen increases from ~20% to 29%, and *Acer saccharum* pollen also rises from ~5 to 11%, then declines somewhat to ~7% by the end of the zone. *Tilia* increases from <1% to 3% and *Tsuga* displays a modest rise from near 0% to 4% during the middle of the zone, followed by a slight decline toward 2% by the end of the zone. Fire-tolerant pollen taxa post a notable decline from ~40% to 25%, including *Quercus* (~30% to 12%) and *Carya* (~8.5% to 3%). *Castanea* pollen rises from ~0.2 to 2% by the middle of the zone, then declines to ~1% at the top of the zone. Total *Pinus* pollen is variable, ranging from ~1% – 4%, but is generally lower than in the preceding Zone NGB-6. NAP values are very low during this period (<1.0%). Charcoal is absent from most of the zone, but small amounts are found at 107 cm (3.3 pieces cm^{-3}) and 101 cm (1.3 pieces cm^{-3}). Most LOI proxies are highly variable during this zone (Figure 4.3), showing much high-frequency, low-amplitude variation, with the exception of coarse sand, which remains very low and relatively constant between 0.7 – 0.8%. Carbonate, which was generally absent from the NGB core in earlier zones, becomes present in the upper half of the zone, although at very low percentages. $\delta^{13}C_{OM}$ values are quite variable during this zone, experiencing numerous fluctuations between -27.9‰ and -25.5‰.

3.1.5. Zone NGB-5 (2740 – 2460 cal. yr BP; 90 – 70 cm; Early Woodland)

Fire-tolerant pollen taxa rise continuously during zone NGB-5 from ~27% to 42% (Figure 4.4). *Quercus* pollen increases during this period from 19% to 26% along with *Carya* (~2.5% to 8%). All *Pinus* taxa maintain very low levels throughout the zone, typically between 1% and 3%, although a notable rise is detectable at the very top of the zone, with values beginning to climb to ~6% (undifferentiated *Pinus*) and ~2% (diploxylon *Pinus*). *Castanea* rises during this zone from ~1.5% to 4%, declines gradually through the remainder of the zone, then rises slightly at the termination of the zone. Although fire-intolerant pollen taxa decline steadily from ~73% to 57% through the zone, most major fire-sensitive taxa (*Acer saccharum*, *Betula*, *Fagus*, *Fraxinus*, *Tilia*, *Tsuga*) display variable frequencies suggesting successive short-term increases and declines. Only *Ulmus* shows a unidirectional decline from ~12% to 4%. NAP taxa register a notable increase in this zone, increasing from ~0.2% to 3.6%. Charcoal is present only at 83 cm, and in very low quantities (1.3 pieces cm^{-3}). As in preceding Zone NGB-4, there is much high-frequency variability in most LOI proxies (Figure 4.3), and a prominent spike in coarse sand (~9%) is evident, centered at ~2500 cal. yr BP. $\delta^{13}C_{OM}$ values mimic the LOI data, with much short-term variability.

3.1.6. Zone NGB-6 (2460 – 1850 cal. yr BP; 70 – 44 cm; mid-Early Woodland – early Middle Woodland)

The transition from Zone NGB-5 to the base of NGB-6 is characterized by a prominent, rapid decline in fire-intolerant arboreal pollen taxa (Figure 4.4). From an initial high of ~65% near the top of Zone NGB-5, fire-intolerant taxa drop suddenly to 50% at the bottom of Zone NGB-6 but maintain relative stability afterwards. The most prominent decline occurs in *Fagus* (25% – 12%), with *Acer saccharum* relatively constant between 5% and 7% for most of the zone. *Betula*, like *Fagus*, experiences a decline at the NGB-5 – NGB-6 transition (13% – 5%), but is much more rapid, occurring within a century (2500 – 2400 cal. yr BP). *Fraxinus*, another mesic taxon, also experiences a progressive decline (10% – 5%), although others, most notably *Tilia* and *Ulmus*, are stable. *Tsuga* pollen increases across the NGB-5 – NGB-6 transition, maintains stability at ~5% for most of the zone, but increases in frequency toward the top to 10%.

The prominent initial decline in fire-intolerant taxa, particularly *Fagus*, is accompanied by a sharp increase in fire-tolerant pollen taxa at the base of Zone NGB-6 from ~30% to 40%, followed by stability and a gradual increase toward the top of the zone to ~45%. This increase is driven primarily by diploxylon and undifferentiated *Pinus* at the NGB-5 – NGB-6 transition, where diploxylon *Pinus* increases from ~2% to 6% and undifferentiated *Pinus* rises from 3% to ~10%. A sharp increase is also detectable in haploxylon *Pinus,* although at much lower frequencies (0% – 2%), and low values are maintained at relative stable levels for the remainder of the zone. Diploxylon and undifferentiated *Pinus* undergo steady increases through the entirety of Zone NGB-6, achieving final values of ~10% and 15%, respectively, by the top of the zone.

Quercus pollen remains relatively stable during NGB-6, hovering at ~25%, with a slight drop to ~18% at the top of the zone. *Carya* shows a slight early decline (~8 – 6%), followed by relative stability at 6%. *Castanea* shows an overall increasing trend during this zone (~1 – 5%), particularly in the latter stages. *Populus* pollen, which was entirely absent in previous zones, appears for the first time and is present in very low, but steady numbers beginning at ~2300 cal. yr BP. Combined NAP taxa exhibit a slight increase at the NGB-5 – NGB-6 transition (2% – 6%), decline slightly to ~4%, and experience a decrease to ~2% toward the top of the zone.

Charcoal is present relatively continuously, but at very low influx rates, during Zone NGB-6, unlike previous zones where a more sporadic presence was evident. LOI and $\delta^{13}C_{OM}$ proxies exhibit substantial low-amplitude variability in this zone (Figure 4.3), continuing the trend from earlier ones. The most notable feature of the LOI data is the sudden, positive excursion in coarse sand at the base of the zone, rising from ~0.5 to 9.5%, coeval with the sudden rise in fire-tolerant pollen taxa.

3.1.7. Zone NGB-7 (1850 – 360 cal. yr BP; 44 – 12 cm; Middle Woodland – Late Woodland)

Zone NGB-7, spanning an extended 1500-year period, continues the trend of increasing fire-tolerant pollen taxa begun in the Zone NGB-6, with some notable differences (Figure 4.4). Whereas *Pinus* was the primary contributor to the overall rise of fire-tolerant taxa in the previous zone, *Quercus* assumes this role in NGB-7, increasing dramatically from the base of the zone (~25%) toward the middle, achieving a peak value for the entire Late Holocene NGB pollen record of ~35% at ~700 cal. yr BP. This global maximum is followed by an equally precipitous decline through the top of the zone to ~15% by 360 cal. yr BP. After slight increases at the bottom of Zone NGB-7, both diploxylon and undifferentiated *Pinus* maintain steady values through the middle of the zone (~10% and 15%, respectively), rising slightly afterwards, a declining slightly toward the top of the zone. Haploxylon *Pinus* shows a steady, low-magnitude increase through most of NGB-7, however, increasing from 0% at the base to ~2% at the top. Other fire-tolerant taxa are variable, exhibiting slight declines (*Carya*: 8% – 5%; *Populus*: 3% – 1%) or slight increases (*Castanea*: 3% – 5%).

Collectively, fire-intolerant taxa, experience a contrasting pattern of sharp decline at the base of the zone (~55% – 40%), followed by a slight decrease toward the middle of the zone (~35%), and a final gradual increase toward the top of the zone (~40%). Individual pollen taxa are variable, though, including *Acer saccharum* (8% – 4%), *Betula* (12% – 5%), and *Ulmus* (8% – 5%), although *Fagus* appears stable at ~10% – 12%, with a very small rise detectable at the top of the zone (~15%). Likewise, *Tsuga* is stable during this time at ~4% and experiences a slight rise near the top of the zone (~6%), followed by a decline to ~3%.

The most notable feature of Zone NGB-7, however, occurs with NAP taxa, both individually and collectively, as an exponential rise is visible, extending through the entire zone. Combined NAP taxa begin at the base of the zone at relatively low frequencies (~3% at 1850 cal. yr BP), undergoing a dramatic, steady increase to ~13% by the top of the zone (360 cal. yr BP). The approximate inflection point of this growth occurs at ~700 cal. yr BP, coeval with the prominent *Quercus* decline described above. Charcoal influx closely mirrors the trend in NAP frequency, showing two prominent peaks within an overall increasing trend.

LOI and $\delta^{13}C_{OM}$ proxies are variable during Zone NGB-7 (Figure 4.3). Overall terrigenous material is relatively stable during the first half of the zone, then experiencing a notable rise after ~1000 cal. yr BP and again at ~650 cal. yr BP, followed by a very sharp decline, and a subsequent increase. The coarse sand fraction, by-and-large, tracks the trend in terrigenous material, although a progressive decline is evident in the bottom half of the zone (3% - 0.5%), followed by an increase toward the top of the zone (~2%). Notably, OM and $\delta^{13}C_{OM}$ values are largely synchronous during this time, with a notable enrichment of $\delta^{13}C_{OM}$ values occurring from 1700 cal yr BP (-27.5‰) to 1200 cal. yr BP (-26.5‰). This is followed by coeval declines in both OM and $\delta^{13}C_{OM}$ toward the top of the zone.

3.1.8. Zone NGB-8 (360 – 0 cal. yr BP; 12 – 0 cm; Historic Native American – Euro-American)

The final zone of the NGB pollen record (Figure 4.4) encompasses the period of transition from Native American to Euro-American occupation of western New York State. The most prominent trend of this zone is the continuation of the dramatic increase in NAP taxa frequencies and charcoal influx values. The lower portion of Zone NGB-8 is coeval with the elimination of indigenous Iroquoian groups (e.g. Neutral and Erie nations) and the incursion of the Seneca, emanating from the western Finger Lakes region to the east. In the NGB core, this phase is initiated by the largest positive excursion in charcoal influx, occurring at ~300 cal. yr BP (1715 CE). Although influx declines after this spectacular peak, overall values still remain high into the Euro-American period, which begins ~205 cal. yr BP (1811 CE) with initial settlement of the Town of Clarendon (Gibson 1979). NAP taxa track the charcoal influx record very closely during the entire zone, exhibiting a continued increase from ~13% (360 cal. yr BP) at the base of Zone NGB-8 to ~35% by 140 cal. yr BP (1875 CE). A prominent decline then occurs between 140 cal. yr BP and 70 cal. yr BP (1945 CE), followed by a second sharp increase, peaking globally at 36% by 45 cal. yr BP (1970 CE), declining slightly to the top of the core.

Fire-tolerant pollen taxa increase from 45% to 50% between ~240 cal. yr BP and 210 cal. yr BP (1775 – 1805 CE), coinciding with Euro-American settlement. This is followed by a decrease through the 20th century CE, a second increase after 70 cal. yr BP (1945 CE), and a more recent decrease to the present. Notably, *Castanea* pollen exhibits a steady decline from ~3% at the beginning of the zone to ~1.5% by the early 20th century CE. Thereafter, *Castanea* falls to insignificant levels (~0.1% - 0.2%) to the top of the core, a consequence of *Endothia parasitica* (chestnut blight) infestation between 1900 and 1925 CE (Paillet 2002). Fire-intolerant pollen taxa decline slightly from ~48% at the start of the zone to 41% by the late 20th century CE, but major late-successional upland taxa experience increases such as *Acer saccharum* (1.5% – 5%), *Fagus* (6% – 9%), and *Tilia* (0.2% – 1%). Minor pollen taxa that were previously rare or absent become established at low frequencies (<1%), including *Acer rubrum*, *Juglans nigra*, and *Morus*.

LOI values reflect generally high levels of disturbance at the NGB site during this final zone (Figure 4.3), with peak terrigenous material occurring at ~275 cal. yr BP (1740 CE), declining sharply thereafter. However, the coarse sand fraction shows a notable increase from <0.5% at ~200 cal. yr BP (1815 CE) to 4.5% by ~100 cal. yr BP (1915 CE), coinciding with the period of Euro-American settlement, forest clearance, and peak agricultural activity during the 19th century. Coeval with the positive excursion in coarse sand flux is an accompanying spike in $\delta^{13}C_{OM}$ values, followed by a progressive decline.

3.2. Principal Component Analysis (PCA) of pollen taxa

Principal component analysis (PCA) of the full NGB pollen spectrum revealed that, collectively, the first two principal components (PC1 and PC2) of the varimax-rotated solution explained 36.9% of the total variance. PC1 accounted for 18.7% of the variance and was very highly positively correlated with percent fire-tolerant arboreal taxa ($r = 0.9406$; $p < 0.0001$; Figure 4.5A) and is interpreted as an indicator of paleo-fire intensity/frequency. PC2 explained an additional 18.7% of the total variance and was very highly positively correlated with percent non-arboreal pollen (NAP) taxa ($r = 0.9118$; $p < 0.0001$; Figure 4.5B) and is regarded as a proxy for openland habitats.

3.3. Temporal dynamics of upland vegetation community types

Prior to 2500 cal. yr BP, the NGB pollen record exhibits quasi-cyclic behavior, with a notable alternation between fire-tolerant and fire-intolerant upland arboreal pollen taxa (Figures 4.4 and 4.5). Time series analysis of PCA factor scores for the pre-2500 cal. BP period (Figure 4.6) indicates dominant, statistically significant periodicities for each principal component (PC1 = 446 and 947 yr; PC2 = 1,895 yr). This periodicity is, by extension, mirrored in the community-level pollen data. Mesic, fire-intolerant pollen taxa comprising AHC Group 1a (*beech-maple mesic forest*; *hemlock-northern hardwood forest*; Figure 4.7A) and AHC Group 1b (*rich mesophytic forest*; *maple-basswood forest*; Figure 4.7B) fluctuate in quasi-cyclical fashion during the first half of the NGB pollen record (~4401 – 2390 cal. yr BP), with values alternating from lows of ~35% (AHC Group 1a) and 25% (AHC Group 1b) during Zones NGB-3 (3530 –

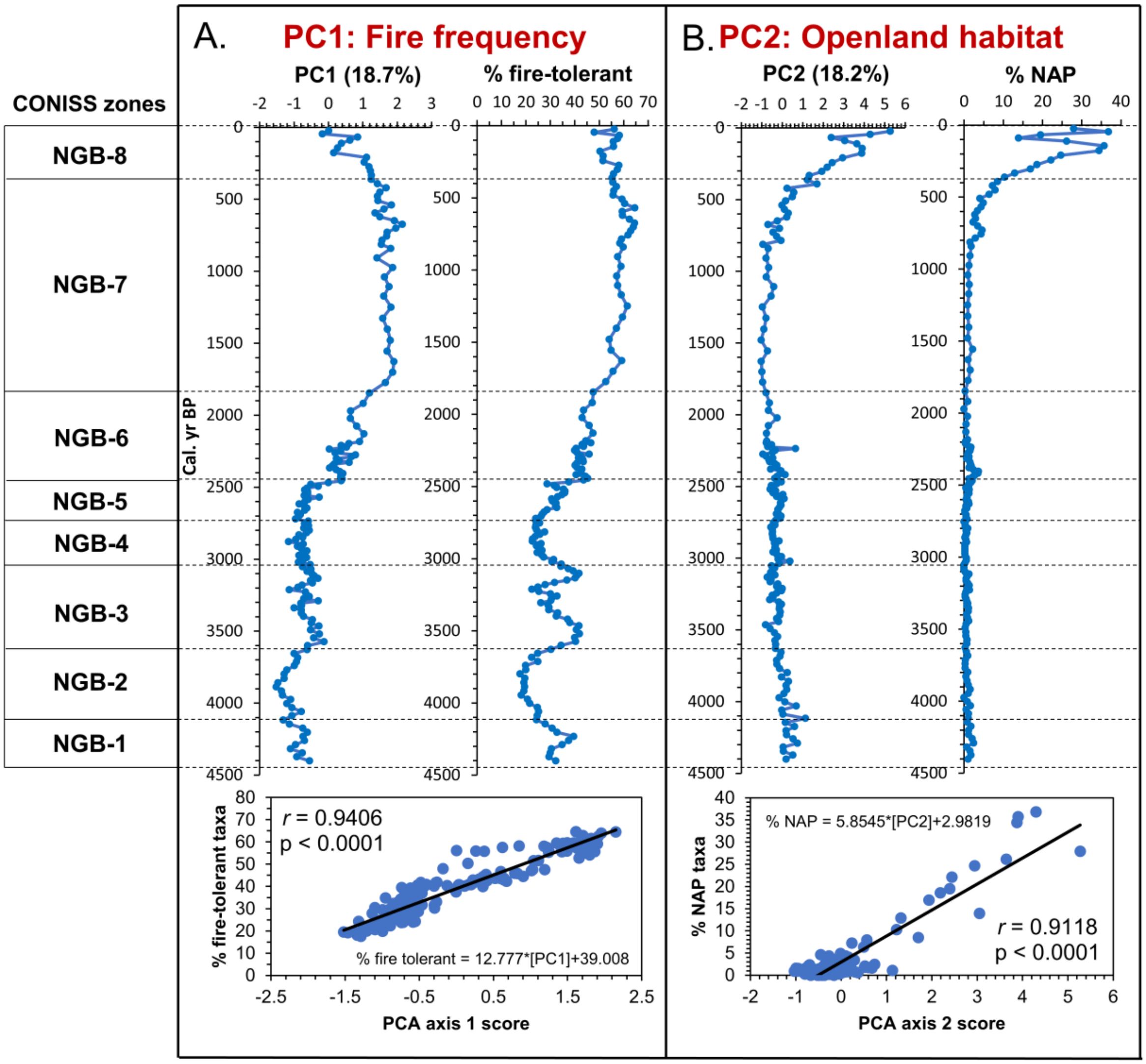

Figure 4.5. Paired comparisons between principal component analysis (PCA) factor scores for principal components PC1 and PC2 of the full NGB pollen spectrum, and associated pollen correlates. A. PC1 explains 18.7% of the total variance in the pollen data and is closely related to percent fire-tolerant arboreal taxa (*r* = 0.9406; p < 0.0001). B. PC2 accounts for an additional 18.2% of the total variance and closely tracks percent non-arboreal pollen (NAP) taxa (*r* = 0.9118; p < 0.0001).

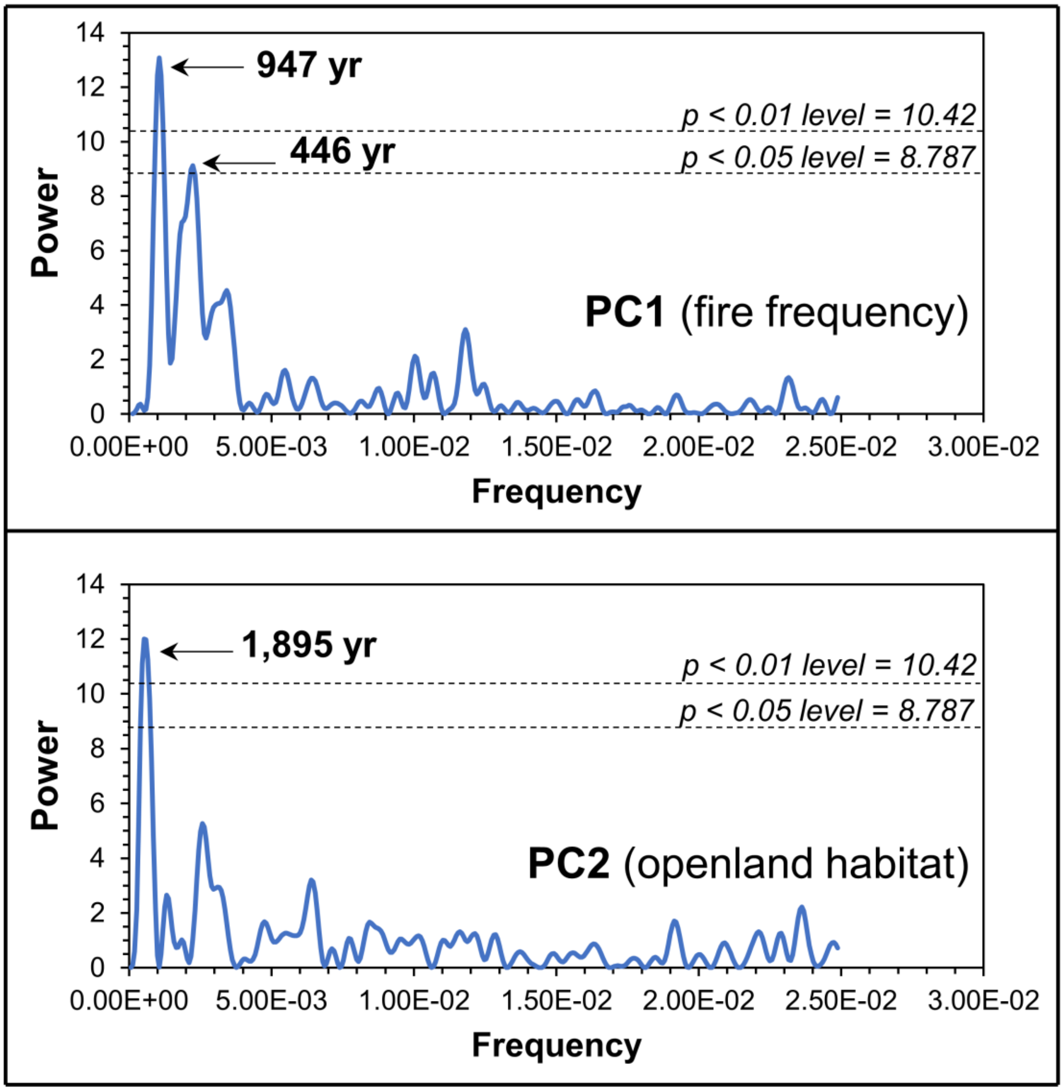

Figure 4.6. Time series analysis Lomb periodograms of principal component analysis (PCA) factor scores PC1 and PC2 for pre-2500 cal. yr BP NGB pollen data (see Figure 4.5). Dashed lines represent spectral power values at 0.01 and 0.05 significance levels, indicating the probability of peaks occurring randomly. A. PC1 (percent fire-tolerant arboreal taxa/fire frequency). B. PC2 (percent non-arboreal pollen [NAP] taxa/openland habitat).

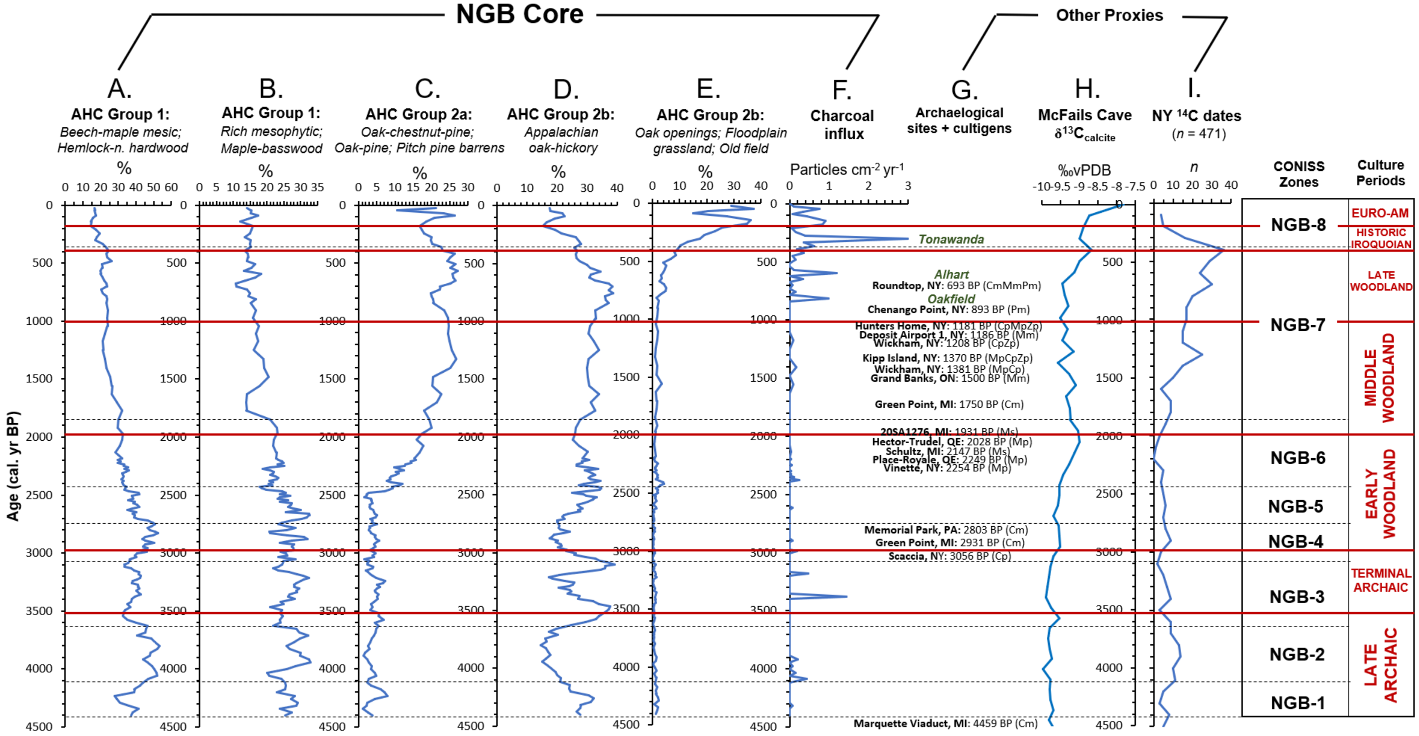

Figure 4.7. Chronology of major upland vegetation community types inferred for the NGB pollen record using indicator taxa derived from agglomerative hierarchical clustering (AHC) of historic vegetation data. A. AHC Group 1 (*beech-maple mesic/hemlock-northern hardwood forests*). B. AHC Group1 (*rich mesophytic/maple-basswood forests*). C. AHC Group 2a (*oak-chestnut-pine/oak-pine forests/pitch pine barrens*). D. AHC Group 2b (*Appalachian oak-hickory forest*). E. AHC Group 2b (*oak openings/floodplain grassland/successional old field*). F. NGB macroscopic sediment charcoal influx. G. Agricultural Iroquoian settlements within 30 km of the NGB coring site (in green). Dated Great Lakes and Northeast archaeological sites and associated cultigens. Prefixes represent cultigen taxa: C = cucurbit/squash (*Cucurbita* spp.); M = maize (*Zea mays*); P = bean (*Phaseolus vulgaris*); Z = wild rice (*Zizania aquatica*). Suffixes represent form of archaeological evidence: m = macrofossil; p = phytolith; s = starch. H. McFails Cave $\delta^{13}C_{calcite}$ record (van Beynen et al. 2004). I. New York State radiocarbon date frequency (*n* = 471; Martindale et al. 2016). CONISS pollen zones and major archaeological culture periods are shown at right.

2988 cal. yr BP) and NGB-5 (2671 – 2390 cal. yr BP) to maxima of ~55% (AHC Group 1a) and 30% (AHC Group 1b) during NGB-2 (4054 – 3530 cal. yr BP) and NGB-4 (2988 – 2671 cal. yr BP). AHC Group 1 pollen taxa subsequently undergo a steady decline during Zone NGB-6 (2390 – 583 cal. yr BP). Aside from a brief increase during Zone NGB-7 (583 – 112 cal. yr BP; LIA/Late Woodland – Historic Native American), this decline continues through most of the remainder of the Late Holocene, with mean values of ~20% (AHC Group 1a) and 15% (AHC Group 1b) near the top of the core (Post-LIA/Euro-American).

Conversely, xeric, fire-tolerant AHC Group 2a (*Appalachian oak-pine forest*; *oak-chestnut-pine forest*; *pitch pine-scrub oak barrens*; *pitch pine-oak-heath rocky summit*; *red pine rocky summit*; Figure 4.7C) pollen taxa maintain relatively low frequencies (range: 2 – 7%) through the first half of the NGB pollen record, suddenly rising at ~2200 cal. yr BP to 25% by 1100 cal. yr BP, with minor decreases at 900 – 700 cal. yr BP and at 350 – 100 cal. yr BP. A final increase is apparent from 100 BP (17%) to the present (26%). Pollen taxa of fire-tolerant AHC Group 2b (*Appalachian oak-hickory forest*; Figure 4.7D) exhibit a cyclical pattern of alternating maxima and minima during the early Late Holocene (4401 – 2390 cal. yr BP), but in an antiphase pattern to that seen in AHC Group 1. Minimum values (~18 – 20%) occur during Zone NGB-2 (4054 – 3530 cal. yr BP) and NGB-4 (2988 – 2671 cal. yr BP), with maxima (~35 – 40%) during Zone NGB-1 (4401 – 4054 cal. yr BP), lower (3600 – 3400 cal. yr BP) and upper (~3037 cal. yr BP) Zone NGB-3, and NGB-6 (2390 – 583 cal. yr BP). AHC Group 2a pollen values remain high for the majority of Zone NGB-7 but undergo a steady decline between 700 and 100 cal. yr BP to ~15%, increasing slightly (~22%) to the present.

Finally, AHC Group 2b (*oak openings*; *floodplain grassland*; *successional old field*; Figure 4.7E) pollen taxa maintain very low frequencies (<2%) for the first half of the Late Holocene (4401 – 2468 cal. yr BP), rising slightly during the latter portion of NGB-6 (2468 – 2076 cal. yr BP) to ~5%, and maintaining values from 2 – 5% for most of Zone NGB-7. Values increase slightly during terminal NGB-7 to ~7%, followed by a dramatic increase in Zone NGB-8 (post-500 cal. yr BP), attaining near-maximum values (~36%) from 177 – 144 cal. yr BP (1838 – 1871 CE). Thereafter, AHC Group 2b pollen taxa decline sharply during the 20th century CE but attain peak values for the entire NGB pollen record circa 1970 CE.

3.4. Archaeological context

The area within ~15 – 20 km of the NGB site was ephemerally occupied by Native American groups for the majority of the area's prehistory. Although no major villages or campsites are present within ~15 km of the bog (Figure 4.8), evidence of occasional human occupation at the NGB study site – undiagnostic surface lithic scatters – suggest transitory resource extraction from Oak Orchard Swamp (Butterbaugh 1984). The study area was peripheral to main centers of Iroquoian occupation during the Late Woodland period (~1000 – 400 cal. yr BP) and served historically as a buffer zone between the Seneca nation of the Genesee River Valley to the east and the Neutral nation to the west (Rayner-Herter 2001). The nearest agricultural Iroquoian villages to the NGB coring site (Figure 4.8) include: (1) the Oakfield sequence, occupied ~1200 – 1350 CE and situated 15 – 18 km to the southwest (Palmer-Niemczycki 1987; Rayner-Herter 2001); (2) the Alhart site, inhabited ~1450 – 1550 CE, and 14 km to the east (Ritchie 1930; Niemczycki 1984); and (3) Fort Hill LeRoy, unknown occupation dates, located 17 km to the

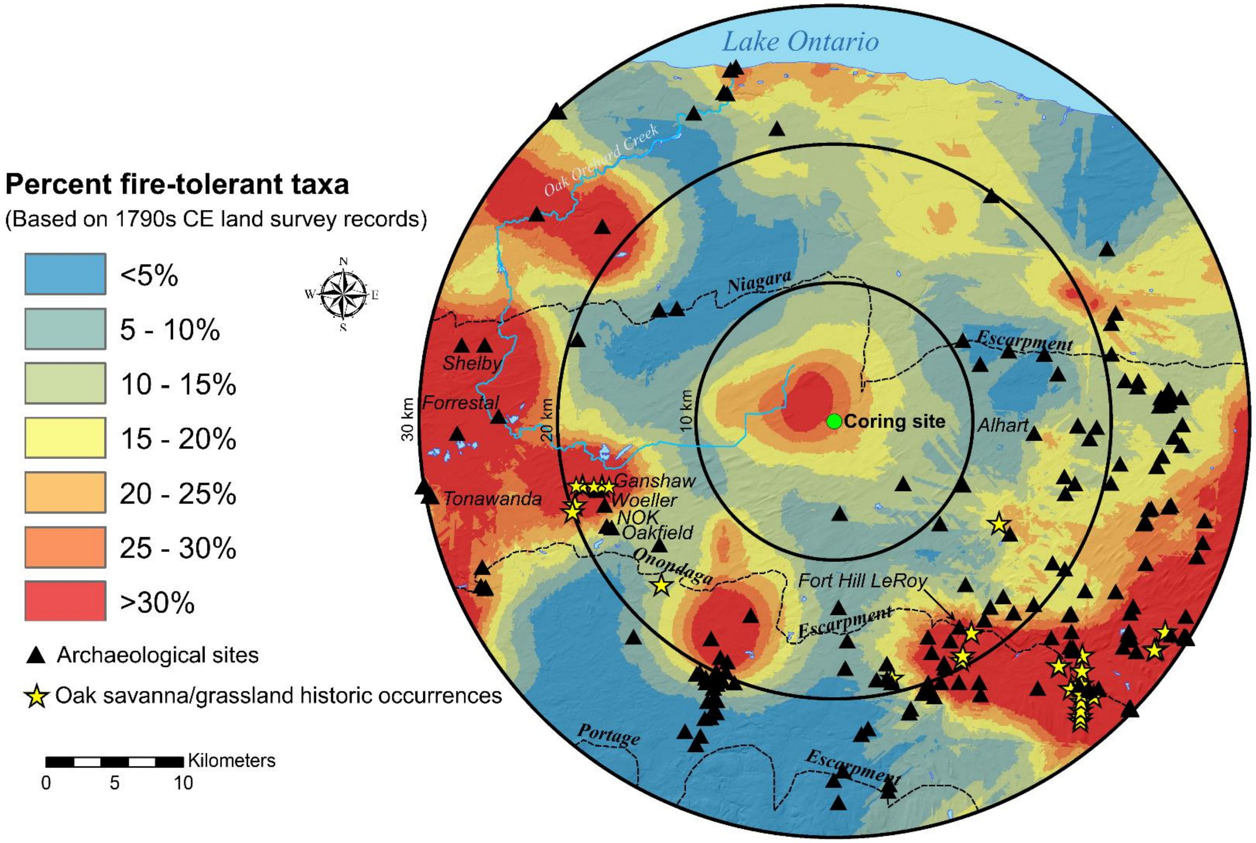

Figure 4.8. Percent frequency of fire-tolerant upland arboreal taxa and Native American archaeological sites (all culture periods; ~13,000 – 150 cal. yr BP; NYSM site file data) within a 30-km radius of the NGB coring site (green circle). Vegetation data compiled and digitized from Holland Land Company (HLC; this chapter), Phelps and Gorham Purchase (PGP; Chapter 2), and Connecticut Tract (this chapter) land survey record (LSR) data recorded during the late-18th century CE. Concentric black rings denote successive 10-km-radii. Note general congruence between archaeological site distribution and elevated frequencies of fire-tolerant forest taxa.

southeast (Niemczycki 1984). Additionally, major Iroquoian trails were located ~15 – 17 km to the north and south of the NGB coring site.

4. Interpretation and discussion

4.1. Vegetation dynamics pre-2500 cal. yr BP: quasi-cyclic climate modulation

The lower half (~4401 – 2443 cal. yr BP) of the NGB pollen record documents a quasi-cyclic, covarying relationship between fire-intolerant (e.g. *Acer*, *Fagus*, *Tsuga*) and fire-tolerant (e.g. *Quercus*, *Carya*, *Castanea*, and *Pinus*) upland forest taxa (Figure 4.4). This alternating pattern of the vegetation, reconstructed from the pollen record, suggests the importance of fire in local and landscape-scale vegetation dynamics and is strongly supported by the results of PCA. For instance, PC1 is very strongly positively correlated with percent fire-tolerant upland forest taxa ($r = 0.9406$; $p < 0.0001$; Figure 4.5A) and encapsulating the greatest percentage of the total variance (21.8%) in the NGB pollen record. The core's sediment charcoal record captures, to a somewhat lesser degree, the cyclicity of the pollen record, with evident peaks during periods of fire-tolerant taxa maxima (Figure 4.6A). Additionally, peaks in coarse sand are characteristic of periods showing increased charcoal influx and maxima of fire-tolerant taxa (Figure 4.3A), suggesting an integrated and consistent response of the local environment to changes in erosion, vegetation, and fire regimes.

I interpret the evident patterns from these proxies as the likely effects of variations in the regional climate during the early Late Holocene (~4400 – 2440 cal. yr BP). Specifically, periods of greater hydroclimate variability – i.e. more frequent alternation between drought and pluvial events (e.g. Booth et al. 2012) – would likely result in greater erosion of surface soils in upland areas surrounding the NGB coring site. Periods of erosion provided detrital minerogenic material to the basin, as reflected in the coarse sand peaks. Increased landscape instability would likely have been amplified as a consequence of decreased forest canopy cover, which would have provided favorable conditions for shade-intolerant taxa such as *Quercus*, *Carya, Castanea*, and *Pinus*. Increasing frequencies of these taxa – which are additionally fire-tolerant – in local and regional forests, thus likely reflects (1) more numerous open-canopy habitat, (2) more active fire regimes, as evidenced by higher charcoal influx values, and (3) more frequent and/or intense erosional events, some of which were likely a result of more numerous ground fires. Climate modulation of the local and regional vegetation in the lower half of the NGB pollen record is further supported by the prominent cyclic pattern seen in the PC1 (fire frequency) chronology (Figure 4.5A), with evident peaks at ~3400, 3000, 2500, and 2200 cal. yr BP.

4.2. Vegetation dynamics post-2500 cal. yr BP

4.2.1. Phase 1 (2500 – 800 cal. yr BP): forest compositional turnover and an emerging anthropogenic influence

The prominent, quasi-cyclic antiphase pattern in fire-tolerant versus fire-intolerant taxa evident in the lower portion of the NGB pollen record largely collapses beginning at ~2500 cal. yr BP (Figure 4.4). The subsequent period, extending until the MCA-LIA transition, is characterized by a steady decline in mesic, late-successional upland (*Acer saccharum*, *Fagus*) and lowland

(*Fraxinus*, *Tilia*, *Ulmus*) pollen taxa. This decline in fire-sensitive taxa is attendant upon a coeval increase in the pollen of several xeric, fire-adapted forest species, particularly *Pinus* (beginning at ~2400 cal. yr BP), *Castanea* (~2350 cal. yr BP), *Populus* (~1800 cal. yr BP), and *Quercus* (~1800 cal. yr BP). A minor increase is also evident at ~2500 cal. yr BP in the frequency of certain NAP taxa, particularly Poaceae and Cyperaceae (Figure 4.4). Other proxy indicators of this transition toward fire-adapted vegetation include slightly higher charcoal influx values (starting at ~2400 cal. yr BP), less variable terrigenous and coarse sand input (~2200 BP), and more enriched $\delta^{13}C_{OM}$ values (~1700 cal. yr BP). Collectively, these trends suggest a unidirectional trajectory towards more active fire regimes, moderate levels of ambient erosional input, more numerous openland habitats, and an increase in C_4 vegetation on the landscape commencing at ~2500 cal. yr BP.

Interestingly, the regional archaeological record indicates that maize (*Zea mays*) was present in upstate New York by ~2275 cal. yr BP (Figure 4.7G; Hart et al. 2007) and began to appear more commonly in archaeological assemblages by ~1500 cal. yr BP (Hart and Brumbach 2005). The period beginning ~2500 cal. yr BP is also generally coeval with the earliest appearance of maize across much of the Northeast and Great Lakes region (Hart and Lovis 2013). The prominent response of local and regional forests beginning at ~2500 cal. yr BP, as interpreted from the NGB pollen record, may be a result of changing Middle Woodland (~2000 – 1000 cal. yr BP) settlement and subsistence patterns. Cultural innovations occurring during this period, as reconstructed from the archaeological record, include: (1) increased sedentism, (2) more frequent use of fire as a landscape management tool, and (3) incipient horticulture, as inferred from the regional archaeobotanical record (e.g. Asch Sidell 2008). The NGB pollen and charcoal records may reflect these cultural developments, as increases in fire-tolerant arboreal taxa (Figure 4.6A), associated vegetation community types (Figure 4.7C, 4.7D, 4.7E), and charcoal influx (Figure 4.7F) are consistent with more frequent, low-intensity ground fires that may have arisen in deliberate or accidental anthropogenic ignitions.

Notably, although charcoal influx became less episodic after ~2500 BP, total charcoal fragment concentrations were still very low (<10 pieces cm^{-3}). Moreover, NAP taxa frequencies were also relatively low during this time (2 – 3%) but were nevertheless higher than during the first half of the NGB pollen record (~1%). This suggests that more active, anthropogenically-enhanced fire regimes postdating 2500 cal. yr BP may have been sufficient to promote a shift toward greater fire-tolerant arboreal taxa in local forests, but fire frequency and/or intensity was still inadequate to facilitate the proliferation of openland habitats such as oak savanna. The overproduction of pollen grains by most arboreal taxa, compared to herbaceous (NAP) taxa, can mask important landscape-scale changes during periods of rapid environmental change, such as shifts in ecotone boundaries or the expansion of such boundaries, resulting from canopy thinning and forest fragmentation.

Importantly, archaeological radiocarbon dates become more numerous after ~2000 cal. yr BP (Figure 4.7I), and markedly so after ~1500 cal. yr BP, suggesting population growth of regional Native American populations during this interval. The simultaneous decline in fire-sensitive, moist upland forest communities (e.g. *beech-maple mesic, hemlock-northern hardwood*) and expansion of fire-adapted, dry upland forest types (*oak-chestnut-pine*; *Appalachian oak-hickory*) is thus consistent with an increasing human population utilizing forested ecosystems in more intensive ways than did previous groups.

4.2.2. Phase 2 (~800 – 210 cal. yr BP): NAP increase, Quercus decline, and an Iroquoian land-use interpretation

The NGB pollen record from ~800 to 210 cal. yr BP, a period broadly coinciding with the transition from the Medieval Climate Anomaly (MCA; ~1115 – 665 cal. yr BP [~900 – 1350 CE]; Booth et al. 2012) to the Little Ice Age (LIA; ~665 – 100 cal. yr BP [~1350 – 1850 CE]; Mann et al. 2009), and which overlaps with the upper half of Zones NGB-7 and the lower portion of NGB-8. This phase is coeval with the regional appearance of agricultural Iroquoian populations in northwestern New York State (Rayner-Herter 2001). Although not differentiated as a single CONISS pollen zone, upon closer examination, there is a definite correlation between archaeological and pollen data that are visible as minor branches in the dendrogram spanning the upper part of Zone NGB-7 and the lower segment of Zone NGB-8 (Figure 4.4). In particular, this phase is characterized by three prominent events, each suggesting important changes to local- and landscape-scale vegetation composition and structure: (1) a dramatic increase in the frequency of herbaceous, non-arboreal pollen (NAP) taxa, (2) a dramatic and coeval rise in charcoal influx, and (3) a prominent decline in *Quercus* pollen.

4.2.2.1. Increased NAP taxa and accelerated charcoal influx

Prior to ~800 cal. yr BP, the temporal trend in NAP taxa frequencies indicates general inertia (Figure 4.4), suggesting the relative scarcity of openland habitats – oak savanna, grassland, and successional old fields – near the NGB coring site. Very low frequencies of herbaceous taxa in the NGB pollen record prior to 800 cal. yr BP suggest that such open-canopy ecosystems most likely existed as small, geographically discontinuous inclusions on sites having the greatest moisture stress and highest incidence of natural fires, such as bedrock escarpments or sandy outwash and deltaic deposits (Fulton, unpublished data). In contrast, European and Euro-American observers during the mid- and late-18th century CE noted that "oak openings" were a prominent feature of the western New York landscape (Cook 1887). These communities were often described in the historical literature and LSRs as "tall grass" or "openings grass," most likely a reference to several fire-tolerant, warm-season C_4 grasses, such as *Andropogon gerardii*, *Schizachyrium scoparium*, and *Sorghastrum nutans* (Shanks 1966).

The discrepancy between (1) the historic abundance of oak savanna communities and (2) their evident rarity only six centuries earlier, raises an important question as to how such a transformation of the regional vegetation had occurred. Clifford and Booth (2015) noted a regional increase in sediment charcoal accumulation rates at peatland sites in portions of the northeastern United States between 500 – 600 cal. yr BP and attributed this increase in fire frequency and/or severity to changes in hydroclimatic variability associated with the MCA – LIA transition. Climate variability at the MCA – LIA transition may have played a role in the sharp rise of NAP taxa visible in the NGB pollen record during this time. However, earlier perturbations identified in the core – which were clearly linked to cyclic increases in the frequency of fire-tolerant pollen taxa (as during the MCA – LIA transition) – were not characterized by abundant sediment charcoal in the NGB core. Rather, charcoal influx values prior to ~800 cal. yr BP generally mirror the NAP record and are very low in absolute magnitude and sporadic. This suggests the overall rarity of fires in the forests surrounding the bog during much of the Late Holocene (Figures 4.4, 4.7F).

Assuming that climate forcing was of a similar character during previous vegetation shifts and the MCA – LIA transition, each event should reasonably have triggered similar responses in vegetation composition and fire regimes. However, the exceptional vegetation and fire conditions of the MCA – LIA transition – exponential increase in NAP taxa and the highest charcoal influx values of the previous 4000 years – were more likely the result of agricultural Iroquoian land-use practices enhancing naturally low fire regimes characteristic of mixed deciduous-coniferous forests. An anthropogenic explanation would therefore more reasonably account for the apparent synchronization of vegetation and fire after Iroquoian incursion at ~800 cal. yr BP.

In Chapters 1 and 2, my analyses of late 18th century CE land survey records (LSRs) of central and western New York State revealed an especially strong spatial relationship between the distributions of Iroquoian settlements and fire-tolerant forest taxa (e.g. *Quercus*, *Pinus*, and *Carya*) and openland habitats (described in the LSRs as “plains,” “clear land,” “open land,” and “thinly timbered”). The inferred association between Native American populations and fire-adapted vegetation is supported by abundant ethnohistorical data. Indigenous groups are known to have actively cleared forests for village construction, preparation of cropland, and firewood collection (Abrams and Nowacki 2008). Additionally, fire was utilized for hunting game (Turner 1850), removing deadwood (van der Donck [1655] 2008), roasting chestnuts prior to collection (Parr 2003), propagating economically-desirable plant taxa (Williams 2000), and, more broadly, managing landscapes to promote wild game populations (Abrams and Nowacki 2008). Importantly, the exponential increase in NAP taxa and sharp rise in charcoal influx in the NGB core from ~800 – 200 cal. yr BP is contemporaneous with important cultural events occurring throughout much of upstate New York and adjacent southern Ontario (Birch 2015), including: (1) settlement nucleation of smaller villages into large, aggregate communities; (2) increase in village areal extent; (3) abandonment of floodplain locales for defensible upland sites; and (4) the appearance of large, multi-generation longhouses.

It is therefore reasonable to infer, based upon ample historical and archaeological evidence, that Native American land-use practices were likely related to the sudden increase in both NAP taxa frequency and charcoal influx observed in the NGB pollen record beginning at ~810 cal. yr BP. This date closely coincides with the arrival of an Iroquoian population at the Oakfield site complex, a series of four summer agricultural villages occupied sequentially between ~815 and 665 cal. yr BP (~1200 – 1350 CE) and situated ~18 km west of the NGB coring site (Figure 4.8; Palmer-Niemczycki 1987). Prior to Iroquoian incursion, NAP percentages were low: 1.6% at 810 cal. yr BP, rising to 4.3% by 760 cal. yr BP (Figure 4.7G), coeval with occupation by the Oakfield population (Palmer-Niemczycki 1987). NAP values subsequently fall with the abandonment of the Oakfield settlements, declining to 2.4% by 680 cal. yr BP (Figure 4.7E).

A similar response is seen during the establishment of a subsequent Iroquoian village at the Alhart site, which was occupied between ~570 and 470 cal. yr BP (~1450 – 1550 CE) and situated ~14 km due east of the NGB coring site (Figure 4.8; Niemczycki 1984). NAP values rise from 2.4% at 680 cal. yr BP to 4.6% by 570 cal. yr BP. Attendant upon these spikes in NAP taxa are coeval peaks in charcoal influx values: 0 pieces cm^{-3} yr^{-1} at 810 cal. yr BP to 1.0 pieces cm^{-3} yr^{-1} by 760 cal. yr BP; 0 pieces cm^{-3} yr^{-1} at 620 cal. yr BP to 1.2 pieces cm^{-3} yr^{-1} by 600 cal. yr BP; Figure 4.7F), suggesting that (1) local ignitions may have been a direct result of Oakfield and Alhart populations setting fires near the NGB coring site, and (2) the bog was well within the subsistence catchment (a.k.a. "silvicultural patch"; Muñoz, Mladenoff, Schroeder, and Williams 2014) of both Iroquoian groups.

4.2.2.2. *Quercus* decline

An unusual, and previously unrecognized, correlate of the increase in NAP taxa during Zone NGB-7 is a corresponding sharp decline in *Quercus* pollen after ~700 cal. yr BP. Fire-tolerant pollen taxa began to decrease as a whole after 700 cal. yr BP, from 64% at 680 cal. yr BP to 51% by 240 cal. yr BP (Figure 4.4), which may represent an effect of LIA cooling on the regional vegetation (as suggested by Muñoz and Gajewski 2010). However, *Quercus* pollen percentages registered the steepest decline of all fire-tolerant taxa, falling precipitously from a high of 34% at 760 cal. yr BP to 17% by 210 cal. yr BP, a net loss of nearly 50%, that cannot be accounted for by climate change alone.

In Chapter 2, I noted that Late Woodland (1000 – 400 cal. yr BP [1000 – 1600 CE]) and Historic (400 – 200 cal. yr BP [1600 – 1800 CE]) Seneca/Iroquoian villages in the Finger Lakes region of west-central New York State tended to be situated in areas of dry upland forest dominated by various species of *Quercus* and *Carya*. The prominent decline in *Quercus* pollen and simultaneous rise in NAP taxa beginning at ~800 cal. yr BP could reasonably be a consequence of preferential Iroquoian settlement in areas with high frequencies of dry upland forest – which likely contained abundant nut- and berry-producing species – followed by their progressive clearing, thinning, and/or burning. Over time, the more frequent application of human-set fires within an already fire-prone, *Quercus*-dominated vegetation community type would have likely encouraged the expansion of oak savanna and grassland ecosystems, and consequently the expansion of herbaceous taxa, at the expense of closed-canopy arboreal species. Open-canopy conditions – often described in late-18th century CE LSRs (see Chapters 2 and 3) as “thinly timbered” or “lightly timbered” sites – were the most common form of disturbance in the forests of western and central New York prior to Euro-American settlement (Fulton, unpublished data).

Notably, open-canopy conditions were likely to have been maintained indefinitely at certain locales by later Native American groups setting periodic fires at preexisting openland sites, whether naturally occurring oak savannas or abandoned village sites. This interpretation is suggested in the NGB pollen record, based upon the exponential increase in NAP taxa during Zone NGB-8 (Figure 4.4), with values climbing from 6.6% at ~480 cal. yr BP (1535 CE) to 25% by the time of initial Euro-American occupation circa 210 cal. yr BP (1805 CE). Notably, the basal portion of this zone (~360 – 240 cal. yr BP [~1653 – 1773 CE]) is associated chronologically with historic Native American groups, such as the Seneca nation (Engelbrecht

2003). The Seneca – whose original tribal territory encompassed the Genesee River Valley and western Finger Lakes region immediately east of the NGB coring site – displaced indigenous Iroquoian groups (the Erie and Neutral nations) of far-western New York State during the mid-17th century CE. The conquered lands were subsequently annexed by the Seneca for settlement, subsistence, and military purposes (Parmenter 2010). For example, the Seneca established the village of Tonawanda – situated ~30 km due west of the NGB coring site – during the early – middle 18th century CE (Hauptmann 2011), and Seneca land-use activities associated with territorial expansion and village establishment during this period may account for the continuous increase in both NAP taxa and charcoal influx in the NGB core (Figures 4.4, 4.7).

This hypothesis of Seneca perpetuation of earlier land-use practices is reinforced by late-18th century CE LSR-derived vegetation data near the study site. Specifically, survey records indicate the presence of open "plains" surrounded by forests of *Quercus alba*, *Quercus rubra/velutina, Carya* spp., and *Pinus strobus* in the immediate vicinity (<2 km) of the Oakfield site complex at 220 cal. yr BP (1799 CE; Fulton unpublished data; see Figure 4.8). These fire-adapted (oak savanna) and fire-tolerant (*Quercus* forest) ecosystems would normally have reverted to late-successional *Acer saccharum–Fagus grandifolia* forest after five centuries of abandonment and fire exclusion (Nowacki and Abrams 2008). Hence, the existence of fire-tolerant vegetation at the site would be highly unlikely given that the Oakfield-phase village sites were situated on silty ground moraine (Muller 1977), which otherwise supported mesic taxa (e.g. *Acer saccharum, Fagus grandifolia*, *Tsuga canadensis*). Lacking an edaphic or climatic explanation for this anomaly, I reason that Seneca land-use practices were more likely responsible for maintaining open savanna conditions, through the intentional setting of fires (Figure 4.8). This has important ramifications for both paleoecological and historical ecological studies of human-environment interactions, as successive populations were capable of producing cumulative legacy effects on the landscape that were visible historically and are likely contained within the paleoecological record.

4.3. Redefining the temporal and spatial dynamics of Native American land-use impacts

Several LSR-based analyses of the historic vegetation of the lower Great Lakes region (e.g. Black et al. 2006; Tulowiecki and Larsen 2015; see Chapters 2 and 3) have noted a strong correspondence between the location of Late Woodland and Historic Iroquoian settlements and the distribution of several fire-tolerant arboreal and mast taxa. Going further, Black et al. (2006) and Tulowiecki and Larsen (2015) suggested that agricultural Iroquoian populations were largely responsible for shifting forest species composition toward higher frequencies of fire-tolerant taxa, particularly those mast species important to aboriginal subsistence economies (Wykoff 1991; Abrams and Nowacki 2008).

However, the present study, based upon chronological trends in the NGB pollen data, has revealed that a major transition in forest species composition antedated the emergence of fully agricultural Late Woodland societies by ~1000 years. Upon examination of the 4400-year pollen record contained at the site, it appears that agricultural Iroquoian populations did not effect a landscape-scale transformation of regional forests toward a greater frequency of fire-tolerant taxa. Rather, this transformation was initiated during the terminal Early Woodland period (~2500 cal. yr BP) and was largely complete by the latter half of the Middle Woodland period (~1500 –

1000 cal. yr BP). A curious phenomenon noted in the NGB core is the prominent high-frequency variability in many pollen taxa, LOI, and $\delta^{13}C_{OM}$ values during Zones NGB-3, NGB-4, NGB-5, and the lower half of NGB-6 (~3500 – 2200 cal. yr BP; Figures 4.3, 4.7). This rapid alternation in proxy values is suggestive of environmental instability, with local ecological systems fluctuating in response to sudden changes in underlying modulators. A possible explanation for this pattern may rest in anthropogenic land-use activities associated with the appearance of Early Agricultural Complex (EAC) cultigens in upstate New York during this time (Asch Sidell 2008). This hypothesis, though speculative, awaits further testing and verification.

Although Iroquoian land-use practices doubtlessly facilitated similar forest compositional changes, taxonomic shifts toward greater frequencies of fire-tolerant forest species probably occurred primarily at a local scale, developing as patches of disturbance within a larger matrix of fire-sensitive species. Evidence of a spatially constrained transformation of this type was noted in the LSR analysis of Chapter 2. Upland vegetation in close proximity (<5 km) to 18th century CE Algonkian-speaking Lenape villages on the Appalachian Plateau in the Phelps and Gorham Purchase (PGP) consisted overwhelmingly of fire-tolerant *Quercus* spp., *Carya* spp, *Castanea dentata*, and *Pinus strobus*. Beyond this 5-km zone, the upland vegetation reverted to fire-intolerant *Acer saccharum*, *Fagus grandifolia*, and *Tsuga canadensis*. This locale lacks archaeological evidence of earlier, agricultural or pre-agricultural populations (NYSM site file data), hence the notable contrast in vegetation was likely due to land-use practices of the Lenape population upon settlement of the area.

The close spatial relationship noted by LSR-based studies between Iroquoian villages and fire-tolerant forest taxa (see Chapters 1 and 2) may have resulted from an Iroquoian preference to settle in areas previously inhabited by Early and Middle Woodland populations. In such continuously-occupied areas (e.g. the boundary between the Lake Ontario Lowland and Appalachian Plateau), forests had likely experienced the greatest compositional turnover between 2500 and 1000 BP, with fire-tolerant taxa representing the dominant arboreal component within local forests. Iroquoian populations may have found such areas more amply supplied with economically desirable biotic resources, possessing more numerous ecotones, and therefore capable of sustaining higher human population densities than densely-forested sites. Archaeological site location data from western New York State in fact suggest considerable geographic continuity between Early, Middle, and Late Woodland populations (NYSM site file data). The scenario proposed above is provisionally supported by the regional LSR data (see Chapters 2 and 3) and the paleoecological data from the NGB coring site (this chapter). Additional analyses of prehistoric and historic archives of environmental change within the broader study area are required to verify and refine this hypothesis.

5. Conclusions

The present study revealed a distinct division of the Late Holocene paleoecological record (based upon pollen, charcoal, LOI, and $\delta^{13}C_{OM}$ proxies) at the NGB coring site into three prominent phases prior to Euro-American settlement. These include an initial period (~4400 – 2500 cal. yr BP) of climate modulation of vegetation and fire, followed by two separate, but related phases documenting an emerging anthropogenic influence (~2500 – 800 cal. yr BP), and culminating in the appearance of a distinctly cultural landscape associated with agricultural Iroquoian societies (~800 – 210 cal. yr BP). The NGB coring site, although situated in an area that was generally marginal to main centers of human population during much of the Late Holocene, was nevertheless positioned as to capture important local- and landscape-scale fluctuations in vegetation composition and structure, fire regimes, and landscape stability. The site's sensitivity to wider environmental changes – most importantly, a mounting regional anthropogenic influence – enabled the temporal reconstruction of key biotic and abiotic responses from a dominantly climate-modulated pattern to a distinctly human-modulated one. This regime shift is provisionally assigned to a date of ~2500 cal. yr BP and is consistent with independent records of coeval cultural and environmental transitions.

These paleoenvironmental events recorded at the NGB coring site were largely modulated by quasi-cyclic climate change during the earlier portion of the pollen record (~4400 – 2500 cal. yr BP). The characteristic response of the local vegetation during this interval was an alternation between dominance by fire-tolerant and fire-intolerant forest taxa. Phases of fire-tolerant domination were generally accompanied by increased erosion (enhanced terrigenous and coarse sand influx), and possibly a heightened prevalence of drought and/or fire, although the sediment charcoal record is equivocal, as charcoal is generally uncommon in the core. Conversely, periods of dominance by fire-intolerant pollen taxa are associated with decreased terrigenous input and increased OM, suggesting greater available moisture and possibly reduced fire frequency. As regional human populations during this interval were comprised of hunter-gatherer groups possessing high residential mobility, and overall populations were likely small, as inferred from the relatively low number of archaeological radiocarbon dates occurring during this time, anthropogenic impacts on vegetation, fire regimes, and landscape processes were conceivably minimal during the early Late Holocene.

Beginning at ~2500 cal. yr BP, the quasi-cyclic pattern collapses and is replaced by an extended period of landscape stability during which fire-tolerant pollen taxa increase progressively at the expense of fire-intolerant ones for the succeeding 1700 years. Forest community types dominated by mesic, late-successional taxa (*beech-maple mesic*, *hemlock-northern hardwood*, *rich mesophytic*, *maple-basswood*) experienced steady declines, being replaced by fire-adapted types (*oak-chestnut-pine*, *oak-pine*, *pitch-pine barrens*, *Appalachian oak-hickory*). Evidence for relatively dry conditions (low sedimentation rates), somewhat higher prevalence of fire (continuous charcoal deposition), less variable ambient erosion (stable terrigenous and coarse sand deposition), more numerous openland habitats (slight increase in NAP taxa), and a greater proportion of C_4 vegetation on the landscape (enriched $\delta^{13}C_{OM}$ values), together suggest a novel combination of an incremental shift toward more active disturbance regimes (e.g. fire) superimposed upon indicators of overall climate stability.

In the cultural sphere, the period after ~2500 cal. yr BP is associated with the earliest appearance of maize in the archaeological record of the Northeast and Great Lakes regions. The increasing visibility of this tropical cultigen at regional archaeological sites post-2500 cal. yr BP parallels the step-like pattern toward a more open landscape containing a continuously-increasing amount of fire-tolerant forest taxa in the study area. Archaeological radiocarbon date frequencies experience a minor increase after 2100 cal. yr BP, followed by a more dramatic rise at ~1500 cal. yr BP, indicating growth of the regional human population. A larger, more sedentary resident population practicing forms of incipient horticulture likely placed greater demands on local forest resources. Clearing of vegetation for garden plots and the more intensive (and extensive) use of fire as a landscape management tool probably account for the environmental changes recorded in the NGB core's proxy records at this time. The progressive trends seen in the pollen of fire-tolerant forest and NAP taxa and charcoal influx are mirrored in the archaeological radiocarbon record and the $\delta^{13}C_{calcite}$ values from McFails Cave, indicating that these trends were not localized to the immediate NGB coring site, but were regional in scope.

The final period from ~800 – 200 cal. yr BP witnessed the dramatic expansion of NAP taxa, the sudden decline of *Quercus* pollen, a surge in charcoal influx, and distinct increases in minerogenic deposition. Together, these indicate a relatively open landscape, more numerous fires, and accelerated landscape instability. These changes were likely triggered by the appearance of agricultural Iroquoian populations in the region, whose land-use practices entailed the habitual use of fire, clearing of extensive tracts of forest for village construction and establishment of cropland, and thinning of stands from firewood collection and acquisition of construction materials. Although no Iroquoian settlements are known from within a ~14-km radius of the NGB coring site, and unequivocal evidence of maize agriculture – i.e. cultigen pollen – was not evident in the NGB pollen record, other indicators of Iroquoian presence were noted in the core. For example, peaks in sediment charcoal and NAP taxa correspond closely to the temporal sequence of Late Woodland village occupation within 14 – 18 km of the bog.

The strong proxy indicators of vegetation and fire regime changes in the NGB core likely result from: (1) its position downwind of major centers of Iroquoian occupation, with resulting deposition of an extra-local component of wind-dispersed, disturbance-related palynomorphs (e.g. NAP taxa, *Pinus*); and (2) the coring site was within the subsistence catchment of several agricultural villages during the Late Woodland period, with archaeological evidence of human presence at the site lacking at the present time. In this instance, the pollen, charcoal, and sedimentological signals of disturbance would probably represent silvicultural land-use practices taking place in close proximity to the NGB coring site.

The results of this study suggest that non-agricultural Native American land-use practices can be detected in the paleoecological record even at lacustrine and peatland coring sites located beyond the normal agricultural zone (typically <5 – 6 km; see Chapters 2 and 3) of Iroquoian villages. Nevertheless, because of several distinct cultural features characteristic of Northern Iroquoian societies – large, semi-permanent villages, high population densities, intensive maize agriculture, and a penchant for territorial expansion – proxy indicators of anthropogenic disturbance likely reflect culture-specific land-use patterns that produced enduring effects on the local and regional landscape. Such effects may not be the norm in other culture areas of prehistoric and historic eastern North America (e.g. Algonkian groups of New England), where high residential mobility, lower population densities, and less intensive maize agriculture were the norm. Future paleoecological studies of Native American land-use impacts must take into account the cultural context of indigenous populations as well as critical spatial variables – distance of prospective basins from archaeological sites, their orientation with respect to prevailing winds and foci of settlement – in selecting potential coring sites. Paleocological proxies derived from carefully chosen lacustrine and peatland sites, when used in conjunction with archaeological site locations and historical vegetation data derived from LSRs, have the potential to refine existing knowledge regarding the nature, chronology, and spatial dynamics of prehistoric Native American land-use impacts on forested ecosystems.

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CHAPTER 5. CONCLUSION

This dissertation contributes to a growing body of historical, ecological, and paleoecological data indicating that prehistoric and historic Native American populations exerted an important influence on forest composition and landscape conditions in northeastern North America in the centuries prior to European contact and subsequent Euro-American incursion. Collectively, the studies contained in this dissertation provide an integrated methodological and temporal approach that assessed the probable nature and timing of Native American land-use practices on local and regional environments during the Late Holocene.

As the main objective of this dissertation was to answer each of the three main questions posed in Chapter 1, it is necessary to revisit these questions and evaluate the relative success of the research presented herein in achieving this goal.

Question #1 – How do ADI signals reflect changes in subsistence and settlement patterns during the transition from hunting-foraging to agricultural subsistence economies during the late Holocene?

Proxy data from the New Guinea Road Bog (NGB) peatland site (Chapter 4) indicate a division of the site's ~4500-year-long paleoecolgical record into two main phases. The first (~4400 – 2500 cal. yr BP) was characterized by centennial-scale fluctuations in fire-tolerant versus fire-intolerant taxa and other proxy indicators, most notably terrigenous matter and coarse sand. These fluctuations possessed a periodicity of ~500 – 600 years, with a complete cycle occurring in ~1000 – 1200 years between major peaks. I hypothesized that the cyclicity likely reflects solar forcing of atmosphere-ocean feedbacks that influenced hydroclimatic variability. The second phase (~2500 – 200 cal. yr BP) represented a period of waning climate cyclicity and an emerging anthropogenic (Native American) modulation of vegetation (changes in the frequencies of major pollex taxa) and landscape dynamics (e.g. increased prevalence of fire, greater erosion).

This phase can be further subdivided into two distinct sub-units: a period of nascent horticultural land-use impacts (~2500 – 800 cal. yr BP) associated temporally with the regional introduction of *Zea mays* and the diffusion of cultigens. Local and regional forests experienced a first-order turnover in species composition toward progressively greater frequencies of fire-tolerant taxa (arboreal ADIs such *Quercus*, *Castanea*, *Pinus*, *Populus*), indicating more active fire regimes. The second sub-unit is coeval with the appearance of fully agricultural Iroquoian populations at the nearby Oakfield (~1200 – 1350 CE) and Alhart (~1450 – 1550 CE) sites. Evidence of Iroquoian land-use patterns is best attested during this time in the NGB core by the sharp decline in *Quercus* pollen and exponential rise in non-arboreal pollen (NAP) ADI taxa. This trend was hypothesized in Chapter 4 as being the result of active forest clearing and thinning for village construction, establishment of maize fields, and firewood collection. This interpretation was supported by evidence from late-18th century CE LSR data indicating elevated frequencies of fire tolerant forest taxa and remnant oak savanna (“plains”) near the Oakfield site complex. Similarly, a buried maize cache at the Alhart site, analyzed by archaeologists, was lined with *Sorghastrum nutans*, a warm-season C_4 grass typical of oak savanna habitats. Thus, there exists strong supporting evidence that fire-adapted openland habitats were within the subsistence catchment of these archaeological sites, and historical data confirm the presence of numerous “oak openings” throughout the dissertation study area.

Question #2 – Can anthropogenic signals be differentiated from non-cultural (i.e. "natural") indicators in the paleoecological record, most importantly climate?

The prominent cyclicity observed in the lower portion of the NGB core (pre-2500 cal. yr BP) was the clearest indicator of predominant climate modulation of vegetation near the coring site (Chapter 3). The collapse of this high-frequency, alternating pattern of pollen taxa dominance (fire-tolerant versus fire-intolerant taxa) at ~2500 cal. yr BP initiated a state change in which pollen trends were unequivocally unidirectional for the first time in the NGB paleoecological record. This time phase was broadly coeval with the earliest appearance of *Zea mays* in the regional archaeological record (at 2275 cal. yr BP). Subsequent climate perturbations such as the Medieval Climate Anomaly (MCA; ~1150 – 500 cal. yr BP) and the Little Ice Age (LIA; ~500 – 100 cal. yr BP), exhibited profound differences from pre-2500 cal. yr BP climate excursions, most notably in the greater prevalence of sediment charcoal and very high frequencies of NAP pollen during the MCA and LIA. I attribute this to the compounding effect of Iroquoian land-use practices on the local and regional vegetation producing a far more open landscape where fire-tolerant forest community types were locally dominant in areas of persistent Native American settlement and subsistence patches. Locales having elevated frequencies of fire-tolerant taxa identified in the LSR data (Chapters 2 and 3) could therefore serve as spatial reference points for future archaeological reconnaissance efforts.

Question #3 – Can data from historical ecology inform the analysis and interpretation of paleoecological data, and vice versa?

The spatial and statistical analyses of vegetation data derived from late-18th century CE land survey records (LSRs) presented in Chapters 2 and 3 employed several methodological innovations that simultaneously improved the quality of the resulting ordinations and facilitated their incorporation into the paleoecological component of this dissertation (Chapter 4). To begin, the LSR studies explicitly utilized structural (i.e. qualitative descriptions of vegetation form and appearance) rather than solely conventional bearing tree data. This resulted in the generation of more detailed, ecologically meaningful ordinations: non-metric multidimensional scaling (NMS; Chapter 2) and detrended correspondence analysis (DCA; Chapter 3). Importantly, both ordination techniques produced results showing similar environmental gradients containing the largely the same taxa in geographically separate, yet adjacent, study areas. These gradients were related to fire frequency, soil productivity, and anthropogenic land-use practices (most likely canopy thinning and forest clearance).

The overwhelming importance of these gradients is attested in their collective explanation of the total variance in the respective LSR datasets. In the Phelps and Gorham Purchase (PGP; Chapter 2; territory of the Seneca nation), NMS axis 1 (fire frequency) explained 53.7% of the total variance, with NMS axis 2 (soil productivity) accounting for 22.6%, and NMS axis 3 (Native American land-use) a further 15.9%, representing 92.2% of the total variance. Similarly, in the adjacent Military Tract (MT; Chapter 3; territory of the Cayuga and Onondaga nations), DCA axis 1 (fire frequency) explained 51.5% of the total variance in the vegetation data, DCA axis 2 (soil fertility) an additional 3.6%, and DCA axis 3 (canopy disturbance) 6.5%, resulting in a total of 61.6% variance explained. The greater proportion of variance explained by the NMS analysis for the PGP LSR data may be a consequence of (1) the more robust mathematical foundation of

NMS as opposed to DCA, the latter of which has been criticized as being a suboptimal ordination technique, despite its popularity in vegetation science, or (2) DCA axes 2 and 3 may represent environmental gradients that were not as strongly expressed in the MT in comparison to the PGP. Future research should help elucidate the cause of this discrepancy in the ordination techniques.

Although PCA ordination of the NGB pollen data (Chapter 4) explained a lower overall proportion of the total variance (36.9%), this was most likely an artifact of inherent biases introduced by pollen over/underproduction, variability in dispersal range, and taphonomic considerations, as well as the coarser taxonomic resolution inherent in the identification of palynomorphs. Nevertheless, fire frequency (PC1; 18.7% of variance explained) emerged as the most important modulator of prehistoric vegetation dynamics, as it was in the LSR-based analyses of the historic forests of the PGP and MT (Chapters 2 and 3), highlighting the critical role of fire in the development of the regional vegetation. The notable absence of soil as an environmental modulator in the NGB pollen record suggests that pedogenic factors were likely insignificant at the temporal scale represented by the core (~4400 years), and that the local and regional vegetation was largely unresponsive to any changes that did occur in the soil environment. In the NGB core, landscape openness (PC2; 18.2% of variance explained) was likely related to NMS axis 3 (Native American land-use) and DCA axis 3 (canopy disturbance) in the PGP and MT LSR analyses, respectively. These synthetic dimensions generated through ordination likely relate to the geographic distribution and chronological development of openland habitats (oak savanna, grassland, successional old fields), which were spatially and temporally (<800 cal. yr BP) associated with Iroquoian agricultural populations.

The use of an integrated ordination–numerical classification statistical methodology in the LSR analyses (agglomerative hierarchical clustering [AHC]) reinforced the accuracy of each statistical method while providing a classificatory scheme for delineating major upland vegetation community types. The AHC results were largely identical between adjacent study areas, the Phelps and Gorham Purchase (PGP; Chapter 2; Seneca nation) and Military Tract (MT; Chapter 3; Cayuga and Onondaga nations). These results indicated (1) the existence of a cultural landscape associated with prior Iroquoian agricultural villages, and (2) a closely-related assemblage dominated by fire-tolerant forest taxa (e.g. *Quercus*, *Castanea*, *Pinus*) that may have been partially modified by Native American land-use practices, particularly through the use of fire and, more equivocally deliberate manipulation of species composition. This latter, fire-tolerant upland community type recorded in the LSR data has notable similarities in species composition to the phase of incipient horticulture (~2500 – 800 cal. yr BP) in the NGB core (Chapter 4), represented during Zone NGB-6 (2460 – 1850 cal. yr BP), and the subsequent "early maize" stage in the lower portion of Zone NGB-7 (1850 – 800 cal. yr BP). This period coincides with the ascendancy of several fire-tolerant pollen taxa (e.g. *Quercus*, *Castanea*, *Pinus*) that were dominants in the dry upland forests recorded in the late-18th century CE LSRs. This convergence suggests that Early (~3000 – 2000 cal. yr BP) and Middle Woodland (~2000 – 1000 cal. yr BP) Native American populations may have been at least partially responsible for the temporal development and geographic expansion of dry upland forests in the study area.

In order to strengthen the inferred relationship between Native American land-use practices and more active fire regimes, I classified arboreal taxa (identified in the LSRs and in the pollen record) into one of two composite groups based upon a taxon's inferred tolerance to low-intensity ground fires. This methodological innovation has heretofore only been applied to LSR-derived vegetation data. This resulted in the identification of very strong, positive correlations between the frequency of fire-tolerant forest taxa and NMS axis 1 (PGP LSR analysis), DCA axis 1 (MT LSR analysis), and PC1 (NGB pollen data), all indicators of a spatio-temporal fire-frequency gradient. These results highlight the benefits of using composite pollen categories in future paleoecological analyses, as these provide more meaningful interpretations of environmental trends than on a taxon-by-taxon basis.

Similarly, the partitioning of LSR-derived vegetation data into discrete upland plant community types (each having a unique set of indicator species and dominant disturbance regime) has the potential to aid in the interpretation of pollen data, as demonstrated in Chapter 4. Through the selection of analogous pollen taxa to serve as indicator species of the major vegetation community types, I was able to reconstruct the chronological trajectory of primary forest assemblages and their relationship to contemporaneous cultural transitions. This approach revealed the progressive decline in fire-intolerant communities such as *beech-maple mesic forest* and *hemlock-northern hardwood forest* after ~2500 cal. yr BP, with a corresponding steady rise in fire-tolerant communities including *Appalachian oak-hickory forest*, *oak-chestnut-pine forest*, *oak openings*, and *floodplain grassland*. A community-based approach to the interpretation of pollen diagrams is likely a more useful indicator of prehistoric anthropogenic land-use impacts on vegetation related to changing subsistence economies than analysis of individual pollen taxa. Importantly, this approach also allows for direct comparisons with historical LSR and modern forest survey data. Vestiges of Native American land-use impacts on the regional vegetation are, in fact, still evident within the dissertation study area, typically in the form of savanna and prairie remnants (Figure 5.1) and are often located in close proximity to areas described as such in late 18th-century LSRs.

Future studies focusing on Native American land-use impacts in the historical ecological and paleoecological records would benefit from more synthetic and innovative approaches. Reducing the temporal, spatial, and conceptual barriers of previous studies would allow for more nuanced interpretations of past vegetation dynamics and its relationship to critical cultural developments, such as the transition from hunting-foraging to agricultural subsistence economies. This requires a greater awareness of key developments in archaeological methodology and the reassessments of regional culture history stemming from these advancements. Synthetic, multifaceted studies, such as those presented in this dissertation, should be tested in a broader range of geographic settings in order to identify similarities and differences between culture groups and their respective environmental settings. Expanding the geographic scope of future studies will shed further light on the mutual roles of past human-climate-vegetation interactions across North America.

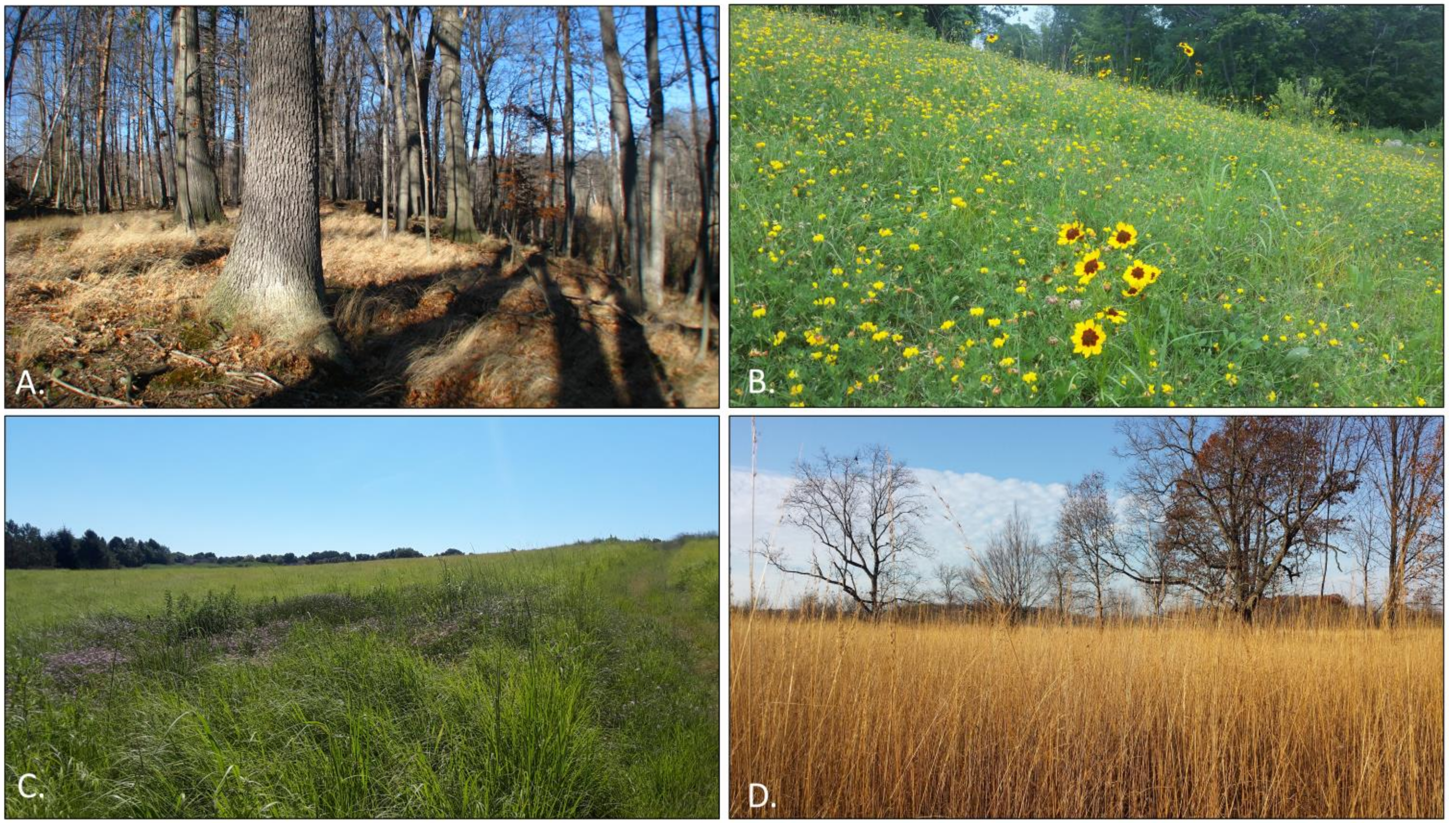

Figure 5.1. Modern savanna and prairie remnants located within the dissertation study area. A. Open-canopy dry upland forest of white oak (*Quercus alba*), black oak (*Q. velutina*), and white pine (*Pinus strobus*) with understory grass patches in canopy gaps. This site was surveyed in 1792 and described as "thinly timbered with white oak and white pine" and was situated adjacent to a Seneca trail. B. Relict hillside prairie of tickseed (*Coreopsis* spp.), Indian grass (*Sorghastrum nutans*), and little bluestem grass (*Schyzachirium scoparium*) growing adjacent to the open woodland pictured in 5A. C. Hilltop prairie of Indian, little bluestem, and big bluestem (*Andropogon gerardii*) grasses on the site of a 17th century Seneca village. D. Restored savanna of Indian and little bluestem grasses with scattered bur oak (*Quercus macrocarpa*) on shallow soil over limestone bedrock near several former Seneca agricultural villages near the Genesee River.