Historical and Computational Analysis of Long-Term Environmental Change: Forests in the Shenandoah Valley of Virginia

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Long-term human-environment interactions have been studied by generations of scholars from multiple disciplines, yet there is still a need to develop better understandings of what changes took place across time and space, and the causes and consequences of those changes. In recent years, a great deal of attention has been focused on the study of land-use and land-cover change, particularly by researchers interested in global environmental change and geographic information science. This area of research is sometimes referred to as land-change science, and national and international organizations have called for the development and analysis of long-term databases of land use and land cover.[1] As local to global assessments of human-environment interactions have proliferated due to increased interest and the availability of new tools and data, a need has arisen to determine if there are "significant variations in local to regional to continental patterns of landscape change and the communities and cultures residing in those lands." In addition, methodological issues about validating analysis conducted with varying types and amounts of sources and comparing studies "across scales, geographic areas and cultures, and methodological approaches" have been raised.[2]

Two approaches researchers use to study long-term, human-induced changes to the environment can be generally categorized as geohistorical and geocomputational. The geohistorical approach is based on thorough analysis of archival material and previous studies, and sometimes includes broader theoretical frameworks. Geocomputational approaches utilize computers to analyze spatial data or to model processes and are exemplified by the common usage of geographic information systems (GIS) and digital image processing programs to analyze remotely sensed data. While geohistorical studies deal with places, the spatial extent of place may be

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loosely defined and not easily conform to the bounded areas that are typically used to store information for geocomputational analysis. Conversely, geocomputational approaches often must ignore data that do not fit into a defined area.

In addition to general issues of approach, issues about spatial and temporal scales also must be considered. Local studies often rely on detailed (or fine-grained) and unique data that can provide rich examples of what happened at a particular place, but linkages to other places and broader-scale processes can be tenuous. Regional to global scale studies often rely on coarse-grained information or attempt to synthesize broader trends from many localized studies. While basing long-term studies on the analysis of data that were collected and published on a regular basis for some defined geography (e.g., county- and state-level census data) or on irregularly spaced time-slice reconstructions based on available maps and digital spatial data sets can be useful, comparing and linking the two can provide additional confidence in what is represented by each type of source and provide clues as to what might be missing.

This article seeks to show that determining spatial and temporal variations in land-use and land-cover change at the local level over long periods of time can best be achieved by combining geohistorical and geocomputational approaches, and that local studies produced in this manner can be integrated into coarser-grained studies to refine our understandings at these coarser scales. Specifically, this article examines the following methodological issues:

- Will geohistorical and geocomputational approaches taken individually give us the same understanding of long-term environmental change?
- Will a combined approach provide us with a better understanding?
- Can a combined approach provide a means to use local studies to improve coarser-grained studies?

These issues are examined in a case study of forest clearance and regrowth over the last 300 years in the North River watershed in the Shenandoah Valley of Virginia. The timing, extent, and impact of forest clearance and regrowth have been researched due to their importance to many environmental issues. Forests provide timber for individual and commercial utilization, decrease the sedimentation of water bodies through the retention of soils, and play an important role in the global carbon cycle by sequestering carbon. The clearing of forests has been linked to changing weather patterns, to the loss of biodiversity, and to changes in forest composition and structure when forests grow back on abandoned farm land.[3] Since the early twentieth century, studies of changes to the forests and farm land in the eastern United States have concluded that the amount of cleared area expanded from the time of initial European settlement until sometime in the nineteenth or early twentieth century, and then began to subside due to the decline or intensification of agriculture and the expansion of settled and protected areas.[4]

Few studies of the Shenandoah Valley have analyzed long-term changes to forests and farmland over the last 300 years, even though the area has been the subject of studies dealing with Quaternary vegetation, settlement systems, agriculture, the charcoal iron industry, and the American Civil War.[5] A preliminary analysis of historic land-use data for the Shenandoah Valley was conducted as part of the renewed interest in long-term environmental change and found potential discrepancies (examined in more detail later) between regional and local trends, possibly calling into question our broader understanding of changes to the forests and their ramifications, and in particular the driving forces behind the changes to the forests.[6] The discrepancies also may raise issues with how the regional studies were conducted. The analysis presented here seeks to determine if the preliminary analysis found actual differences in changes to the forests or if the analysis is erroneous due to problems with the data or methods used. In particular, the study seeks to determine when the maximum clearance of forests occurred in the study area; whether there is a difference in the timing of maximum clearance in the study area and larger regional trends; and, if there is a difference, whether we can determine where and why forest regrowth took place after maximum clearance.

In examining these methodological and topical issues, the article is organized into several sections. The background section covers previous research on forests and farmland in the eastern U.S. and provides an overview of the study area. The data and methods section examines the sources and methods used in the study. The results section reports the findings of the case study, and finally the discussion section will analyze the methodological and topical implications of the research presented here.

Background

The forests of eastern North America provided resources for and impediments to the establishment and expansion of permanent European settlements. One of the main drivers of forest clearance was the creation of farm land.[7] In the U.S., federal reports from the early twentieth century indicate that the maximum amount of agricultural land along most of the East Coast likely occurred in the late-nineteenth or early twentieth century, and that the abandonment of marginal farmland was occurring across the eastern seaboard in the early twentieth century. A 1917 bulletin from the U.S. Department of Agriculture looked at farmland changes between 1880 and 1910 and noted that in the eastern states, the area of unimproved and unwooded farmland increased by more than 34 percent, while total farmland increased less than 12 percent, suggesting that as some new farmland was being created, more land was being abandoned but had not reverted back to forest. The report also stated that in New England there was a decrease in farmland due to the abandonment of "rough, unprofitable farms." For Virginia, the report indicated that farmland as a percent of the total area decreased from 77.0 to 75.6 percent from 1880 to 1910. While the study is based on agricultural census data collected at the county level, the summaries and interpretation are based on state and multi-state aggregations.[8]

The 1933 publication, *A National Plan for American Forestry*, further documents the decline in farmland in the eastern U.S. and indicates that there were 26 million acres of abandoned farmland, 22 million acres of idle and fallow agricultural land, and 30 million acres of unforested and unplowable pasture land that could be converted to forests through passive or active means. This report also states that the peak in farmland in Virginia was reached in 1910, even though the 1917 report showed a decline from 1880 to 1910, and that Augusta and Rockingham counties had a decrease in farmland from their unspecified peak until 1930.[9] Like the study published in 1917, this study is based on county-level information but is primarily analyzed at a regional scale (e.g. Mid-Atlantic states). The creation of federal conservation programs in the early twentieth century also lent credence to the notion of the abandonment of farm land and the expansion of forested areas in the early twentieth century in the eastern U.S. because federal land acquisition was often aimed at protecting and better managing the natural resources of the region from previous overexploitation.[10]

Modern analyses of forest clearance and regrowth in the eastern United States reinforce the notion that the maximum amount of farmland and, hence, the maximum clearance of forests likely occurred in the late-nineteenth or early twentieth century. John Fraser Hart found that the majority of the counties in the eastern U.S. lost farmland between 1910 and 1959.[11] While Hart's analysis is conducted at the county level, the analysis does not address whether farmland might have expanded before declining in the intervening years. Michael Williams' overview of the historical geography of American forests shows the amount of forested area increasing during this time period.[12] Other regional narratives tell of extensive human alterations to the environment but they do not provide any further details about the timing and extent of forest clearance in the study area.[13] The Chesapeake Bay Program, a regional partnership focused on the restoration of the Chesapeake Bay, has published reports indicating that on a basin-wide basis the maximum amount of cleared land occurred in the last half of the nineteenth century.[14] A recent study based on sediment cores taken in the Chesapeake Bay also suggests that the maximum amount of clearance took place in the late-nineteenth or early twentieth century. The sediment study included the analysis of pollen from *Ambrosia* (ragweed), a plant that quickly establishes itself on cleared land. While the dating of the *Ambrosia* pollen spikes is partially based on published trends of farmland, the first and largest spike at multiple sampling sites is dated between 1880 and 1920, and the sample taken near the mouth of the Potomac River spiked around 1890.[15]

The Study Area

The extent of forests in the Shenandoah Valley has been debated for a long time. Nineteenth-century histories of the region claim that the Shenandoah Valley was an open prairie when settlers arrived, suggesting that earlier, transient native populations had managed it as a hunting ground for bison and other large animals. While the concept of the area being a prairie was cited by later researchers, the area is now believed to have been predominately forested when European settlers arrived.[16] Lying between the Blue Ridge and Allegheny Mountains, the Shenandoah Valley was part of the backwoods, or frontier, of the New World in the eighteenth century. The study area, the North River watershed, is part of the headwaters of the South Fork of the Shenandoah River and straddles the border between Augusta and Rockingham counties in Virginia (Figure 1). Watersheds have been identified as an appropriate landscape unit to study human-environment interactions because of the integration of various environmental processes and human impacts on the landscape. The North River watershed makes up approximately 10 percent of the Shenandoah River watershed.[17]

The North River watershed contained a frontier agricultural and industrial community in the eighteenth century. The industrial developments in the eighteenth century centered on the Mossy Creek Iron Works, which was a diversified frontier industrial plantation and existed until around the middle of the nineteenth century.[18] Intense exploitation of the forests in the western and mountainous portion of the watershed did not occur until the late-nineteenth and early twentieth centuries. Perceptions of overexploitation and poor land-use practices in the Shenandoah Valley helped lead to the creation of Shenandoah National Park and Shenandoah National Forest (now known as the George Washington and Jefferson National Forest) to help preserve and restore the area's natural beauty. It should be noted that recent scholarship has called into question the degree to which portrayals of the region's residents and their activities were accurate.[19]

Throughout the nineteenth century, agriculture was important to the region, which has been characterized as the "breadbasket of the Confederacy."[20] Agriculture is still important today. In 1997, Augusta and Rockingham counties were rated as the top two agricultural counties in Virginia based on cash receipts.[21] Agricultural activities in the region have also been identified as a major contributor to water-quality problems for the Chesapeake Bay. The U.S. Environmental Protection Agency has classified the South Fork of the Shenandoah River watershed as having more

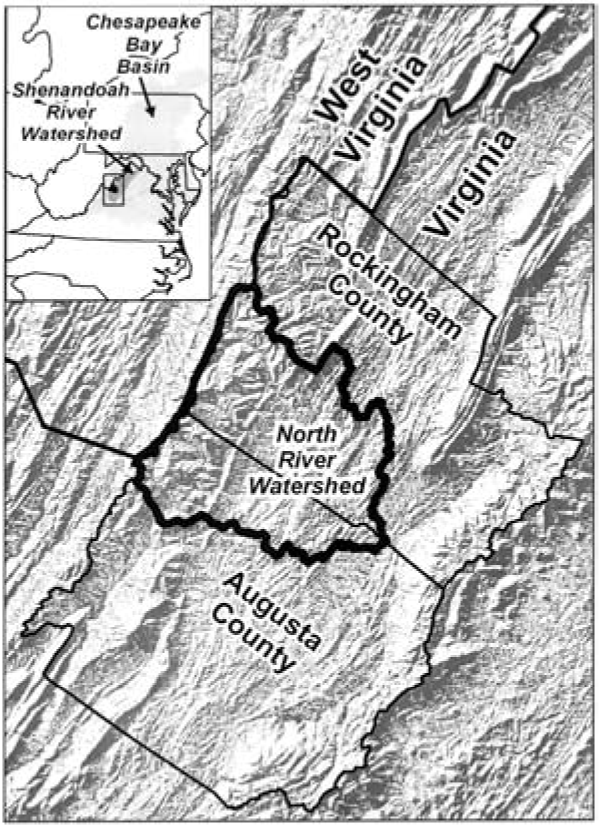

Figure 1. Location of the North River Watershed in the Shenandoah Valley of Virginia. The North River is part of the headwaters of the Shenandoah River, which flows into the Potomac River and then the Chesapeake Bay.

Sources: Chesapeake Bay Program, "Chesapeake Bay Hydrologic Units" (Annapolis, Md.: Chesapeake Bay Program, 1999); Chesapeake Bay Program, "Chesapeake Bay Outline" (Annapolis, Md.: Chesapeake Bay Program, 1999); U.S. Geological Survey, "National Elevation Database" (Sioux Falls, S.D.: The Survey, 1999); U.S. Geological Survey, "National Hydrography Datatset – High Resolution" (Reston, Va.: The Survey, 2003).

than 25 percent of its water miles impaired, the most severe category of impairment in its national assessment.[22]

Determining whether Augusta and Rockingham counties and the North River watershed followed the same trends of forest clearance and regrowth as those described earlier for the eastern U.S. and the Chesapeake Bay Basin requires further investigation. One of the primary sources used in many of the previously mentioned studies of farm expansion and abandonment is the agricultural census. Depending on which attributes from the census are used, the agricultural census data for Augusta and Rockingham counties either support or contradict regional trends in forest clearance and regrowth (Figure 2). Total farmland does peak in the late-nineteenth and early twentieth centuries, but "improved" farmland peaks later, particularly in Augusta County.[23] The original definition of improved farmland included croplands and pastures while unimproved farmland included areas with trees such as wood lots. Improved farmland is not a category that was consistently recorded in the census, so other categories like cropland and pastures were combined in this study to create the most consistent definition possible.

Are the discrepancies between the study area and regional trends due to different approaches, different levels of aggregation, or a true difference in what happened on the ground? Can we determine what actually

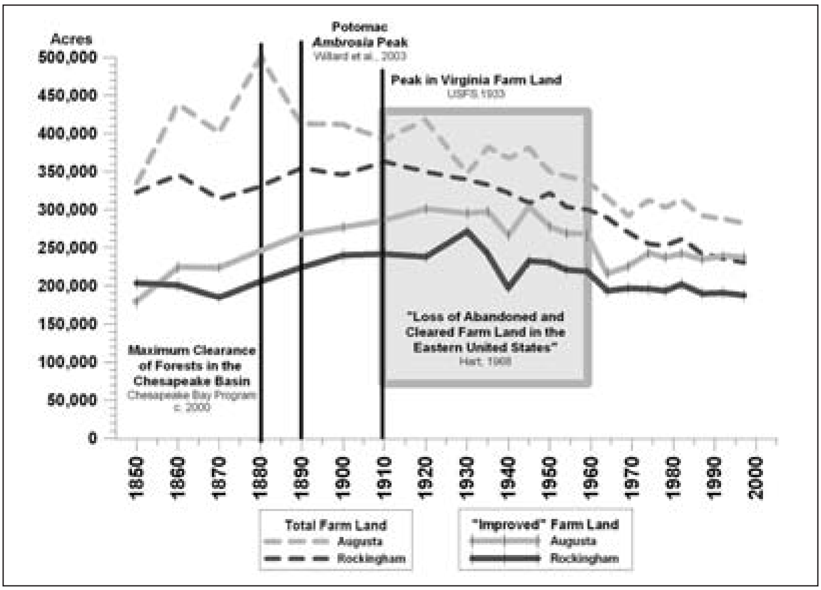

Figure 2. Farm Land: Census Data and Published Reports. While total farm land peaks in the late-nineteenth century for Augusta and Rockingham counties, "improved" farm land peaks later in the twentieth century. Improved farm land includes areas such as crop lands, pastures, and fallow fields. Multiple published reports reinforce the notion that maximum clearance was reached in the late-nineteenth or early twentieth centuries: (1) the Chesapeake Bay Program indicates that maximum clearance for the entire Chesapeake Basin occurred around 1880; (2) the maximum *Ambrosia* peak at a sampling site near the mouth of the Potomac River has been dated to around 1890; (3) the U.S. Forest Service reported in 1933 that the maximum amount of farm land in Virginia was reached in 1910; and (4) John Fraser Hart found an overall decline in farm land between 1910 and 1959. Tic marks along the "improved" farm land graph represent the year of the census.

Sources: Chesapeake Bay Program, *Chesapeake Basin Forests* (Annapolis, Md.: Chesapeake Bay Program, October 25, 2004), http://www.chesapeakebay.net/status.cfm?sid=112&subjectarea=FORESTS (accessed November 28, 2004); Debra A. Willard, Thomas M. Cronin, and Stacey Verardo, "Late-Holocene Climate and Ecosystem History from Chesapeake Bay Sediment Cores, USA," *The Holocene* 13:2 (2003): 201-14; U.S. Forest Service, *A National Plan for American Forestry. Letter from the Secretary of Agriculture Transmitting in Response to S. Res. 175 (Seventy-Second Congress), Report of the Forest Service of the Agricultural Department on the Forest Problem of the United States*, 2 vols. (Washington, D.C.: Government Printing Office, 1933): 149-61; John Fraser Hart, "Loss and Abandonment of Cleared Farm Land in the Eastern United States," *Annals of the Association of American Geographers* 58:3 (1968): 417-40. See note 23 for sources of the agricultural census information.

happened in a watershed that does not conform to the geographic boundary (e.g., county) used in collecting much of the data used previously? Can a geohistorical or a geocomputational approach resolve the issue? Will both approaches give us the same answer? Can a combined approach provide greater insight into the local and regional dynamics? This case study seeks to answer these questions.

Data and Methods

Long-term changes to agricultural lands in physically based study units such as watersheds are difficult to examine because agricultural census data are generally only available at the county level (except for some nineteenth-century records). Spatial characteristics of where changes might be taking place are also difficult to ascertain from county-level aggregates or anecdotal evidence that might be found in local records. For these reasons, I combined geohistorical and geocomputational approaches through historical GIS to explore the spatial and temporal dimensions of forest changes in the North River watershed. I sought out cartographic and digital spatial data sources that contained some level of detail about farmland and forests in the region for computational analysis. In addition to a historical analysis of the activities taking place in the study area, I analyzed the methods used to produce each source and its historical purpose to aid in understanding the contents and their relationship to data represented in the agricultural census. Without this analysis, the contents of the maps and digital spatial data could not be analyzed with any confidence since it would not be known whether the symbols represented specific features or were merely fanciful decorations. The sources were analyzed and compared to county-level census data to determine the comparability between the two types of sources before being analyzed within the watershed to determine local changes. Comparison with county-level census data also allows for placing the study in a broader context since many regional studies have been based on the same agricultural census data.

Sources

Three cartographic sources (1864, 1906, and circa 1945) and two digital spatial data sets derived from aerial photography (circa 1973) and satellite imagery (circa 1992) were used in this study. The earliest map available for the study area with forest boundaries comes from the period of the American Civil War. The 1864 Lower Shenandoah Valley I map was produced by the Confederate Engineer Bureau.[24] As there is no legend on the map, research was conducted into the cartographic and military practices at the time to determine which of the map's symbols represented woodland. The symbol on the map is similar to other maps of the period where a green tint is also present, and follows the convention outlined in military topographical drawing manuals from the first half of the nineteenth century.[25] The manuals provide no definitions as to what should be mapped as woodlands, but the "duties of officers of engineers serving with the armies of the Confederate states" included making "reconnaissances and surveys of the sections of country occupied by our forces, and, as far as possible, of the country held by the enemy, embracing all the information that can be obtained in reference to … roads, bridges, fords, topographical, and military features, … the extent of wooded and cleared lands, … and the capacity of the country to supply the general wants of the army."[26] The passage of this general order has been attributed to Jeremy Francis Gilmer, the chief of the Confederate Engineer Bureau, who was likely to be familiar with the military mapping standards of the day. Gilmer graduated fourth in his class from the U.S. Military Academy at West Point in 1839, was commissioned a second lieutenant of engineers, and became an assistant professor of engineering at West Point from 1839-1840. Another teacher at West Point in the 1830s, Lieutenant Seth Eastman, wrote a mapping manual published in 1837 that became the official text for classes at West Point and included the previously mentioned woodlands symbol.[27]

The remaining cartographic and digital spatial data sources used in the study came from different U.S. Geological Survey (USGS) mapping and research programs. The earliest maps of the study area produced by the USGS in the late-nineteenth century did not contain a forest symbol, but they likely formed the base maps for a study of the Potomac River watershed conducted in the first decade of the twentieth century where woodland was clearly marked. The study was intended to assess the impact of land use and land cover on water quality in the Potomac River. The forestry analysis and field mapping was conducted in 1906 by William W. Ashe, a botanist who became the first secretary of the National Forest Reservation.[28] Unfortunately, the report does not include any information about the mapping techniques or standards utilized. Even though the USGS had developed a standardized symbol for forests in the late-nineteenth century, period manuals from the USGS do not provide any guidance for the mapping of wooded areas either. By 1928, the USGS had detailed instructions on how to define and draw woodlands. These instructions could be the codification of long-standing principle given the earlier interest of the military in mapping wooded areas. Woodlands were defined to include "all timber, woods, or brush, whether alone or mixed, of sufficient stand and height to impede ordinary travel or afford cover for small detachments of troops" and "logged over or burned areas, if covered by second growth or brush."[29] While Ashe's 1906 map was printed at a scale of 1:633,600 and wooded areas appear as generalized shapes, it is the best available source and is used to obtain a general idea of what areas were forested and cleared at the beginning of the twentieth century, a key time period in determining when the maximum extent of forest clearance occurred.

The next representation of woodlands comes from USGS 15-minute topographic maps produced from 1920 to 1950 at a scale of 1:62,500. The definition of woodlands remained fairly consistent during this period, except for a brief period during World War II when the USGS agreed to adopt War Department guidelines of breaking woodlands into three separate classes.[30] All eighteen maps from the series that were used in this study used a single symbol to represent woodlands and are used as a circa 1945 reconstruction.[31] While the maps were published over the course of thirty years, most of the maps were produced in the early 1940s and only small portions of the study area come from the earliest or latest maps.

The next two data sets come from more detailed analysis of the landscape by the USGS. The first comes from a series of land-use and land-cover (LULC) maps that were printed at scales of 1:250,000 and 1:100,000. These were derived primarily from National Aeronautical and Space Administration high-altitude aerial photographs and National High-Altitude Photography (NHAP) program photographs. Land use was categorized based on the Anderson Level II system and the maps for the study area were based on photography from 1973 and 1974, creating a circa 1974 reconstruction.[32] The last data set was produced by a consortium of federal agencies and distributed by the USGS as the National Land Cover Data (NLCD). The data are based on a modified Anderson Level II classification system and were derived from Landsat satellite images collected in the late 1980s and early 1990s, creating a circa 1992 reconstruction.[33]

Data Processing

A variety of methods were used to digitize the information and bring them into alignment with each other so that further analysis could take place. Unless otherwise noted, all processing was conducted using ArcGIS software from ESRI.[34] A digital image of the Confederate Engineer Bureau's map was obtained from the Virginia Historical Society and georeferenced. Initial attempts to georeference the map using the visible grid lines on the map proved unsatisfactory. While the grid lines could easily be made to match modern reference systems, the cultural and natural features on the map did not align properly. In order to create a better alignment of these features, a "rubber-sheeting" or "triangle-based rectification" tool in Erdas Imagine (version 8.5) was used to independently move portions of the map to more accurate locations.[35] Once the image of the map was georeferenced, the woodlands information was manually digitized on the computer screen to create polygons of wooded areas.

A high-resolution (800 dpi) large-format scanner was used to scan the Potomac Watershed and 15-minute topographic maps in 24-bit color. The resulting images were georeferenced using the latitude and longitude grids and tic marks present on the maps. The forested areas were manually digitized from the image of the 1906 map. In order to expedite the process of extracting the woodlands information from the eighteen USGS 15-minute map sheets, a commercial automated feature extraction tool (Feature Analyst for ArcGIS from Visual Learning Systems) was utilized.[36] The software uses machine-learning technology to learn how to classify geographic features using examples provided by the user of the program. Simple image-processing programs could have been used to extract all of the pixels with a green tint (color of woodlands symbology) from the scanned version of paper maps, but these would miss all areas that were intended to be represented by green (and the human eye would interpret as green) but were not due to the overlay of other symbols (e.g. contours) or lettering (e.g. place names) on the original paper map. Feature Analyst was trained to extract woodland areas through an iterative process to classify areas of symbol overlap the same as it would classify the green pixels by looking at the spatial pattern of the pixels. The training, done on one map, consisted of manually digitizing areas of woodlands with and without overlapping symbols, running the extraction process, and then adding and deleting areas from the initial results to identify correct and incorrect features. The learning and verification processes were repeated until the learned model was satisfactory, and then the model was used to extract information from the remaining seventeen maps.

The LULC and NLCD data sets were already available as digital and georeferenced files.[37] The multiple classes of land use and land cover for each data set were collapsed into two new classifications. The first was a binary woodlands/non-woodlands classification for later analysis of the woodlands. The second classification contained woodlands, agriculture, and a third category of everything else so that the agricultural information could be compared to the agricultural census.

In order to compare the open space from the various cartographic and spatial data sources with information from the agricultural census, a common boundary was needed to extract and quantify the woodlands and agricultural information. The agricultural census was collected by the county, and sometimes by districts within counties, so the boundaries of the county or census district were needed. The outer boundaries of the counties have not changed since the early nineteenth century so a modern boundary file was used for all but the mid-nineteenth century comparison.[38] The Confederate Engineer Bureau's map did not cover all of Augusta County so the northern subdivision census district was used to compare the census data with information derived from the engineer's map. The boundary of the census district was reconstructed based on the period description of the district and an 1870 map of Augusta County. The boundary followed major roads and was manually digitized from an existing digital and georeferenced version of the 1870 map using the written description of the boundary as a guide.[39] The amount of wooded and open land in the census district was calculated from the information contained in the Confederate Engineers Bureau's map (Figure 3).

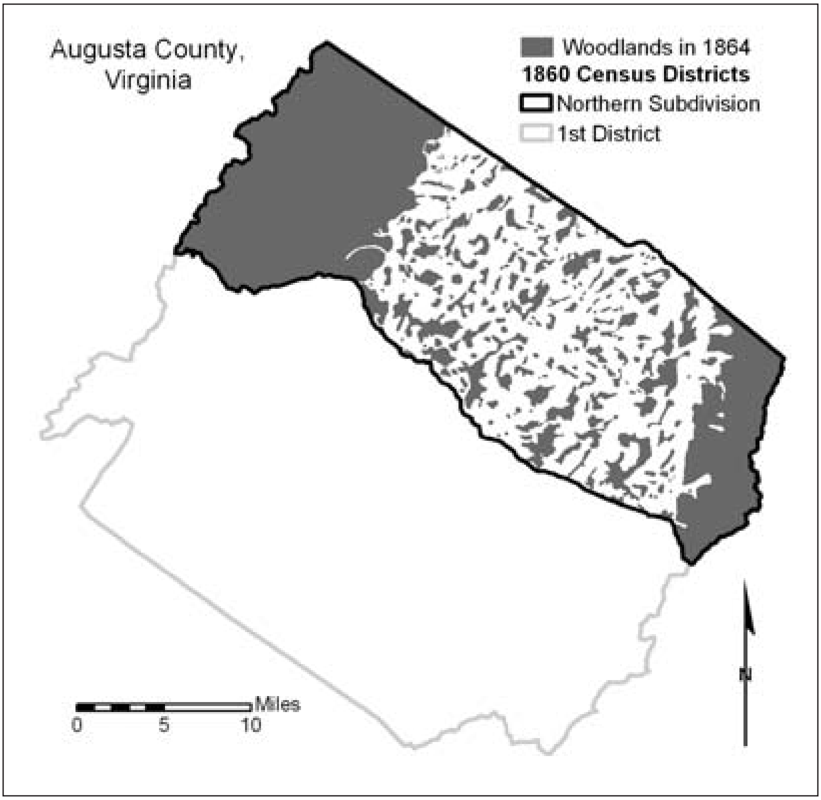

Figure 3. Woodlands in 1864 in the Northern Subdivision Census District of Augusta County, Virginia. A reconstruction of the 1860 census district boundary was used to exclude all woodlands outside of the district. The woodlands were derived from an 1864 Confederate Engineer Bureau map.

Sources: Confederate Engineer Bureau, "Lower Shenandoah Valley I" (no scale, 1864), Jeremy Francis Gilmer Collection, Virginia Historical Society, Richmond, Virginia; Virginia Department of Conservation and Recreation, "Virginia's Jurisdiction Boundaries" (Richmond, Va.: Virginia DCR-DSWC, 1995); National Archives and Records Administration, *Descriptions of Census Enumeration Districts, 1830-1950*, Microfilm Publication T1224 (Washington, D.C.: National Archives and Records Administration, 2002); Jedediah Hotchkiss, "Map of Augusta County, Virginia," (Lexington, Va.: Trustees of Washington College, 1870), obtained from Virginia Center for Digital History.

The woodlands symbol on the USGS 1906 Potomac River watershed map only covered the Potomac watershed so it did not cover all of Augusta County. Rockingham County was used to compare the cartographic and census data for this period. A direct comparison of the amount of open space or agricultural land derived from the spatial data sets with the agricultural census provided a means of evaluating the content of the maps and digital spatial data sets. A direct comparison of the reconstructions at different time periods within the watershed is best conducted when the data have been harmonized to the same minimum mapping unit. Based on published standards and examination of the data sets in the GIS, I determined that the USGS LULC data had the largest threshold for the minimum area to be mapped, 40 acres, so all of the other data sets were processed to remove any polygons less than 40 acres. The smaller polygons were merged into the adjoining polygon with the largest adjoining edge.[40]

Additional data sets and tools were also obtained or created for use in the analysis of forest changes through time. A digital file of the modern boundary of the George Washington and Jefferson National Forest (GW-JNF) was obtained for use in evaluating land within the National Forest.[41] In order to examine the differences in landscape changes in the mountainous area versus the valley floor, a generalized soils data file was obtained and modified to differentiate between these two areas based on a visual comparison with the topography.[42] National Elevation Data (NED) from the USGS was used to determine areas with slopes over 3 percent to evaluate the amount of forest clearing on steep slopes, and was used and in conjunction with National Hydrography Data (NHD) to calculate the watershed boundary using the ArcHydro extension to ArcGIS.[43]

Results

The amount of non-wooded or open space derived from geographical sources and the agricultural census differs by only 0.5 to less than 3 percent for each time slice (Table 1). Comparisons of census data with data from cartographic and digital spatial sources were all conducted with the original extraction of the data, before they were harmonized to dissolve polygons less than 40 acres. Even with some variation in the amount of open space or improved farmland being interpreted from the different sources, the two types of data correspond well enough to support the general timing of the maximum clearance as revealed in the improved farmland census data at the county level, which is much later than the regional analysis would lead us to believe. The historical analysis and the comparison also provides validation that the woodlands represented in the cartographic and digital data sets provide a good representation of features on the landscape.

After harmonizing the data to dissolve all polygons less than 40 acres and eliminating woodlands outside of the North River watershed boundary, the data were reanalyzed to look at forest changes within the watershed. The first analysis considers the watershed as a whole and a second analysis separates mountain and valley areas (Table 2.a). The percent of total area covered in woodlands for the entire watershed was at its lowest in 1906, similar to the broader regional interpretation of the timing of maximum clearance, but earlier than the two counties represented in the watershed. However, dividing the watershed into mountains and valley, we see that while the mountainous area also reached maximum clearance in 1906, the valley area reached maximum clearance in the circa 1945 data, just as the county-level census data suggests for Augusta County.

Table 1. Comparing Cartographic and Digital Spatial Data Sources with Agricultural Census Data.

Location and area compared	Map or Digital Spatial Data			Ag. Census		Difference between sources
	Source	Date	Open (Ag.)	Date	Improved Ag.	
Augusta Co., Northern Subdivision	Confederate Engineers' Map	1864	44.19%	1860	44.66%	0.46%
Rockingham Co.	USGS Potomac River Study	1906	45.17%	1900 1910	43.08% 43.36%	2.09% 1.81%
Augusta Co.	USGS 15' Maps	c.1945	48.28%	1945	47.45%	0.83%
Augusta Co.	USGS LULC	c.1974	(40.33%)	1974	37.68%	2.65%
Augusta Co.	USGS NLCD	c.1992	(37.62%)	1992	37.11%	0.51%

Open spaces on the maps were compared to improved agricultural land from the agricultural census for the first three sources. Since the USGS LULC and NLCD data provided more refined categories of land use and land cover, only agricultural categories were compared with the improved agricultural land from the censuses for these periods. The amount of non-wooded or open areas derived from the cartographic sources matches well with the census data for improved farm land, and the amount of agricultural land derived from the digital spatial data sources matches well with the agricultural census data for improved farmland.

If the timing of maximum clearance at the county level and in the valley portion of the watershed are later than the larger region, can previous explanations hold true for why the maximum clearance occurred when it did, and why forest regrowth took place? Without detailed accounts for this specific location, textual and aggregate records such as the census data cannot assist in answering these questions. Now that we have increased the level of confidence with which to evaluate the spatial data we now have in the GIS because of the historical analysis and its comparison to the census data, we can use the GIS to assist in seeking answers.

One of the explanations for the timing of maximum clearance and the subsequent reduction of farmland is the expansion, and later abandonment, of agriculture into poorly suited areas such as the mountains and areas with steep slopes. An examination of the non-woodland areas in the mountains (Figure 4 and Figure 5) and on slopes over 3 percent shows

Table 2. Woodlands and Non-woodlands in the North River Watershed.

Date	a. Woodlands			b. Non-woodlands over 3% slope		
	Entire Watershed	Mountains	Valley	Entire Watershed	Mountains	Valley
1864	59.37%	98.14%	23.44%	33.27%	1.77%	62.40%
1906	**50.39%**	**93.39%**	10.65%	**41.19%**	**6.27%**	**73.43%**
c.1945	52.48%	98.46%	**9.90%**	39.04%	1.43%	**73.83%**
c.1974	54.50%	98.29%	13.99%	37.35%	1.48%	70.49%
c.1992	56.31%	99.08%	16.73%	35.67%	0.79%	67.94%

The woodlands columns show calculations of wooded areas derived from the sources after they were harmonized to a minimum mapping area of 40 acres. The least amount of wooded area in the mountainous portion of the watershed occurs in the 1906 data, while in the valley portion it occurs in the c. 1945 data. Non-woodlands on land with greater than 3 percent slope follows the same temporal pattern as the woodlands area.

Sources (Tables 1 and 2)
Confederate Engineer Bureau, "Lower Shenandoah Valley I" (no scale, 1864), Jeremy Francis Gilmer Collection, Virginia Historical Society, Richmond, Virginia; W.W. Ashe, "Plate X: Potomac River Drainage Basin above Washington Showing Forest Areas and Cleared Lands (June 1906)," in Horatio Parker, Newton Bailey Willis, R. H. Bolster, W. W. Ashe, and M. C. Marsh, *The Potomac River Basin* (Washington, D.C.: Government Printing Office, 1907); U.S. Geological Survey, "Land Use and Land Cover (LULC)" (The Survey, c. 1974) and "National Land Cover Data (NLCD)" (The Survey, c. 1992). See note 23 for sources of agricultural census information and note 31 for references to individual U.S. Geological Survey, 15-minute series topographic maps.

several relevant trends. First, a significant portion of the non-wooded areas in the watershed since 1864 has been on slopes over 3 percent (Table 2.b). Second, just as the total amount of non-wooded areas for the entire watershed and the mountainous areas peaked in 1906, the amount on steep slopes also peaked in 1906. However, the amount of open space on steep slopes in the valley continued to increase between 1906 and circa 1945. This suggests that while agricultural expansion in the early twentieth century included the push onto steeper slopes and into mountainous areas, the overall expansion did not cease even as the mountainous areas were abandoned in the early twentieth century.

One possible explanation of why mountainous areas were abandoned in the early twentieth century is the creation of national parks and forests. Much of the mountainous areas in the North River watershed were incorporated in the 1920s and 1930s into what is now known as the George Washington and Jefferson National Forest. While historical changes to the boundary of the national forest are not represented in the modern boundary file, only 38 percent of the mountainous area that was cleared

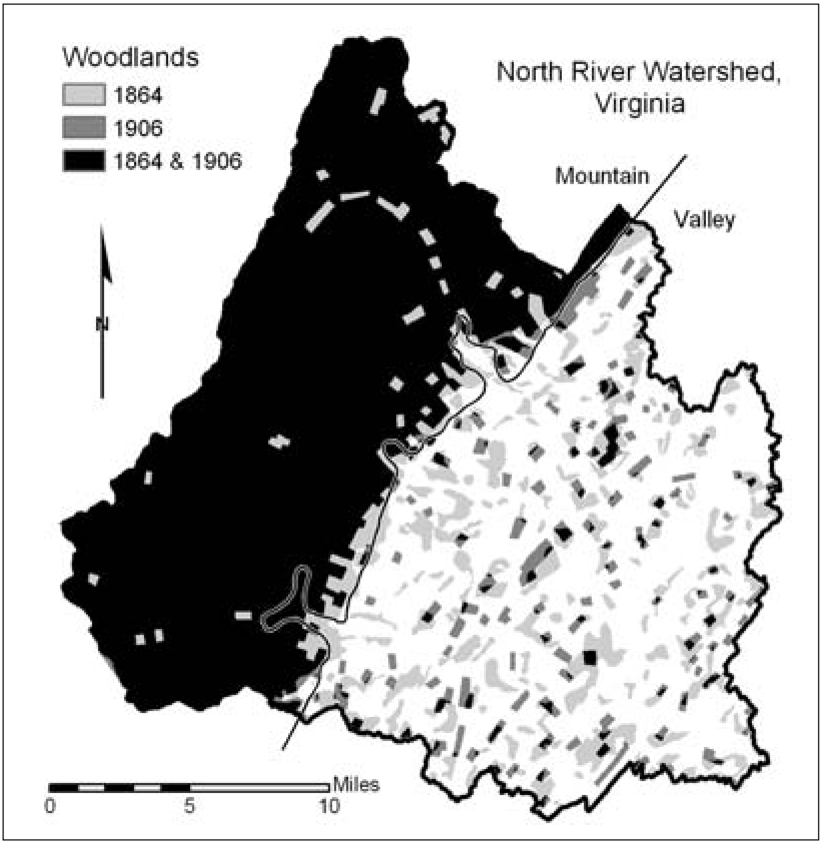

Figure 4. Woodlands of the North River watershed in 1864 and 1906. Woodlands were derived for the watershed from maps dated 1864 and 1906. While woodlands covered most of the mountainous area at both time periods, the eastern edge and some interior areas were cleared by 1906. The valley portion of the watershed was predominately open at both time periods and the wooded areas shifted locations from one time period to the next.

Sources: Confederate Engineer Bureau, "Lower Shenandoah Valley I"; W.W. Ashe, "Plate X: Potomac River Drainage Basin above Washington Showing Forest Areas and Cleared Lands (June 1906)," in Horatio Parker, Newton Bailey Willis, R.H. Bolster, W.W. Ashe, and M.C. Marsh, *The Potomac River Basin* (Washington, D.C.: Government Printing Office, 1907).

by 1906 and reforested circa 1945 are presently included in the national forest. Soil type might be a better explanation of the abandonment of these areas since the division between mountains and valley for this study were based on soil types.

Conclusion

While much has been written about the history of the forests in the eastern United States, changing spatial and temporal patterns of forest clearance and regrowth were a dynamic process that cannot be fully un-

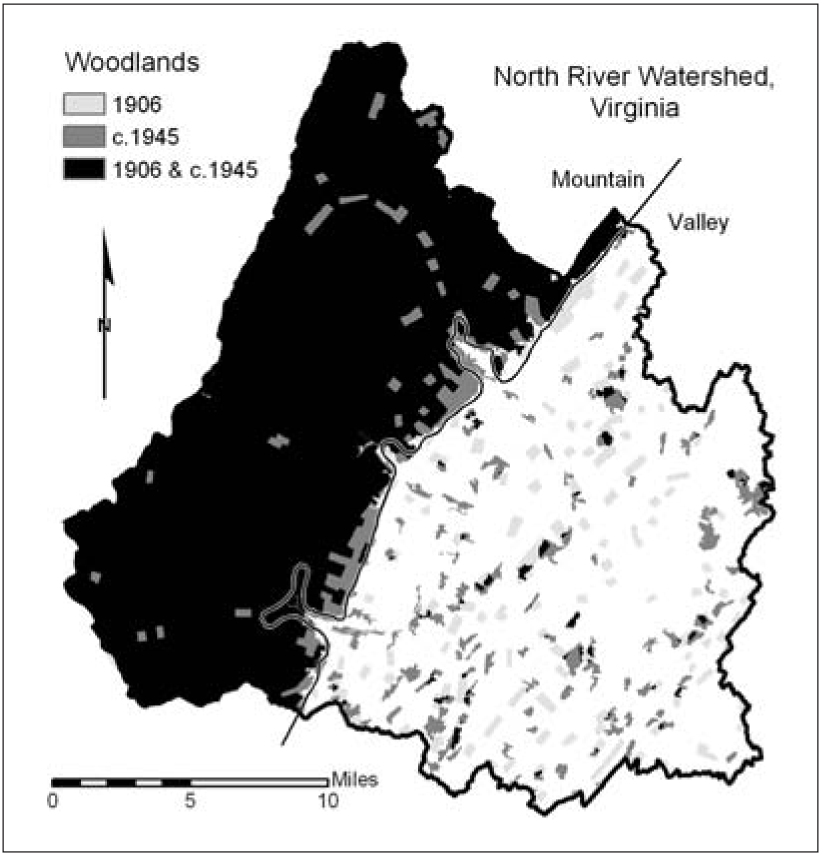

Figure 5. Woodlands of the North River watershed in 1906 and c. 1945. Woodlands were derived for the watershed from maps dated 1906 and c. 1945. The mountainous area of the watershed remained predominately wooded from one time period to the next, and most of the interior and eastern areas that had been cleared by 1906 had reverted back to woods by c. 1945. Wooded areas in the valley portion of the watershed continued to shift locations and declined from 1906 to c. 1945.

Sources: W.W. Ashe, "Plate X"; U.S. Geological Survey, 15-Minute Series Topographic Maps, (Washington, D.C.: The Survey): "Broadway, Virginia" (1950); "Fort Seybert, West Virginia" (1947, 1958 ed.); "Harrisonburg, Virginia" (1943); "McDowell, Virginia" (1946); "Parnassus, Virginia" (1947).

derstood from regional analysis alone. More detailed studies can add to our knowledge about these processes. For some areas, local changes and the reasons for them varied considerably from regional trends. In the Shenandoah Valley, these variations may have been due to the continued importance of agriculture to the local economy and culture. This study also confirms John Fraser Hart's earlier assertion that total farmland is not a good indicator of open land and not sufficient for examining issues related to woodlands. Aggregating census variables to create an improved farmland calculation more closely matches what is recorded in other data sources such as maps and spatial data produced from remotely sensed images.

From a methodological perspective, it has been shown that historical interpretations and modern coarse-grained analysis often hide local variations in changing land use, which should be examined closely before being accepted as true for a given location. Textual and spatially explicit sources of different scales can be integrated through a combined geohistorical and geocomputational approach to assess the content and value of each source and of regional trends. These combined sources and approaches can provide more detailed and accurate information about local areas and can also provide a bridge between local and regional studies since long-term regional studies are often based on county level data.

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