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SPATIOTEMPORAL ANALYSIS OF LONG-TERM AND SHORT-TERM LAND COVER TRENDS ALONG THE KITTATINNY RIDGE CORRIDOR IN PENNSYLVANIA'S APPALACHIAN LANDSCAPE

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ABSTRACT: *Stretching more than 185 miles from the Mason-Dixon Line to the Delaware River, the Kittatinny Ridge is "one of Pennsylvania's most treasured landscapes" (Kittatinny Ridge Coalition, 2017). Identified as a principal bird flyway zone of international importance, the Ridge contains a bounty of natural ecosystems and scenic beauty. Thousands utilize the Ridge for outdoor recreation each year. As a critical ecological landscape, it is crucial to understand human-environmental interactions at work across the Ridge. Such understanding can be used to more effectively develop conservation and management strategies unique to the Ridge and its trends. Accordingly, this manuscript analyzes the Ridge's spatiotemporal trends of long-term (1940-1990) and short-term (2001-2011) forested, agricultural, and developed land cover changes. Municipal-level changes are assessed relative to the Ridge to further understand land cover dynamics. These data suggest a corridor-wide long-term (1940-1990) trend of afforestation and agricultural abandonment, while more recent (2001-2011) trends point to forest cover decline in favor of urbanization. Given the complex and heterogeneous local political structures that dominate the Ridge, short- and long-term land cover (and the overall rates of change) vary by municipality. Results presented here provide a baseline understanding of the dynamic spatiotemporal nature of the Kittatinny Ridge, and can support targeted management strategies specific to the spatially unique trends across the landscape.*

Keywords: *land cover, land use, Kittatinny Ridge, Pennsylvania, Appalachian*

INTRODUCTION

As a prominent feature in Pennsylvania's Appalachian Highlands, the Kittatinny Ridge stretches more than 185 miles from the Mason-Dixon Line to the Delaware River (Figure 1). It spans across 12 counties and 138 municipalities (here referred to as the "Kittatinny Ridge Corridor") in Pennsylvania's central Appalachian landscape. The area occupies more than 360,000 acres, 34% of which are protected through state, local, and federal measures, and is 80% forested (Kittatinny Ridge Coalition, 2016a). Headwaters of the Delaware, Lehigh, Schuylkill, and Susquehanna River Basins are found throughout the Ridge. Such drainage provides valuable clean drinking water to the proximate communities. Additionally, seven Important Mammal Areas are identified across the Ridge (Kittatinny Ridge Coalition, 2016a; 2016b).

The Ridge earned the designation of a Global Important Bird Area (IBA) from the National Audubon Society in 2015. Hawks and other raptors use wind currents along the Ridge during migration, making it one of the most important raptor migration corridors in the world. Particular sites along the Ridge, such as Hawk Mountain and Waggoner's Gap, also provide biologists and citizen scientists a means for monitoring migration, and ultimately, population trends of migratory species. Such data collection began in 1934 and continues today (Bednarz et al., 1990). The entire IBA provides habitat for neotropical migrant raptors, songbirds, butterflies, and several rare and endangered animals. Additionally, the Ridge is further internationally recognized for its outdoor recreational opportunities as the Appalachian National Scenic Trail spans its crest. Hiking, hunting, bird watching, camping, skiing, fishing, and biking are made available by the Ridge (Kittatinny Ridge Coalition, 2016b).

The Ridge was recognized by the Open Space Institute (OSI) in 2013 as one of four climate-resilient landscapes in the northeastern United States. The Resilient Landscapes Initiative was launched by OSI to focus conservation efforts on areas that have the greatest diversity of habitat features and, therefore, have the greatest ecological value in a world subject to transformation due to global climate change (OSI, n.d.). Due to the bounty of ecological services and recreational opportunities the Ridge provides, it is thus identified as "one of the Commonwealth's most treasured landscapes" (Kittatinny Ridge Coalition, 2016a; 2017).

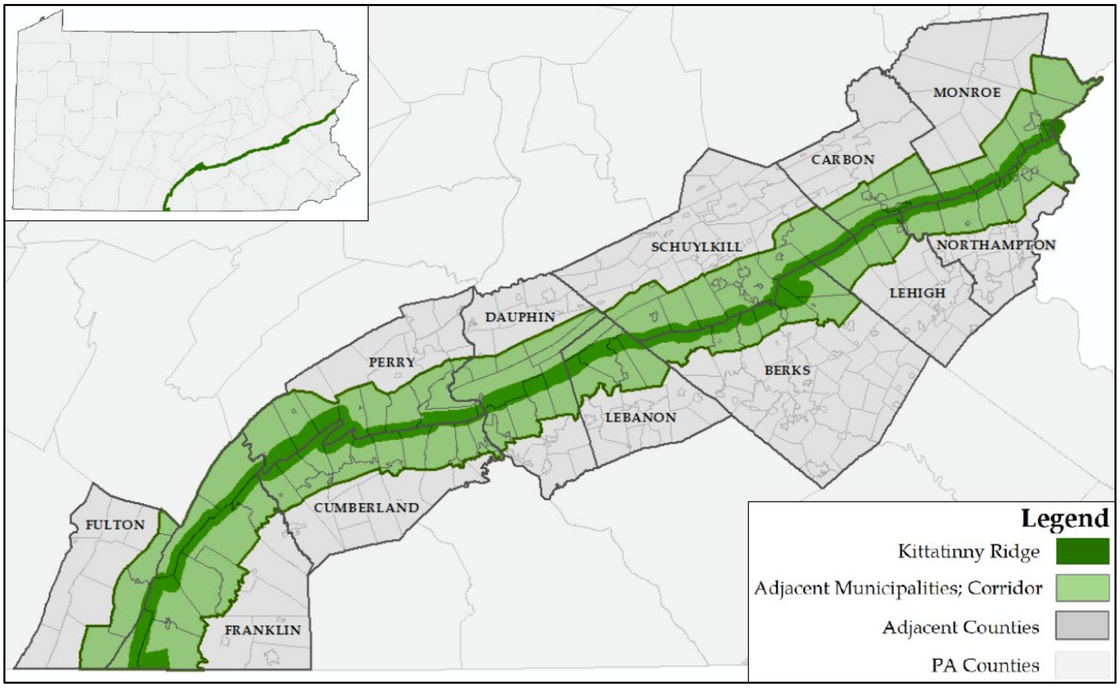

Figure 1. The Kittatinny Ridge stretches across 12 counties in Pennsylvania's Appalachian highlands. The "Kittatinny Ridge Corridor," the study area for this investigation, is delineated by those municipalities adjacent to the Ridge (Data Sources: US Census Bureau, 2016; US Census Bureau, 2017).

Despite the ecologic and economic importance of the landscape, the Ridge faces multiple anthropogenic threats. As development trends increase, many areas of the Ridge are vulnerable to urban expansion and growth. Development pressure also threatens aquatic ecosystems within the Kittatinny Ridge corridor, especially with respect to potential riparian buffer compositional changes. Forest buffer systems enhance water quality by filtering nonpoint source pollutants before they can enter streams, whereas agricultural and urban lands tend to facilitate surficial runoff and increase the amount of pollutants entering waterways (Lowrance et al., 1997). Native plants face competition from non-native species, and although the area is identified as climate-resilient, it is not immune to the impacts of changing global climates (Kittatinny Ridge Coalition, 2016b; 2017).

These challenges are intensified in that many local residents and local governments fail to recognize the global significance of the landscape. Given the aesthetic beauty of the Ridge, it is also difficult for the public to realize that such threats exist. Facing limited funding, local governments and nonprofit organizations are thus forced to develop creative strategies to continue preservation efforts (Kittatinny Ridge Coalition, 2016b; 2017). Recognizing the threats to the ecological and economic character of the Ridge, the Kittatinny Ridge Coalition was formed in 2002 as a partnership alliance between "organizations, agencies, and academic institutions working with municipal officials and private landowners to conserve the natural, scenic, cultural, and aesthetic resources of the Kittatinny Ridge and Corridor" (Kittatinny Ridge Coalition, 2017). Their mission, "To preserve the integrity of the Kittatinny Ridge and Corridor, a rugged forested mountain surrounded by a mosaic of working lands, healthy streams, and pastoral beauty" (Kittatinny Ridge Coalition, 2017) is made possible through community support, education, outreach, and partnership. Goal 2, Objective A of the Kittatinny Ridge Coalition's *2015-2018 Goals, Objectives, and Action Items* states a mission to "conserve native habitat and wildlife by conducting a GIS-based baseline land cover analysis of the Kittatinny Ridge and Corridor..." To support this Objective, the Coalition partnered with the Shippensburg University Center for Land Use and Sustainability to "create and maintain a series of GIS datasets...and baseline landscape metrics... [used] to support research and conservation activities" (Center for Land Use and Sustainability, 2017). Such data and metrics of land, water, and wildlife resources provide a means to track conservation progress on the Ridge over time. Thus, using a subset of these data, this manuscript analyzes the short- (2001-2011) and long-term (1940-1990) spatiotemporal land cover trends across the Ridge. Data are analyzed quantitatively and qualitatively to describe *how* and *where* the Ridge is changing.

At its core, this research attempts to address two major goals with the following four objectives:

(1) (a) Analyze long-term (every five years from 1940-1990) forest, agricultural, and developed land cover composition trends.

(b) Analyze short-term (every five years from 2001-2011) forest, agricultural, and developed land cover composition trends.

(2) (a) Quantify the spatial distribution of long-term forest, agricultural, and developed land cover trends by calculating location quotients by municipality from 1940-1990.

(b) Quantify the spatial distribution of short-term forest, agricultural, and developed land cover trends by calculating location quotients by municipality from 2001-2011.

With the ever-growing land development pressure across the Ridge, there is a mounting need to understand these land cover transitions and their implications to the surrounding landscape. Results presented here assist in the development of informed management decisions specific to the Ridge's needs and offer justification for the environmental goals and proposed management strategies across the Ridge. This work also informs our understanding of the broader historical and geographical context of this landscape, especially relative to forest transition trajectories (e.g. Mather and Needle, 1998; Drummond and Loveland, 2010). Finally, this report contributes to the growing body of literature that seeks to understand the complex human-environmental interactions in the context of land cover/land use science (Liu et al., 2007; Turner et al., 2007), a contribution especially valuable given the Ridge's global significance.

METHODS AND DATA

The 138 municipalities adjacent to the Ridge (see Figure 1) were collectively referred to as the Kittatinny Ridge Corridor and served as the study area for this investigation. We assessed land cover trends across the corridor using two land cover datasets of different temporal and spatial resolutions. Sohl et al. (2016) provided modeled annual national-scale data at 250m resolution from 1938-1992. This dataset, created by backcasting from 1992, was used for analysis of long-term land cover trends. This long-term analysis was conducted every 5 years from 1940-1990. Short-term analysis (2001-2011) was accomplished using the 2001, 2006, and 2011 United States Geological Survey's National Land Cover Database (Homer et al., 2007; Fry et al., 2011; Homer et al., 2015), a nation-wide dataset derived from satellite observations with 30m resolution.

As is common in assessments of land use and land cover, these datasets differ in their spatial and temporal resolutions (Turner et al. 2007; Klemas 2014; Wentz et al. 2014). Additionally, they differ in their land cover classification schemes. Despite the differences in spatial and temporal scale, these data were suitable for their respective long- and short-term analyses considering they represent some of the best land cover datasets for this region that can be compared consistently across time and space. Furthermore, these differences were mitigated in that results from either dataset were not directly compared to one another; rather, we interpreted each set of results individually to analyze their respective representations of temporal change. To address the classification differences, both datasets were reclassified into a consistent classification scheme (Table 1).

Area tabulations were performed on these data to calculate the area of each land cover type within a given municipality during each analysis year. Land cover areas were then used to express the proportion of a particular land cover type in a given municipality during the indicated data year. When combined across multiple years, these proportions illustrated trends in land cover composition.

Spatial dynamics across municipalities were quantified using location quotients (Jantz et al., 2014). A location quotient compares the rate of change in the proportion of land cover L between time t_1 and t_2 in municipality M compared to the corresponding corridor-wide comparative proportion C. These values represent the rate of a particular land cover change in a given municipality relative to that land cover's average rate of change across the entire corridor. Location quotients (LQ) were expressed as:

$$Q_{L_M,L_C,t_1,t_2} = \left(\frac{L_{Mt_2}-L_{Mt_1}}{L_{Mt_1}}\right) \div \left(\frac{L_{Ct_2}-L_{Ct_1}}{L_{Ct_1}}\right) \quad \text{(Eq.1)}$$

Where,

Q= location quotient of municipality M
L=specific land cover type
t_1=proportion of land cover at time 1
t_2=proportion of land cover at time 2
C=respective corridor-wide values

Table 1. Cross-walk Table Used to Create Consistent Land Cover Categories

250m (Sohl et al. 2016) Land Cover Category (class value)	**Reclassified Land Cover Category (class value)**	**2001, 2006, 2011 NLCD Land Cover Category (class value)**
Water (1)	Water (1)	Open Water (11)
Developed (2)	Developed/Impervious (2)	Developed, Open Space (21) Developed, Low Intensity (22) Developed, Medium Intensity (23) Developed, High Intensity (24)
Mining (6) Barren (7)	Mining/Barren (3)	Barren (31)
Deciduous Forest (8) Evergreen Forest (9) Mixed Forest (10)	Forest (4)	Deciduous Forest (41) Evergreen Forest (42) Mixed Forest (43)
Grassland (11) Shrubland (12)	Low Vegetation (5)	Shrub/Scrub (52) Grassland/Herbaceous (71)
Cultivated Cropland (13) Hay/Pasture Land (14)	Agriculture (6)	Pasture/Hay (81) Cultivated Crops (82)
Herbaceous Wetlands (15) Woody Wetlands (16)	Wetlands (7)	Woody Wetlands (90) Emergent Herbaceous Wetlands (95)
No Data (3) No Data (4) No Data (5) Perennial Snow/Ice (17)	No Data	Perennial Ice/Snow (12) Dwarf Scrub (51) Sedge/Herbaceous (72) Lichens (73) Moss (74)

If a corridor-wide trend was of land cover increase, location quotient values greater than 1 indicated that land cover in a given municipality was growing faster than the corridor average. Likewise, a location quotient value less than 1 (but greater than 0) indicated that the given land cover was growing at a rate slower than the corridor average. Conversely, if the corridor-wide trend for a given cover type was decreasing, positive location quotient values greater than 1 indicated that a municipality was losing that land cover faster than the corridor average. Similarly, quotient values less than 1 (but greater than 0) indicated that a municipality was losing a given land cover type slower than the corridor average. In the same scenario of net corridor land cover loss, negative values represented land cover gain in a given municipality. Quotient values greater than -1 (but less than 0) indicated that the rate of increase was less than the corridor-wide rate of decrease. Values less than -1 illustrated a rate of land cover increase faster than the overall rate of decrease.

Due to the large and significant representation of forested, agricultural, and developed/impervious land cover across the landscape, location quotients were only calculated for these 3 principal land cover types. Furthermore, while land cover composition trends were analyzed every 5 years from 1940 through 1990, along with 2001 and 2011, only two sets of location quotients were calculated, 1940-1990 and 2001-2011, in order to express the overall respective long-and short-term trends.

RESULTS AND DISCUSSION

Long-term Analysis of Land Cover Trends

Long-term land cover change analysis using 250m data from 1940-1990 revealed agricultural loss met with increases in forest and developed land cover (Figure 2). The loss in agricultural land appears to mirror the observed gains in forested cover, suggesting a long-term trend of agriculture abandonment consistent with the forest transition theory (Mather and Needle, 1998), which describes a transition from deforestation in early stages of economic development to one of net forest gain, as agricultural, technological, and other efficiencies cause the abandonment of sub-optimal farm land. Additionally, some of the observed urban growth may be preferentially encroaching on the agricultural land, though such a conclusion is difficult to confirm given the coarse data scale.

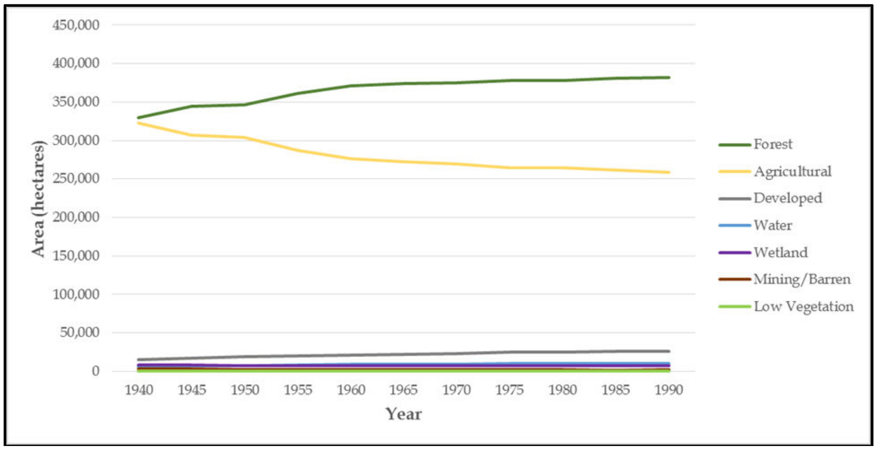

Figure 2. Long-term land cover trends at the 250m resolution across the Kittatinny Ridge Corridor from 1940-1990. The loss of agricultural land appears to be made up by the gains in forest along with some urban outgrowth.

Forest remained the dominant land cover across the corridor throughout the entire long-term study period from 1940-1990 (Table 2). In 1940, forests comprised nearly 48% of the landscape while agriculture accounted for 47%. By 1990, however, forested land cover grew to 56% coverage while agriculture declined to only 38%. Urban land covers grew steadily during this time, starting with a composition of 2% and ending with 4%.

Table 2. Corridor-Wide Land Cover Composition from 1940-1990.

		Percentage										
Value	**Land Cover**	**1940**	**1945**	**1950**	**1955**	**1960**	**1965**	**1970**	**1975**	**1980**	**1985**	**1990**
1	Water	1	1	1	1	1	1	1	1	1	1	1
2	Developed	2	3	3	3	3	3	3	4	4	4	4
3	Mining/Barren	0	0	0	0	0	0	0	0	0	0	0
4	Forest	48	50	50	53	54	54	55	55	55	55	56
5	Low Vegetation	0	0	0	0	0	0	0	0	0	0	0
6	Agricultural	47	45	44	42	40	40	39	39	39	38	38
7	Wetland	1	1	1	1	1	1	1	1	1	1	1

**Annual proportions may not equal 100 due to rounding*

While these data offer a glimpse into historic land cover trends across the corridor, it is important to remember that they do not necessarily represent the trends exhibited by each municipality (discussed in greater detail below). Further, these results are derived from a coarse resolution, 250m land cover dataset. With analysis at the municipal scale, this coarse resolution is unable to capture all forms of development. For example, road features and neighborhoods, driving forces behind land fragmentation, are beyond the minimum mapping unit of 250m data (see Figure 4). A further limitation of the Sohl et al. (2016) data is that the forest class is treated as a land *use*, which means that forested land used for timbering activity is mapped as "forest" even if the forest *cover* has declined. Nonetheless, Sohl et al. (2016) offers among the most widely available historic datasets for the Kittatinny region, and Jawarneh and Julian (2012) and Sohl et al. (2016) note the difficulties associated with historic land cover modeling.

Short-term Analysis of Land Cover Trends

To expand on these long-term observations, this research also explored short-term land cover trends using higher resolution, 30m land cover data. It must be noted that long-term results derived from the 250m modeled data are not directly comparable to short-term results derived from the 30m observational data. Aside from the differences in how each data set was generated, the 30m data must be aggregated to 250m before any direct comparisons can be made. Such analysis, however, is beyond the scope of this report. Rather, this manuscript explores spatiotemporal trends using two different data resolutions representative of the individual time scales they attempt to model.

Short-term corridor-wide trends at the 30m resolution from 2001-2011 were considerably less dynamic than those of the long-term trends (Figure 3). Such patterns are expected given the shorter analytical time frame. No significant losses or gains are observable in the corridor-wide land cover compositions, albeit slight forest and agricultural losses are noted from 2006-2011 along with a small urban/developed gain (Table 3). Forest, the dominant corridor-wide land cover, declined slightly from 53.7% in 2001 to 53.2% in 2011. Similarly, the representation of agricultural land declined slightly from 31.1% in 2001 to 30.7% in 2011. The developed category was the only land cover type to experience noticeable growth, increasing from 12.7% in 2001 to 13.3% in 2011.

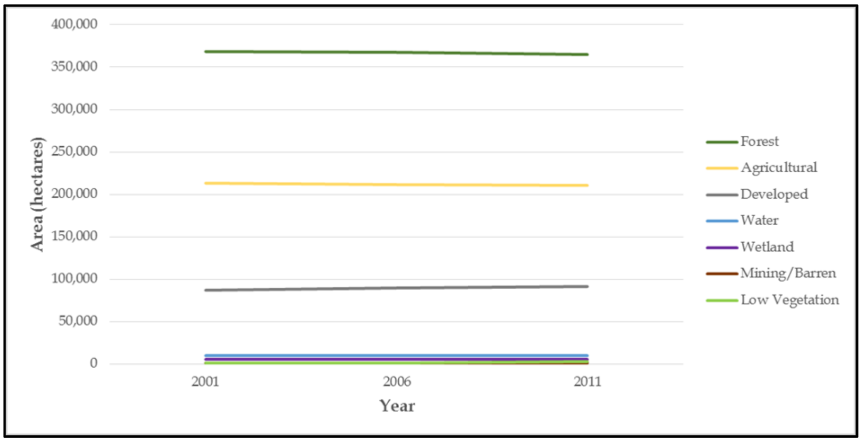

Figure 3. Short-term land cover trends at the 30m resolution across the Kittatinny Ridge corridor from 2001-2011. Corridor-wide land cover change appears generally stable, though a slight decline in forest and agricultural land is observed which is met with a small gain in developed land.

As mentioned above, these proportions are not directly comparable with those of the 1940-1990 analysis due to differences in resolution from which these data are derived. That is, the perceived "growth" of urban land cover from 1990 (4%, as represented in the 250m data set) to 2001 (12.7%, as represented in the 30m data set) is not necessarily real, rather it is a reflection of the ability of the 30m data to capture and represent the landscape in greater detail (Figure 4).

Table 3. Corridor-Wide Land Cover Composition from 2001-2011.

		Percentage		
Value	**Land Cover**	**2001**	**2006**	**2011**
1	Water	1.4	1.4	1.4
2	Developed	12.7	13.0	13.3
3	Mining/Barren	0.1	0.1	0.1
4	Forest	53.7	53.6	53.2
5	Low Vegetation	0.1	0.2	0.5
6	Agricultural	31.1	30.9	30.7
7	Wetland	0.8	0.8	0.9

**Annual proportions may not equal 100.0 due to rounding*

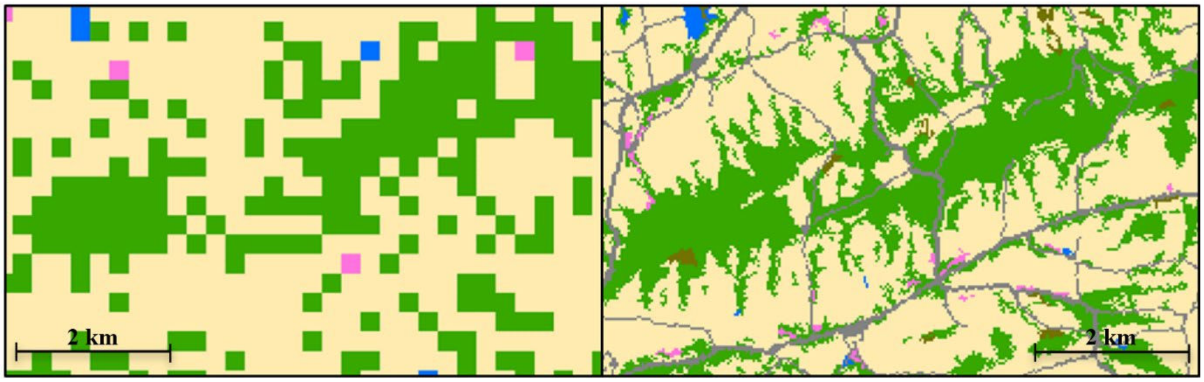

Figure 4. Land cover data with 250m resolution (left) offer only a coarse and generalized illustration of the landscape. Higher resolution data like that of the 30m NLCD (right) provide a more detailed presentation of the landscape. Both images were captured at the same location and drawn at the same scale. Visual differences are a result of data resolution.

The 30m NLCD data are not without their own limitations in representing the landscape. Land cover changes are local and vary by municipality. Given that such change occurs across a relatively small spatial area, 30m may still present too coarse a data resolution for modeling land cover change at the municipal scale. The 30m NLCD data are especially biased against estimating low-density residential neighborhoods (Irwin and Bockstael, 2007). Such a land use is the very developmental pattern that presents some of the greatest risks to the corridor given its ability to promote land fragmentation and sprawl. As such, analysis using finer resolution, multi-temporal data is necessary to fully understand the coupled human-environmental land cover trends that characterize the corridor.

Although minor, the long- and short-term trends discussed above mirror those in eastern US forests that Drummond and Loveland (2010) describe. They suggest that the early 20th century trend of forest expansion following agricultural abandonment is being replaced by a forest- and agricultural-cover loss trajectory driven largely by timber cutting cycles (in the case of forest loss) and, as is the case in the Kittatinny Ridge corridor, urbanization.

Spatial Dynamics of Land Cover Trends

Three sets of location quotients (LQs) were calculated for each time series to compare municipal-scale change to corridor-wide change. Some calculations produced “undefined” LQ values because of the inability of the equation to produce real numbers – in other words, when a municipality lacked a given land cover type (value of zero) in the initial date period (1940 or 2001) (see Eq.1). All municipalities with undefined LQ values start the particular time period with a zero-value proportion. They then either experienced increase in that given land cover or remained at a zero proportion at the end of the time period. The first situation represents gain in a given land cover where it had not previously been detected and the second represents the complete absence of a given land cover throughout the entire time period. Although these gains are not quantitatively compared to corridor-wide trends through location quotients, we do differentiate them from those undefined values representing a complete absence of a particular land cover. It is important to note that six of the 138 municipalities were represented by a relatively small number of 250m pixels (range: 2-8 pixels). Potential inflation of these small municipalities' long-term LQ values was not a concern, however, as no change in land cover composition was detected in these municipalities from 1940 to 1990 (LQ = 0 or undefined) with the exception of one municipality that experienced only a moderate increase in urban land (LQ = 0.48).

Long-term location quotient analysis (1940-1990) for agriculture revealed that most municipalities (116 of 138) experienced agricultural loss, which follows the corridor-wide trend (Figure 5a). Seventy-seven of these municipalities lost agricultural land at a faster rate than the corridor's rate of loss (LQ > 1) with 34 of these losing agricultural land at a rate greater than or equal to two times the corridor's rate of decrease (LQ >= 2). Parryville in Carbon County was the only municipality that gained agricultural land over this time period (LQ = -0.32). Nineteen municipalities experienced no change detectable by the 250 m resolution data (LQ = 0).

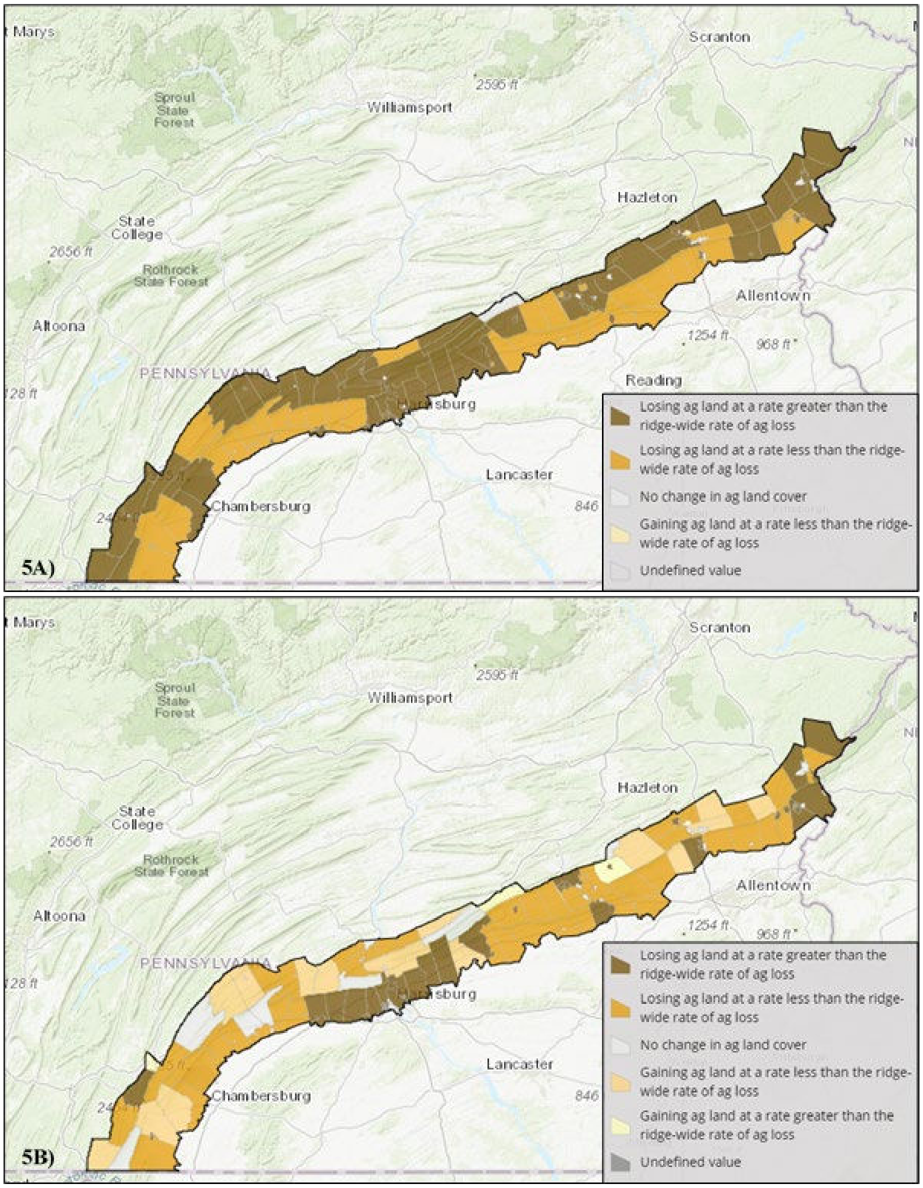

Figure 5. Qualitative summary of agricultural location quotient values for municipalities within the Kittatinny Ridge corridor from a) 1940-1990 (Sohl et al., 2016; US Census Bureau, 2016; 2017) and b) 2001-2011 (NLCD 2001; 2011; US Census Bureau, 2016; 2017).

Short-term location quotient analysis (2001-2011) for agriculture revealed rates of decrease for 78 municipalities, which followed the overall corridor-wide trend (Figure 5b). High rates of agricultural loss are observed in a stretch of municipalities starting in northeastern Cumberland County and continuing through central Dauphin County and ending in northern Lebanon County. Agricultural gains were experienced in 19 municipalities with four of these increasing at a rate greater than the corridor's rate of decrease. Six municipalities were classified as "undefined" but all represented a complete absence of agriculture from 1940 to 1990. One particular municipality, Deer Lake in Schuylkill County, produced an extreme LQ value of -579.80. Further investigation using historic images on Google Earth revealed that much of this change in "agricultural land" resulted from earthworks and excavation during the construction of a small housing development. Thus, the spectral characteristics of this area were considered "agriculture" by the NLCD's classification of exposed soil as agricultural land.

Long-term location quotient analysis (1940-1990) for forested land indicated a broader range of rates (Figure 6). Nineteen municipalities experienced rates of forest decrease ($LQ < 0$), despite the corridor-wide trend of forest gain. These municipalities were concentrated in two regions. The first is in Cumberland County with Hampden and East Pennsboro representing the largest of these municipalities. The second is in Carbon County and includes Parryville, which was the only municipality to experience agricultural gain from 1940-1990. Seventeen municipalities had no detectable change in forest land. Their forest composition remained constant but, among these municipalities, forest land ranged from 11-99%. The remaining municipalities experienced forest gain with three municipalities, West Pennsboro and Newville in Cumberland County and Chapman in Northampton County, increasing at roughly six times the corridor's rate of increase.

Short-term location quotient analysis (2001-2011) for forested land revealed that all but four municipalities experienced either forest loss or no significant change in their forest composition, supporting the corridor-wide trend of slight forest decline (Figure 6). These four municipalities increased in forest land at small rates compared to the corridor-wide rate (LQ values ranged from -0.01 to -1.02). The greatest forest losses occurred in the same stretch of municipalities described previously for short-term agricultural loss from northeastern Cumberland County to northern Lebanon County. Additionally, trends of both forest and agricultural loss are seen in the easternmost corner of the corridor, where Pike, Northampton, and Monroe Counties meet.

Long-term location quotient analysis (1940-1990) for urban land revealed no municipalities with urban loss, which supports the corridor-wide trend of urban gain (Figure 7). The largest rate of increase occurred in Bushkill Township in Northampton County ($LQ = 19.48$). Fifty-one municipalities increased in urban land at a rate greater than the corridor-wide growth rate, and 47 municipalities increased at a rate less than that of the corridor. Nineteen municipalities were classified as undefined. Each of these started with zero percent urban land in 1940 and experienced either urban gain (8 municipalities) or complete absence of urban cover (11 municipalities) by 1990. The largest increase within these undefined municipalities occurred in the borough of Blain in Perry County, where urban cover increased from 0% in 1940 to 15.3% in 1990.

Short-term location quotient analysis (2001-2011) for urban land indicated gains in 80 municipalities and no significant change in 58 municipalities (Figure 7). Urban land decrease was not detected. The majority of municipalities that experienced no urban change are composed predominantly of forest. The greatest increases of urban land occurred within the stretch of municipalities described previously for short-term agricultural and forest loss from northeastern Cumberland County to northern Lebanon County. The second cluster of municipalities mentioned previously in the easternmost corner of the corridor that experienced both forest and agricultural loss also exhibited significant increases in urban land. Overall, each of the six sets of location quotient analyses reveal not a pattern of expansive corridor-wide change, but rather significant changes limited to small, concentrated areas.

CONCLUSION

Results presented here capture the best representation (given data availability) of spatiotemporal land cover changes across the Kittatinny Ridge corridor from 1940-2011. Our results suggest that corridor-wide land cover trends are relatively stable with more significant changes occurring at the municipal or local level. The continuation of this analysis--studying individual municipal-level land cover dynamics--is necessary to track further changes and conservation progress within the corridor. Nonetheless, the historic land cover trends reported in this manuscript offer a valuable baseline for assessing future changes.

Our corridor-wide perspective on land use and land cover trends has great value for organizations (e.g. the Kittatinny Ridge Coalition) working on land preservation throughout the Kittatinny Ridge. This analysis clarifies which municipalities experienced the greatest development pressure and can help prioritize where scarce resources should be invested for land preservation. Our analysis also helps tell the story of the Kittatinny Ridge region within the broader context of American history. Because the land cover dynamics within the corridor reflect the forest transition theory, the reforestation trend we observe during the 1940-1990 period can be qualitatively linked to broader economic and technologic changes in agriculture, forestry, and transportation. At the same time, the forest decline observed in the 2001-2011 period reflects contemporary pressures from suburban sprawl.

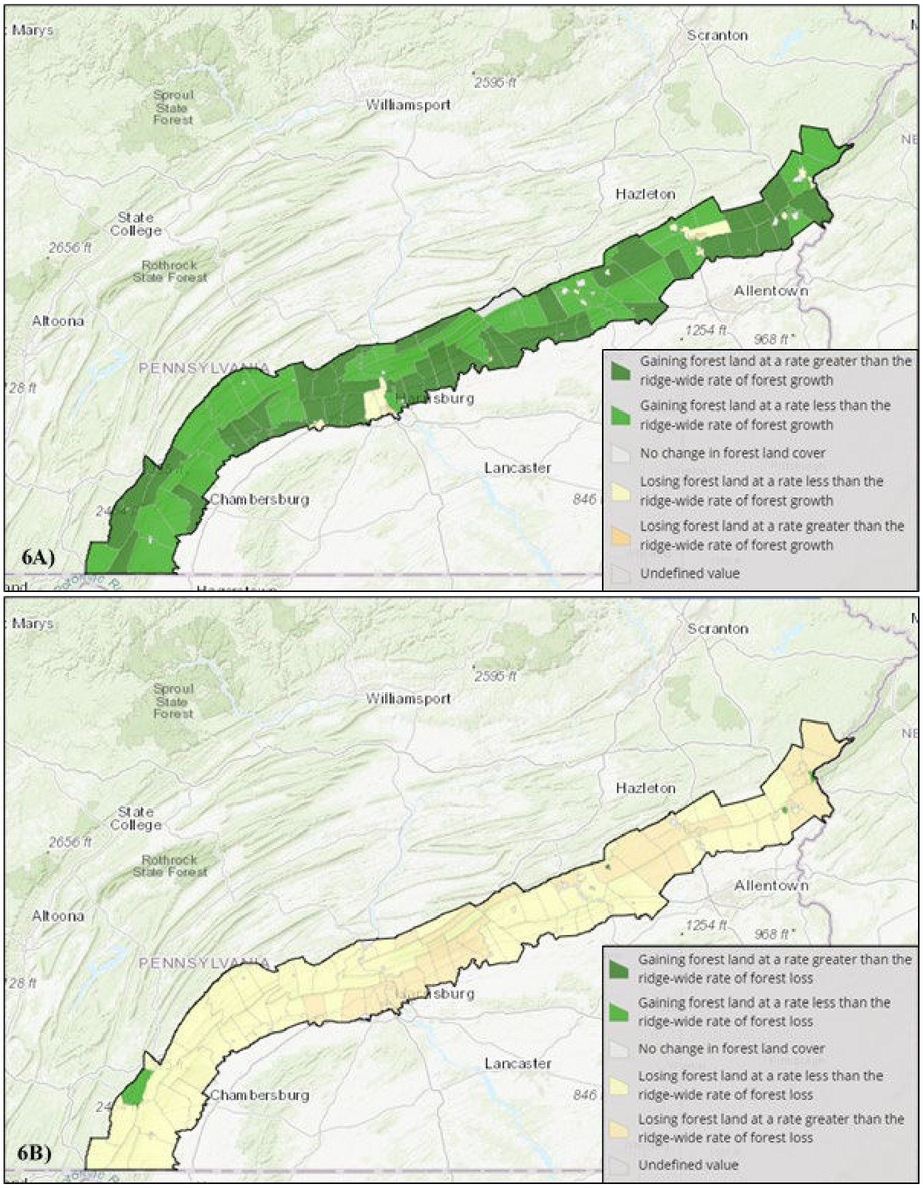

Figure 6. Qualitative summary of forest location quotient values for municipalities within the Kittatinny Ridge corridor from a) 1940-1990 (Sohl et al., 2016; US Census Bureau, 2016; 2017) and b) 2001-2011 (NLCD 2001; 2011; US Census Bureau, 2016; 2017).

We recognize the limitations that differences in data resolution (250m and 30m) and mapping approaches can introduce to the results. While assessing corridor-wide and municipal-level change is valuable, significant changes could have occurred, or may currently be occurring, at a scale not able to be monitored with a coarse resolution like 30m (coarse with regards to municipal analysis). Analysis at such a level was beyond the scope of this project given the limited availability of region-wide fine resolution data, though such could provide a more complete understanding of spatiotemporal land cover trends across the corridor. Indeed, understanding the exact locations of land cover change enables further identification of the drivers behind such change.

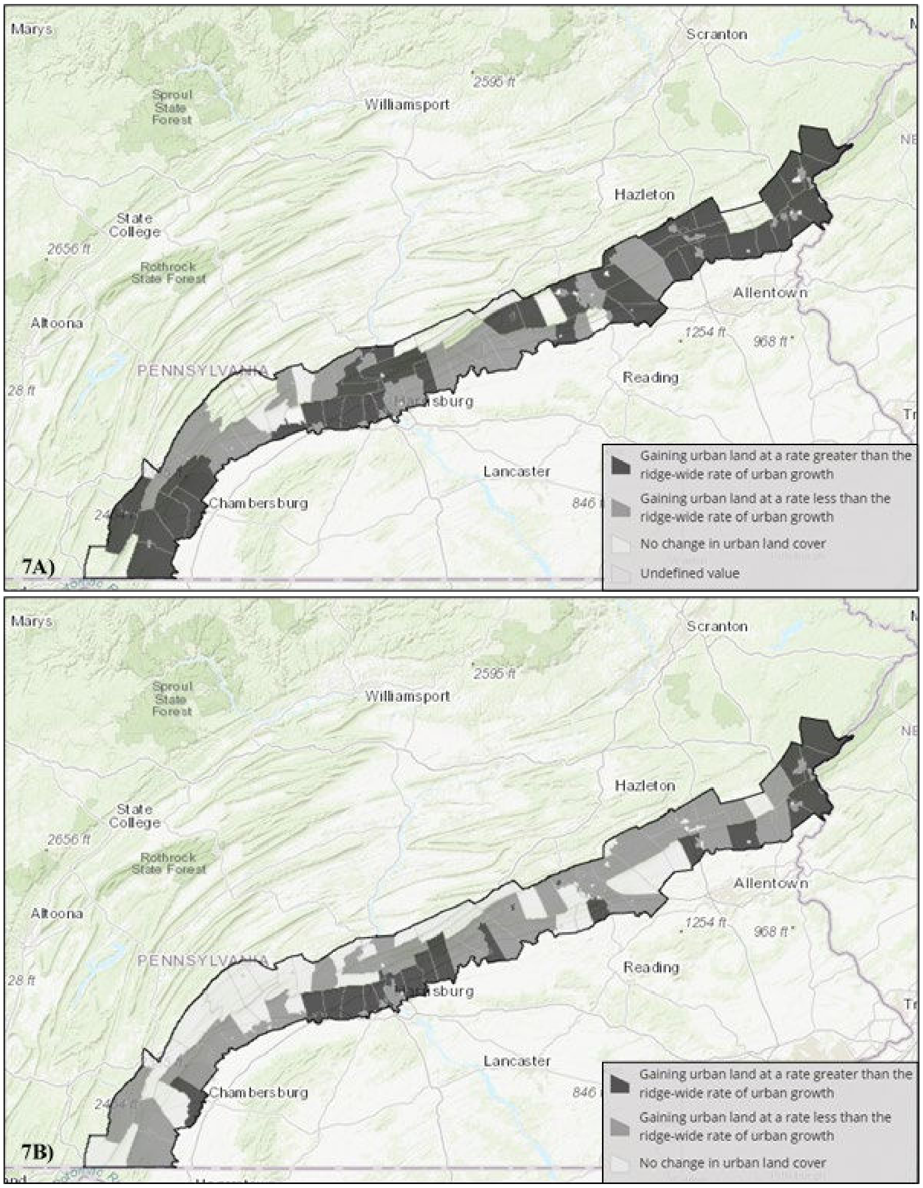

Figure 7. Qualitative summary of urban location quotient values for municipalities within the Kittatinny Ridge corridor from a) 1940-1990 (Sohl et al., 2016; US Census Bureau, 2016; 2017) and b) 2001-2011 (NLCD 2001; 2011; US Census Bureau, 2016; 2017).

The limitations of available data sets were demonstrated throughout this report. Long-term analysis was conducted using Sohl et al. (2016)'s 250m resolution land cover dataset, while short-term analysis was conducted using NLCD's 30m resolution land cover dataset. These scale differences limit comparison of land cover proportions between the long-term and short-term data. Instead, we generalize changes in these proportions to reveal overall land cover trends characteristic of each temporal period, though we recognize such trends are relative to the dataset from which they are derived. This is especially true when considering long-term forest trends because, as noted earlier, the 250m data set considers forest as a land use rather than a land cover (Sohl et al., 2016) and will therefore not capture forest cover dynamics related to timber activities. Thus, a mounting need exists for datasets with higher spatial and temporal resolution. Although land cover data with finer resolutions have recently become available (Delaware River Basin Land Use Dynamics, 2018; Chesapeake Conservancy, 2018), they lack multiple temporal iterations. Furthermore, analysis involving any additional data of coarser resolutions limit the use of the finer ones.

With the ever-growing land development pressure across the corridor, there is a growing need to understand these land cover transitions and the implications they have on the proximate landscape. Despite the limitations described above, results presented throughout this manuscript can assist in the development of informed management decisions specific to the corridor's needs and offer justification for the environmental goals and proposed management strategies across the corridor. This analysis can be used by management partners to facilitate community outreach and education, and will serve as a baseline for ongoing preservation efforts. In addition to this manuscript, an ArcGIS Online web map has been developed to interactively illustrate these results. It is accessible at https://centerforlanduse.org/resources/documents/.

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