# Spatial and temporal patterns of public and private land protection within the Blue Ridge and Piedmont ecoregions of the eastern US

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# HIGHLIGHTS

- Landscape configuration matters for conserving biodiversity and ecosystem function.
- Private land conservation may serve an important role in future land protection.
- Compared to public protected lands, private lands are smaller, and more isolated.
- Management either allows for extraction or is unknown in private protected lands.
- Work is needed to improve the effectiveness of land protection as a conservation tool.

## Abstract

Protected lands are an established method for conserving biodiversity and ecosystem services. Moreover, agencies and organizations are increasingly looking to private lands as places for new protected lands establishment. However, the effectiveness of protected lands in guarding against the loss of species or services can vary based on their coverage of habitat and species, management strategy, and their size and configuration across the landscape. We compare protected lands patches between two adjacent ecoregions, the public lands centric Blue Ridge and the private land dominated Piedmont, using estimates of land cover, management practices, and landscape configuration as a proxy for their relative contribution towards the long-term conservation of biodiversity and ecosystem services. We conducted a hotspot analysis to evaluate geographic changes in spatial clustering of protected lands establishment between the years 1985 and 2015. In addition, we evaluated climate resiliency of protected lands patches using metrics developed by Anderson et al (2016). We found that, compared to public lands, private protected lands contain larger amounts of agriculture than forest, allow for more utilitarian use than public lands, and are less resilient to climatic change. Furthermore, although total area of private protected lands increased since 1985, they are smaller and more disconnected, contributing less to overall connectivity of the protected lands network. To improve upon past efforts, we must improve management accounting and practice and prioritize land for protection that improves coverage, network connectivity, and climate resilience.

Key words: Protected Lands; Biodiversity; Reserve Design; Hot Spot Analysis; Conservation Planning; Network Connectivity

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## 1. Introduction

Human-dominated land uses now represent just over half of earth's terrestrial landscape (Watson et al. 2016). Rapid growth and opportunistic land use have resulted in habitat loss and fragmentation, two of the greatest threats to biodiversity (Flynn et al. 2009, Bellard et al. 2014, Isbell et al. 2015, Thompson et al. 2016). Slowing biodiversity loss is a key objective for conservation biologists (Tilman et al. 2014, Di Marco et al. 2016) who are motivated by both intrinsic and cultural valuations of species and role they play in supporting ecosystem function and services (Loreau et al. 2001, Millennium Ecosystem Assessment 2005, Hausmann et al. 2016).

For several decades, the primary method for mitigating the negative impacts of land use on biodiversity and ecosystem services has been to establish protected lands (Watson et al. 2014, Gray et al. 2016). Individual protected lands have been shown to be effective at safe-guarding habitat (Geldmann et al. 2013), biodiversity (Gray et al. 2016), and ecosystem services (Watson et al. 2014) from anthropogenic threats. However, in order for protected lands to meaningfully contribute to national or global conservation goals and targets, they must be considered in the context of an overarching network that represents biodiversity and sustains the natural function of ecosystems (Margules and Pressey 2000). Achieving this requires adequate geographic coverage (Jenkins et al. 2015, Watson et al. 2016), conservation-oriented management strategies (Kamal and Brown 2014, Owley and Rissman 2016), and consideration of their placement within current and potential future landscapes (Goetz et al. 2009, Martinuzzi et al. 2015, Rissman et al. 2015). Unfortunately one or more of these criteria often go unmet resulting in protected lands that do not achieve their full potential as effective conservation tools (Clark et al. 2013, Watson et al. 2014, Jenkins et al. 2015). A detailed assessment of the spatial and temporal patterns of land conservation at a regional scale can highlight where protected areas have been placed in line with the above conservation criteria, and where they have not, and can provide lessons for improving the effectiveness of land conservation programs, both regionally and internationally.

To provide coverage that effectively contributes towards biodiversity conservation both the size of individual protected lands and the connectivity of protected lands networks are important considerations (Minor and Lookingbill 2010). Large protected lands are more likely to protect large habitat patches, an important consideration given that habitat size has been shown to be a positive predictor of species richness for many taxa (Rosenzweig 1999). Minor and Lookingbill (2010) found that protected lands can contribute to biodiversity conservation simply by being of sufficient size to maintain ecosystem components. Large protected areas can also protect a larger number of smaller habitat patches as well as the corridors between patches. Preserving this habitat connectivity may be important for wildlife movement (Gilbert-Norton et al. 2010) and gene flow between populations (Jump and Peñuelas 2005, Birand et al. 2012). When land use results in fewer, smaller, more isolated habitat patches with greater edge to core ratios, landscape scale dynamics which sustain species can be disrupted, potentially increasing the vulnerability of habitat to further degradation (Goetz et al. 2009, Allen et al. 2013, MacLean and Congalton 2015). It is often logistically infeasible to acquire a single comprehensively large area for conservation. In these instances adequate coverage can be achieved by establishing multiple protected lands that together capture species and habitat diversity in a spatial configuration that supports ecosystem function (Di Marco et al. 2016).

Historically, within the United States, protected lands have been mostly publicly owned and managed (Raymond & Fairfax 2000) but this is changing. The establishment of the Uniform

Conservation Easement Act of 1981 (UCEA), which authorizes favorable tax benefits to be used in the creation of conservation easements on private land, has led to an increase in private protected lands (Kamal and Brown 2014, Owley and Rissman 2016). There is also a growing international emphasis on the use of private lands to meet conservation goals, as signatories of the Convention on Biological Diversity work towards their country level targets. Private lands conservation programs have been implemented in several countries (Chile, Mexico, Brazil, Colombia, Australia, South Africa, among others) and the World Commission on Protected Areas has produced a guidance document on design and implementation (Stolton et al. 2014). Because of the continued need for land protection, and the unlikely establishment of new, large, public lands in many places, land protection on private property may serve an important role in biodiversity conservation into the future (Wade et al. 2011).

Understanding the implications of this shift is important because the degree to which protected lands are managed for conservation can be determined by both their level of governance (i.e. federal, state, NGO, private) and the category of protection within that governance (e.g. World Commission on Protected Areas (Dudley 2008). For example, although U.S. national parks and national forests are both federal lands, the parks have a mission to protect natural and cultural resources through controlled public access while the forests allow for extraction of natural resources, albeit through sustainable methods. Privately owned protected lands include a much wider suite of management practices, including specific designations for the protection of agricultural lands (Merenlender et al. 2004). As of the writing of this manuscript, a universal, formal definition or reporting method for the classification of private protected lands management does not exist in the U.S., decreasing the transparency of management practices to the public and studies such as this one (Stolton et al. 2014). Villamagna et al. (2015) illustrated the potential for private protected lands to conserve ecosystem services such as water quality, carbon storage, and erosion control at equal or greater capacity than public protected lands within the same region but it is vital that conservation agencies monitor private lands to ensure they are meeting that potential.

Even with adequate coverage, network connectivity, and management practices in place, for protected lands to be an effective tool for long-term conservation of biodiversity and ecosystem services, their establishment on the landscape must also maximize opportunities for species migration and adaptation following climatic change. For example, the migration and dispersal of species towards suitable climate may rely on appropriately protected habitat connectivity (Loarie et al. 2009, Mantyka-Pringle et al. 2012). Anderson et al. (2016) developed a scoring system for “climate resiliency” which identified areas with potential to sustain biodiversity under a changing climate. Studies such as Anderson’s can provide guidance on the placement of protected lands. It is just one facet of a larger approach which must consider coverage, management, and the current and future landscape in order to successfully mitigate the harmful impacts of land use change and conserve biodiversity and ecosystem services for generations to come. The long-term protection of these resources requires us to strategically identify areas that protect underlying mechanisms of ecosystem function (Costanza et al. 1997, Loreau et al. 2001, Flynn et al. 2009, Cardinale et al. 2012, Naeem et al. 2012, Brose et al. 2016), requiring effective conservation planning to be done at a landscape scale (Heller and Zavaleta 2009, Hansen et al. 2014).

This study aims to address the question: How well do landscape networks of public and privately-owned protected lands fulfill criteria for spatial configuration, management, and climate resiliency identified as essential for the long-term conservation of biodiversity and ecosystem function? We focus on an area of the southeastern US that includes the Blue Ridge ecoregion, an area recognized for its high biodiversity value (Jenkins et al. 2015). Protected lands patches within the Blue Ridge are primarily large and publicly owned, while those in the neighboring Piedmont are primarily small and privately owned (USGS 2016). This geographic dissimilarity in ownership grants an opportunity to treat each ecoregion as a protected lands landscape defined by ownership, allowing for comparisons to be made between both ecoregions and ownership. We compared and contrasted the spatial configuration, management, land cover, and climate resiliency of private and public protected lands patches in and around the Blue Ridge ecoregion and adjacent Piedmont sub-regions through time. These comparisons allow us to assess the contribution of private and public protected lands to overall network connectivity. We also consider the socio-economic factors that may have driven protected lands establishment across the decades. From this analysis, we draw broader insights into the future application of protected lands as a conservation tool and suggest potential improvements to improve future assessments and strategic planning efforts.

## 2. Methods

### 2.1 The study area

Our study area was defined using the ecoregion framework developed by Omernik and Griffith (2014), which divides North America into ecologically similar geographic zones at four nested levels of increasing resolution (Levels I to IV). Our analysis includes the entire Level III Blue Ridge, and several Level IV ecoregions nested within the Level III ecoregions of the Northern Piedmont and Piedmont, for a combined total area of 11,042,665 ha. We selected Level IV ecoregions (hereafter jointly referred to as the Piedmont) that immediately adjoin the eastern border of the Blue Ridge (Figure 1). Ideally, we would compare protected lands within two geographic areas that were more similar in size, topography, and land use. However, the complexity of these traits means this is an unlikely, or even impossible scenario. We believe the geographic distinction in protected lands ownership between the two focal ecoregions provides a unique opportunity for addressing an important question in conservation. Furthermore, the Blue Ridge and Piedmont regions that are the focus of our analyses are adjacent and share similar geographic features, climate, histories, and species.

The Blue Ridge ecoregion totals approximately 4,651,900 ha and includes portions of Pennsylvania, Maryland, West Virginia, Virginia, Tennessee, North Carolina, South Carolina, and Georgia. It is a mountainous region with its highest peak reaching over 2000 meters elevation. It is composed primarily of Appalachian oak forests, northern hardwoods, and at high elevations, southeastern spruce-fir forests. Shrub, grass, and heath balds, hemlock, cove hardwoods, and oak-pine communities are also common. The Blue Ridge ecoregion is relatively narrow, especially at the northern end, and is bordered to the east by lower elevation areas with relatively high levels of agricultural and commercial development. Our Piedmont region encompasses 6,390,800 ha and occurs within the same eight states as the Blue Ridge ecoregion, plus Alabama. This geographic area is characterized by rounded hills, open valleys, and flat plains. Although also primarily forest, the Piedmont also contains substantial grasses and cropland. We also included a 25km buffer around the study area so the full extent of protected lands patches overlapping the outer edge of both ecoregions were included in our landscape metrics.

## 2.2 Data

We acquired protected lands data through the Protected Lands Database of the United States (PADUS V1.4, USGS 2016). PADUS data were amended to include additional information on year of establishment, which we acquired via personal communications with regional conservation organizations and local governmental agencies. Data on ownership (categorized here as public or private), managing entity (public, private, non-governmental, other), and management status (GAP) were provided by the PADUS database. We confine our analysis to patches of publicly and privately owned protected lands and, for the sake of brevity, henceforth will refer to these as public and private lands or patches. We used land cover data from the National Land Cover Database (Homer et al. 2015) as the basis for eight broad land cover classes: Open Water, Developed Open Space, Development, Barren, Forest, Grass, Cropland, and Wetland. This reclassification involved grouping the NLCD's original development classes of low, medium, and high into 'Development'; forest types deciduous, evergreen, and mixed forest, and shrub/ scrub into 'Forest', Grassland/Herbaceous and Pasture/Hay into 'Grass'; and woody wetland and emergent wetlands into 'Wetland'. These land cover designations are broad generalizations and do not represent quality measures for ecological habitat. Climate resiliency data came from The Nature Conservancy's online Conservation Gateway (https://conservationgateway.org), where Anderson et al. (2016) identified areas that contribute to climate resiliency based on confirmed biodiversity, habitat connectivity, and projected changes in climate. Political boundaries and city data were collected from Tiger Census (US Census Bureau 2015).

We brought all spatial data layers into a GIS environment (ARCMap V10.4; ESRI) and converted the PADUS polygon layer to raster format, aggregating the grain size, or resolution, of existing rasters from 30m to 180m on one side (0.09 to 3.24 ha). There is no ideal resolution, rather it is guided by geographic extent, study focus, statistical concepts, and complexity of terrain or question (Turner et al. 1989, Hengl 2006). Therefore, we feel that a resolution of 3.24

ha is acceptable for this study because this resolution captures the location, area, and shape of small and large, protected lands and accurately estimates spatial configuration across a large geography, using landscape-scale analyses, without compromising computational performance. Other landscape-scale studies report grain sizes of 1km$^2$ for analysis of core habitat connectivity between protected lands in the northeastern U.S.; 3.1 km$^2$ for identifying spatial clusters of deforestation in India (Singh et al. 2017); and10km$^2$ for evaluating impacts of changing land use around U.S. national parks (Martinuzzi et al. 2015). We used the R programming platform (R Core Team 2016) and the packages raster (Hijmans et al. 2013), dplyr (Wickham et al. 2016), and ‘SDMTools’, which includes the proper spatial pattern analyses algorithms (FRAGSTATS V4, McGarigal et al. 2012).

### 2.3 Defining protected lands patches

Protected lands patches are defined as clumps of adjacent raster cells that were established in the same year. Therefore, adjacent protected lands patches established in different years were categorized as separate patches while adjacent patches established in the same year were categorized as the same patch. The PADUS database provided the year of establishment for most protected lands. Where possible, through independent research and phone consultations, we amended the PADUS database to include previously unknown years of establishment. We removed patches where year of establishment remained unknown. In total, 4179 were removed prior to further analyses, representing 9.8% of the total area of all patches in the study area and buffer. In some cases, land management agencies redefined portions of protected lands after their establishment (e.g. wilderness areas designated within existing national park boundaries). The result is a dataset for protected lands that contains overlapping polygons where year of establishment changed In these cases we used the earliest establishment year to define the patch, but the most recent year to define GAP status. In a few cases (n =22) we identified the associated conservation entity, but not the year of establishment, so we assigned the protected lands(s) the year the organization came into existence. All 22 of these patches were classified as privately owned and managed easements, mostly located in North Carolina (n=15). We defined core area as area within one raster cell, or approximately 180 m from the edge .We used the ‘PatchStat’ function in R to calculate patch statistics, including core area, based on landscape metrics computed within the software package FRAGSTATS (McGarigal et al. 2012). We set a minimum core area requirement of one cell, or 3.24 ha, which resulted in the removal of thin, linear patches and patches smaller than 29 ha from further analysis. Across the entire study area and buffer, we removed 3594 patches that met neither the year or core area requirements (1.4% of total patch area), 585 patches that met the core minimum alone (8.9% of total patch area), and 6997 patches that met the year requirement alone (4.5% of total patch area). This resulted in 3570 patches, or 85.7% of total patch area that have known years of establishment and suitable minimum core area. We report upon the total number of patches established as of 1985 and 2015 as well as new patches established between the years 1985 and 2015.

## 2.4 Landscape configuration

We used three measures to evaluate the spatial pattern of protected lands within the study area. First, we calculated total area and core area of individual protected patches and computed their cumulative sum. We recalculated patches at five year increments between 1985 and 2015 by coalescing adjacent patches into existing patches (i.e. patches established before 1985 were incorporated into the total area of protected lands established between the years 1986 and 1990). This allowed for individual patches to grow through time and core area to increase proportionally in these cases. Second, we evaluated patch aggregation across the landscape. The Aggregation

Index evaluates the degree to which protected lands patches are lumped together on the landscape. Values for the Aggregation Index range from zero (disaggregated) to one hundred (aggregated). To do this, we assigned protected lands to the Blue Ridge or Piedmont, based on majority area within each ecoregion, taking the buffer area into consideration. This avoided the cropping of patches by ecoregion boundaries that would skew estimates of area and core area for individual patches. We calculated the Aggregation Index at five year increments between the years 1986 and 2015. To evaluate the role of individual patches in aggregation, we identified patches that were established within and outside of a buffer distance of three raster cells, or approximately 540 m, of existing patches. Habitat connectivity distance thresholds vary depending on the study subject (Keitt et al. 1997). For example, Théau et al. (2015) used dispersal distances for mammals and bird species that varied from 3.13 km to 31.3 km to evaluate the contribution of forest patches to total landscape connectivity in southern Quebec, Canada. Thus, we consider the distance of 540 m, or approximately 0.5 km, to be conservative for capturing dispersal distances, and thus biodiversity relevant connectedness of protected lands patches.

Third, we used the Getis-Ord Gi* statistic to identify significant spatial clustering of protected patches as they were established across the 30 year period of 1985 to 2015. The Getis-Ord Gi* statistic differs from the aggregation index in that it calculates the value of each protected lands patch and puts this value in context of surrounding patches. A cluster is statistically significant when it has both a high value and is surrounded by other patches with high values. In this study, we assigned each patch a value based on the number of nearby patches of protected lands. We used ArcMap (V10.4 ESRI) to calculate nearest neighbor, or the minimum geodesic distance (in km) between protected lands patches across the study area. For this analysis, we incorporated the 25 km buffer around the ecoregions, allowing protected patches outside of the study area to influence nearest neighbor estimates of patches within the study area. A spatial weights matrix identified neighboring patches through Delaunay triangulation, which ensures that each patch has at least one neighbor, but uses the distribution of the data to determine the number of neighboring patches. For each patch, we identified the minimum distance to the nearest neighboring patch established in the same year or earlier.

## 2.5 Ownership, managing entity, management status, and land cover

We categorized individual patches within the study area and buffer by ownership (public, private), managing entity (public, private, NGO, other), management status (natural, primarily natural, extraction permitted, no known management), land cover (forest, grasses, crop). Patches can be owned and managed by different entities. Because of how patches were defined, we performed this classification in two ways: we used a majority rule to assign a single category to each patch and we calculated the actual total area using the sum of raster cells within each category. We calculated the total area for patches established on or before the years 1985 and 2015 and the cumulative sum in area for new patches established between the years 1985 and 2015.

## 2.6 Climate Resiliency

We assigned categories to all protected lands patches based on their potential contribution to climatic resiliency based on TNC criteria (Anderson et al. 2016). Anderson et al. (2016) define a resilient site as “a structurally intact geophysical setting that sustains a diversity of species and natural communities, maintains basic relationships among ecological features, and allows for adaptive change in composition and structure.” Their resiliency measures are a combination of landscape complexity and permeability. Landscape complexity is based on the diversity of landform, elevation, and soils (Anderson et al. 2016). Landscape permeability is based on the similarity of adjacent land cover classes and the presence of hard movement barriers. There are different categories of resiliency that emphasize the contribution of these geophysical landscapes to biodiversity, riparian systems, or both. Most resilient landscapes in the eastern US are focused along defined corridors but they can also be diffuse landscapes where there are adjacent, large protected areas. Anderson et al. (2016) also use circuit theory (McRae and Shah 2009) to map resistance to species movement between highly resilient landscapes. These linkages between core areas are either diffuse across broad protected landscapes or concentrated along narrow corridors that can be protected or vulnerable to development. With the completion of a resiliency and linkage map for the eastern US (Anderson et al. 2016), we were able to evaluate the resiliency value of each protected lands patch which existed on the landscape in 2015. We did not assign resiliency scores as patches were established because past landscapes likely had very different land uses outside of protected areas, a factor used in Anderson et al.'s (2016) resilience estimates.

## 3. Results

### 3.1 Protected Lands Patches

We identified 2034 protected patches established between 1985 and 2015; 707 are located within the Blue Ridge and 1327 patches are located within the Piedmont (Table 1). In 2015, protected lands within the combined Blue Ridge and Piedmont totaled 2.17 million ha (approximately 20% of study area). There is substantially more protected land area within the Blue Ridge than the Piedmont, with protected lands within the Blue Ridge totaling 1,778,690 ha, or 38% of the ecoregion (Table 1). In the Piedmont, protected lands total 388,230 ha and only account for approximately 6% of the ecoregion’s total area (Table 1). Furthermore, protected lands patches within the Piedmont are much smaller on average (300 ha, sd ±2700) than within the Blue Ridge (2500 ha, ±16900) (Table 1).

## 3.2 Landscape configuration

Patch statistics calculated using PatchStats revealed core area totaled 1,431,380 ha and contributed to approximately 81% of total protected lands area within the Blue Ridge and 214,140 ha, or 55% of total protected lands area within the Piedmont (Table 1). Between the years 1985 to 2015, the number of protected lands patches increased by 379 in the Blue Ridge and 1,138 in the Piedmont, with differing contributions to overall area and core area (Figure 2a). The total area of protected lands within the Blue Ridge increased by approximately 115,450 ha, a 7% increase in area, with a relatively stable contribution to core area. Conversely, total area of protected lands in the Piedmont increased by approximately 168,730 ha, a 77% increase in area, with a decreasing contribution to core area across the same period.

The Aggregation Index was higher overall for the Blue Ridge than the Piedmont (Figure 2b). Across the thirty year focal period, the Aggregation Index decreased for both ecoregions, but at a faster rate within the Piedmont. This suggests that when established, protected lands patches were more isolated from one another overall, and more so in the Piedmont than in the Blue Ridge. Between the years 1985 to 2015, 1313 protected lands patches were established within the buffer distance of 540m of existing patches and 1590 distinctly separate patches within the entire study area (Figure 2c). Between the years 1985 and 2015, the Blue Ridge added 199 nearby patches and 185 separate patches and the Piedmont added 558 nearby and 617 separate patches.

Results of the Getis-Ord analysis illustrates several geographic shifts in the spatial clustering of protected lands as they are established between the years 1985 to 2015 (Figure 3b). Up until 1985, spatial clustering of newly established protected lands occurred primarily in the northern Blue Ridge, with a focus around the Shenandoah National Park. Over the next 30 years, focal areas of protected area establishment can be seen within the southern portion of the Blue Ridge as well as within the northern Piedmont. By 2015, clusters of protected areas are most prominent in the southern portion of the Blue Ridge, around large, federal lands including the Great Smoky Mountains National Park, the Chattahoochee-Oconee National Forests, and Camp Merrill (an active military base) (Figure 3b). Also, by 2015 the northern portion of the Piedmont exhibits significant spatial clustering within small, private lands (Figure 3c). In addition to this small cluster within the Piedmont, there are areas across the Blue Ridge where patches of private lands contribute to an increase in core area of existing patches.

### 3.3 Ownership, managing entity, management status, and land cover

Our measures of protected lands patches in 2015 estimate that within the combined study area, 89% of protected area is under public ownership. The Blue Ridge contains the vast majority (1,702,500 ha, 90%) of public protected lands area, which comprises approximately 96% of total protected land area within the Blue Ridge ecoregion (Table 1). These public lands include two national parks (Great Smoky Mountains National Park and the Shenandoah National Park) and several national forests (i.e. Chattahoochee National Forest, Nantahala National Forest, Pisgah National Forest, and George Washington/Jefferson National Forest) but also multiple state, county, and city lands, in addition to designated wilderness areas and wildlife management areas. Private lands comprise only 4% of the Blue Ridge ecoregion. Conversely, protected areas in the Piedmont are more equally split between public and private ownership (60% and 40%, respectively) (Table 1). Many of the privately owned protected lands patches within the Piedmont are located in the northern portion; on the eastern side of the Shenandoah National Park (Figure 1).

As of 2015, publicly managed protected lands make up 1,558,600 ha (90%) of protected land area within the Blue Ridge and 182,800 ha (48%) protected land area within the Piedmont (Table 1). Privately managed protected lands make up 73,900 ha (4%) of protected land area within the Blue Ridge and 153,800 ha (40%) protected land area within the Piedmont (Table 1). In the Blue Ridge approximately 30% of protected land area is managed in a natural or primarily natural state (GAP status 1 and 2), compared to approximately 12% of land protected within the Piedmont. In addition, 59% of protected land area within the Blue Ridge is classified as GAP status 3 (open for resource extraction) compared to 35% within the Piedmont, while 12% of protected land area within the Blue Ridge is classified as GAP status 4 (no known management in place) compared to 53% within the Piedmont (Table 1). That means that approximately 88% of protected lands within the Piedmont are not under full protection from habitat loss and degradation, the vast majority of which are also privately owned and managed. Protected lands within both the Blue Ridge and Piedmont are composed primarily of forest (96% and 65%, respectively). However, unlike the Blue Ridge, protected lands within the Piedmont include relatively larger amounts of grassland (18%) and cropland (4%), compared to the Blue Ridge (1.5% and 0.04% respectively) (Table 1).

Protected lands patches established in the Blue Ridge between the years 1985 and 2015, were fairly evenly split between patches managed by public and private entities (62,500 and 49,900 ha, respectively), while privately managed lands make up the vast majority of new protected lands patches established in the Piedmont during the same time period (approximately

145,300 ha, or 88% of all new protected lands area) (Table 1 and Figure 4a). Comparing figures 4a-b with 4c-d illustrates the close relationship between managing entity and management status, particularly for the Piedmont. Within the Piedmont, land classified as GAP Status 4 dominates the landscape, comprising 87% of the area of patches established after 1985 (Table 1 and Figure 4d). Within the Blue Ridge, the total area of protected lands patches added is split into almost equal thirds between land classified as GAP Status 2, 3, and 4. Of protected land established after 1985, forest is the dominant land cover type within the Blue Ridge (93% of total new area) (Figure 4e). In the Piedmont, forest comprises 56% of total new area and grasses comprise 38% of total new area. In addition, in 2015 the Piedmont contains a notable amount of protected lands area classified as cropland, with an increase of approximately 10,000 ha, or almost 4 times the total protected cropland area before 1985 (Figure 4f).

## 3.4 Climate Resiliency

Approximately 51% of the entire study area is comprised of prioritized resilient lands or linkages as defined by Anderson et al. (2016), with protected lands covering only 16% of these resilient areas. Of those resilient landscapes within the study area, the vast majority (89%) are found within the Blue Ridge. Of the protected lands within the Blue Ridge, approximately 1.5 million ha (87%) of protected land or 34% of the ecoregion is classified as resilient and prioritized for the long term protection of biodiversity and connectivity in response to climate change (Table 1). In comparison, only 127,400 ha (31%) of protected land within the Piedmont, or 1.5% of the ecoregion has been classified as resilient, or is not prioritized for its potential role in climate resiliency (Table 1). Most protected lands within the study area (76%) overlap regions with high confirmed diversity. The overlaps in protected and resilient lands predominantly occur in a small number of larger protected land properties however, as only approximately 14% of protected properties include lands that have been prioritized for conservation based on diffuse or concentrated flow and less than 1% of protected lands include linkages, landscape features which occur outside of resilient sites but link together areas with confirmed diversity according to Anderson et al (2016). Not all of the cells in the climate resiliency raster (i.e. bodies of water) have a score assigned to it, resulting in a slight discrepancy compared to the total area of the respective ecoregion.

## 4. Discussion

In response to rapidly changing landscapes, conservationists continue to rely on protected lands as a method for preventing further habitat loss and degradation due to land and resource use. However, the effectiveness of protected lands for biodiversity and ecosystem services conservation has been shown to vary considerably across the globe. The populous eastern U.S., a region with high species richness, faces greater land use pressure than the west, yet has less protected lands coverage (Jenkins 2015). This discrepancy between need and coverage led us to explore the state of protected lands within two ecoregions of the southeastern U.S.: the Blue Ridge and Piedmont. We examined the degree to which protected lands within the Blue Ridge and Piedmont ecoregions fulfill three criteria we identified as essential factors for sustained conservation of biodiversity and ecosystem services across landscapes. These criteria are geographic coverage and configuration, management, and the degree to which they capture climate resilient lands.

Our analyses revealed distinct differences between landscape configuration, land cover, management, and climate resiliency of public and private protected lands patches between the Blue Ridge and Piedmont. The Blue Ridge contains the vast majority of total protected lands area in our study area. Furthermore, protected lands within the Blue Ridge are mostly public, while those in the Piedmont are mostly private. This allowed us to make additional comparisons in the three criteria listed above between public and private protected lands.

Protected lands patches within the Blue Ridge are fewer in number, but on average much larger, than those in the Piedmont, resulting in a greater contribution to total core area across the landscape in the year 2015. Large protected lands established in the early 19th and 20th centuries may have provided a geographic focus for the establishment of new patches that increase core area or the network connectivity of protected lands, particularly in the Blue Ridge. When we examined protected lands establishment between the years 1985-2015, we observed a larger relative increase in the number of individual patches and total area within the Piedmont compared to the Blue Ridge. However, protected lands patches established within the Piedmont during this time were much smaller in size and on average further away than existing patches, resulting in lower aggregation and thus lower network connectivity across the ecoregion over time. Unlike the Blue Ridge, the addition of protected lands in the Piedmont ecoregion between 1985 and 2015 increased total area of protected cropland and grasses almost as much as that of forest, contributing to the preservation of agricultural landscapes as well as some habitat for native biodiversity. This is representative of land classified as “no known conservation management strategy” (GAP status 4), a classification that is present in a higher proportion within the Piedmont than the Blue Ridge, where many protected lands fall under permanent protection (GAP status 1 & 2). Overall, protected lands within the entire study area capture only 16% of resilient areas, but not all land within the study area are classified as resilient by Anderson et al. (2016). The Blue Ridge contains the vast majority of climate resilient land and also captures more total area of climate resilient land within its protected areas compared to the Piedmont. Therefore, the total area of climate resilient protected lands in the Piedmont are not only driven by smaller protected lands area, but also less opportunity for capturing resilient land in the ecoregion overall. The difference in total climate resilient land area between ecoregions is a bit of a chicken and egg problem, whereby it is difficult to evaluate if the presence of climate resilient land is due to the effect of land protection and/or inherent landscape features that define climate resiliency (topography and elevation are key criteria in Anderson et al.'s 2016 study as well as defining features of the Blue Ridge).

Differences in the placement of protected lands observed between the Blue Ridge and Piedmont are the product of each region's topography and its influence on historic land use patterns. Differing social and economic factors have strong influence on the placement and size of protected lands (Rissman et. al 2015, Geldmann et al. 2013) driving availability (location and size of land), perceived risk, and the cost of easement acquisition (Di Marco et al. 2016). For example, the flat, arable land and moderate climate within the Piedmont was historically more suitable for agricultural development than the mountainous landscape of the Blue Ridge (see Watson et al. 2014). As a result, land within the Blue Ridge would be less economically valuable and also under less development pressure, allowing for higher forest cover and connectivity compared to land within the Piedmont. This likely contributed to the geographic and economic feasibility of protecting large tracts of forested land in the Blue Ridge during the early 19th and 20th centuries. In the decades to follow, urban and agricultural land use intensified and private land ownership increase, further fragmenting habitat, particularly within the Piedmont. It is plausible to reason that the small, disaggregated, privately owned protected lands patches present within the Piedmont today represent an opportunistic approach to protected lands establishment that is an indirect outcome of this region's land use history.

Given the socioeconomic considerations and the pressure imposed by a growing human population, we may see more opportunistic land protection, especially as we become increasingly dependent on private land. Although the rapid changes we are witnessing on our landscapes provide impetus for some degree of opportunism in protected lands establishment, we must adapt more strategic planning practices that will conserve and sustain biodiversity and ecosystem services into the future. The necessity of strategic placement was recently observed in a payment-for-ecosystems-services program in Costa Rica (Wood et al. 2017), where the lack of spatial prioritization of investments has resulted in a failure to enhance the national biological corridors program, even though these national level programs had this as a specific goal.

Because many conservation easements across the US are owned and managed by private citizens (Merenlender et al. 2004, Hardy et al. 2016), and because private land conservation is likely to continue, there are clear management implications for future prioritization of new private protected areas. The network connectivity of smaller protected areas can be amplified if government agencies and land managers encourage future private protected area designations that contribute to aggregations and corridors on the broader landscape. In our analysis we discovered the development of a significant cluster of privately owned protected lands within the northern Piedmont between the years 1985-2015. The true drivers for this cluster are unknown, and its presence may or may not be illustrative of more strategic placement of protected lands. Nonetheless, these private protected lands help to improve regional and local network connectivity and may even thwart the arrival of fragmentation thresholds that can impair ecological resilience and dramatically alter species composition and abundance (Andrén 1994, Pardini et al. 2010).

While this study makes broad generalizations on the ability of protected lands to support biodiversity and ecosystem services within each ecoregion, it is difficult to accurately assess the true implications of differing management strategies. GAP Status codes are accepted nationally and internationally as a way to broadly categorize the management state of protected lands, they do not necessarily depict local management which may be more or less effective that recorded. GAP status 4 is specifically used as an open categorization of diverse management efforts and just in the study area used in this analysis, we discovered more than 500 different management authorities for Status 4 lands. The lack of a formally-recognized classification scheme across private protected lands like those in our study area contributes to the difficulty in developing even broad generalizations of the benefits of land protection in sustaining biodiversity and ecosystem services. Additionally, discrepancies have been discovered between wildlife conservation goals described in private conservation land trust mission statements and conservation action (e.g. Dayer et al. 2016) that convolute our ability to assess our ability to conduct accurate, large-scale assessments on the contribution of private protected lands to biodiversity and ecosystem services conservation. Although it is needed, there are few established programs that actively promote, provide resources, and monitor conservation action geared towards protecting biodiversity and few land trusts recruit private landowners and easements based on a scientific analysis of conservation value (Hardy et al. 2016).

Furthermore, it is difficult to tease out the impact of protected lands on biodiversity and ecosystem services without access to a true reference state. The conservation value of protected lands can be based upon numerous factors including the maintenance of plant species in the broader landscape, those protected species' potential contribution to natural regeneration, and the ability of smaller fragments to support viable populations of particular species or serve as stepping stones for species moving across the landscape. The ability for protected lands to sustain populations of species and ecosystem function is largely influenced by land use outside of their borders. Surrounding land use can increase the ratio of habitat edge to inner core area, further isolating habitat patches from one another (Haddad et al. 2015); indirectly alter ecosystem processes such as hydrology, disturbance regimes, dispersal, and invasive species establishment (Hamilton et al. 2014); and trigger a downward spiral of increasing biodiversity loss, resulting in the decay of ecosystem function and services within established protected lands (Krauss et al. 2010, Haddad et al. 2015, Isbell et al. 2015, Thompson et al. 2016).

Landscape analyses such as the one presented by our study cannot assess whether private protected areas make a contribution to overall conservation beyond a null hypothesis of no private conservation. We can, however, advance our understanding for how to move forward, utilizing advances in geospatial data and analysis to identify options of high quality, representative habitat that captures target species ranges and places protected lands within the context of each other. Further efforts towards ecologically based prioritization can be informed by studies like this one, particularly with regard to location, governance, and the protected land's place in a strategic framework. Although the specifics vary between protected lands and regions, challenges related to management, governance, collaboration, and data sharing remain as key obstacles to the effectiveness of protected lands in conservation (Lacher et al. 2012). Detailed studies such as this one, focused on a particular region, can highlight important issues related to site-specific characteristics but can also inform efforts in other regions.

## 5. Conclusions

This study compared the spatial configuration, management, and climate resiliency scores of protected lands across two ecoregions (Blue Ridge and Piedmont), in order to develop a better understanding of the relative contribution of public vs. privately-owned protected lands in sustaining biodiversity and ecosystem services. We conclude that, compared to public protected lands, private lands are less connected, have less stringent management strategies, contain a higher proportion of grasses and crop cover compared to forest, and capture less climate resilient lands. These differences in protected lands illustrate a greater potential for long-term biodiversity conservation, given our criteria, within the Blue Ridge compared to the Piedmont. Furthermore, we identified over 500 different management across privately-owned protected lands in our study area. Although management practices do very among public protected lands classified under the same GAP status, the fact that a standardized classification exists and is recognized globally, provides a solid starting point for developing broad generalizations on their level of protection. This is, unfortunately, not the case for privately-owned protected lands; an issue that significantly hinders our ability to develop similar assessments. Further work is needed to better describe and understand how private lands are managed and to prioritize their placement to improve their contribution to conservation goals and targets (Stolton et al. 2014). The lack of congruence of new protected areas, private and public, relative to larger landscape conservation objectives is a global problem, and detailed regional level analyses like ours can highlight specific, landscape-scale components that need improvement.

Because many conservation easements across the US are owned and managed by private citizens (Merenlender et al. 2004, Hardy et al. 2016), and because private land conservation is likely to continue, we need assessments such as this one to form the basis of understanding for optimizing the conservation effectiveness of these new protected lands. The future of conservation is dependent upon integrating all of our tools to enhance the coverage and management of land in a complex spatial context. This includes the many forms and functions of protected areas. Landscape managers must assess all new protected areas in relation to the spatial configuration of these patches on the regional landscape and there is an urgency to do so as land-use practices will intensify in light of increasing resources demands. We must consider not only the habitat type and distribution within protected lands, but the direct and indirect impacts that permeate inward from the broader landscape (Goetz et al. 2009, Piekielek and Hansen 2012, Hamilton et al. 2013, 2014, Loyola et al. 2013, Hansen et al. 2014, Théau et al. 2015). Finally, all future conservation must be viewed through the lens of climate change. We believe that detailed regional scale studies can reveal problems, and solutions that have broader, global relevance and that are actionable by land managers and conservation practitioners, specifically because they are conducted at the scale of effective management.

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## Tables

Table 1. Total area (in 1000 hectares) for each of the protected lands classifications used in this study. Protected land classifications are defined in text.

**Table 1.**

| | | Total Area (1000 hectares) | | | | Percent of Ecoregion | | | | Percent of Protected Lands in Ecoregion | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Blue Ridge | | Piedmont | | Blue Ridge | | Piedmont | | Blue Ridge | | Piedmont | |
| Total Area of Ecoregion | | 4,651.90 | | 6,390.80 | | 100 | | 100 | | N/A | | N/A | |
| **Protected Lands** | | 1985 | 2015 | 1985 | 2015 | 1985 | 2015 | 1985 | 2015 | 1985 | 2015 | 1985 | 2015 |
| Patches | Total number | 328 | 707 | 189 | 1,327 | - | - | - | | - | - | - | - |
| | Average Size | 5.1 | 2.5 | 1.2 | 0.3 | - | - | - | | - | - | - | - |
| | Standard Deviation | 24.6 | 16.9 | 7.1 | 2.7 | - | - | - | | - | - | - | - |
| | Total Area | 1,663.24 | 1,778.69 | 219.5 | 388.23 | 35.8 | 38.2 | 3.4 | 6.1 | 100 | 100 | 100 | 100 |
| | Total Core Area | 1,363.42 | 1,431.38 | 148.13 | 214.14 | 29.3 | 30.8 | 2.3 | 3.4 | 82.0 | 80.5 | 67.5 | 55.2 |
| Ownership | Public | 1639.1 | 1702.5 | 210.5 | 232.4 | 35.2 | 36.6 | 3.3 | 3.6 | 98.5 | 95.7 | 95.9 | 59.9 |
| | Private | 24.1 | 76.2 | 9.0 | 155.8 | 0.5 | 1.6 | 0.1 | 2.4 | 1.5 | 4.3 | 4.1 | 40.1 |
| Management | Public | 1496.1 | 1558.6 | 162.8 | 182.8 | 32.2 | 33.5 | 2.5 | 2.9 | 89.9 | 87.6 | 74.2 | 47.1 |
| | Private | 24.0 | 73.9 | 8.6 | 153.8 | 0.5 | 1.6 | 0.1 | 2.4 | 1.4 | 4.2 | 3.9 | 39.6 |
| | Non-Governmental | 0.1 | 2.2 | 0.4 | 1.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.2 | 0.4 |
| | Other | 143.1 | 144.0 | 47.7 | 49.9 | 3.1 | 3.1 | 0.7 | 0.8 | 8.6 | 8.1 | 21.7 | 12.9 |
| GAP Status[a] | 1 | 360.3 | 362.8 | 7.2 | 7.9 | 7.7 | 7.8 | 0.1 | 0.1 | 21.7 | 20.4 | 3.3 | 2.0 |
| | 2 | 128.7 | 164.3 | 23.1 | 39.3 | 2.8 | 3.5 | 0.4 | 0.6 | 7.7 | 9.2 | 10.5 | 10.1 |
| | 3 | 1007.8 | 1043.2 | 127.8 | 135.8 | 21.7 | 22.4 | 2.0 | 2.1 | 60.6 | 58.6 | 58.2 | 35.0 |
| | 4 | 166.5 | 208.4 | 61.4 | 205.2 | 3.6 | 4.5 | 1.0 | 3.2 | 10.0 | 11.7 | 28.0 | 52.9 |
| Land Cover | Forest | 1599.3 | 1704.9 | 164.6 | 253.1 | 34.4 | 36.6 | 2.6 | 4.0 | 96.2 | 95.9 | 75.0 | 65.2 |
| | Grasses | 19.7 | 26.7 | 10.2 | 70.8 | 0.4 | 0.6 | 0.2 | 1.1 | 1.2 | 1.5 | 4.6 | 18.2 |
| | Cropland | 0.2 | 0.6 | 3.9 | 14.2 | 0.0 | 0.0 | 0.1 | 0.2 | 0.0 | 0.0 | 1.8 | 3.6 |
| Climate Resiliency | Non-resilient | 96.9 | 109.4 | 48.0 | 159.9 | 2.1 | 2.4 | 0.8 | 2.5 | 5.8 | 6.2 | 21.9 | 41.2 |
| | Resilient-Not Prioritized | 60.4 | 70.4 | 38.3 | 73.1 | 1.3 | 1.5 | 0.6 | 1.1 | 3.6 | 4.0 | 17.5 | 18.8 |
| | Resilient-Priority: Diversity | 1225.7 | 1296.7 | 59.5 | 76.5 | 26.3 | 27.9 | 0.9 | 1.2 | 73.7 | 72.9 | 27.1 | 19.7 |
| | Resilient-Priority: Riparian | 20.2 | 23.0 | 13.1 | 14.4 | 0.4 | 0.5 | 0.2 | 0.2 | 1.2 | 1.3 | 6.0 | 3.7 |
| | Resilient-Priority: All Factors | 225.9 | 243.9 | 22.1 | 24.2 | 4.9 | 5.2 | 0.3 | 0.4 | 13.6 | 13.7 | 10.1 | 6.2 |
| | Resilient-Priority: Diffuse Fl. | 4.4 | 4.5 | 5.7 | 6.3 | 0.1 | 0.1 | 0.1 | 0.1 | 0.3 | 0.3 | 2.6 | 1.6 |
| | Linkage-Resilient Portion | 10.0 | 10.1 | 2.9 | 3.0 | 0.2 | 0.2 | 0.0 | 0.0 | 0.6 | 0.6 | 1.3 | 0.8 |
| | Linkage- Vulnerable Portion | 14.1 | 14.5 | 2.8 | 3.0 | 0.3 | 0.3 | 0.0 | 0.0 | 0.8 | 0.8 | 1.3 | 0.8 |

a. 1= Permanent protection in natural state; 2 = Permanent protection in mostly natural state; 3 = Variable protection with extraction permitted; 4 = no known management plan

## Figures

**Figure 1.** Map of study area with ownership of GAP status (management status) for patches within the Blue Ridge ecoregion (dark gray), Piedmont (medium gray), and 25 km buffer (light gray). GAP status 1= Permanent protection in natural state; 2 = Permanent protection in mostly natural state; 3 = Variable protection with extraction permitted; 4 = no known management plan. The Piedmont region is composed of these Level IV ecoregions: Piedmont uplands, Triassic low lands, trap rock and conglomerate uplands (Northern Piedmont); and the Northern inner Piedmont, Triassic basins, Southern inner Piedmont, Talladega upland (Piedmont).

**Figure 2.** Patch attributes for public and private lands with protected status. a) Cumulative totals of protected lands between the years 1985 and 2015 for area (solid line) and core area (dotted line) in thousands of hectares for the Blue Ridge and Piedmont. Core area is defined as area of patch within a perimeter of 180 $m^2$ (one raster cell), in all directions. b) The Aggregation Index for all patches established by 1985 and at five year increments until 2015 for the Blue Ridge and Piedmont. Values for Aggregation Index range from 0 (disaggregated) to 100 (aggregated). c) The number of new patches added each year within (solid line) or beyond (dotted line) 540 m of a previously established patch within the Blue Ridge or Piedmont.

**Figure 3**. Results of nearest neighbor and Getis-Ord* hot-spot analyses across the study area and surrounding buffer. a) Protected lands patches colored by the number of patches established in the same or prior year as other patches within a 1000 m buffer. b) Spatial clusters of protected lands patch establishment for patches established on or before 1985, 1995, 2005, and 2015. c) Insets highlighting formation of hotspot composed of patches of private lands for each time increment.

**Figure 4.** Management and land cover summaries for protected lands patches added between 1985 through 2015 for study area. a-b) Cumulative area of new protected lands by managing entity for the Blue Ridge and Piedmont. c-d) Cumulative total area of new protected lands added since 1985 represented by management status for the Blue Ridge and Piedmont. e-f) Cumulative total area of new protected lands added since 1985 represented by land cover for the Blue Ridge and Piedmont.

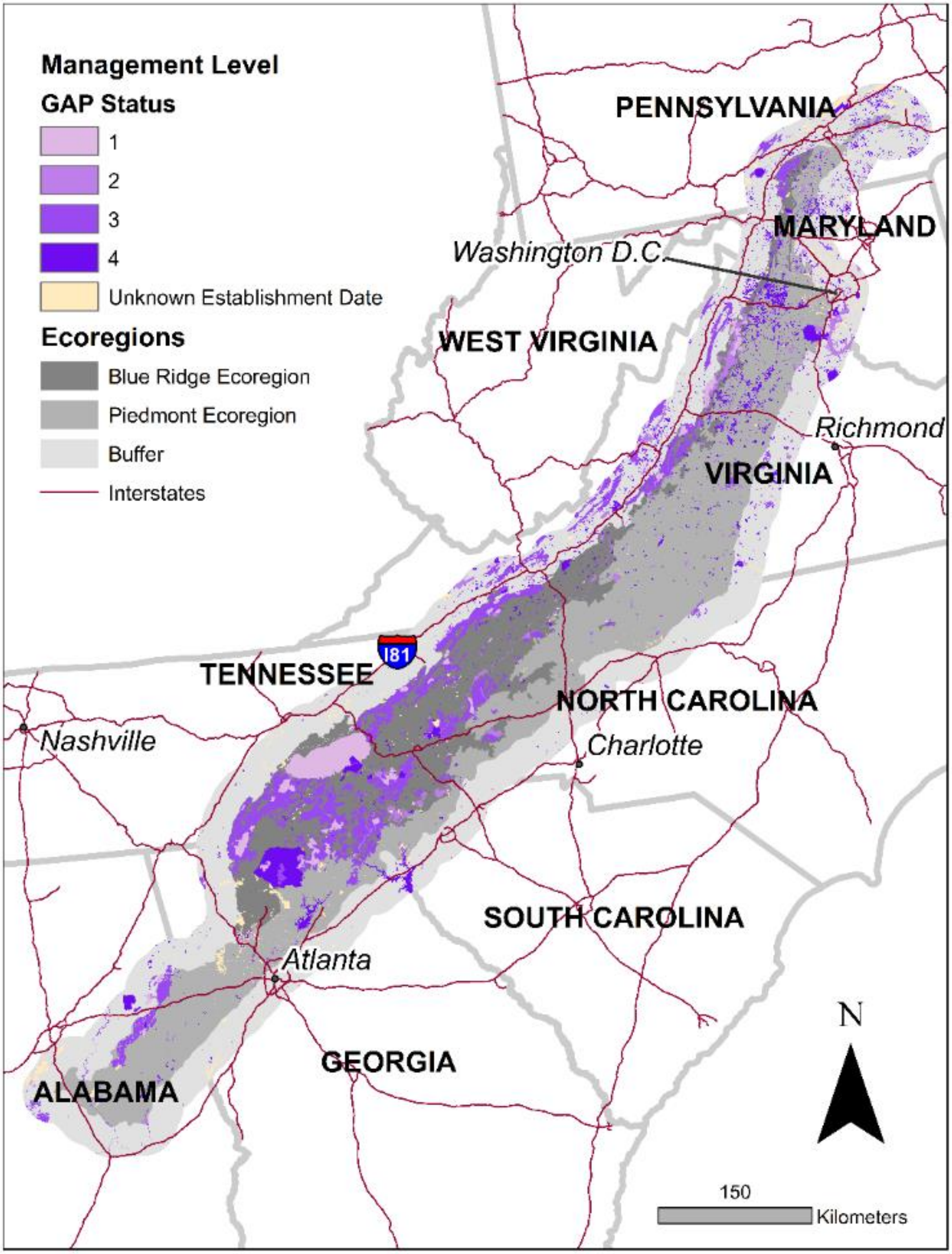
Management Level
GAP Status
1
2
3
4
Unknown Establishment Date
Ecoregions
Blue Ridge Ecoregion
Piedmont Ecoregion
Buffer
Interstates
PENNSYLVANIA
MARYLAND
Washington D.C.
WEST VIRGINIA
Richmond
VIRGINIA
I81
TENNESSEE
NORTH CAROLINA
Nashville
Charlotte
SOUTH CAROLINA
Atlanta
GEORGIA
ALABAMA
N
150
Kilometers

**Figure 1**

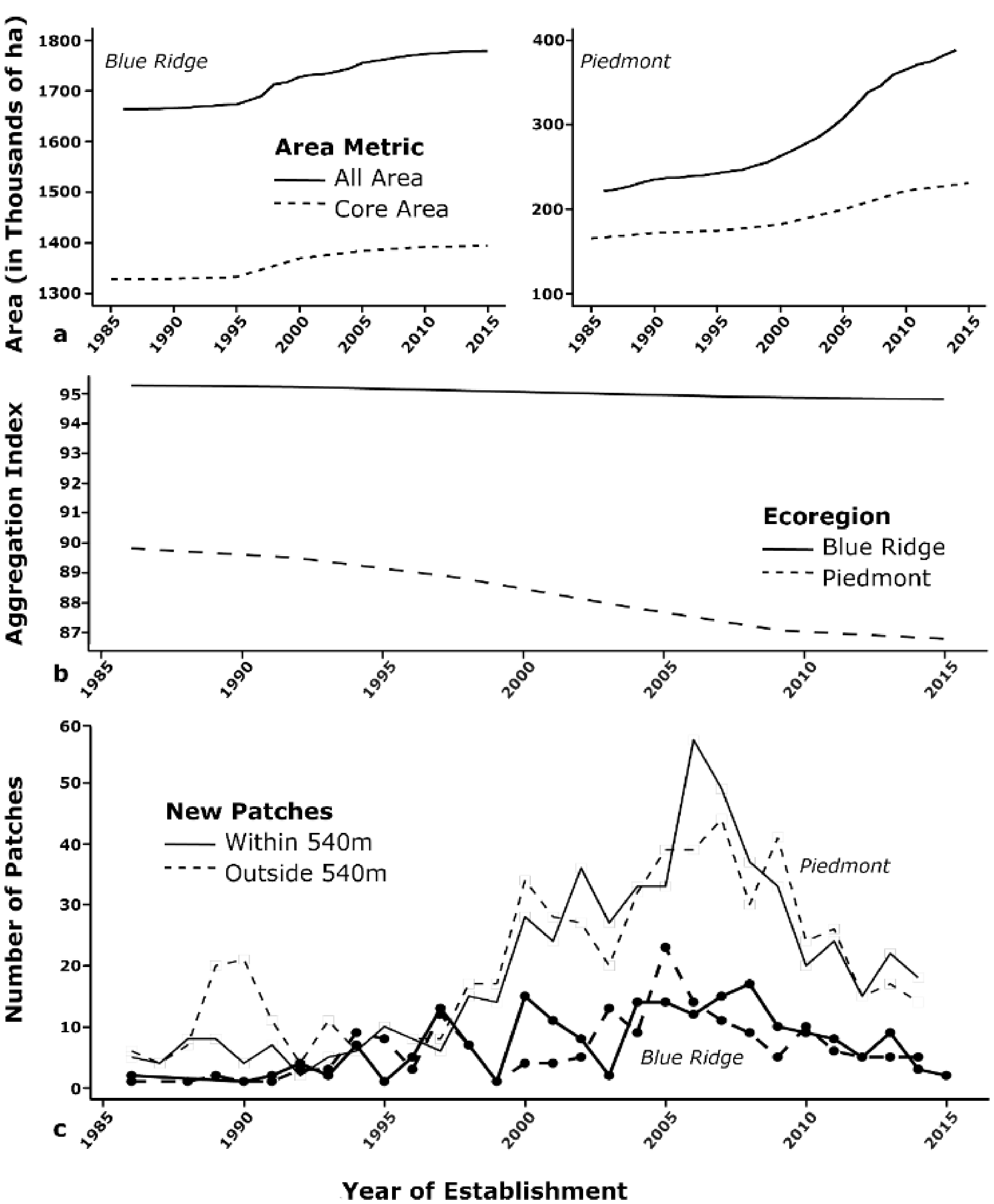
Area (in Thousands of ha)
Blue Ridge
Piedmont
Area Metric
All Area
Core Area
1800
1700
1600
1500
1400
1300
400
300
200
100
a
1985
1990
1995
2000
2005
2010
2015
Aggregation Index
Ecoregion
Blue Ridge
Piedmont
95
94
93
92
91
90
89
88
87
b
Number of Patches
New Patches
Within 540m
Outside 540m
Piedmont
Blue Ridge
60
50
40
30
20
10
0
c
Year of Establishment

Figure 2

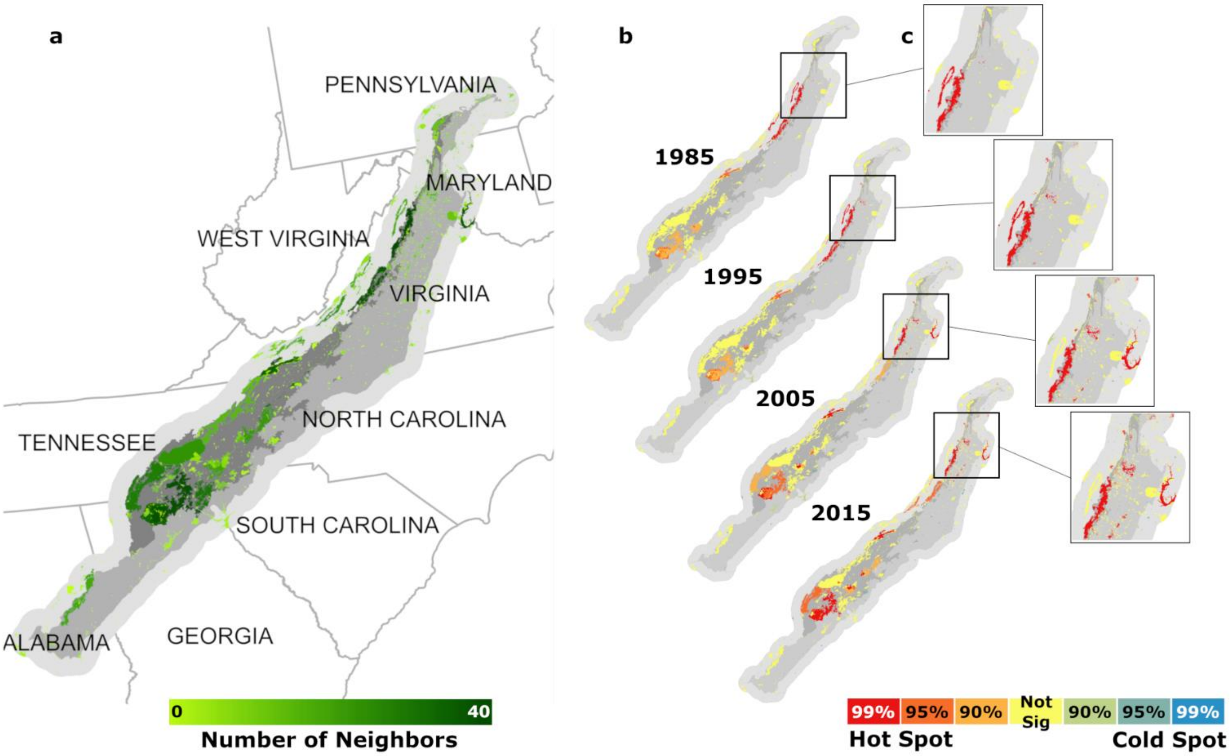
a
PENNSYLVANIA
MARYLAND
WEST VIRGINIA
VIRGINIA
TENNESSEE
NORTH CAROLINA
SOUTH CAROLINA
ALABAMA
GEORGIA
0
40
Number of Neighbors
b
c
1985
1995
2005
2015
99%
95%
90%
Not Sig
90%
95%
99%
Hot Spot
Cold Spot

Figure 3

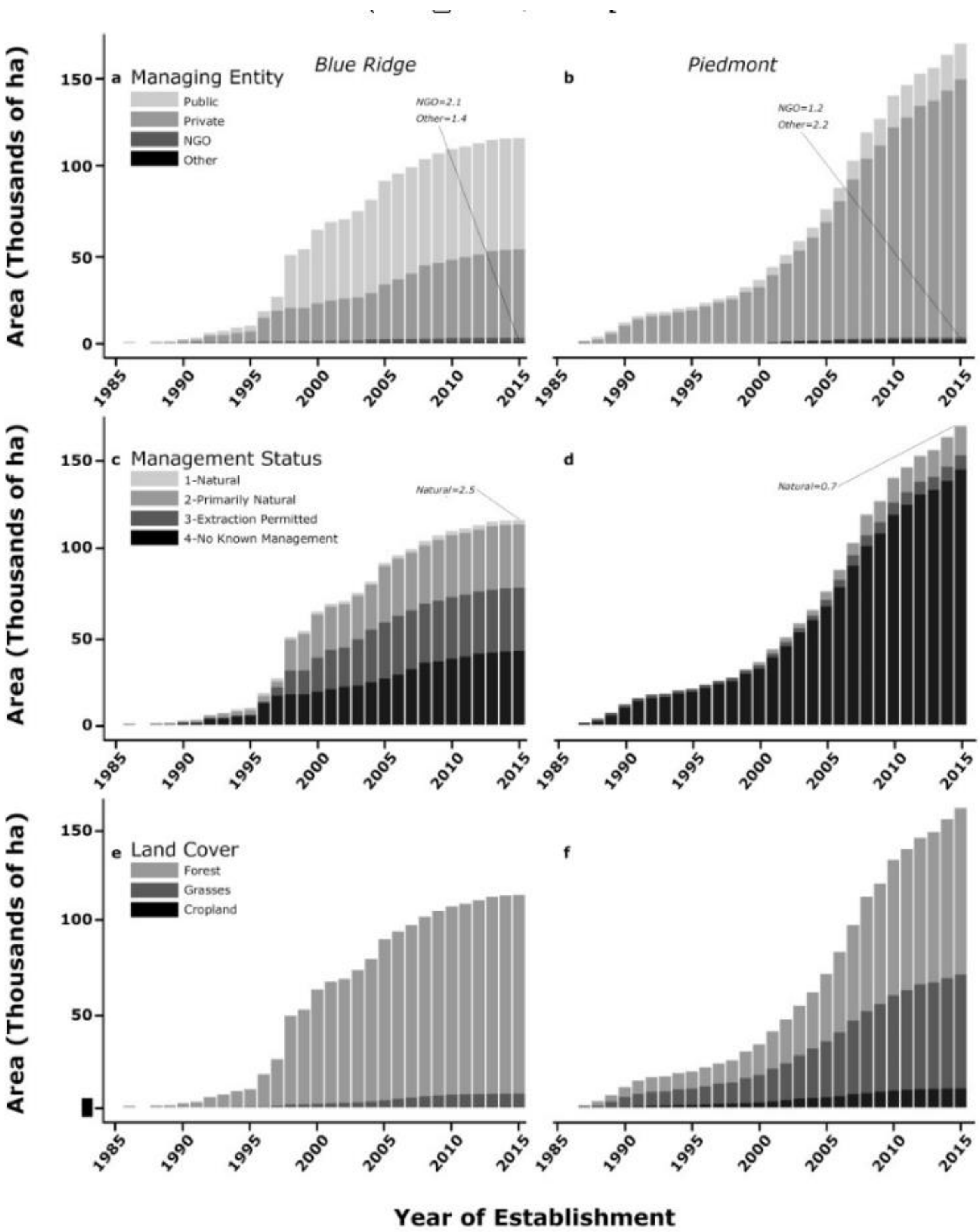
Area (Thousands of ha)
a Managing Entity
Blue Ridge
Public
Private
NGO
Other
NGO=2.1
Other=1.4
b
Piedmont
NGO=1.2
Other=2.2
c Management Status
1-Natural
2-Primarily Natural
3-Extraction Permitted
4-No Known Management
Natural=2.5
d
Natural=0.7
e Land Cover
Forest
Grasses
Cropland
f
0
50
100
150
1985
1990
1995
2000
2005
2010
2015
Year of Establishment

**Figure 4**