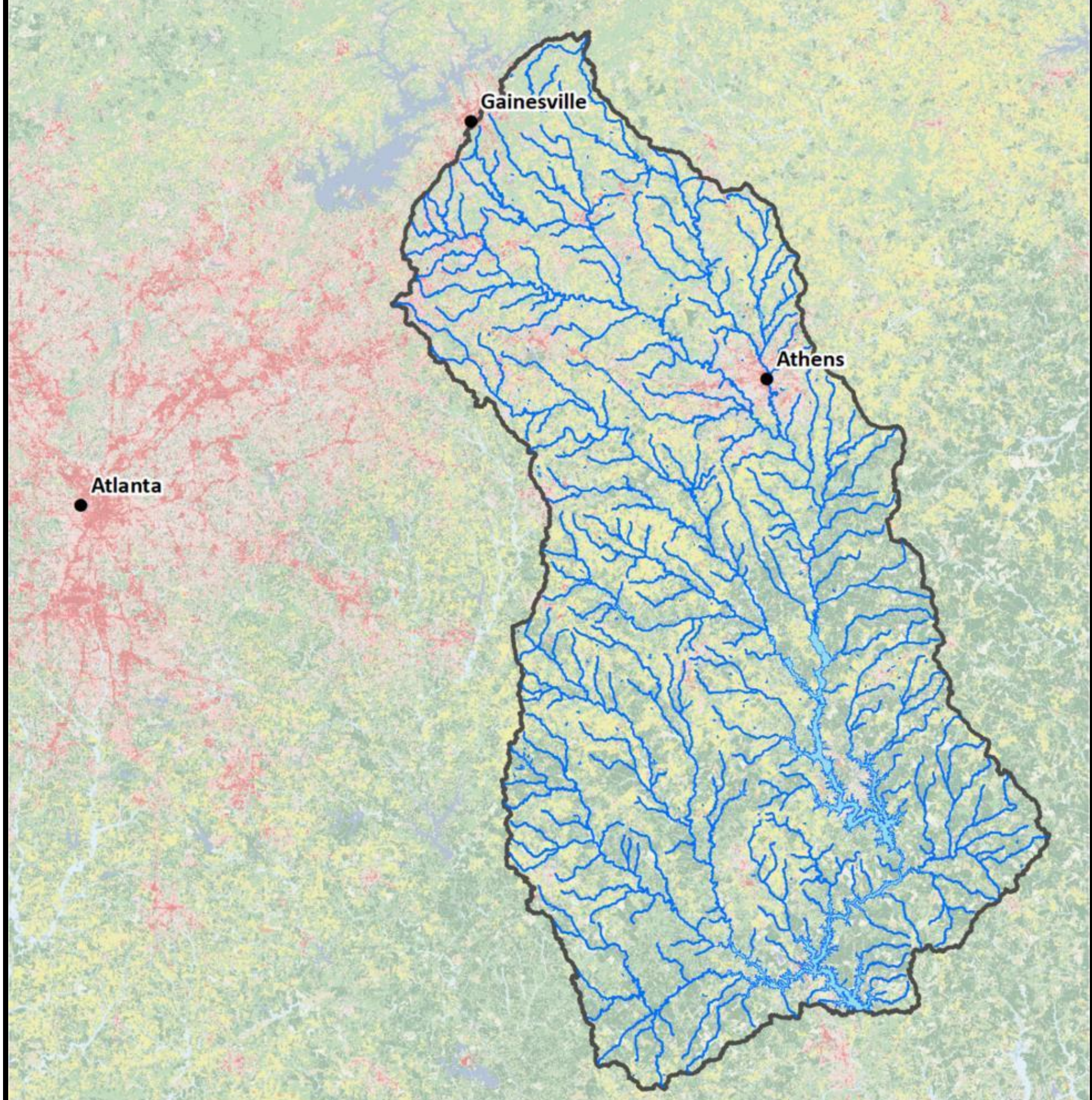
Conservation and Restoration Priorities in the Upper Oconee River Basin



Puneet Dwivedi[1]; Fabio J. Benez-Secanho[1]; Jonathon Skaggs[2]; Duncan Elkins[1]; Wesley L. Gerrin[1]; Cassidy Lord[1].

[1]Warnell School of Forestry and Natural Resources, University of Georgia
[2] River Basin Center, Odum School of Ecology, University of Georgia

2020

Executive Summary

Forested landscapes are important sources of ecosystem services, including the provision of clean drinking water. Comparisons of water quality across land cover types show that forests provide the highest quality surface water. Currently, the Upper Oconee River Basin is above the 60% threshold for natural land cover after combining the areas under forest, wetland, and grasslands but is slightly below (57.67%) this threshold when only the area under forestland is considered. If net forest to non-forest land conversion further increases in the Upper Oconee River Basin, sediment and nutrient delivery to surface water would increase, resulting in harmful algal blooms and increased treatment costs for about half a million residents of the river basin. In this context, this study aims to protect and enhance surface water quality in the Upper Oconee River Basin by defining current high-value conservation or restoration areas, projecting the future land cover, and prioritizing high-value conservation or restoration areas based on their vulnerability to the future land cover. We performed advanced spatial analysis for identifying land parcels (> 50 acres) with the highest conservation and restoration values. We also modeled future land use changes in the river basin. Then, we combined both analyses for prioritizing those land parcels which provide the highest conservation and restoration values but are vulnerable to the development in the foreseeable future. Our results suggest that high priority conservation and restoration land parcels are mainly located near wetlands or streams in areas with steeper slopes. Our land use change model indicated that an additional 11.9% of low-intensity urban lands and 38.19% of high-intensity urban lands between 2016 and 2030. We found that most of the future urbanization will happen in Athens, Gainesville, and the Atlanta Metropolitan Area. We also found that forestland will decrease by about 20,000 acres in the same period. A total of 167 parcels covering an area of 19,039 acres were selected as key for conservation. The total market value of these parcels was $171 million. Parcels selected for restoration purposes totaled 14,699 acres spread over 121 parcels, worth $115 million. Also, we identified 69 parcels with a total area of 7,853 acres that appeared in both selections. These parcels were worth $71 million. We hope that our study will feed into ongoing attempts to design multifunctional landscapes for striking a balance between the growing population and ecosystem services in the Upper Oconee River Basin.

Table of Contents

List of Tables

List of Figures

Introduction

Funding sources and intent of this document

This study was commissioned by the Southeastern Partnership for Forests and Water and the Georgia Forestry Commission using a United States Forest Service (USFS) 2016 Landscape Scale Restoration Grant and is modeled after similar analyses of the Lower Savannah River Basin (Kreuger & Jordan, 2014) and the Middle Chattahoochee River Basin (Elkins & Gerrin, 2019). This study intends to guide Upper Oconee River Basin stakeholder groups for defining key strategies for achieving forestland stewardship goals.

Land use change, water quality, and water treatment

Forested landscapes are essential sources of ecosystem services, including the provision of clean drinking water. In the USFS Southern Region, approximately 35% of mean annual water supplies originate on forested lands. Surface water originating in or above National Forests provides at least some of the drinking water for 34% of the population in Southern Region (17.3 million of 50.3 million people), and state and privately owned forests provide at least some drinking water to 96% of the population in the Southern Region (48.4 million of 50.3 million people) (Caldwell & Muldoon, 2012). Comparisons of water quality across land cover types repeatedly show that forests provide the highest quality surface water (Holmes, Vose, Warziniack, & Holman, 2017; Neary, Ice, & Jackson, 2009). Two primary drivers of poor water quality are excess nutrients and sediment. Forested areas often exhibit net losses of nutrients due to uptake by forest vegetation (Lowrance et al., 1984). In the Middle Chattahoochee River Basin, elevated nitrate, ammonium, and total phosphorous concentrations were significantly higher in urban watersheds than forested watersheds (Schoonover, Lockaby, & Pan, 2005). Additionally, forest vegetation reduces sedimentation by stabilizing soil and reducing overland flow that may transport sediment to surface water (Holmes et al., 2017). Even in mixed-use watersheds where runoff from agricultural and urban areas is often associated with increased nutrients and sediment (Schoonover & Lockaby, 2006; Tong & Chen, 2002), forest areas contribute to higher downstream water quality by diluting lower-quality water (Clinton & Vose, 2006). In a 30-year study of nutrient export from the Altamaha River Basin, upstream population growth led to increased nutrient export; however, downstream nutrient processing, dilution, and relatively fewer inputs led to low nutrient export at its outlet relative to other large river basins (Weston et al., 2009).

Human population growth often leads to increased pressure for land conversion from forested to agricultural and urban land covers (Riitters et al., 2002). This leads to a reduction in forest area and an increase in forest fragmentation (Johnson & Beale, 2002; Radeloff, Hammer, & Stewart, 2005). In the USFS Southern Region, 11-23 million acres of forestlands are projected to be converted to developed and other uses between 1997 and 2060 (Wear, 2012). Concurrent with increased population growth is increased demand for drinking water, and when coupled with a loss in forest area, can result in higher costs of drinking water treatment (Postel & Thompson, 2005). In a recent literature review, Warziniack et al. (2016) found a negative relationship between water treatment cost and source water quality. This finding follows previous research that found a negative correlation between water treatment costs and watershed forest cover (Ernst, Hopper, & Summers, 2004). Freeman et al. (2008) surveyed drinking water suppliers in the USFS Northeastern Area and found that reduced forest cover leads to increased turbidity and total organic carbon in source water, thereby increasing treatment costs.

Based on a national survey of 37 water treatment utilities with watersheds averaging 60% forest cover, Warziniack et al. (2016) estimate that a 1% reduction in forest area would increase turbidity by 3.9-6.3%, depending on the ultimate land cover type. However, there was no relationship between land cover change and total organic carbon, which their data suggest is over twice as expensive for utilities to treat for the same marginal increase. Nevertheless, their study estimated that converting 10% of the watershed area from forest to developed would increase chemical treatment costs from $2.52 to $20.48 annually per million gallons treated. The authors conclude that the large variation in estimated treatment cost relative to previous studies (Ernst et al., 2004; Freeman et al., 2008) may be due to small sample sizes that include watersheds predominantly over or under 60% forest cover. Ernst et al. (2004) suggest this is the threshold for when treatment costs begin to increase rapidly with additional forest loss.

Description of the river basin

The North and Middle Oconee Rivers originate near Gainesville, Georgia, and flow south to form the Oconee River near Athens. The Oconee River joins the Apalachee River (headwaters near Lawrenceville) at Lake Oconee before flowing into Lake Sinclair near Milledgeville. The Oconee River flows for approximately 128 miles to its confluence with the Ocmulgee River to form the Altamaha River, which ultimately drains into the Atlantic Ocean near Darien. The Upper Oconee River Basin comprises 14% (2,916 mi^2) of the overall area of the Altamaha River Basin (20,784 mi^2).

The United States Geologic Survey Hydrologic Unit Codes divide the Oconee River Basin into two sub-basins: the Upper Oconee River Basin and the Lower Oconee River Basin, delimited at the Fall Line near Lake Sinclair Dam. The Upper Oconee River Basin (Figure 1) drains 1,866,597 acres (2,916 mi^2) and is entirely within the Piedmont physiographic province. The Upper Oconee River Basin includes portions of highly urbanized Atlanta and Gainesville and completely contains the urban areas of Athens, Madison, Monroe, Winder, and others (Figure 2). Agricultural activities in the Upper Oconee River Basin are dominated by confined poultry production and grazing land (Fisher et al., 2000). As of 2016, forest is the primary land cover type in the Upper Oconee River Basin, covering 1,076,466 acres (1681 mi^2). Forest cover encompasses 57.67% of total basin area (deciduous: 25.19%; evergreen: 22.13%; mixed: 10.35%), followed by pasture/hay (18.25%) and low-intensity urban (10.13%) (Table 1 and Figure 3).

Of the 180 assessed streams in the Upper Oconee River Basin, most streams are designated for fishing; however, almost 187 stream miles are designated for drinking water use (Georgia Environmental Protection Division, 2018). The Upper Oconee Regional Water Plan (2017) estimated 2015 water demand was highest from the municipal sector (45%), followed by industrial (37%), agricultural (18%), and energy (<1%) for a total demand of approximately 166 million gallons per day (MGD).

Population growth estimates highlight the growing demand for water resources in the Upper Oconee River Basin. According to the last decennial census in 2010, the total population within the river basin was 530,731. The population of counties within the Upper Oconee River Basin is expected to grow by 61% between 2018 and 2040 (160,249 to 258,051), more than twice the state average (27%). The population of counties completely and partially within the Upper Oconee River Basin is expected to grow 39.4% (1,436,900 to 1,974,100) over the same time (Georgia Governor's Office of Planning and Budget, 2019). Water demand is also projected to increase by approximately 36% from 2015 to 2050 (166 to 226 MGD), and the municipal sector is expected to continue to be the largest user (Upper Oconee Regional Water Plan, 2017).

Conservation within the river basin

As of 2016, a total of 157,400 acres (8.4% of the total area of the river basin) were in conservation, including national forests and easements (United States Geological Survey, 2020). The land cover class with the largest protected area was the evergreen forest, with 62,800 acres in conservation, followed by deciduous and mixed forests, with 40,363 and 20,050 acres in conservation, respectively (Table 2). The total area of these three forest classes in conservation represents 11.4% of all the forestlands within the river basin. As for wetlands, 9,599 acres were protected as of 2016, representing 14.3% of all wetlands within the Upper Oconee River Basin. The largest protected area is the Oconee National Forest, which has an area of about 84,200 acres and is located in the southern region of the river basin. Figure 4 shows all protected areas within the river basin and their ownership.

Goal and Objectives

Based on the 2016 land cover data (Table 1), the Upper Oconee River Basin is above the 60% threshold for natural land cover if the forest, wetland, and grasslands are combined but is slightly below this threshold when only forest land cover classes are considered (57.67%). If net forest to non-forest land conversion increases as is projected for this region, sediment and nutrient delivery to surface water would also be expected to increase. This will contribute to eutrophic conditions in streams and reservoirs, which may result in harmful algal blooms and increased treatment costs (Bachoon, Nichols, Manoylov, & Oetter, 2009). In this context, the goal of the study is to protect and enhance surface water quality in the Upper Oconee River Basin. The objectives of the study are a) to define current high-value conservation or restoration areas, b) project the future land cover, and c) prioritize high-value conservation or restoration areas based on their vulnerability to the future land cover for protecting and enhancing surface water quality for the residents of the Upper Oconee River Basin.

Methodology

All analyses in this study were conducted using geographic information system (GIS). GIS applications are used to perform spatial analyses and make maps that communicate and share information in many different fields. In this report, GIS is used to combine a variety of spatial data layers and conduct a spatial analysis to identify critical areas for conservation and restoration within the Upper Oconee River Basin.

Land cover reclassification

We used data from the National Land Cover Dataset (NLCD) (Yang et al., 2018) to represent the land cover of the river basin. However, we modified all layers (2001, 2006, 2011, and 2016) to reduce the number of land cover classes from 15 to 10 (Table 3), which improved the accuracy of the land cover change model (Eastman, 2016). The NLCD provides data at a 30m (98.42 feet) spatial resolution. Therefore, we conducted all our analysis at this spatial resolution.

Parcel preparation

Parcel layers for individual counties were acquired from the University of Georgia Information Technology Outreach Service, which compiles parcel data from Georgia counties that are willing to share data. Parcel level attributes (parcel number, owner, total value, improvement value, and land classifications) were joined to individual parcels from the WinGAP parcel data tracking system (except for Gwinnett County, which uses a different tracking system). Attribute tables for all 18 counties present in the Upper Oconee River Basin were assigned the same column naming schematic and appended to one another, creating one large parcel layer. This layer was clipped to the Upper Oconee River Basin boundary to eliminate parcels that were not within the perimeter of the watershed.

To achieve an accurate analysis using parcel data, the data must first be conditioned to remove overlapping geometry. A topological rule was used to identify overlapping areas, which occurred in four major ways: 1) parcels which had exact duplicates, 2) parcels with condominium boundaries stacked on top of the original land parcel, 3) errors in parcel surveying along county borders, and 4) sliver polygons created along borders of parcels by the merge procedure. Parcels with exact duplicates were eliminated by exporting and dissolving on the parcel number attribute, and condominium complexes were exported and erased from the overall parcel layer to remove their area from their surrounding land. Both of these layers were added back to the overall parcel layer. Overlap errors along county borders had no dissolvable attributes, so they were selected and erased from the overall layer. This resulted in the removal of 9,164 acres of land from the overall parcel layer. Sliver polygons identified by the topological rule were selected and removed from the overall parcel layer. The successful removal of all overlapping areas was again verified by a “no overlap” topological rule.

Watershed Management Priority Index

The Watershed Management Priority Index (WMPI) is a GIS model used for analyzing landscape attributes associated with water quality (Zhang, 2006; Zhang & Barten, 2009). We employed two of its components: Conservation Priority Index (CPI) and Restoration Priority Index (RPI). The former targets areas that contribute to the water quality of the watershed and should be prioritized for conservation. The latter identifies areas that are neither forested nor developed that would likely have a positive impact on water quality if converted to forest. To calculate these indices, we first obtained the relevant spatial data (Table 4) and then assigned ranks within all seven layers (land cover, distance to streams, distance to ponds and wetlands, floodplain, soil group, soil erodibility, and slope) on a scale ranging from 1 to 3 (land cover ranges from 0 to 3 and floodplain has only two values: 0 or 3). We used Jenks Natural Breaks for this rank, which is an algorithm commonly employed in GIS applications and is used for optimal data classification (North, 2009). Once ranked, we added all layers together using the Raster Calculator tool in ArcGIS to create the CPI and RPI layers. The scores of these layers ranged from 5 to 21. Except for the land cover, all other six layers have the same ranks in both CPI and RPI calculations and are shown in Table 5. Table 6 displays the ranks associated with land cover.

Land cover projection

We used the module Land Change Modeler (LCM), embedded in the software TerrSet 18.31 (Eastman, 2016), to project future changes in the land cover within the river basin. The LCM identified all land cover transitions (e.g., forest to urban lands) and persistence (e.g., forestlands remaining forestlands) between two land cover layers from distinct periods (2001 and 2011). By using layers from 2001 and 2011, we created multiple models to project the land cover in 2016. Since we have the actual land cover of 2016, we compared the actual and projected layers and use the model with the highest overall accuracy to project the future land cover in 2020, 2025, and 2030. Table 7 shows the overall accuracy and other details of the model chosen for this analysis. We used the most recent layer (2016) as the base year to project the land cover in the future years.

After identifying land cover changes between 2001 and 2011, the LCM generated a square matrix of land cover transition and persistence probabilities (Markov matrix). Each entry of the matrix represents the probability that a land cover class (in the row) will be converted to other land cover classes (in the columns). These probabilities were used to determine the total land cover change and persistence within the river basin between 2016 and 2030. Then, we used the Multi-Layer Perceptron (MLP) neural network approach to spatially allocate these changes based on predictor variables, which are factors, such as distance to streets and population density, that explain land cover changes. MLP uses a machine-learning algorithm to identify patterns in the data, relating predictor variables (input) and land cover transitions and persistence (output) (National Research Council, 2014).

Once those patterns were identified, we determined the dominant land cover transitions within the river basin and selected a group of predictor variables that best explains each transition. These groups of predictor variables are called sub-models and are used by MLP to create transition potential maps showing the suitability of each pixel to change from one land cover class to another. A constraint/incentive layer was used to prevent any urban growth within existing protected areas based on the PADUS (United States Geological Survey, 2020). Finally, LCM combined all transition potential maps and the Markov matrix to create future land cover layers (2020, 2025, and 2030).

Parcel selection

First, we used the tool Zonal Statistics in ArcGIS to calculate the mean CPI and RPI for each parcel within the river basin with an unprotected area equal to or greater than 50 acres. These parcels were divided into four CPI/RPI categories according to conservation priorities, with 1 being the highest priority and 4 the lowest. We used Jenks Natural Break for this classification (North, 2009). Then, using our projected land cover layer of 2030, we identified all parcels that are projected to receive new urban lands by that year. Finally, we were able to identify all parcels with the highest CPI/RPI priorities and threatened by urbanization and selected them as key areas for conservation and restoration.

Results

Figure 5 displays all parcels with an unprotected area equal to or greater than 50 acres classified into four categories according to their relative value ($/acre). Land parcels located in the southern portion of the watershed have lower relative values, while land parcels close to the Atlanta Metropolitan Area, Gainesville, and Athens have the highest relative values. Figures 6 and 7 show the distribution of CPI and RPI scores, respectively, across the parcels over the river basin. These are the continuous scores rather than categorized and highlight the sensitivity of the areas located close to water streams, where runoff from land-disturbing activities can rapidly enter surface waters. These areas are vital for conservation and restoration efforts focused on water quality. Figures 8 and 9 categorize the CPI and RPI scores and highlight the parcels with the highest CPI and RPI priorities, respectively. These parcels are mainly located near wetlands or streams in areas with steeper slopes.

Table 8 shows the projected land cover class distribution in each year of our land cover projection and the differences in the distribution between 2016 and 2030. Figure 10 displays the projected land cover of the river basin in 2030. An additional 11.9% of low-intensity urban lands and 38.19% of high-intensity urban lands are predicted for the river basin from 2016 to 2030. Most of this urbanization will happen in Athens, Gainesville, and the Atlanta Metropolitan Area. A forest loss of more than 20,000 acres is predicted in this same time period. Figure 11 shows all parcels with an unprotected area equal to or greater than 50 acres that are projected to transition into urban lands by 2030. We selected 50 acres as a cutoff to identify parcels that are big enough to be worth conserving, given that transaction costs make up a large proportion of the purchase price for small parcels. These parcels are divided into four categories according to the total area of new urban lands that they will transition to in the future.

A total of 167 parcels covering an area of 19,039 acres were selected as key for conservation. The total market value of these parcels was$171 million. Parcels selected for restoration purposes totaled 14,699 acres spread over 121 parcels, worth $115 million. In addition, we identified 69 parcels with a total area of 7,853 acres that appeared in both selections. These parcels were worth $71 million. Both indices prioritize steep slopes, highly erodible soils, and proximity to water. If a parcel with such physical properties also has a mixture of forested and restorable land-cover, it will score high for both conservation and restoration. Figure 12 points out all selected parcels for conservation (CPI), while Figure 13 shows all selected parcels for restoration (RPI). Both figures show that most of these parcels are in the northern portion of the river basin, where urbanization is projected to be more intense.

Conclusions

Between 2001 and 2016, the forest cover in the Upper Oconee River Basin remained almost unchanged and accounted for approximately 57% of the landcover within the watershed, yet during this time, the area of high-density urban land cover almost doubled (0.77% to 1.42%). Our models extend the last two decades' trends in land use change and indicate that nearly 33,000 acres (a total of 1.75% of the river basin) of land is likely to be converted to urban land uses between 2016 and 2030. Populations projections from the State of Georgia indicate that the counties that make up the river basin are growing faster than the state average and where these new people live and work will have effects on the local water quality. Our analysis helps to identify conservation and restoration opportunities in the Upper Oconee River Basin for protecting water quality. Our land cover change models predict which parcels are most likely to see the conversion from natural to developed land uses. Combining this information with the conservation and restoration priority models gives us insight into which actions at the parcel level are likely to have short-term impacts on surface water quality. There is a clear opportunity to preserve water quality, while still maintaining a substantial level of development options for local communities and citizens, through targeted protections and perhaps judicious restorations in high-scoring parcels that are currently poised for land use conversion. It is generally accepted that maintaining close to 60% forest cover is ideal for drinking water source protection (Elkins and Gerrin, 2019; Ernst et al., 2004; Kreuger and Jordan, 2014).

Although the upper portions of the river basin are severely impacted by urbanization extending from the east and north, and from development in Clarke and Oconee counties, it is still possible to protect the rural landscape that maintains the water quality for users much of the remaining river basin. Actions taken to reduce sediment delivery in the majority of the basin would be expected to preserve water quality in the reservoirs at the lower end. The Upper Oconee River Basin has a strong set of partners involved in research, monitoring, and planning for the multiple user groups in the area.

This prioritization seeks to identify parcels where the topography, soils, and landcover predict an elevated risk of erosion. While we used the best available data for analysis at this scale, the combination of aggregated and often noisy datasets gathered at different times inevitably leads to error in predictions and the landcover dataset. Our landcover change models work with relatively high-resolution data, but they do not incorporate economic indicators that could substantially affect the rate of land conversion. Further, the aggregation of raster cells into a single score for each parcel smooths over some potentially essential features, such as a healthy vegetated buffer strip along the edge of a large pasture. This type of regional analysis must always be "ground-truthed" with a site-level assessment before undertaking management actions; our maps should supplement local expertise, not replace it.

Our prioritized results should not be viewed as a "shopping list" of parcels to acquire but as a component of a broader strategy for land stewardship that may be variously implemented by groups and organizations acting alone or in concert. It is unlikely that protecting surface water quality by preventing erosion would be the sole criterion, free of geographic or financial considerations, governing a management action such as securing a new easement. While all stakeholders may agree that maintaining surface water quality is a management goal and that land protection is a critical means for achieving that objective, each entity will have additional priorities or constraints that affect their actions and decisions. For example, a municipality interested in expanding the recreational opportunities for its residents might seek to secure funding for the purchase of green space. To identify sites for a new park proposal, their staff could combine our results with county transit and population density maps to identify high-priority parcels in our set that are also close to a bus line, distant from existing parks, and near the greatest number of their citizens. These particular parcels would be undesirable for a stakeholder with a different goal, however. Consider, instead, an agency or NGO trying to increase wildlife habitat. In this case, an analyst could use our results to select high-priority parcels adjacent to protected lands, ideally those between disconnected patches with high habitat value. Other reasonable scenarios might include parcels with high CPI that enclose records in the Georgia DNR's rare species database or that are contiguous with a community trail network. In such cases, the inclusion of our prioritizations can assist in the selection of parcels, which would be expected to best protect surface water quality from among those that satisfy other management goals.

References

Bachoon, D. S., Nichols, T. W., Manoylov, K. M., & Oetter, D. R. (2009). Assessment of faecal pollution and relative algal abundances in Lakes Oconee and Sinclair, Georgia, USA. *Lakes and Reservoirs: Research and Management*, *14*(2), 139–149. https://doi.org/10.1111/j.1440-1770.2009.00396.x

Caldwell, P., & Muldoon, C. (2018). *Quantifying the role of National Forest System lands in providing surface drinking water supply for the Southern United States*. Government Printing Office.

Clinton, B. D., & Vose, J. M. (2006). Variation in stream water quality in an urban headwater stream in the southern Appalachians. *Water, Air, and Soil Pollution*, *169*(1–4), 331–353.

Eastman, J. R. (2016). TerrSet Geospatial Monitoring and Modeling System - Manual. *Clark Labs*, 393.

Elkins, D., & Gerrin, W. (2019). Conservation and Restoration Priorities in the Middle Chattahoochee River Basin. *Georgia Forestry Commission*, 1–18.

Ernst, C., Hopper, K., & Summers, D. (2004). Protecting the source: Land conservation and the future of America's drinking water. *Trust for Public Land*, 1–55. Retrieved from https://www.tpl.org/sites/default/files/cloud.tpl.org/pubs/water-protecting_the_source_final.pdf

Fisher, D. S., Steiner, J. L., Endale, D. M., Stuedemann, J. A., Schomberg, H. H., Franzluebbers, A. J., & Wilkinson, S. R. (2000). The relationship of land use practices to surface water quality in the Upper Oconee Watershed of Georgia. *Forest Ecology and Management*, *128*(1–2), 39–48.

Freeman, J., Madsen, R., & Hart, K. (2008). Statistical analysis of drinking water treatment plant costs, source water quality, and land cover characteristics. *Washington, DC: US Environmental Protection Agency*.

Georgia Environmental Protection Division. (2018). *305(b)/303(d) Integrated Report (Water Quality in Georgia Report)*.

Georgia Governor's Office of Planning and Budget. (2019). County Residential Population, 2018-2063. Retrieved November 15, 2019, from opb.georgia.gov

Holmes, T. P., Vose, J., Warziniack, T., & Holman, B. (2017). Forest Ecosystem Services: Water Resources. *General Technical Report SRS-226. Asheville, NC: US Department of Agriculture Forest Service, Southern Research Station.*, *226*, 31–48.

Johnson, K. M., & Beale, C. L. (2002). Nonmetro recreation counties: Their identification and rapid growth. *Rural America*.

Kreuger, E., & Jordan, N. (2014). Preserving Water Quality in the Savannah River - Protecting the Future of Drinking Water Supply. *The Nature Conservancy*, 1–32.

Lowrance, R., Todd, R., Fail Jr, J., Hendrickson Jr, O., Leonard, R., & Asmussen, L. (1984). Riparian forests as nutrient filters in agricultural watersheds. *BioScience*, *34*(6), 374–377.

National Research Council. (2014). *Advancing Land Change Modeling*. https://doi.org/10.17226/18385

Neary, D. G., Ice, G. G., & Jackson, C. R. (2009). Linkages between forest soils and water quality and quantity. *Forest Ecology and Management*, *258*(10), 2269–2281.

North, M. A. (2009). A Method for Implementing a Statistically Significant Number of Data Classes in the Jenks Algorithm. *2009 Sixth International Conference on Fuzzy Systems and Knowledge Discovery*, 35–38. https://doi.org/10.1109/FSKD.2009.319

Postel, S. L., & Thompson, B. H. (2005). Watershed protection: Capturing the benefits of nature's water supply services. *Natural Resources Forum*, *29*(2), 98–108. https://doi.org/10.1111/j.1477-8947.2005.00119.x

Radeloff, V. C., Hammer, R. B., & Stewart, S. I. (2005). Rural and suburban sprawl in the US Midwest from 1940 to 2000 and its relation to forest fragmentation. *Conservation Biology*, *19*(3), 793–805.

Riitters, K. H., Wickham, J. D., O'neill, R. V, Jones, K. B., Smith, E. R., Coulston, J. W., … Smith, J. H. (2002). Fragmentation of continental United States forests. *Ecosystems*, *5*(8), 815–822.

Schoonover, J. E., & Lockaby, B. G. (2006). Land cover impacts on stream nutrients and fecal coliform in the lower Piedmont of West Georgia. *Journal of Hydrology*, *331*(3–4), 371–382. https://doi.org/10.1016/j.jhydrol.2006.05.031

Schoonover, J. E., Lockaby, B. G., & Pan, S. (2005). Changes in chemical and physical propertiesof stream water across an urban-rural gradient in western Georgia. *Urban Ecosystems*, *8*(1), 107-124.

Soil Survey Staff, N. R. C.-U. S. D. of A. S. (2018). Web Soil Survey. Retrieved August 30, 2018, from https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_053627

Tong, S. T. Y., & Chen, W. (2002). Modeling the relationship between land use and surface water quality. *Journal of Environmental Management*, *66*(4), 377–393.

United States Fish & Wildlife Service. (2020). National Wetlands Inventory. Retrieved January 12, 2020, from https://www.fws.gov/wetlands/

United States Geological Survey. (2019a). National Elevation Dataset (NED). Retrieved April 10, 2019, from https://viewer.nationalmap.gov/basic/?basemap=b1&category=ned,nedsrc&title=3DEP View

United States Geological Survey. (2019b). National Hydrography Dataset. Retrieved March 6, 2019, from https://www.usgs.gov/core-science-systems/ngp/national-hydrography

United States Geological Survey. (2020). Protected Areas Database of the United States (PADUS). Retrieved January 28, 2020, from https://gapanalysis.usgs.gov/padus/

Upper Oconee Regional Water Plan. (2017). Upper Oconee Regional Water Plan. Retrieved from waterplanning.georgia.gov

Warziniack, T., Sham, C. H., Morgan, R., & Feferholtz, Y. (2016). Effects of forest cover on drinking water treatment costs. *American Water Works Association. 51 P.*

Wear, D. N. (2013). Forecasts of land uses. *In: Wear, David N.; Greis, John G., eds. 2013. The Southern Forest Futures Project: technical report. Gen. Tech. Rep. SRS-GTR-178. Asheville, NC: USDA-Forest Service, Southern Research Station. 45-71.*, *178*, 45-71.

Weston, N. B., Hollibaugh, J. T., & Joye, S. B. (2009). Population growth away from the coastal zone: Thirty years of land use change and nutrient export in the Altamaha River, GA. *Science of the total environment*, *407*(10), 3347-3356.

Yang, L., Jin, S., Danielson, P., Homer, C., Gass, L., Bender, S. M., … Xian, G. (2018). A new generation of the United States National Land Cover Database: Requirements, research priorities, design, and implementation strategies. *ISPRS Journal of Photogrammetry and Remote Sensing*, *146*, 108–123. https://doi.org/10.1016/j.isprsjprs.2018.09.006

Zhang, Y. (2006). Development and validation of a Watershed Forest Management Information System. *Doctoral Dissertations Available from Proquest*, *AAI3242323*(September), 1–145. Retrieved from https://scholarworks.umass.edu/dissertations/AAI3242323

Zhang, Y., & Barten, P. K. (2009). Watershed Forest Management Information System (WFMIS). *Environmental Modelling & Software*, *24*, 569–575.

List of Tables

Table 1: Land cover class distribution in Upper Oconee River Basin based on National Landcover Database (2016)

Land cover class	2001		2006		2011		2016	
	Acres	%	Acres	%	Acres	%	Acres	%
Water	44,351	2.38	44,888	2.40	45,400	2.43	45,450	2.43
Urban (low)	161,744	8.67	183,248	9.82	188,379	10.09	189,046	10.13
Urban (high)	14,420	0.77	20,943	1.12	24,520	1.31	26,483	1.42
Barren land	8,287	0.44	7,017	0.38	6,756	0.36	7,205	0.39
Deciduous Forest	503,910	27.00	476,089	25.51	469,948	25.18	470,158	25.19
Evergreen Forest	391,521	20.98	385,637	20.66	406,557	21.78	413,119	22.13
Mixed Forest	177,468	9.51	182,615	9.78	188,146	10.08	193,179	10.35
Shrub/herbaceous	126,687	6.79	148,103	7.93	127,570	6.83	114,323	6.12
Pasture/crop	371,108	19.88	351,154	18.81	342,482	18.35	340,651	18.25
Wetlands	67,101	3.59	66,904	3.58	66,840	3.58	66,983	3.59

Table 2: Land cover distribution of protected areas in the Upper Oconee River Basin based on the Protected Areas Database of the United States (PADUS) in 2016. The percentage of each land cover class in conservation is shown in the last column.

Land cover class	Total	Protected	
	Acres	Acres	%
Water	45,450	2,869	6.31
Urban (low)	189,046	6,543	3.46
Urban (high)	26,483	365	1.38
Barren	7,205	185	2.57
Deciduous Forest	470,158	40,363	8.58
Evergreen Forest	413,119	62,800	15.20
Mixed Forest	193,179	20,050	10.38
Shrub/herbaceous	114,323	7,448	6.51
Pasture/crop	340,651	7,225	2.12
Wetlands	66,983	9,599	14.33

Table 3: Reclassification of land cover classes.

NLCD		Reclassification	
Land cover class	ID	Land cover class	ID
Open water	11	Water	1
Developed, open space	21	Urban (low intensity)	2
Developed, low intensity	22		
Developed, medium intensity	23	Urban (high intensity)	3
Developed, high intensity	24		
Barren land	31	Barren land	4
Deciduous forest	41	Deciduous forest	5
Evergreen forest	42	Evergreen forest	6
Mixed forest	43	Mixed forest	7
Shrub/Scrub	52	Shrub/herbaceous	8
Grassland/Herbaceous	71		
Pasture/Hay	81	Pasture/crops	9
Cultivated crops	82		
Woody wetlands	90	Wetlands	10
Emergent herbaceous wetlands	95		

Table 4: Input data used in this study and their respective sources.

Layer	Dataset	Source
Land cover	National Land Cover Dataset (NLCD)	(Yang et al., 2018)
Streams	National Hydrography Dataset	(United States Geological Survey, 2019b)
Ponds/wetlands	National Hydrography Dataset	(United States Geological Survey, 2019b)
Floodplain	National Wetlands Inventory	(United States Fish & Wildlife Service, 2020)
Soil group	SSURGO Database	(Soil Survey Staff, 2018)
Soil erodibility	SSURGO Database	(Soil Survey Staff, 2018)
Slope	National Elevation Dataset	(United States Geological Survey, 2019a)
Protected areas	Protected Areas Database of the United States (PADUS)	(United States Geological Survey, 2020)

Table 5: Layers used in the CPI/RPI calculation, and their ranks according to their characteristics.

		Rank (CPI/RPI)		
Layer	**Unit**	**1**	**2**	**3**
Distance to streams	Meters	> 375	170 - 375	< 170
Distance to ponds/wetlands	Meters	> 341	160 - 341	< 160
Floodplain	Presence	-	-	Any area
Soil group	Code	A	B	C, D, A/D, B/D, C/D
Soil erodibility	K-factor	< 0.24	0.24 - 0.28	> 0.32
Slope	Degrees	< 3.18	3.18 - 6.83	> 6.83

Table 6: CPI and RPI scores of each land cover class. The land cover classes “water,” “urban (low and high intensities),” and “barren land” were assigned a score of zero in both CPI and RPI calculations.

		Rank	
Land cover class	**ID**	**CPI**	**RPI**
Deciduous forest	5	3	0
Evergreen forest	6	3	0
Mixed forest	7	3	0
Shrub/herbaceous	8	0	2
Pasture/crops	9	0	3
Wetlands	10	3	0

Table 7: The overall accuracy and other details of the land use change model. Columns represent sub-models used to predict each land cover transition. Rows show the predictor variables used in each sub-model. The accuracy rate of sub-models indicates the ability of them to predict the correct land cover class. Kappa indices of agreement show the overall accuracy (amount of changes) and the level of agreement of location (allocation of changes) of the prediction.

Predictor variables	**Land cover transitions (Reclassified IDs*)**								
From:	**2**	**5**	**5**	**6**	**6**	**7**	**8**	**9**	**9**
To:	**3**	**2**	**3**	**2**	**3**	**2**	**2**	**2**	**3**
Distance to streets		X		X		X	X	X	
Distance to streets (Natural log)	X		X		X				X
Population density	X	X	X	X	X	X	X		
Dist. to urban disturbance (high)	X	X	X	X	X	X	X	X	X
Dist. to urban disturbance (low)		X	X	X	X	X	X	X	X
Dist. to retail stores	X								
Slope								X	X
Accuracy rate (sub-models):	79.0	88.5	92.3	94.0	95.6	88.2	88.6	86.9	90.1
Kappa indices of agreement (overall)	**Accuracy (K_{no}):**								92.70%
	Level of agreement of location (K_l):								91.20%

*Land cover IDs: 2 = urban (low intensity); 3 = urban (high intensity); 5 = deciduous forest; 6 = evergreen forest; 7 = mixed forest; 8 = shrub/herbaceous; 9 = pasture/crops.

Table 8: Land cover classes distribution based on land cover projection.

Land cover class	**2020**		**2025**		**2030**		**(2016-2030)**	
	Acres	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**
Water	45,450	2.43	45,450	2.43	45,450	2.43	0	0.00
Urban (low)	194,200	10.40	203,278	10.89	211,579	11.34	22,533	11.92
Urban (high)	29,000	1.55	32,863	1.76	36,597	1.96	10,114	38.19
Barren land	7,205	0.39	7,205	0.39	7,205	0.39	0	0.00
Deciduous Forest	467,405	25.04	460,978	24.70	455,485	24.40	-14,672	-3.12
Evergreen Forest	412,106	22.08	410,313	21.98	408,383	21.88	-4,736	-1.15
Mixed Forest	193,017	10.34	192,702	10.32	192,422	10.31	-757	-0.39
Shrub/herbaceous	113,821	6.10	113,374	6.07	112,933	6.05	-1,390	-1.22
Pasture/crop	337,409	18.08	333,449	17.86	329,559	17.66	-11,092	-3.26
Wetlands	66,983	3.59	66,983	3.59	66,983	3.59	0	0.00

List of Figures

Figure 1. Location of the Upper and Lower Oconee River Basins in Georgia.

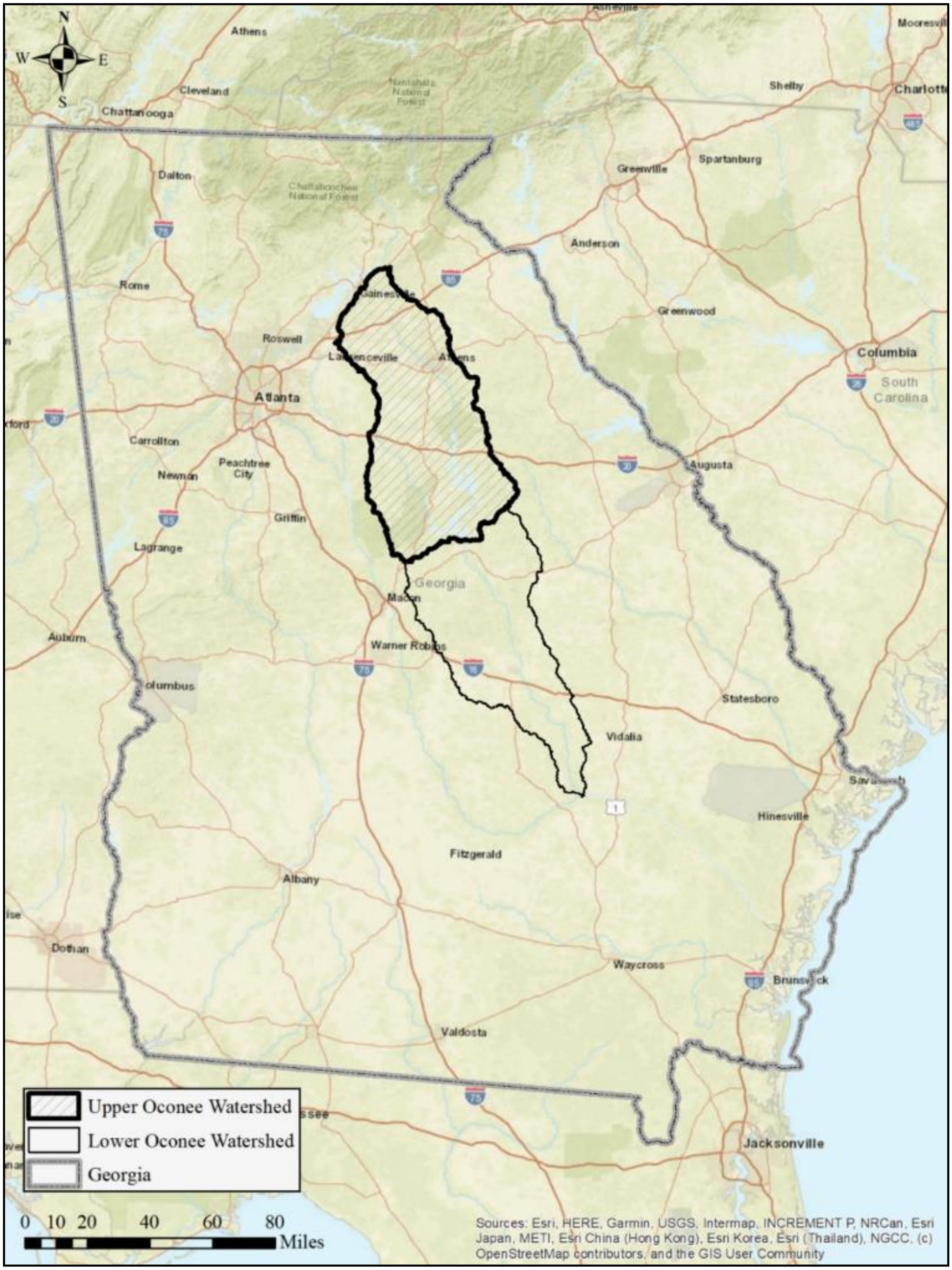


Figure 2. Administrative borders (cities and counties) that intersect the river basin boundary.

Figure 3. Land cover of the Upper Oconee River Basin in 2016.

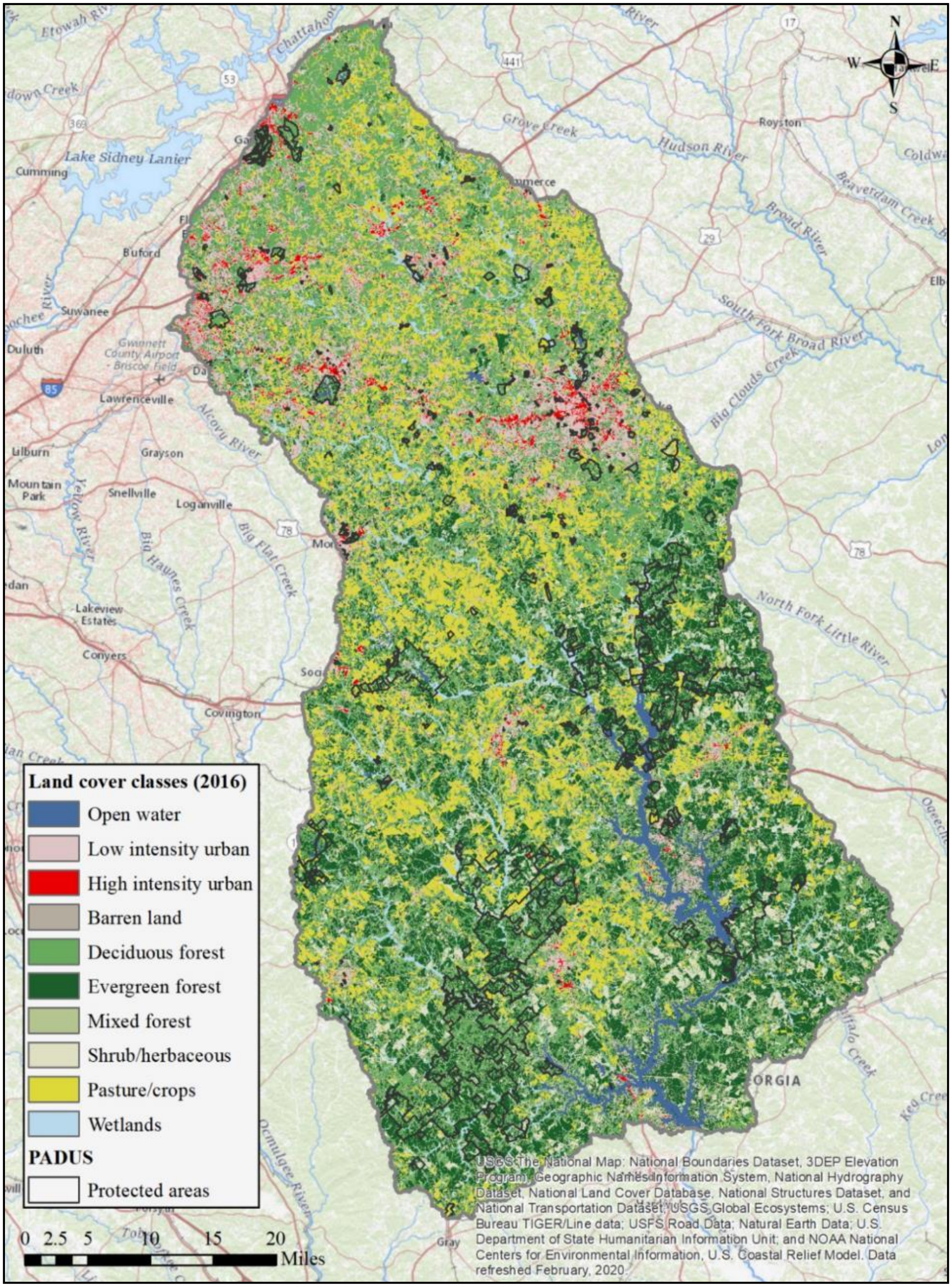


Figure 4. Protected areas within the Upper Oconee River Basin.

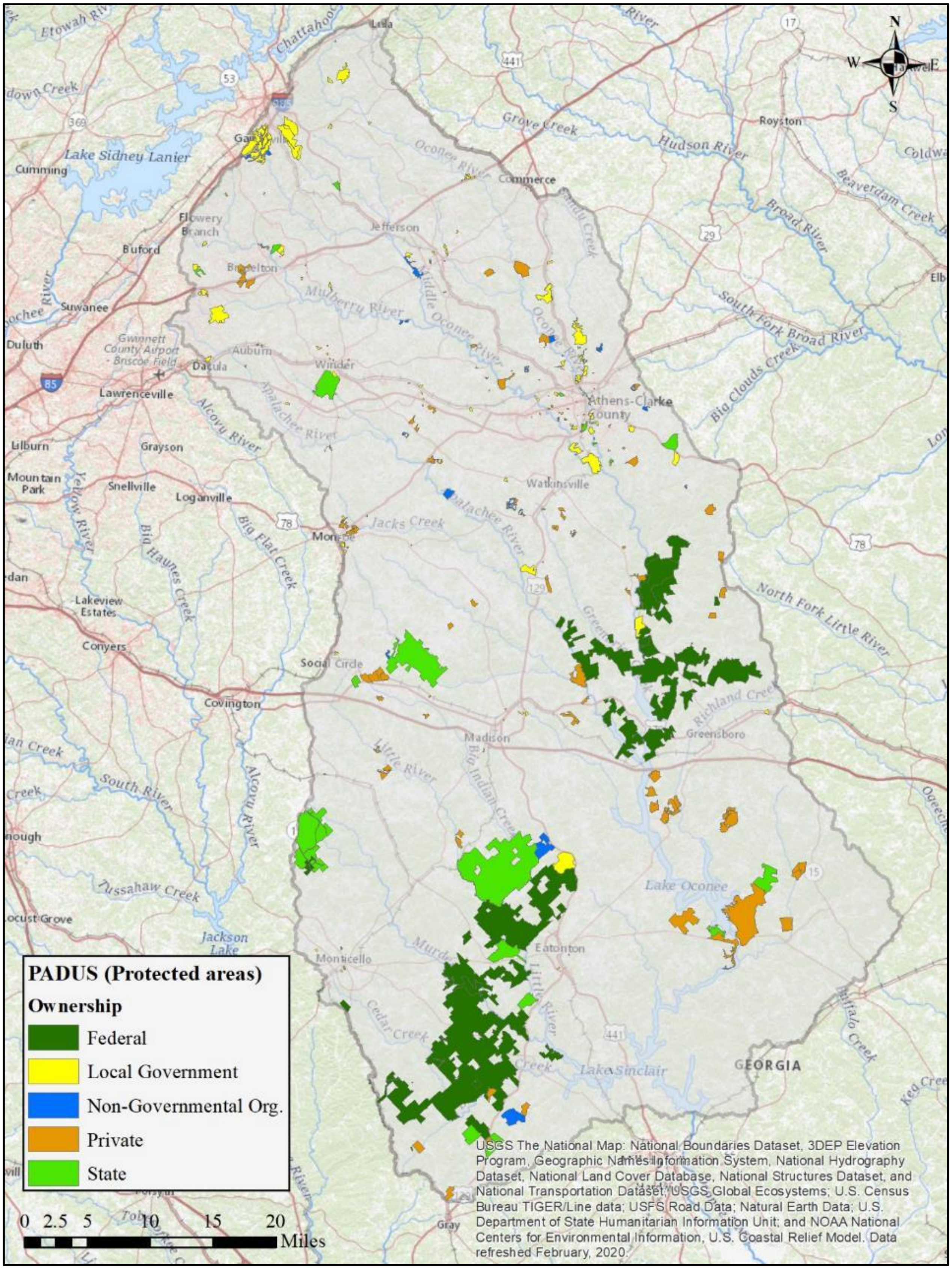


Figure 5. Land value ($/acre) of all parcels with an unprotected area (> 50 acres).

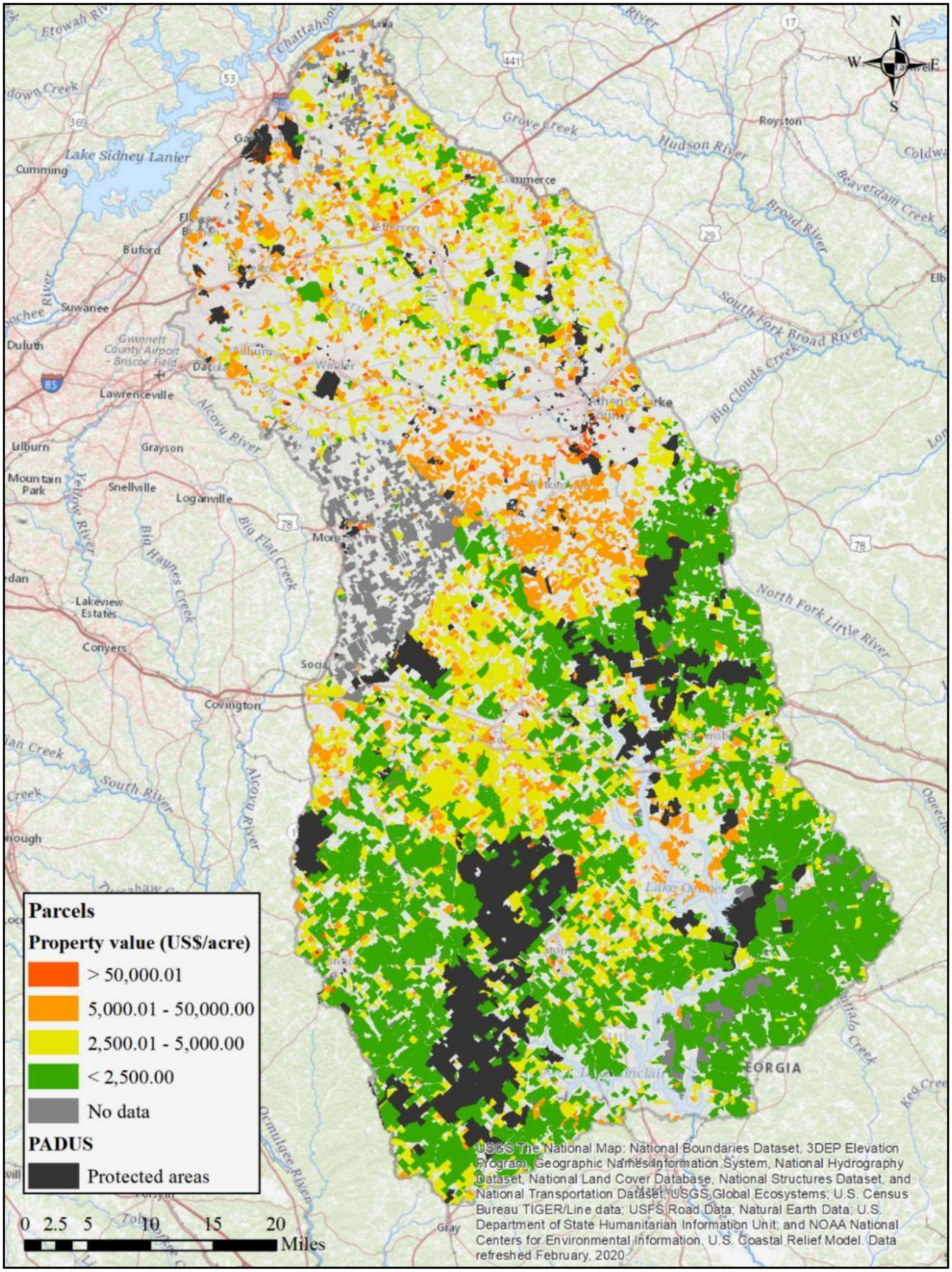


Figure 6. Results of the CPI ranging from 5 (lowest) to 21 (highest).

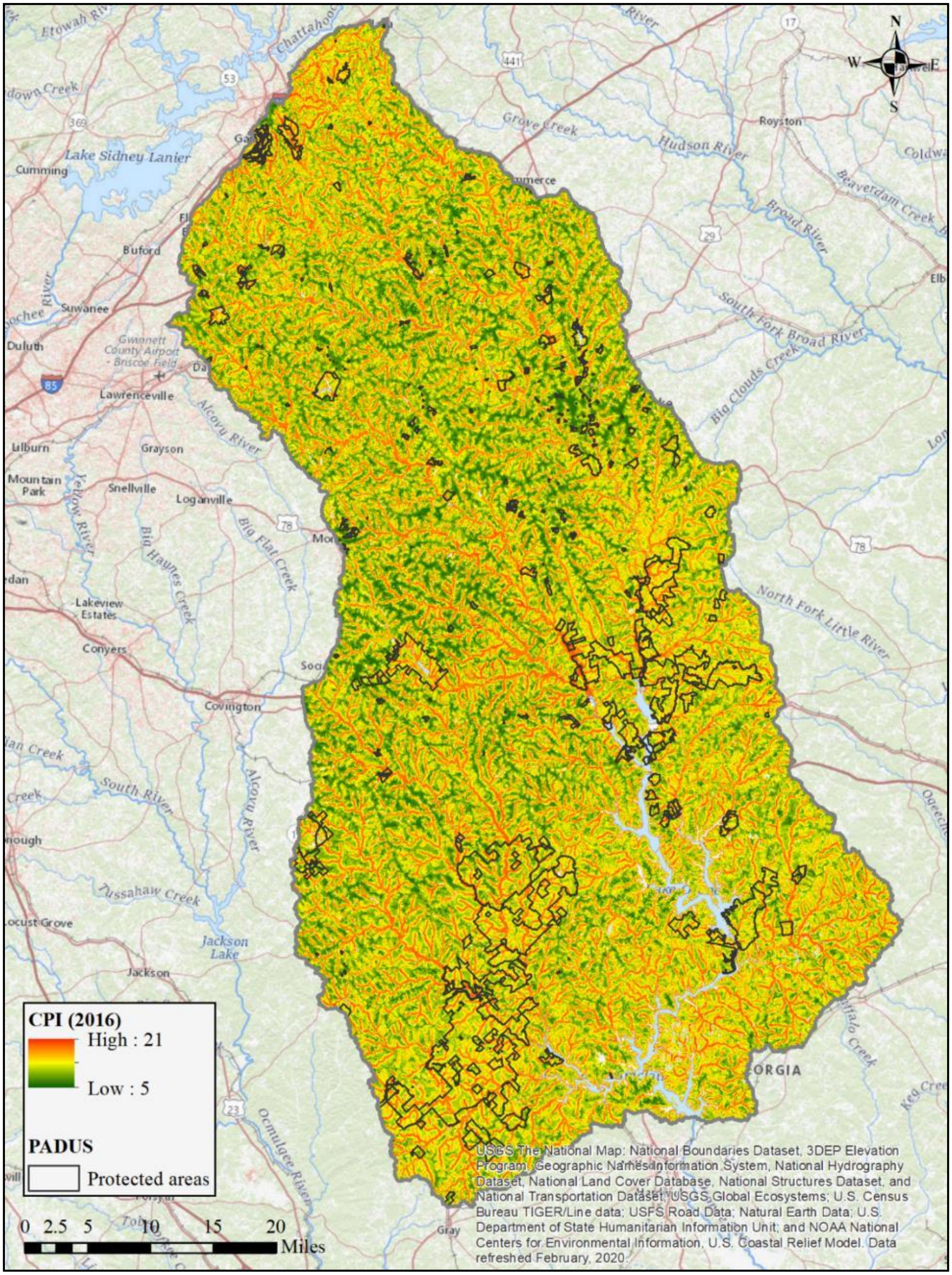


Figure 7. Parcels ranked according to their conservation priority.

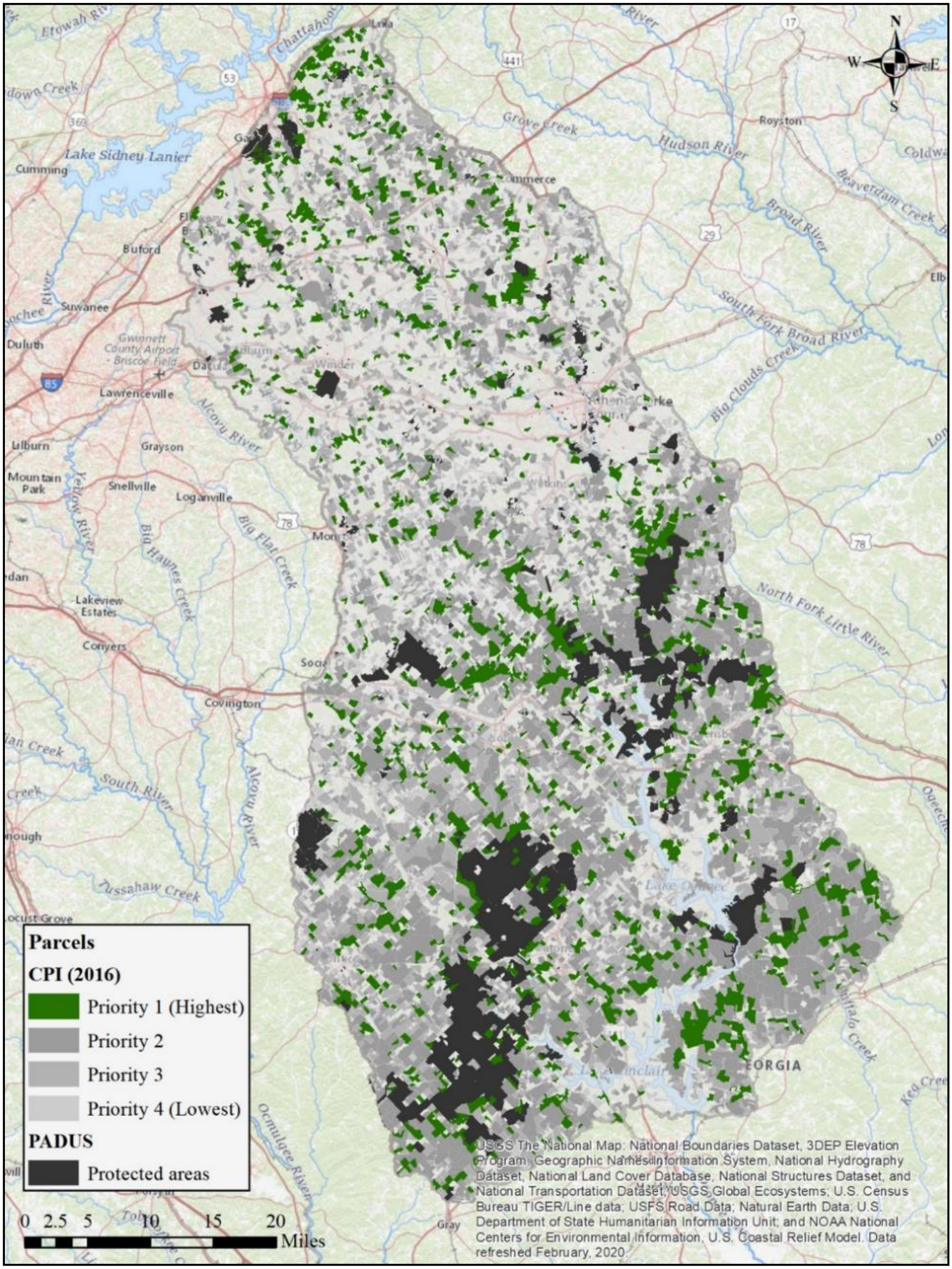


Figure 8. Results of the RPI ranging from 5 (lowest) to 21 (highest).

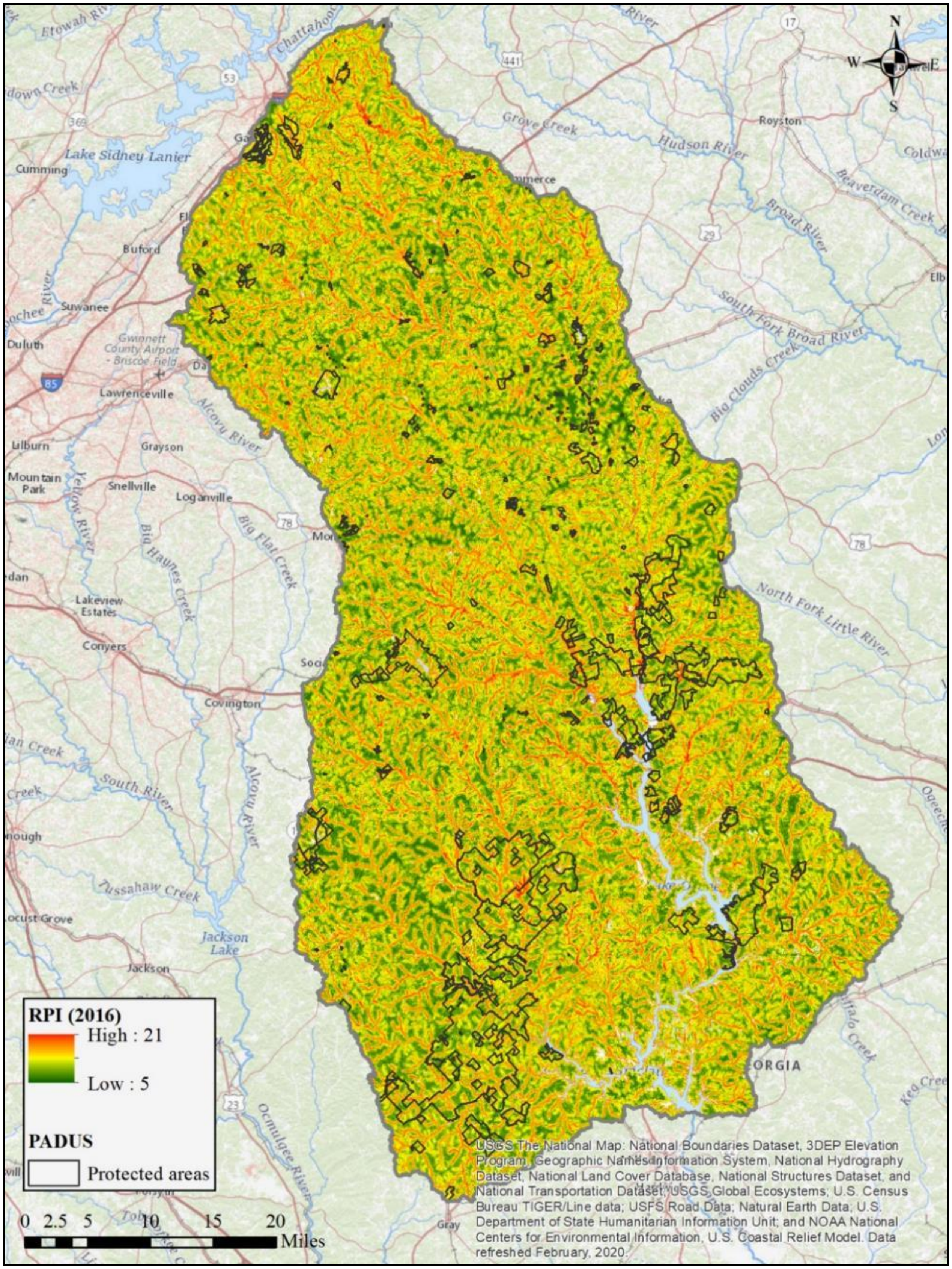


Figure 9. Parcels ranked according to their restoration priority.

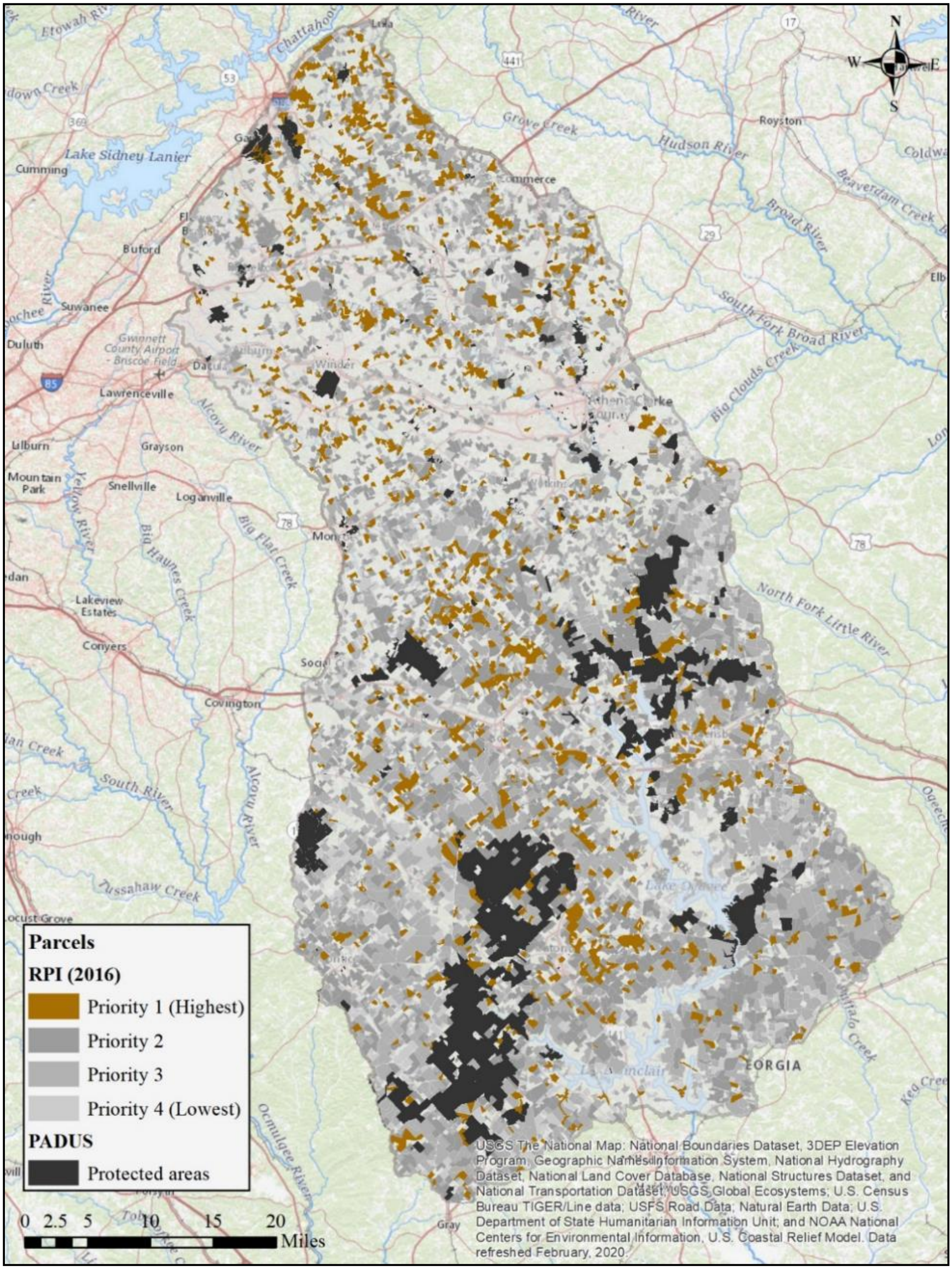


Figure 10. Projected land cover of the Upper Oconee River Basin in 2030.

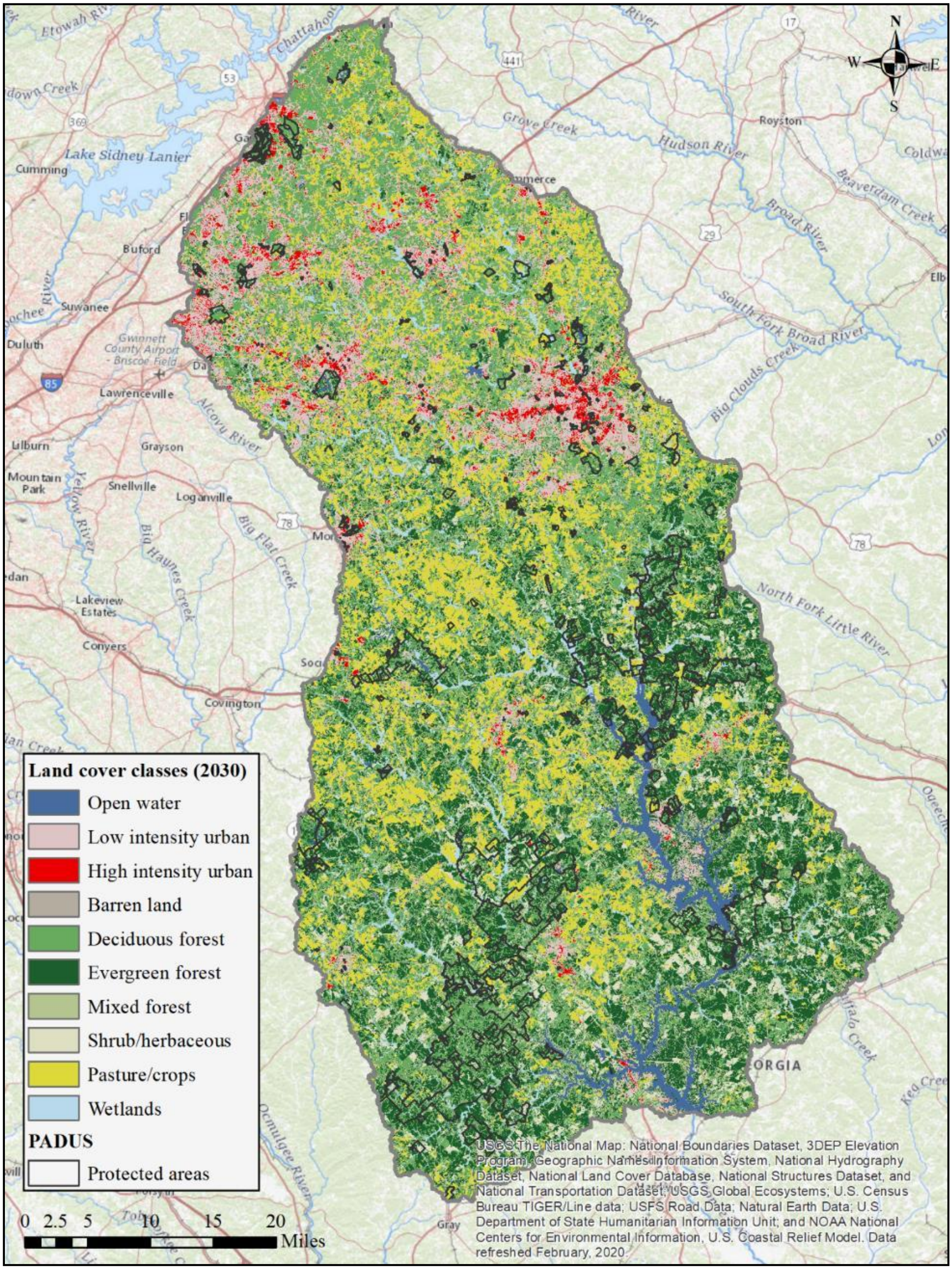


Figure 11. Projected urbanization in parcels with an unprotected area greater than 50 acres.

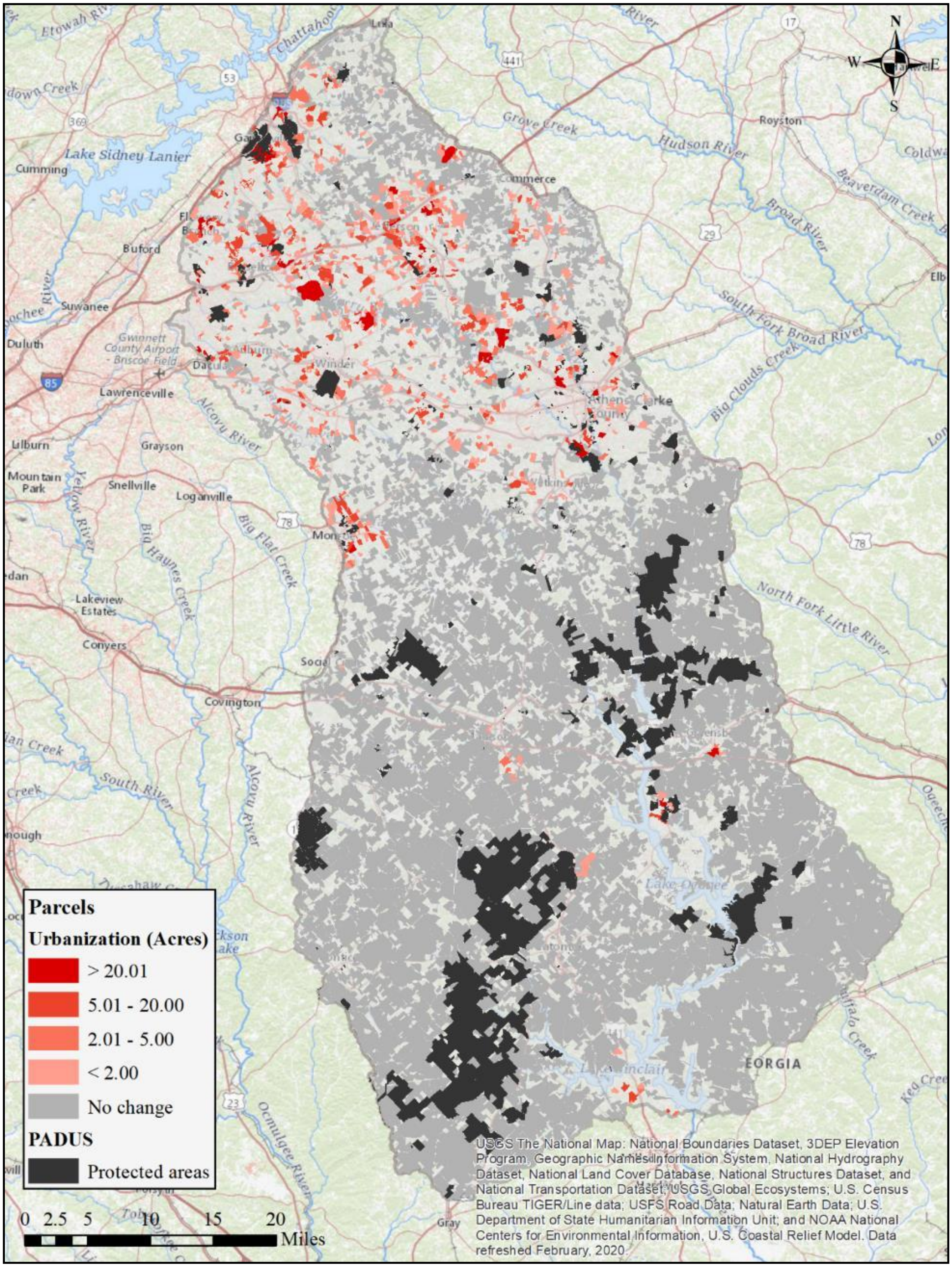


Figure 12. Parcels with the highest CPI priority and projected to receive new urban lands.

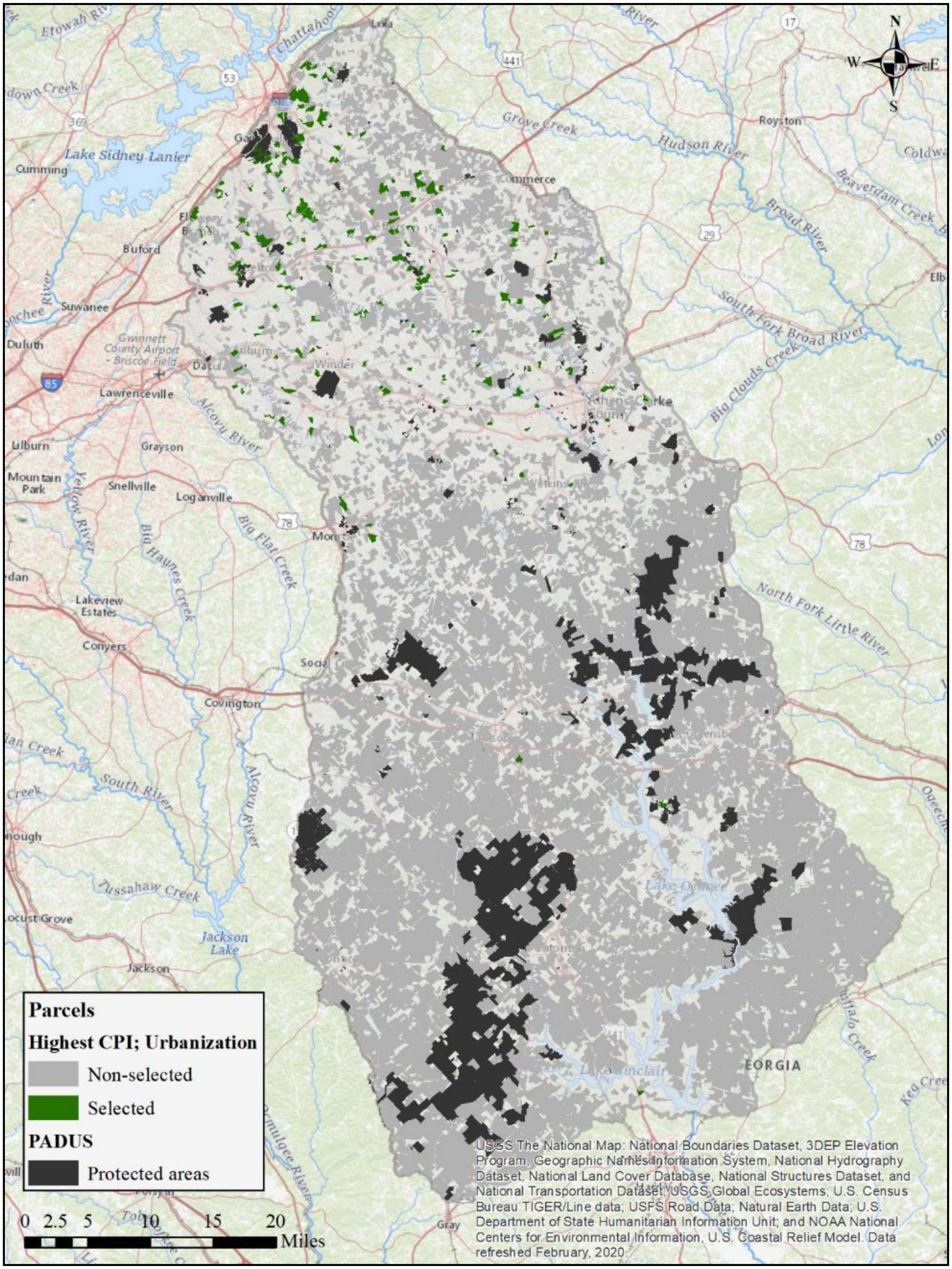


Figure 13. Parcels with the highest RPI priority and projected to receive new urban lands.