

Article

Assessing Land-Cover Change and Urbanization Impact on Riparian Zones in South Carolina: A Decade of Transition

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Abstract: This study investigates land-cover changes along riparian zones in South Carolina, focusing on intermittent and perennial streams to assess the impact of urbanization, forest loss, and impervious surface expansion on sensitive ecosystems. South Carolina's diverse geography, ranging from coastal marshes to the Blue Ridge Mountains, and subtropical humid climate, offers a rich context for understanding environmental changes. The research utilizes various geospatial datasets, including the National Land Cover Database (NLCD), National Hydrography Dataset (NHD), and National Agricultural Imagery Program (NAIP) imagery, to evaluate changes in forest cover, urbanization, and impervious surfaces from 2011 to 2021 as a decade of transition. The study areas were divided into buffer zones around intermittent and perennial streams, following South Carolina's riparian management guidelines. The results indicate significant land-cover transitions, including a total of 3184.56 hectares of non-urban areas converting to forest within the 100 m buffer around intermittent streams. In contrast, 137.43 hectares of forest transitioned to urban land in the same buffer zones, with Spartanburg and Greenville leading the change. Intermittent stream buffers exhibited higher imperviousness (4.6–5.5%) compared to perennial stream buffers (3.3–4.5%), highlighting the increased urban pressure on these sensitive areas. Furthermore, tree canopy loss was significant, with counties such as Greenwood and Chesterfield experiencing substantial reductions in canopy cover. The use of high-resolution NAIP imagery validated the land-cover classifications, ensuring accuracy in the results. The findings emphasize the need for effective land-use management, particularly in the riparian zones, to mitigate the adverse impacts of urban expansion and to safeguard water quality and biodiversity in South Carolina's streams.

Keywords: land-use–land-cover; riparian; streams; hydrology; urbanization



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1. Introduction

Riparian zones, situated at the interface of river channels and upland ecosystems, are critical for the exchange of energy, and organic and inorganic matter, and support a rich diversity of biota [1–5]. These areas are among Earth's most productive and biologically diverse landscapes [6] and are classified as one of the fifteen globally recognized terrestrial biomes. Although they represent a small geographic area, riparian zones support significantly higher biodiversity than surrounding landscapes [7–9]. For example, riparian forests in the American southwest occupy less than 2% of land surface but are recognized for their exceptional biological productivity and ecological importance [10,11].

The unique soil, vegetation structure, topography, microclimate, and moisture regimes make riparian zones distinct from adjacent uplands. Their biophysical diversity varies over time and space, creating a complex ecosystem [7,12]. Periodic flooding and the connectivity between upland and aquatic systems are defining features, as they facilitate material exchange through surface and subsurface water flows [13]. Key characteristics of riparian zones include high edge–area ratios, environmental gradients, connectivity, and

biodiversity [14,15]. Hydrological processes strongly influence the structural and functional dynamics within riparian zones [16,17].

Riparian zones are vital for river ecosystem health by supporting functions such as sediment and nutrient filtration, bank stabilization, shading to regulate water temperature, and provision of habitats [7,13,18]. They help improve stream quality and serve as natural buffers between waterways and agricultural fields [19,20]. Riparian vegetation also contributes to aquifer recharge, which is crucial for watershed sustainability. Additionally, riparian zones provide valuable ecosystem services for human well-being, including livestock forage, fuelwood, genetic resources, carbon sequestration, air quality improvement, and flood regulation [21–25]. Despite these benefits, riparian zones face numerous threats from human activity and environmental changes, such as agriculture, urbanization, river modifications, pollution, and invasive species [22,26].

Conserving riparian zones is essential for sustaining ecosystem functions that support human well-being and for maintaining river health [27–29]. Addressing the complex challenges associated with riparian area protection—such as accurately predicting land-use changes, assessing ecosystem services, and modeling hydrological impacts—requires an integrated management approach. Advanced machine learning and artificial intelligence methods, coupled with various analytical tools, and integrating in situ data can provide more precise and actionable outcomes [30]. Human modifications, including grade-control structures and channelization, have significantly altered river systems globally, often causing narrowing, incision, and transformation of river channels [31–37]. These changes shape how major flood events impact river landscapes, as the effects of floods are closely tied to channel condition, as well as shifts in vegetation and channel structure [38,39]. A dynamic interaction exists between water flow, sediment movement, channel formation, and riparian vegetation, which collectively influence the ecosystem's spatial and temporal changes. This feedback loop supports fluvial ecosystems by enabling transitions from unstable geomorphological conditions, such as sparsely vegetated bars, to stable configurations with denser vegetation, like willow cover, which increases productivity but may reduce biodiversity [40,41]. Riparian vegetation is essential for water retention and resistance, supporting diverse plant and pioneer species, which, in turn, influence ecosystem diversity. Land-change studies aim to explain where and how land cover is transformed, the types of transitions taking place, and the rates and causes of these changes. The purpose of examining these characteristics is to understand emerging land-change trends, as various land-use practices and development can threaten the ecological health of streams. For example, shifts in land cover can influence surface water runoff, affecting both the quantity and quality of water entering these ecosystems.

Monitoring riparian ecosystems is vital for understanding their responses to various pressures and management efforts. While field sampling provides valuable data, it is often resource-intensive and challenging due to the vast, dynamic nature of riparian zones [42]. Remote sensing has become an invaluable tool for this purpose, offering the ability to observe changes over extensive areas and long periods. Since 1972, the Landsat program has allowed large-scale satellite-based monitoring, greatly advancing landscape and riverine research by enabling detailed, long-term assessments of riparian changes [43].

South Carolina is experiencing significant urban expansion, placing increasing pressure on its riparian zones. This urbanization poses a serious threat to riparian areas, which plays a key role in preserving biodiversity, water quality, and ecosystem stability. The primary objectives of this study are twofold: (1) to assess patterns of forest loss and gain in areas surrounding both perennial and intermittent streams, and (2) to prioritize South Carolina's counties based on their levels of forest change. By identifying areas with the most significant forest cover changes, this study aims to inform regional conservation efforts and promote sustainable development practices to protect riparian ecosystems and the essential services they provide.

2. Methods

2.1. Study Area

South Carolina, located in the southeastern United States, serves as the study area for this research (Figure 1). With a population of approximately 5.1 million as of the 2020 census, South Carolina ranks as the 40th largest state by area and 23rd by population. Its economy is substantial, generating a gross domestic product (GDP) of USD 213.45 billion in 2019. The state is composed of 46 counties and features three distinct geographic regions: the Atlantic Coastal Plain, the Piedmont, and the Blue Ridge Mountains in the northwestern corner. These varied landscapes provide a range of ecological contexts, from coastal salt marshes and estuaries to the mountainous highlands in the northwest.

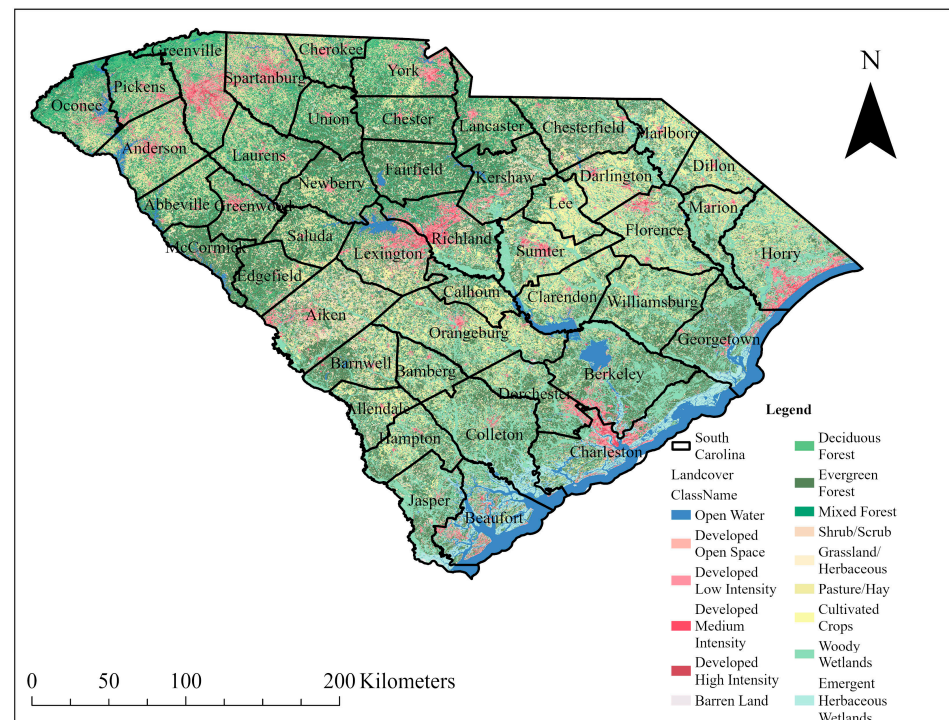


Figure 1. The study was conducted in South Carolina, U.S.A.

South Carolina's climate is largely subtropical humid, characterized by hot, humid summers with daytime temperatures typically between 30 and 34 °C and milder coastal winters with average highs around 16 °C. The state's eastern coastal plain includes salt marshes and estuaries, along with sections of the Sea Islands chain of barrier islands along the Atlantic Ocean. This variability in topography, soil, and climate creates unique ecological conditions, which, in turn, affect the types of vegetation found across the state. Hydrologically, South Carolina is influenced by both the Atlantic Ocean and its inland rivers, resulting in a complex system of freshwater and tidal interactions that significantly affect riparian zones and floodplains. This combination of diverse geography and climate variability, particularly between the coastal and inland regions, makes South Carolina an ideal setting for analyzing environmental and land-cover changes, especially within sensitive riparian zones.

2.2. Data Collection

This study primarily focuses on land-cover changes in riparian areas along intermittent and perennial streams in South Carolina. To support this analysis, multiple geospatial datasets were collected from reputable sources. The South Carolina state boundary shapefile was downloaded from the TIGER/Line Shapefiles (TIGER/Line® Shapefiles accessed on 10 March 2024) to delineate the study area accurately. Land cover, tree canopy, and impervious surface data were sourced from the National Land Cover Database (NLCD),

provided by the Multi-Resolution Land Consortium (MRLC) (Data | Multi-Resolution Land Characteristics (MRLC) Consortium accessed on 15 March 2024). The National Agricultural Imagery Program (NAIP accessed on 11 October 2024) imagery was obtained from the ArcGIS Pro version 3.1.2 living atlas. These datasets allowed for detailed analysis of forest and urbanization trends along riparian zones.

Stream and river data were obtained from the National Hydrography Dataset Plus High Resolution (NHDPlus HR) through The National Map (TNM Download v2 accessed on 25 March 2024), which provided precise layers for both intermittent and perennial streams. NAIP data were used to validate the land-cover classifications, enhancing the reliability of our category distinctions within these sensitive ecological corridors. This suite of data sources provided a strong foundation for examining forest loss, urban encroachment, and overall landscape change in South Carolina's riparian areas.

2.3. Data Analysis

2.3.1. Streams Layer

The analysis focused on intermittent and perennial streams in South Carolina to evaluate land-cover changes in riparian areas. The NHDPlus HR was downloaded from The National Map and imported into ArcGIS Pro version 3.2.1 (Figure 2), where the data were refined to include only intermittent and perennial streams. Using these selected stream types, we created a targeted framework for examining forest and urbanization trends within different buffer zones along each stream. This buffer distance aligns with South Carolina's recommended riparian management guidelines and was applied to both stream types to allow for consistent, comparable analysis of land-cover changes in these ecologically sensitive areas.

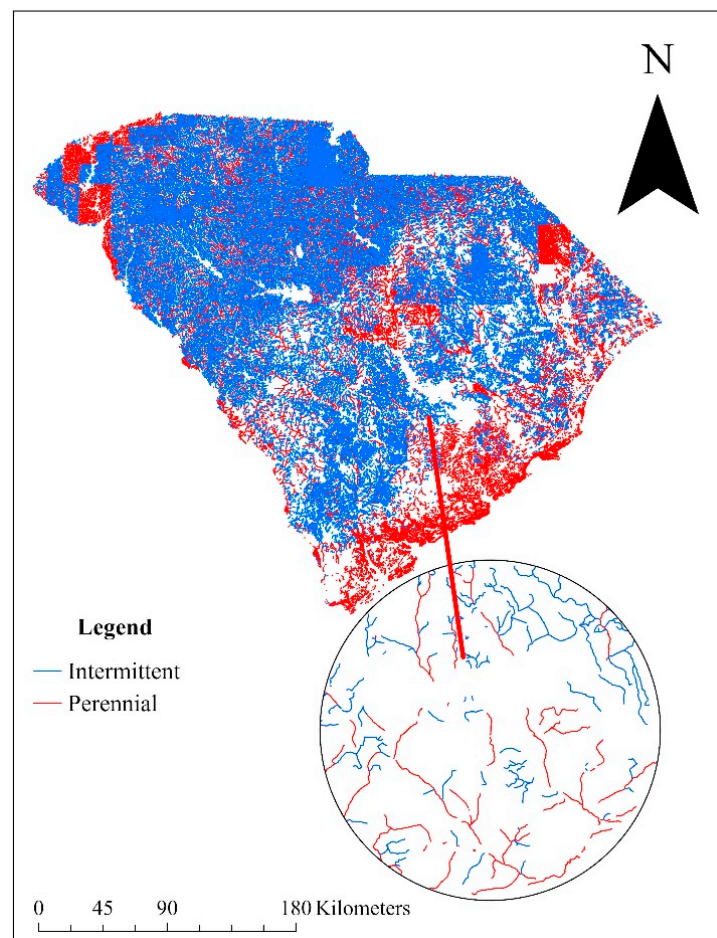


Figure 2. Intermittent and perennial streams in South Carolina, U.S.A.

2.3.2. National Land-Cover Change

To evaluate land-cover changes in riparian areas, we used the NLCD layers from 2011 and 2021, downloaded from the Multi-Resolution Land Consortium. The NLCD data were imported into ArcGIS Pro and classified into three primary categories: forest, urban, and non-urban areas. Each category was assigned a unique value (e.g., 20 for forest, 40 for urban, and 60 for non-urban (all other land-cover class except forest and urban) in both 2011 and 2021 datasets. We then reclassified each layer based on these categories to create consistency between the years.

Using the Raster Calculator, we subtracted the 2011 layer from the 2021 layer, allowing us to quantify specific land-cover transitions. We focused on areas where changes occurred, such as:

- Forest changing to urban;
- Forest changing to non-urban;
- Urban reverting to forest;
- Non-urban converting to forest.

All other land-cover changes were excluded from the analysis, as our primary interest was identifying the extent of forest areas converted to urban and non-urban land uses within riparian zones. This approach provided targeted insights into the impact of urban and non-urban expansion on forested areas near streams, helping to highlight potential areas of concern for riparian ecosystem health and water resource management. The zonal statistics as table was used to extract the value of all change for each county of South Carolina.

2.3.3. Impervious Surface Layer

We used the NLCD impervious layer for 2011 and 2021, along with intermittent and perennial stream layers from the NHD HR, to assess impervious surface changes around South Carolina's streams. The impervious data from NLCD were reclassified into two categories: class "0" for areas with less than 1% imperviousness and class "1" for areas with more than 1% imperviousness. Using the Raster Calculator, we computed the change in imperviousness between 2011 and 2021 and categorized the changes into four classes: 11 (no imperviousness), 12 (none to impervious), 21 (impervious to none), and 22 (impervious and no change). Three buffer zones—30, 45, and 60 m—were created around both intermittent and perennial streams. We then extracted impervious surface changes within each buffer and calculated the percentage of impervious areas in each zone.

2.3.4. Tree Canopy Cover Change Layer

Forest canopy changes across South Carolina from 2011 to 2020 were examined using the MRLC site (NLCD tree canopy cover). The tree canopy cover with a 30 m resolution Landsat Thematic Mapper (TM) imagery was downloaded.

To assess these changes, raster layers from 2011 and 2021 were processed in ArcGIS Pro. Tree canopy data specific to South Carolina were extracted using the "Extract by Mask" tool with the state boundary. For classification, the original data values (ranging from ≤ 13 to ≤ 255) were examined through histogram analysis, revealing a mean value near 50. Consequently, canopy values below 50 were categorized as non-forest (0), while values at or above 50 were classified as forest (1) using the "Reclassify" tool. The 2011 and 2021 canopy layers were then compared in the "Raster Calculator," producing a raster with values of -1 (forest loss), 0 (no change), and 1 (forest gain).

Following the statewide analysis, changes in forest cover were further examined along South Carolina's intermittent and perennial streams at the county level. South Carolina's best management practices for riparian zones recommend buffer widths between 30 and 100 m for ecological, water quality, and scenic value preservation [44]. To meet these guidelines, a 30 m buffer was applied to each of the intermittent and perennial streams, capturing forest canopy changes within these critical riparian areas.

Finally, for all changes zonal statistics as table was used to summarize the change for each county of South Carolina. This approach provides a spatially detailed view of forest dynamics near waterways, supporting conservation efforts and illustrating the impacts of land-cover changes on South Carolina’s riparian ecosystems.

2.4. Validation

For validation, the NAIP imagery, with its 1 m spatial resolution, was utilized to ensure the accuracy of the location assessments. This high-resolution imagery provided detailed ground information necessary for precise validation. Initially, the raster to polygon tool was used to convert the forest to urban, urban to forest, forest to non-urban, and non-urban to forest raster to the polygons. Then the polygons were merged, and then random points were created based on the polygon, then from all four classes, all together 600 points were randomly selected and then these points were compared with NAIP and world imaginary to identify the points matched or unmatched between the land-cover class in the inside buffer and NAIP or world imagery. This validation process involved analyzing the alignment between the land-cover class categories derived from this NLCD raster and those observable in the NAIP imagery, thus allowing for a reliable evaluation of the accuracy of the land-cover classification within the study area.

$$\text{Accuracy (\%)} = (\text{Matched Points} / \text{Total Points}) \times 100$$

The approach ensured that the classifications matched real-world conditions as represented by the high-resolution NAIP data.

3. Result

3.1. Summary of Land-Cover Changes from 2011 to 2021

Land-cover changes within intermittent and perennial stream buffer areas reveal significant trends. In 100 m buffers, the highest non-urban to forest conversion occurred in Aiken, Fairfield, and Chesterfield counties, totaling 3184.56 hectares statewide for intermittent streams and 8408.07 hectares statewide for perennial streams. Forest to urban transitions were most pronounced in Spartanburg, Greenville, and York, with 137.43 hectares statewide affected in 100 m intermittent buffers and 448.65 hectares statewide in 100 m perennial buffers. The analysis highlights key spatial patterns of land-cover dynamics across South Carolina (Figure 3, Table 1).

Table 1. Top counties and area changes for land-cover transitions in riparian stream buffer zones.

Change Type	Buffer Zone	Top Five Counties	Total Area Change Statewide (Hectares)
Non-urban to forest	100 m intermittent	Aiken, Lexington, Chesterfield, Newberry, Edgefield	3184.56
	30 m intermittent	Chester, Saluda, Williamsburg, Dorchester, Berkeley	614.61
	100 m perennial	Fairfield, Chester, Edgefield, Union, Laurens	8408.07
	30 m perennial	Fairfield, Spartanburg, York, Edgefield, Cherokee	1310.49
Forest to urban	100 m intermittent	Spartanburg, Greenville, York, Lexington, Richland	137.43
	30 m intermittent	Greenville, York, Lexington, Spartanburg, Richland	29.43
	100 m perennial	Greenville, Spartanburg, Berkeley, Richland, Pickens	448.65
	30 m perennial	Greenville, Spartanburg, Pickens, Richland, Berkeley	80.1
Urban to forest	100 m intermittent	Greenville, Spartanburg, Aiken, Lexington, Anderson	40.32
	30 m intermittent	Spartanburg, Greenville, Greenwood, Aiken, Cherokee	9.09
	100 m perennial	Greenville, Pickens, Spartanburg, Oconee, Anderson	154.53
	30 m perennial	Greenville, Pickens, Spartanburg, Oconee, Anderson	39.42
Forest to non-urban	100 m intermittent	Greenwood, Chesterfield, Aiken, Lexington, McCormick	3704.58
	30 m intermittent	Greenwood, Aiken, Lexington, Saluda, Chesterfield	719.28
	100 m perennial	Chesterfield, Fairfield, Lancaster, Kershaw, Edgefield	9951.75
	30 m perennial	Fairfield, Lancaster, Chesterfield, York, Chester	1397.61

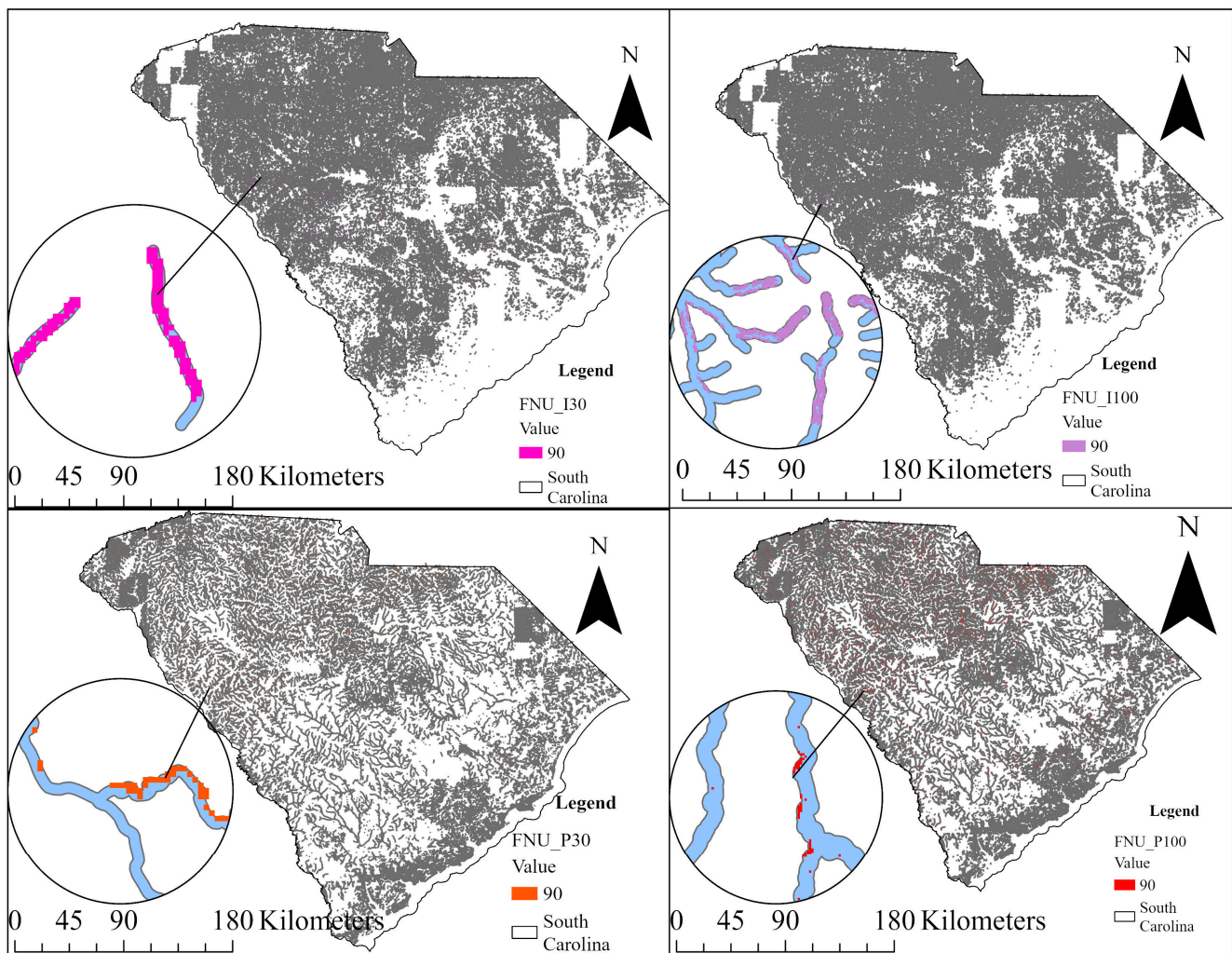


Figure 3. The forest converted to non-urban for intermittent and perennial streams at 30 and 100 m buffer. FNU_I30 forest converted to non-urban for intermittent stream with 30 m buffer, FNU_I100 forest converted to non-urban for intermittent stream with 100 m buffer, FNU_P30 forest converted to non-urban for perennial stream with 30 m buffer, and FNU_P100 forest converted to non-urban for perennial stream with 30 m buffer. The 90 value is given to represent forests to non-urban change. A similar approach was performed for forests to urban, urban to forest, and non-urban to forest.

3.2. Forest Change to Impervious Surface from 2011 to 2021

The analysis reveals distinct patterns in impervious surface change across buffer zones and stream types. Impervious areas were consistently higher along intermittent streams, occupying 4.6% to 5.5% of these buffers, compared to 3.3% to 4.5% along perennial stream buffers (Figures 4 and 5). Additionally, the imperviousness tended to increase with increasing distance from the stream, with the highest imperviousness observed within the 60 m buffer zone. The higher imperviousness along intermittent streams, which often lack continuous water flow, presents a unique concern. Development in these areas can disrupt natural drainage and groundwater recharge, potentially elevating flood risks in nearby urban regions. This impact on intermittent streams, which have less natural capacity to carry water continuously, highlights the critical need for protective measures to mitigate urban water management challenges.

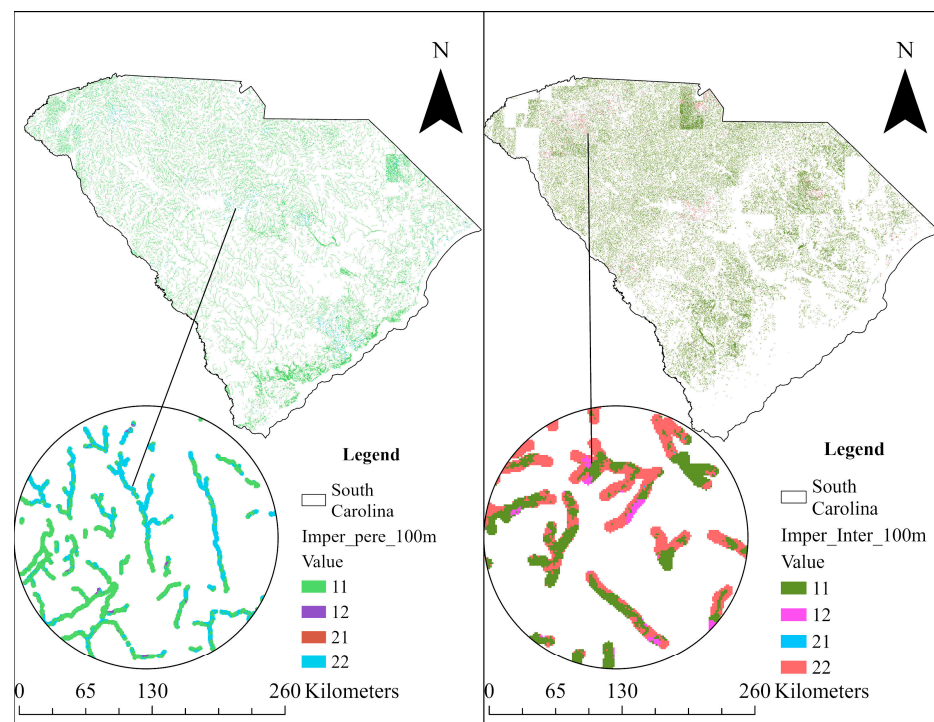


Figure 4. The left figure represents the change in impervious cover from 2011 to 2021 along perennial streams at 100 m buffer and the right figure represents the impervious intermittent streams at 100 m buffer. The values represent the following: 11 (no imperviousness means all green), 12 (none to impervious), 21 (impervious to none), and 22 (impervious in both time periods). Figure was created for better visualization.

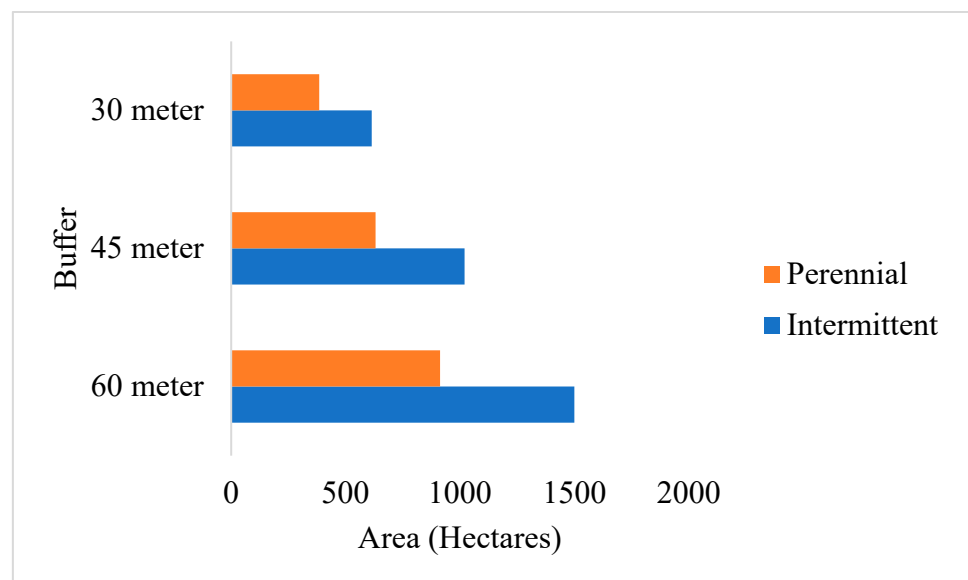


Figure 5. Area of imperviousness for each stream type from 2011 to 2021.

3.3. Forest Cover Change from 2011 to 2021

The forest cover change was compared in the buffer for the perennial and intermittent streams. For the perennial streams at the 30 m buffer, the forest loss was high in Berkeley, Greenville, Dillon, Anderson, and Spartanburg. The total loss in the forest statewide was 7809.57 hectares. The highest gain was found in Horry, Georgetown, Chesterfield, Dillon, and Orangeburg. The total gain of forest canopy statewide was 5327.55 hectares. In the case of 100 m buffer, the forest loss was high in Berkeley, Spartanburg, Charleston, Greenville,

and Anderson. The total loss statewide was 34746.48 hectares. The highest gain in the case of the 100 m buffer was found in Chesterfield, Lancaster, Fairfield, Orangeburg, and York. The total gain statewide was found to be 9496.17 hectares (Figure 6).

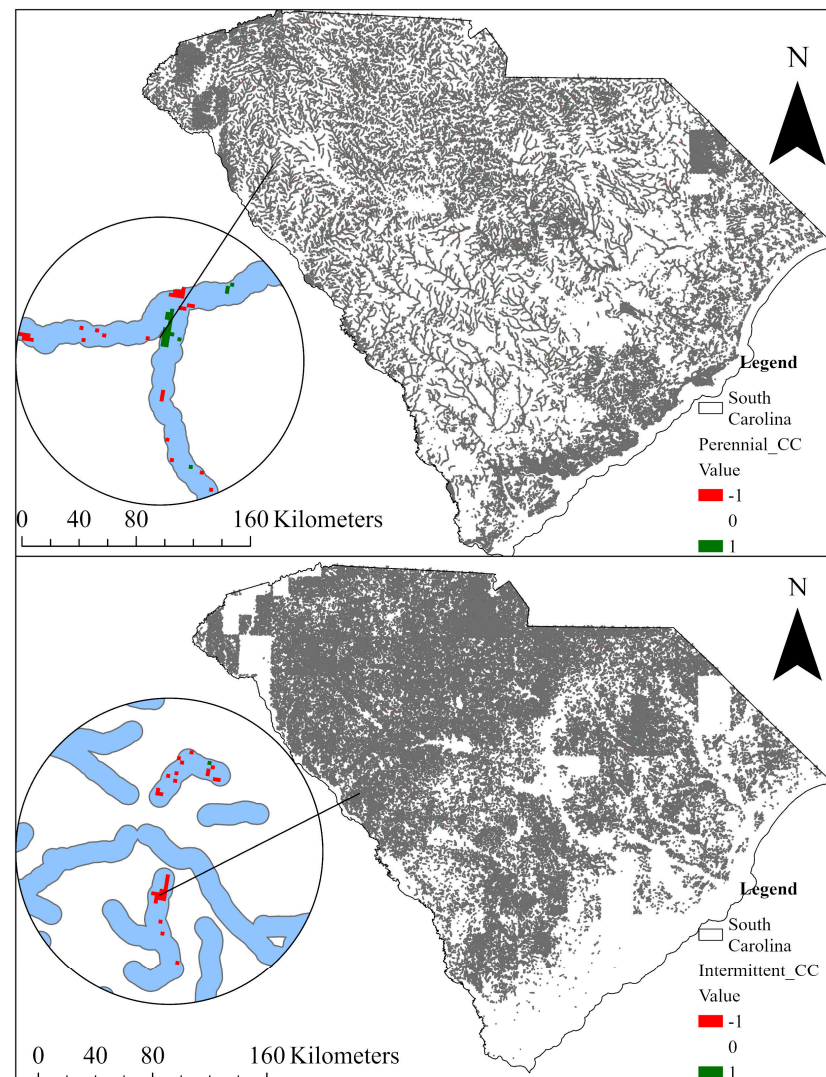


Figure 6. The forest canopy cover changes from 2011 to 2021. The red represents forest loss, and the green represents the forest gain, and the white represents no change in the 100 m intermittent and perennial streams.

For the intermittent streams at 30 m buffer, the forest gain was high in Orangeburg, Hampton, Aiken, Colleton, and Williamsburg. The total gain in forest cover at the 30 m buffer statewide was 18936.81 hectares. The highest loss was found in York, Greenville, Florence, Spartanburg, and Colleton. The total loss of forest canopy statewide was 16233.93 hectares. In the case of the 100 m buffer, the forest, gain was high in Orangeburg, Hampton, Colleton, Chesterfield, and Aiken. The total gain statewide was 78883.65 hectares. The highest loss in the case of the 100 m buffer was found in York, Spartanburg, Greenville, Aiken, and Colleton. The total loss statewide was found to be 70877.7 hectares.

3.4. Validation

This process yielded an accuracy of 88.7% (Figure 7), indicating a high level of agreement between the four-raster forest converted to urban, urban converted to forest, forest

converted to non-urban, and non-urban to forest, and the actual conditions depicted in the NAIP imagery.

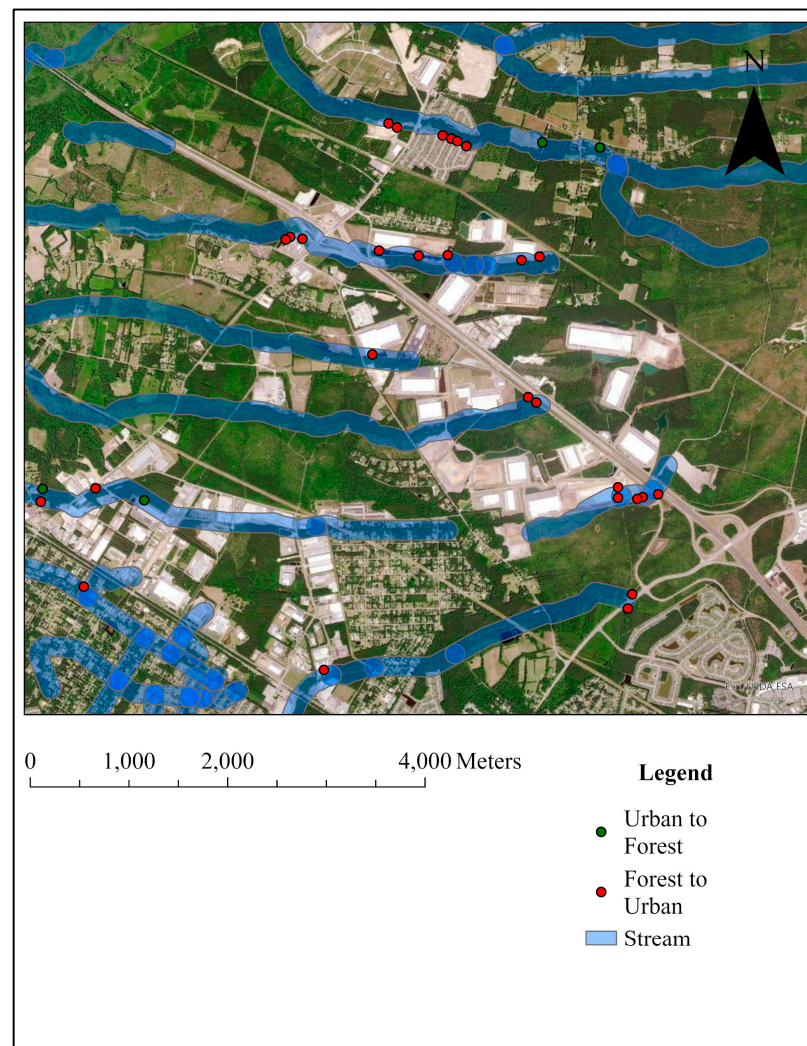


Figure 7. The random points for the urban to forest and forest to urban created based on the polygon obtained after the raster conversion. The comparison was performed either with actual conversion to forest or urban using NAIP and world imagery. This accuracy rate reflects the reliability of the change and demonstrates that the classification approach aligns well with real-world data in the study area.

4. Discussion

This study on riparian forest loss and gain along intermittent and perennial streams in South Carolina reveals important insights into land-cover changes and highlights potential ecological implications for riparian zones. Analyzing shifts from forest to urban and non-urban areas and assessing impervious surface changes within designated buffer zones provides a deeper understanding of the human-induced pressures on these sensitive ecosystems [45]. As riparian zones are crucial for ecosystem stability, water quality, and biodiversity, understanding the extent and type of land-cover changes in these areas is essential for environmental conservation and sustainable land management [46]. Riparian buffer protection and restoration are widely recognized as critical conservation strategies to sustain a variety of ecosystem services across catchment and basin scales [47,48]. Moderate-resolution satellite imagery (e.g., 30–60 m resolution) offers a practical approach to track changes in riparian land cover, potentially reflecting shifts in interconnected ecosystem

services, and in this study, the NLCD land cover, forest canopy cover, and the impervious surface data with 30 m spatial resolution were used. Research has established specific riparian buffer widths linked to ecosystem benefits. For instance, buffers ranging from 25 to 176 m are effective in removing up to 90% of nitrates in highly conductive soils [49], while a width of 30 m supports fish populations [50], and buffers of 35 m or greater help sustain aquatic ecosystems [51]. Larger buffers, such as those extending 200 m over 2–3 km, have been shown to enhance fish populations, while widths of 50 m or more are essential for maintaining benthic communities [52]. Additionally, buffers of 75–175 m can support 90% of bird diversity, while widths of 15–30 m help preserve 90% of plant species [53]. Buffers exceeding 200 m are critical for preserving intact riparian communities with complete species assemblages [54]. In this study, the 30 m and 100 m buffers were used based on SCFC guidelines [44].

The findings indicate that counties in South Carolina are experiencing significant changes within riparian areas, driven largely by urban expansion. Forest-to-urban transitions, particularly near intermittent streams, were most pronounced in counties such as Spartanburg, Greenville, and York. These counties show clear trends of forest conversion to urban areas within both 30 and 100 m buffers. While forest-to-urban transitions near intermittent streams appear most pronounced in counties such as Spartanburg, Greenville, and York, additional context is necessary to confirm the broader applicability of this trend. These counties show significant forest conversion to urban areas within both 30 and 100 m buffers, highlighting potential encroachment into riparian zones. Such changes may have implications for water quality, biodiversity, and natural water filtration processes [55,56]. However, given the nature of intermittent streams, further investigation is warranted to understand the specific impacts and to distinguish these transitions from broader land-use trends that may not directly target riparian environments. This shift in land use underscores the growing demand for residential and commercial spaces in South Carolina, necessitating targeted conservation strategies to mitigate environmental impacts near these critical areas.

In contrast, certain counties, including Fairfield, Chester, and Edgefield, exhibit positive trends where non-urban areas converted back to forest, reflecting either active reforestation efforts or natural regeneration. The benefits of increased forest cover around streams are well-documented, including enhanced water quality, reduced soil erosion, and improved habitats for aquatic and terrestrial species [57,58]. These gains, however, are not consistent across all riparian zones, and the net balance of forest loss to urban expansion often outweighs such regrowth in areas experiencing high development pressure. This disparity emphasizes the need for strategic land management to promote forest recovery where possible, particularly in counties with high potential for natural regeneration [59,60]. The forest canopy cover loss in South Carolina not only influence by land-cover change but also is influenced by natural disturbance like hurricanes, forest fire, forest disease, and forest management practices [61]. A prominent factor has been the increasing frequency and intensity of storms, which result in significant tree damage, especially in coastal and lowland areas [61].

The analysis of impervious surface change further reveals concerning trends. Higher imperviousness in intermittent stream buffers, compared to perennial ones, is likely due to the less stringent protections often afforded to these temporary watercourses [62,63]. Intermittent streams, despite lacking continuous water flow, play essential roles in local hydrology, supporting groundwater recharge and acting as buffers against extreme weather events. The increased imperviousness observed in 30 m buffer zones suggests a high level of urban encroachment, which can alter natural drainage patterns, reduce groundwater infiltration, and exacerbate flood risks, especially during heavy rainfall. This pattern is critical for urban planners and environmental agencies to consider, as the vulnerability of intermittent streams to urban runoff could lead to heightened flood risks in downstream urban centers [53,54]. As imperviousness increases beyond 20–30%, more pronounced effects on water quality, stream health, and biodiversity are commonly noted [62,64]. Even

lower levels, such as 5%, can affect sensitive ecosystems, particularly in urbanizing regions where riparian buffers are essential for mitigating runoff and filtering pollutants.

The prioritization of counties is based on forest loss and gain, and highlights that some counties face greater challenges in balancing development and conservation. Counties such as Aiken, Chester, and Edgefield, with significant non-urban-to-forest transitions, demonstrate a successful example of land-cover stability in riparian areas. Conversely, the forest-to-urban conversions observed in counties like Greenville and Spartanburg raise concerns about the lasting impact of urban expansion on riparian health. Prioritizing these counties for targeted riparian conservation efforts could mitigate some of the ecological impacts while supporting sustainable growth. The authors in [65] highlighted that over 31 years, natural land cover and forests in riparian zones increased, while urban and disturbed land cover decreased, likely reflecting enhanced protection efforts such as zoning, conservation projects, education programs, and public awareness. Stable wetland areas suggest the effectiveness of wetland protection programs [65]. These trends indicate growing recognition of riparian ecosystem importance, though further research is needed to identify the drivers of these changes. However, in South Carolina we observed that forest to non-urban area is 15773.22 hectares, non-urban to forest is 13517.22 hectares, forest to urban is 695.52 hectares, and finally the urban to forest is 243.36 hectares from the just decadal study. We observed the development of other areas in riparian zones compared to forest, which aligns with the study conducted by [66]. Brazilian environmental laws impose stricter land-use restrictions on riparian forests than non-riparian areas to conserve biodiversity and ecosystem services [66]. However, a 22-year Landsat analysis in Paragominas, Pará, revealed higher deforestation rates in riparian zones and limited compliance with restoration mandates. Key challenges include low awareness of regulations, inadequate technical capacity for mapping, and insufficient financial and technical support for restoration efforts [66].

The approach to buffer zone analysis, following South Carolina's best management practices for riparian zones, underscores the critical role of defined buffer widths in capturing the full extent of forest changes [44]. The 30 m buffer zones effectively highlighted the immediate impacts of land-use changes on riparian health, while the 100 m buffers allowed for a broader assessment of trends within a wider ecological context. By integrating high-resolution data from sources like NAIP imagery, the study achieved a detailed validation process, ensuring the reliability of results and enhancing the relevance of findings for future land-use planning. These findings suggest that broad riparian buffers, often over 100 m wide and extending for several kilometers, are necessary to maintain multiple ecosystem services, especially in landscapes undergoing significant human-induced changes. Although moderate-resolution satellite data may not capture changes in individual ecosystem services, they provide valuable insights into broader trends and ecosystem service bundles. However, many existing models for ecosystem service evaluation lack parameters specific to riparian zones, limiting their utility in predicting service responses to land-cover changes. Developing more comprehensive, multi-scale riparian models is hindered by the scarcity of field data on ecosystem services [30]. Strengthening monitoring efforts to track ecosystem service indicators across diverse riparian landscapes will be vital for improving management practices. Future analyses of riparian habitat changes could benefit from incorporating measurements of riparian land-cover extent, as this factor has been closely associated with the health of aquatic ecosystems [52,67,68]. Additionally, emerging methodologies now allow for the assessment of riparian zone ecological services without relying on predetermined buffer widths or fixed dimensions, providing greater flexibility and precision [69].

5. Conclusions

This study provides a comprehensive analysis of forest cover changes in riparian zones along intermittent and perennial streams across South Carolina, highlighting the impact of urban expansion and land-use changes on these sensitive ecological corridors. The

findings reveal significant patterns in forest loss and gain within these areas, underscoring the importance of conservation measures to protect riparian zones critical for water quality, biodiversity, and flood mitigation.

Key observations include substantial forest-to-urban transitions in rapidly urbanizing counties such as Greenville, Spartanburg, and Lexington, while certain counties like Fairfield and Chester show gains in forest cover along perennial streams, indicating potential recovery or conservation efforts. The higher impervious surface percentages near intermittent streams compared to perennial further emphasize the vulnerability of these areas to urban development, as increased impervious surfaces can disrupt natural hydrological processes, increasing the risk of flooding and reducing groundwater recharge.

Based on these observations, counties with extensive forest loss around streams, especially in urbanized regions, should be prioritized for riparian conservation initiatives. By focusing efforts on areas exhibiting the greatest forest-to-urban transitions and impervious surface increases, South Carolina can better preserve the ecological functions of its riparian zones, promoting both environmental health and sustainable development in the region.

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References

1. Ballinger, A.; Lake, P.S. Energy and Nutrient Fluxes from Rivers and Streams into Terrestrial Food Webs. *Mar. Freshw. Res.* **2006**, *57*, 15–28. [\[CrossRef\]](#)
2. Hansen, B.D. *Minimum Width Requirements for Riparian Zones to Protect Flowing Waters and to Conserve Biodiversity: A Review and Recommendations with Application to the State of Victoria*; Monash University: Melbourne, Australia, 2010.
3. Fu, B.; Li, Y.; Wang, Y.; Zhang, B.; Yin, S.; Zhu, H.; Xing, Z. Evaluation of Ecosystem Service Value of Riparian Zone Using Land Use Data from 1986 to 2012. *Ecol. Indic.* **2016**, *69*, 873–881. [\[CrossRef\]](#)
4. de Mello, K.; Randhir, T.O.; Valente, R.A.; Vettorazzi, C.A. Riparian Restoration for Protecting Water Quality in Tropical Agricultural Watersheds. *Ecol. Eng.* **2017**, *108*, 514–524. [\[CrossRef\]](#)
5. Lacko, J.; Topercer, J.; Súľovský, M. How Disturbances and Management Practices Affect Bird Communities in a Carpathian River Ecosystem? *Acta Oecologica* **2018**, *88*, 29–40. [\[CrossRef\]](#)
6. Kardynal, K.J.; Hobson, K.A.; Van Wilgenburg, S.L.; Morissette, J.L. Moving Riparian Management Guidelines towards a Natural Disturbance Model: An Example Using Boreal Riparian and Shoreline Forest Bird Communities. *Ecol. Manag.* **2009**, *257*, 54–65. [\[CrossRef\]](#)
7. Naiman, R.J.; Decamps, H.; Pollock, M. The Role of Riparian Corridors in Maintaining Regional Biodiversity. *Ecol. Appl.* **1993**, *3*, 209–212. [\[CrossRef\]](#) [\[PubMed\]](#)
8. Palmer, G.C.; Bennett, A.F. Riparian Zones Provide for Distinct Bird Assemblages in Forest Mosaics of South-East Australia. *Biol. Conserv.* **2006**, *130*, 447–457. [\[CrossRef\]](#)
9. Glass, J.R.; Floyd, C.H. Effects of Proximity to Riparian Zones on Avian Species Richness and Abundance in Montane Aspen Woodlands. *J. Field Ornithol.* **2015**, *86*, 252–265. [\[CrossRef\]](#)
10. Debano, L.; Baker, M.B., Jr. Riparian Ecosystems in Southwestern United States. In *Ecology and Management of Forests, Woodlands, and Shrublands in the Dryland Regions of the United States and Mexico: Perspectives for the 21st Century*; Ffolliott, P.F., Ortega-Rubio, A., Eds.; University of Arizona: Tucson, AZ, USA, 1999; pp. 107–120.
11. Lee, M.-B.; Rotenberry, J.T. Effects of Land Use on Riparian Birds in a Semiarid Region. *J. Arid. Environ.* **2015**, *119*, 61–69. [\[CrossRef\]](#)
12. Pettit, N.E.; Naiman, R.J. Fire in the Riparian Zone: Characteristics and Ecological Consequences. *Ecosystems* **2007**, *10*, 673–687. [\[CrossRef\]](#)
13. Vidon, P. Riparian Zone Management and Environmental Quality: A Multi-Contaminant Challenge. *Hydrol. Process.* **2010**, *24*, 1532–1535. [\[CrossRef\]](#)
14. Malanson, G.P. *Riparian Landscapes*; Cambridge University Press: Cambridge, UK, 1993; p. 296.

15. Wang, J.; Zhang, Z.; Greimann, B.; Huang, V. Application and Evaluation of the HEC-RAS—Riparian Vegetation Simulation Module to the Sacramento River. *Ecol. Model.* **2018**, *368*, 158–168. [\[CrossRef\]](#)
16. Mitsch, W.J.; Bernal, B.; Nahlik, A.M.; Mander, Ü.; Zhang, L.; Anderson, C.J.; Jørgensen, S.E.; Brix, H. Wetlands, Carbon, and Climate Change. *Landsc. Ecol.* **2013**, *28*, 583–597. [\[CrossRef\]](#)
17. Ye, C.; Cheng, X.; Zhang, K.; Du, M.; Zhang, Q. Hydrologic Pulsing Affects Denitrification Rates and Denitrifier Communities in a Revegetated Riparian Ecotone. *Soil. Biol. Biochem.* **2017**, *115*, 137–147. [\[CrossRef\]](#)
18. Li, G.; Jackson, C.R.; Kraseski, K.A. Modeled Riparian Stream Shading: Agreement with Field Measurements and Sensitivity to Riparian Conditions. *J. Hydrol.* **2012**, *428*, 142–151. [\[CrossRef\]](#)
19. Dosskey, M.G.; Vidon, P.; Gurwick, N.P.; Allan, C.J.; Duval, T.P.; Lowrance, R. The Role of Riparian Vegetation in Protecting and Improving Chemical Water Quality in Streams. *J. Am. Water Resour. Assoc.* **2010**, *46*, 261–277. [\[CrossRef\]](#)
20. O'Toole, P.; Chambers, J.M.; Bell, R.W. Understanding the Characteristics of Riparian Zones in Low Relief, Sandy Catchments That Affect Their Nutrient Removal Potential. *Agric. Ecosyst. Environ.* **2018**, *258*, 182–196. [\[CrossRef\]](#)
21. Fitch, L.; Adams, B.W. Can Cows and Fish Co-Exist? *Can. J. Plant Sci.* **1998**, *78*, 191–198. [\[CrossRef\]](#)
22. Capon, S.J.; Chambers, L.E.; Mac Nally, R.; Naiman, R.J.; Davies, P.; Marshall, N.; Pittock, J.; Reid, M.; Capon, T.; Douglas, M.; et al. Riparian Ecosystems in the 21st Century: Hotspots for Climate Change Adaptation? *Ecosystems* **2013**, *16*, 359–381. [\[CrossRef\]](#)
23. Hale, R.; Reich, P.; Daniel, T.; Lake, P.S.; Cavagnaro, T.R. Assessing Changes in Structural Vegetation and Soil Properties Following Riparian Restoration. *Agric. Ecosyst. Environ.* **2018**, *252*, 22–29. [\[CrossRef\]](#)
24. Mander, Ü.; Hayakawa, Y.; Kuusemets, V. Purification Processes, Ecological Functions, Planning and Design of Riparian Buffer Zones in Agricultural Watersheds. *Ecol. Eng.* **2005**, *24*, 421–432. [\[CrossRef\]](#)
25. Croke, J.; Thompson, C.; Fryirs, K. Prioritising the Placement of Riparian Vegetation to Reduce Flood Risk and End-of-Catchment Sediment Yields: Important Considerations in Hydrologically-Variable Regions. *J. Environ. Manag.* **2017**, *190*, 9–19. [\[CrossRef\]](#) [\[PubMed\]](#)
26. Richardson, D.M.; Holmes, P.M.; Esler, K.J.; Galatowitsch, S.M.; Stromberg, J.C.; Kirkman, S.P.; Pyšek, P.; Hobbs, R.J. Riparian Vegetation: Degradation, Alien Plant Invasions, and Restoration Prospects. *Divers. Distrib.* **2007**, *13*, 126–139. [\[CrossRef\]](#)
27. Fernández, D.; Barquín, J.; Álvarez-Cabria, M.; Peñas, F.J. Land-Use Coverage as an Indicator of Riparian Quality. *Ecol. Indic.* **2014**, *41*, 165–174. [\[CrossRef\]](#)
28. Yang, S.; Chen, B. Environmental Impact of Manwan Hydropower Plant on River Ecosystem Service. *Energy Procedia* **2014**, *61*, 2721–2724. [\[CrossRef\]](#)
29. Morton, C.; Knowler, D.; Brugere, C.; Lymer, D.; Bartley, D. Valuation of Fish Production Services in River Basins: A Case Study of the Columbia River. *Ecosyst. Serv.* **2017**, *24*, 101–113. [\[CrossRef\]](#)
30. Sharma, S.; Beslity, J.O.; Rustad, L.; Shelby, L.J.; Manos, P.T.; Khanal, P.; Reinmann, A.B.; Khanal, C. Remote Sensing and GIS in Natural Resource Management: Comparing Tools and Emphasizing the Importance of In-Situ Data. *Remote Sens.* **2024**, *16*, 4161. [\[CrossRef\]](#)
31. Škarpich, V.; Hradecký, J.; Dušek, R. Complex Transformation of the Geomorphic Regime of Channels in the Forefield of the Moravskoslezské Beskydy Mts.: Case Study of the Morávka River (Czech Republic). *Catena* **2013**, *111*, 25–40. [\[CrossRef\]](#)
32. Ziliani, L.; Surian, N. Evolutionary Trajectory of Channel Morphology and Controlling Factors in a Large Gravel-Bed River. *Geomorphology* **2012**, *173*, 104–117. [\[CrossRef\]](#)
33. Wyźga, B.; Zawiejska, J.; Radecki-Pawlik, A. Impact of Channel Incision on the Hydraulics of Flood Flows: Examples from Polish Carpathian Rivers. *Geomorphology* **2016**, *272*, 10–20. [\[CrossRef\]](#)
34. Scorpio, V.; Zen, S.; Bertoldi, W.; Surian, N.; Mastrorunzio, M.; Dai Prá, E.; Zolezzi, G.; Comiti, F. Channelization of a Large Alpine River: What Is Left of Its Original Morphodynamics? *Earth Surf. Process. Landf.* **2018**, *43*, 1044–1062. [\[CrossRef\]](#)
35. Rădoane, M.; Obreja, F.; Cristea, I.; Mihailă, D. Changes in the Channel-Bed Level of the Eastern Carpathian Rivers: Climatic vs. Human Control over the Last 50years. *Geomorphology* **2013**, *193*, 91–111. [\[CrossRef\]](#)
36. Brierley, G.J.; Mum, C.P. European Impacts on Downstream Sediment Transfer and Bank Erosion in Cobargo Catchment, New South Wales, Australia. *Catena* **1997**, *31*, 119–136. [\[CrossRef\]](#)
37. James, L.A. Channel Incision on the Lower American River, California, from Streamflow Gage Records. *Water Resour. Res.* **1997**, *33*, 485–490. [\[CrossRef\]](#)
38. Hooke, J.M. Variations in Flood Magnitude–Effect Relations and the Implications for Flood Risk Assessment and River Management. *Geomorphology* **2015**, *251*, 91–107. [\[CrossRef\]](#)
39. Kijowska-Strugał, M.; Wiejaczka, I.; Gil, E.; Bochenek, W.; Kiszka, K. The Impact of Extreme Hydro-Meteorological Events on the Transformation of Mountain River Channels (Polish Flysch Carpathians). *Z. Fur Geomorphol.* **2017**, *61*, 75–89. [\[CrossRef\]](#)
40. Parsons, M.; Thoms, M.C. Hierarchical Patterns of Physical–Biological Associations in River Ecosystems. *Geomorphology* **2007**, *89*, 127–146. [\[CrossRef\]](#)
41. Francis, R.A.; Corenblit, D.; Edwards, P.J. Perspectives on Biogeomorphology, Ecosystem Engineering and Self-Organisation in Island-Braided Fluvial Ecosystems. *Aquat. Sci.* **2009**, *71*, 290–304. [\[CrossRef\]](#)
42. Hestir, E.L.; Brando, V.E.; Bresciani, M.; Giardino, C.; Matta, E.; Villa, P.; Dekker, A.G. Measuring Freshwater Aquatic Ecosystems: The Need for a Hyperspectral Global Mapping Satellite Mission. *Remote Sens. Environ.* **2015**, *167*, 181–195. [\[CrossRef\]](#)
43. Tomsett, C.; Leyland, J. Remote Sensing of River Corridors: A Review of Current Trends and Future Directions. *River Res. Appl.* **2019**, *35*, 779–803. [\[CrossRef\]](#)

44. SCDNR Guide to Best Management Practices for Riparian Lands. Available online: <https://www.dnr.sc.gov/Water/River/Pdf/Guide-Riparianlands2020-Aug.Pdf> (accessed on 20 March 2024).
45. Seto, K.C.; Güneralp, B.; Hutyrá, L.R. Global Forecasts of Urban Expansion to 2030 and Direct Impacts on Biodiversity and Carbon Pools. *Proc. Natl. Acad. Sci. USA* **2012**, *109*, 16083–16088. [[CrossRef](#)] [[PubMed](#)]
46. Naiman, R.J.; Décamps, H. The Ecology of Interfaces: Riparian Zones. *Annu. Rev. Ecol. Syst.* **1997**, *28*, 621–658. [[CrossRef](#)]
47. Iverson, L.R.; Szafoni, D.L.; Baum, S.E.; Cook, E.A. A Riparian Wildlife Habitat Evaluation Scheme Developed Using GIS. *Environ. Manag.* **2001**, *28*, 639–654. [[CrossRef](#)]
48. Bernhardt, E.S.; Palmer, M.A.; Allan, J.D.; Alexander, G.; Barnas, K.; Brooks, S.; Carr, J.; Clayton, S.; Dahm, C.; Follstad-Shah, J.; et al. Synthesizing U. S. River Restor. Efforts Sci. **2005**, *308*, 636–637.
49. Vidon, P.G.F.; Hill, A.R. Landscape Controls on Nitrate Removal in Stream Riparian Zones. *Water Resour. Res.* **2004**, *40*, W03201. [[CrossRef](#)]
50. Jones, K.L.; Poole, G.C.; Meyer, J.L.; Bumback, W.; Kramer, E.A. Quantifying Expected Ecological Response to Natural Resource Legislation: A Case Study of Riparian Buffers, Aquatic Habitat, and Trout Populations. *Ecol. Soc.* **2006**, *11*, 26. [[CrossRef](#)]
51. Barker, L.S.; Felton, G.K.; Russek-Cohen, E. Use of Maryland Biological Stream Survey Data to Determine Effects of Agricultural Riparian Buffers on Measures of Biological Stream Health. *Environ. Monit. Assess.* **2006**, *117*, 1–19. [[CrossRef](#)]
52. Scarsbrook, M.R.; Halliday, J. Transition from Pasture to Native Forest Land-Use along Stream Continua: Effects on Stream Ecosystems and Implications for Restoration. *N. Z. J. Mar. Freshw. Res.* **1999**, *33*, 293–310. [[CrossRef](#)]
53. Spackman, S.C.; Hughes, J.W. Assessment of Minimum Stream Corridor Width for Biological Conservation: Species Richness and Distribution along Mid-Order Streams in Vermont, USA. *Biol. Conserv.* **1995**, *71*, 325–332. [[CrossRef](#)]
54. Lees, A.C.; Peres, C.A. Conservation Value of Remnant Riparian Forest Corridors of Varying Quality for Amazonian Birds and Mammals. *Conserv. Biol.* **2008**, *22*, 439–449. [[CrossRef](#)] [[PubMed](#)]
55. Paul, M.J.; Meyer, J.L. Streams in the Urban Landscape. *Annu. Rev. Ecol. Syst.* **2001**, *32*, 333–365. [[CrossRef](#)]
56. Booth, D.B.; Jackson, C.R. Urbanization of Aquatic Systems: Degradation Thresholds, Stormwater Detection, and the Limits of Mitigation 1. *JAWRA J. Am. Water Resour. Assoc.* **1997**, *33*, 1077–1090. [[CrossRef](#)]
57. Palmer, M.A.; Bernhardt, E.S.; Allan, J.D.; Lake, P.S.; Alexander, G.; Brooks, S.; Carr, J.; Clayton, S.; Dahm, C.N.; Follstad Shah, J.; et al. Standards for Ecologically Successful River Restoration. *J. Appl. Ecol.* **2005**, *42*, 208–217. [[CrossRef](#)]
58. Rood, S. Riparia: Ecology, Conservation, and Management of Streamside Communities. *Bioscience* **2006**, *56*, 353–354. [[CrossRef](#)]
59. Seto, K.; Reenberg, A. *Rethinking Global Land Use in an Urban Era*; The MIT Press: Cambridge, MA, USA, 2014; pp. 1–394. [[CrossRef](#)]
60. Meyer, J.L.; Wallace, J.B.; Press, M.C.; Huntly, N.J.; Levin, S.A. *Lost Linkages and Lotic Ecology: Rediscovering Small Streams*; Blackwell Science: Hoboken, NJ, USA, 2001.
61. Brandeis, T.J.; Brandeis, C.; Hartsell, A.J. *South Carolina's Forests*; No. 57; Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: Asheville, NC, USA, 1979.
62. Walsh, C.J.; Roy, A.H.; Feminella, J.W.; Cottingham, P.; Groffman, P.M.; Morgan, R.P.I.I. The Urban Stream Syndrome: Current Knowledge and the Search for a Cure. *J. N. Am. Benthol. Soc.* **2005**, *24*, 706–723. [[CrossRef](#)]
63. Brabec, E.; Schulte, S.; Richards, P.L. Impervious Surfaces and Water Quality: A Review of Current Literature and Its Implications for Watershed Planning. *J. Plan. Lit.* **2002**, *16*, 499–514. [[CrossRef](#)]
64. Booth, D. Urbanization and the Natural Drainage System—Impacts, Solutions, and Prognoses. *Northwest Environ. J.* **1991**, *7*, 93–118.
65. Jones, K.B.; Slonecker, E.T.; Nash, M.S.; Neale, A.C.; Wade, T.G.; Hamann, S. Riparian Habitat Changes across the Continental United States (1972–2003) and Potential Implications for Sustaining Ecosystem Services. *Landsc. Ecol.* **2010**, *25*, 1261–1275. [[CrossRef](#)]
66. Nunes, S.S.; Barlow, J.; Gardner, T.A.; Siqueira, J.V.; Sales, M.R.; Souza, C.M. A 22 Year Assessment of Deforestation and Restoration in Riparian Forests in the Eastern Brazilian Amazon. *Environ. Conserv.* **2015**, *42*, 193–203. [[CrossRef](#)]
67. Storey, R.G.; Cowley, D.R. *Recovery of Three New Zealand Rural Streams as They Pass Through Native Forest Remnants*; Kluwer Academic Publishers: Dordrecht, The Netherlands, 1997; Volume 353.
68. Lee, K.E.; Goldstein, R.M.; Hanson, P.E. Relation between Fish Communities and Riparian Zone Conditions at Two Spatial Scales. *J. Am. Water Resour. Assoc.* **2001**, *37*, 1465–1473. [[CrossRef](#)]
69. Baker, M.E.; Weller, D.E.; Jordan, T.E. Improved Methods for Quantifying Potential Nutrient Interception by Riparian Buffers. *Landsc. Ecol.* **2006**, *21*, 1327–1345. [[CrossRef](#)]

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