Exploring Carbon Markets as a Conservation-Focused Land Management Strategy in Bull Run, Virginia: Exploring Community Perspectives and Carbon Sequestration Value

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1. Executive Summary

This paper introduces the use of nature-based solutions (NbS), specifically the carbon market, to protect forested land masses in the Bull Run Mountain Region, from infrastructure development. Deforestation rates and regional hotspots are calculated using various databases to determine which areas need protection the most. The carbon storage values of selected parcels in the region were calculated using LiDAR and ArcGIS Pro. A brief description of the carbon market is introduced, as well as an explanation of current and past carbon projects. To determine the preferences and values of landowners, we interviewed five different landowners. The interview results highlighted their conservation motives and proved their interest in the market, specifically family forest programs that involve multiple landowners. However, there were many concerns, including the current political framework in Virginia, the expensive and time-consuming enrollment process, and the difficulties in calculating the precise monetary value of their land. Although enrollment in the carbon market may not be feasible in the near future, we suggested that the landowners within the region continue to add conservation easements and work to conserve and restore wetlands.

2. Introduction

In the face of global threats like climate change and rapid land development, society is facing the challenge of protecting the natural resources we depend upon for public health, access to natural resources, and human well-being. Although policies and laws for climate change mitigation are consistently expanding, implied global greenhouse gas (GHG) emissions in 2030 indicate warming is still likely to exceed 1.5°C during the 21st century and make it harder to limit warming below 2°C. CO2 is one of the GHGs that have a longer residence time, and the effects of elevated CO2 on global climate and ecosystems will last for a millennium or more (McKinley et al., 2011). Moreover, rampant land development, including deforestation and urbanization, exacerbates habitat loss and biodiversity decline, further amplifying climate change impacts. Studies have shown these land use changes significantly affect ecosystems and biodiversity, highlighting the need for sustainable resource management (Marques et al, 2019) .

Nature-based solutions have been proposed as sustainable strategies to protect natural resources from global challenges, such as climate and land use. Nature-based solutions (NbS) use natural features and processes to increase resilience to climatological and environmental stresses and change, while providing environmental, economic, and social benefits (Nelson et al., 2020). It is believed to be one of the most effective and cost-saving strategies for achieving net zero emissions in CO2. However, three general challenges hinder the evidence-based integration of NbS into international, national, and local climate and development policy and practice: measuring uncertainty, financial model uncertainty, and inflexible governance (Seddon et al., 2020). This research will explore context-specific metrics with these challenges at the local level. We will work on the challenge of measuring and predicting the effectiveness of NbS which can influence its cost-effectiveness compared to alternatives.

An example of an NbS that can be used for land protection in the BRM region includes the use of carbon markets. The carbon market allows investors to trade for both carbon credits and carbon offsets, to mitigate the negative effects of climate change and create new investment opportunities. Carbon credits are within the regulated carbon market and are essentially a carbon allowance placed onto companies, as one carbon credit permits for a company to emit one ton of CO2 emissions. Carbon offsets are when a company removes a unit of carbon from the atmosphere as part of their normal business activity, and are part of the Voluntary (non-regulated) carbon market (Carbon Credits, 2023). For this project, the focus is on the voluntary market and carbon offsets, as the forested lands in the BRM region can be used to offset carbon emissions. The voluntary carbon market specifically is an effective nature-based solution to utilize, as it involves protecting forests, as well as implementing reforestation and other conservation practices to improve the carbon sequestration values of the area. Although the voluntary carbon market is difficult to measure, it was estimated to be worth around $400 million in 2020. Forecasts predict the voluntary market will continue to grow rapidly, with predictions of it being worth $10-25 billion by 2030, and $90-480 billion by 2050. The rapid growth of the carbon market is primarily motivated by companies attempting to reach their emissions targets. These targets have been laid out by the Kyoto Protocol of 1997 and the Paris Agreement of 2015 (Carbon Credits, 2023). These new regulations have put increased pressure on businesses to find a way to reduce their carbon footprint, and most of these solutions involve the use of carbon markets.

Although the introduction of carbon markets as NbS is relatively new, there are still a couple of successful examples of implementing carbon markets as a strategy for land management. One project we found interesting and applicable to the BRM region is a carbon

project in Vermont, one of the first states in the US to implement significant carbon sequestration projects that are tied to the carbon market. They are tapping on the potential of trees in three different ways: VT Carbon Projects, Forrest Carbon Co-op, and Family Forest Carbon. The Carbon projects will aim to compensate landowners in Vermont that have forested land areas to motivate carbon sequestration and storage. The largest current project is the 5,487-acre Burnt Mountain Natural Area project, which will aim to yield more than 236,772 carbon credits and generate $2 million in revenue over the next ten years. The Forest Carbon Co-ops Program aims to bundle land masses held by many different landowners, so they can enter the carbon market as one property. Since the average Vermont family woodlot is 100 acres, most of them are unable to enter the markets due to their small size. When these woodlots are combined, they can enter the market as long as they can get through the registration process (Forest Carbon in Vermont, 2021). However, this registration process can be quite extensive and costly, as we will soon get into.

One reason the carbon market is still relatively unknown in many areas is due to the difficult, time-consuming, and expensive barriers to entry. To learn about how to enter the carbon market, we had a conversation with Chandler Van Voorhis, the co-founder and managing partner of ACRE Investment Management. He also works for the GreenTrees reforestation project, which is designed to help corporations with emissions targets using the carbon market, and is powered by ACRE. To be approved for the carbon market, GreenTrees utilizes the American Carbon Registry (ACR), which oversees the registration and verification of carbon offset and credit projects. There are four layers of assurance for verification through the ACR, which are pre-verification, verifier selection, verification report, and the ACR review and credit insurance. All of these steps individually take months to years to be approved. Also, the quantification

process involves sophisticated measurements and calculations to determine the amount of carbon dioxide a particular land area can absorb and store. This process is not only technically challenging but also requires substantial investment in terms of time and resources (ACR, 2022). The accurate assessment of carbon sequestration is essential for generating reliable carbon credits, which are the basis for transactions in the carbon market. At the same time, the verification for carbon measuring costs millions, so you want to have big acres of land to even consider entering the process. The difficult barriers to entry prevent many entities from entering the carbon market for the time being. Also, due to the immense demand for carbon offsets and credits with emission goals in place, companies try to do everything in their power to speed up the process. After the verification process is concluded, offsets and credits can finally be sold on the carbon market. There isn't a specific location for the market, but there are different auctions and markets that can be accessed by companies with approved credits. One auction that GreenTrees utilizes is the Intercontinental Exchange (ICE) carbon credit auction, where buyers can access a range of developers for a one-site transaction. The ICE auction hosts the four largest and most liquid carbon allowance futures markets in the world, as it specializes in connecting a global network of high-quality developers with a wide range of potential buyers (ICE Carbon Credit Auctions, 2020). GreenTrees wanted to put the appropriate price as soon as they could, so they could motivate other landowners to put up credits.

To go along with the extensive registration process previously mentioned, successfully implementing carbon markets as an effective land management and climate mitigation strategy requires an understanding of the social and environmental context of the BRM area. First of all, the perceptions of the landowners of these forested land masses need to be understood as well as the ways they value and use their land. If the landowners do not have conservation as a high

priority for their land, the use of a NbS such as the carbon market would never be attainable. This goes along with the current political climate of the state, as certain laws and regulations may prevent any project like this from gaining any relevant traction. The forest's potential for carbon mitigation must also be understood, to provide an accurate value to the landowners and on the auctions, and to see whether the entire process would be worthwhile. The community needs to understand the implications of having their land on the carbon market and must be fully invested in the process if these projects were to occur.

The Bull Run Mountains in Northern Virginia function as both a living laboratory and an open-air museum, known for their natural beauty and their proximity to Washington, D.C. This region, however, faces pressure from the expanding urban areas surrounding the capital. The Bull Run Mountains Conservancy (BRMC) is a committed, independent, non-profit organization that champions the preservation of this region through education, research, and active stewardship. BRMC is seeking to work with landowners to explore whether carbon markets may be a potential strategy for promoting conservation-focused land management that mitigates climate change, prevents land development, and provides benefits to local landowners.

The objective of this project is to aid the Bull Run Mountains Conservancy in determining the viability of integrating the carbon market as a successful land management strategy in the region while giving less emphasis on political factors. Our approach involves two key perspectives: quantifying the carbon storage within the study area and understanding the preferences of local landowners. In pursuit of these objectives, we aim to:

- Summarize landowner perspectives on the intrinsic, monetary, and ecological value of these lands.
    a. Summarize the landowner's existing knowledge of the carbon market

- Identify deforestation hotspots by creating land cover change maps using ArcGIS pro.
- Measure the carbon sequestration value of the forest within the study area by parcels, and convert it into a relative monetary value

3. Methods

3.1 Study Area

Fig1. Location of study area

The Bull Run Mountains, Virginia's easternmost range, stretch northward approximately 15 miles from New Baltimore in Fauquier County to Loudoun County (Fig 1.). The area encompasses about 66,700 acres, including diverse ecosystems such as forests, wetlands, hay

fields, and pastures. Situated roughly 35 miles west of Washington, D.C., it buffers the metropolitan expansion from the capital.

To safeguard this landscape from development, two primary land management strategies are in place: conservation easements and state-designated natural area preserves. Conservation easements are voluntary legal pacts permitting landowners to restrict property use to uphold its ecological value while keeping ownership rights, with benefits like tax incentives and the ability to preserve family heritage. Natural area preserves aim to keep the land in its pristine state, fostering conservation efforts, education, and limited public use. Within these preserves, ten distinct plant communities and numerous uncommon or endangered species thrive. Yet, parts of the Bull Run Mountains region that are not under these protective measures remain vulnerable to urban encroachment from Washington, D.C.

Climatically, the region experiences a humid subtropical climate with four distinct seasons. The "Ecological Communities of the Bull Run Mountains, Virginia" report suggests that the area's dry, exposed ridges have long been prone to natural fires ignited by lightning, as evidenced by historical burn marks and charcoal remnants in the soil, highlighting the role of fire in shaping the region's ecological past.

	Conservation Land	***Conservation Easement***
Definition	Land designated for preserving natural resources and cultural sites.	A legal agreement that restricts development on a landowner's property to preserve its conservation values.
Ownership	Owned by public entities or private conservation organizations.	Remains under the private ownership of the landowner.
Primary Function	Protects natural environments from development or degradation.	Limits specific types of development to protect ecological, scenic, or historical values of the land.

Use	Often used for public enjoyment and education (parks, trails, reserves).	The landowner retains use of the land but adheres to agreed-upon restrictions.
Benefits	Preserve wildlife habitats, forests, watersheds, and scenic areas.	Offers tax incentives for landowners; ensures long-term conservation of land.

Table 1 Comparison between Conservation Land and Conservation Easement

3.2 Landowner interviews

To learn more about the landowner's preferences for land use, existing knowledge of the carbon market, and willingness to explore options within it, we conducted 5 interviews with different landowners in the region. The base interview questions were essentially the same, which included learning information about the land masses they own, current/future uses, awareness of the carbon market and current projects, and willingness to consider entering. Based on their responses, we sometimes asked additional questions relevant to the answers provided. We also planned on interviewing carbon market experts, to learn more about the market in general, their past projects, their successes and failures, and any other information they'd be willing to share. Additional information from experts would be immensely helpful, especially so we can relay information over to the landowners. The more knowledgeable we are of how the market works, the higher the likelihood of success in regards to the BRM region becoming involved.

3.3 Deforestation Hotspots and Carbon Storage

This study utilized publicly accessible datasets from the United States Geological Survey (USGS), the USDA Forest Service Forest Inventory, and Analysis (FIA) programs(Appendix 1). These databases, offering detailed 30m resolution data, are instrumental in assessing deforestation rates and carbon storage capacities. Recognizing the potential for even greater

accuracy through techniques like LiDAR data integration, the study nonetheless opted for a more streamlined method. This decision was driven by the need to navigate time constraints and the intricate challenges of image processing. Within the robust framework of ArcGIS Pro, we embarked on an exhaustive analysis of deforestation trends and carbon storage estimations, utilizing these valuable datasets. However, it's important to note that while this method offers a solid foundation, engaging in the carbon market demands more advanced technologies and deeper, more precise analysis.

3.4 Developed and Potential Development Area

This study integrates local land management strategies and zoning plans to assess areas of development and potential expansion. A particular focus is placed on Fauquier County's Conservation District, a zone classified under Agriculture that encompasses environmentally sensitive mountains rich in timber resources. These critical areas are protected from developmental impacts under the zoning plan. Thus, conservation lands, conservation easements, and Conservation districts were excluded from the developmental analysis. What remained were the areas most vulnerable to deforestation, highlighting the urgent need for targeted conservation efforts.

4. Results

4.1 Themes from landowner interviews

The 5 different landowners all had relatively similar values for their land, as they were all primarily focused on the conservation of the land.

Value of the Land

Landowners primarily indicated that the primary value of their land was to maintain the natural beauty, with a few mentioning economic, recreational, and educational values. Many of the landowners didn't even have any uses for their land other than conserving its natural beauty and peace, some for education and trail use. These individuals seemed to enjoy the close-knit community with similar-minded neighbors who embrace conservation practices. Some timber management practices, such as selective cutting, have been done with some of the landowners, but their future plans still revolve around allowing the forest to grow back. Every landowner we spoke to had at least part of their land within conservation easements, with the hopes of having more under easements within the near future. Although they claim to receive tax benefits from these easements, they are more motivated by the land protection from surrounding infrastructure projects.

Threats to Land

A couple of the landowners claimed their properties have been threatened by the Disney expansion plan, created in the early 1990s. This proposed park was planned to be a $650 million development, taking up 3000 acres of land including parts of the BRM region. This plan would have not only taken land, but brought additional crowding, road congestion, and smog to the area (Perez-Pena, 1994). Luckily, conservation easements and other restrictions in place were part of the reason the project was prevented. Other infrastructure plans that have threatened their lands in the past include clear-cutting of land, data center expansion in Prince William County, unsolicited real estate inquiries, and the construction of radar and microwave towers nearby. Prince William County officials are planning to put about $123.2 million toward these types of capital projects in the upcoming fiscal year.

Knowledge and Perception of Carbon Markets

The landowners had varying knowledge of the carbon market, but all had heard of it. After we gave a brief description of the market and how it can be applied to the BRM region, they were understanding of its potential to be implemented for land protection. Many of them have been looking for ways to protect their property in perpetuity, which is why the carbon market sparked their interest. However, many of them had their fair share of concerns about the market. They were all adamant about not giving up ownership of their land, but some didn't seem to mind restrictions on uses, especially since many of them didn't have many uses to begin with. They were also concerned with companies using the carbon market exclusively to reduce emissions while continuing to use the same production methods that emit tons of carbon dioxide. One other major concern most had in common was the current political framework in Virginia, with the governor, secretary of state, and attorney general under Republican control. Many of them had conservation projects that haven't been able to gain any traction due to Virginia Politics.

Since many of the landowners had varying property sizes, some much too small to enter the market alone, we wanted to make sure we brought up the idea of family-forest carbon projects, so they could join the market together. All landowners seemed generally interested in this idea, especially considering the tight-knit community present. Other conservation practices landowners seemed interested in include wetland restoration and more involvement in solar farms. Although we primarily focused on land protection within the BRM region, a couple of them suggested we look into homeowners in the Virginia Oaks golf course, as well as farmers, as they might be more interested in the financial compensation received from having their land on the market.

4.2 Deforestation hotspots

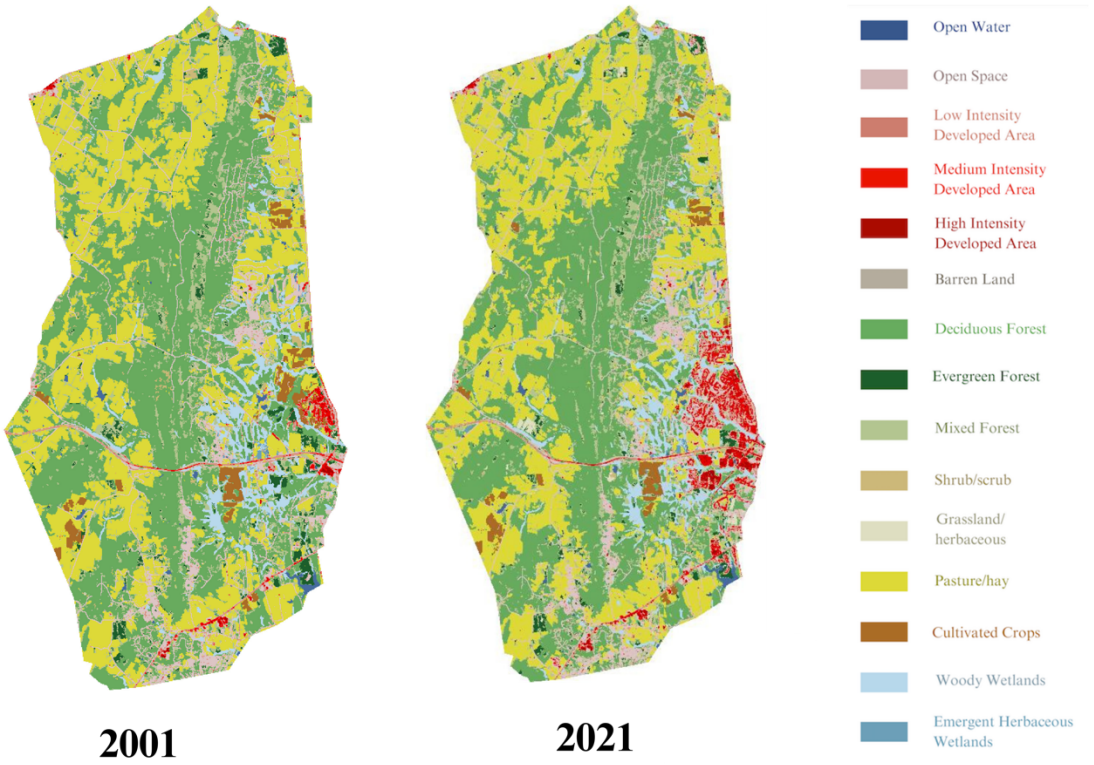

Fig 2. Comparison between and land cover for 2001 and 2021. The development area in red drastically increased on the eastern side of the BRMR

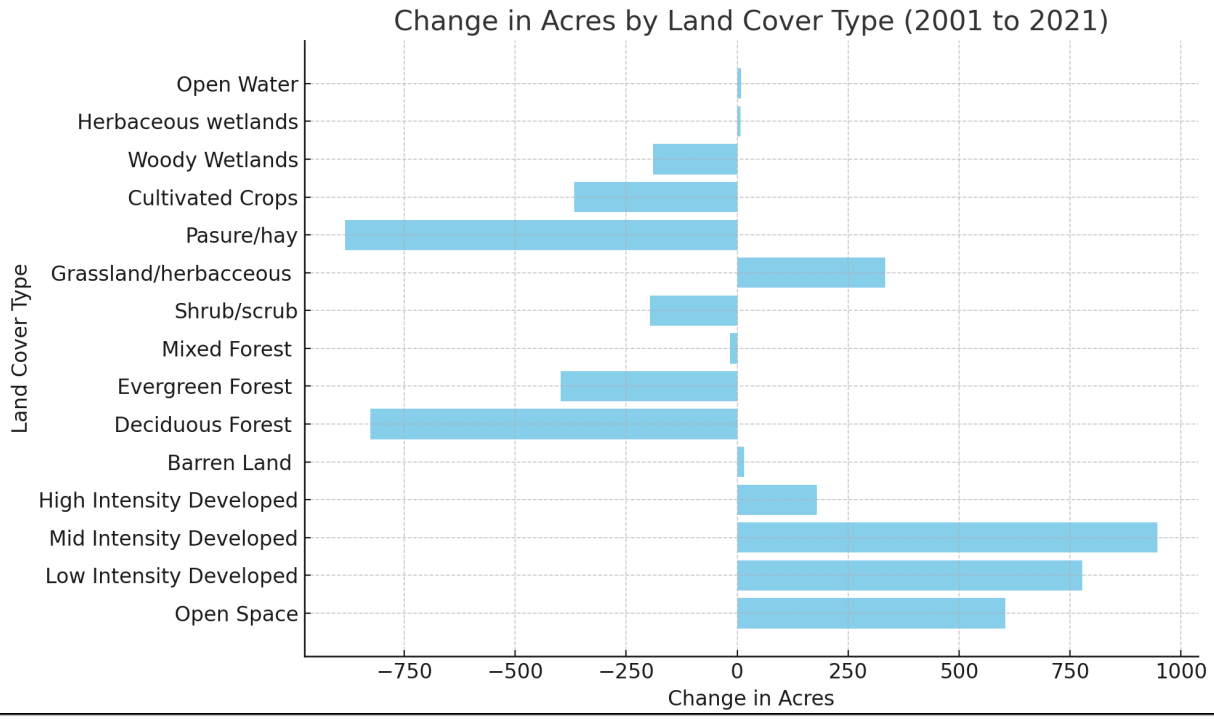

Fig 3. The net change in acres across all land covers in 20 years.

Over the last 20 years, the most striking transformations observed are the expansion of developed areas and the corresponding shrinkage of forested and agricultural lands (Fig 3). The scale of change is dramatic, with the developed area (encompassing open spaces, and low to high-density zones) more than doubling, a 100% increase relative to the base year of 2001. This trend of development and deforestation saw a particularly sharp escalation from 2001 to 2006, coinciding with the expansion of Dominion on the eastern side of the study area. Notably, there was also a surge in development rates from 2016 to 2021 (Fig. 4). Despite the overall decrease in forest cover, it's important to highlight that certain forested areas under conservation easements have witnessed a slight growth. In terms of net loss, the BRMR region experienced an average decline of 3.74%, starkly surpassing the local county rates and state level (-2%).

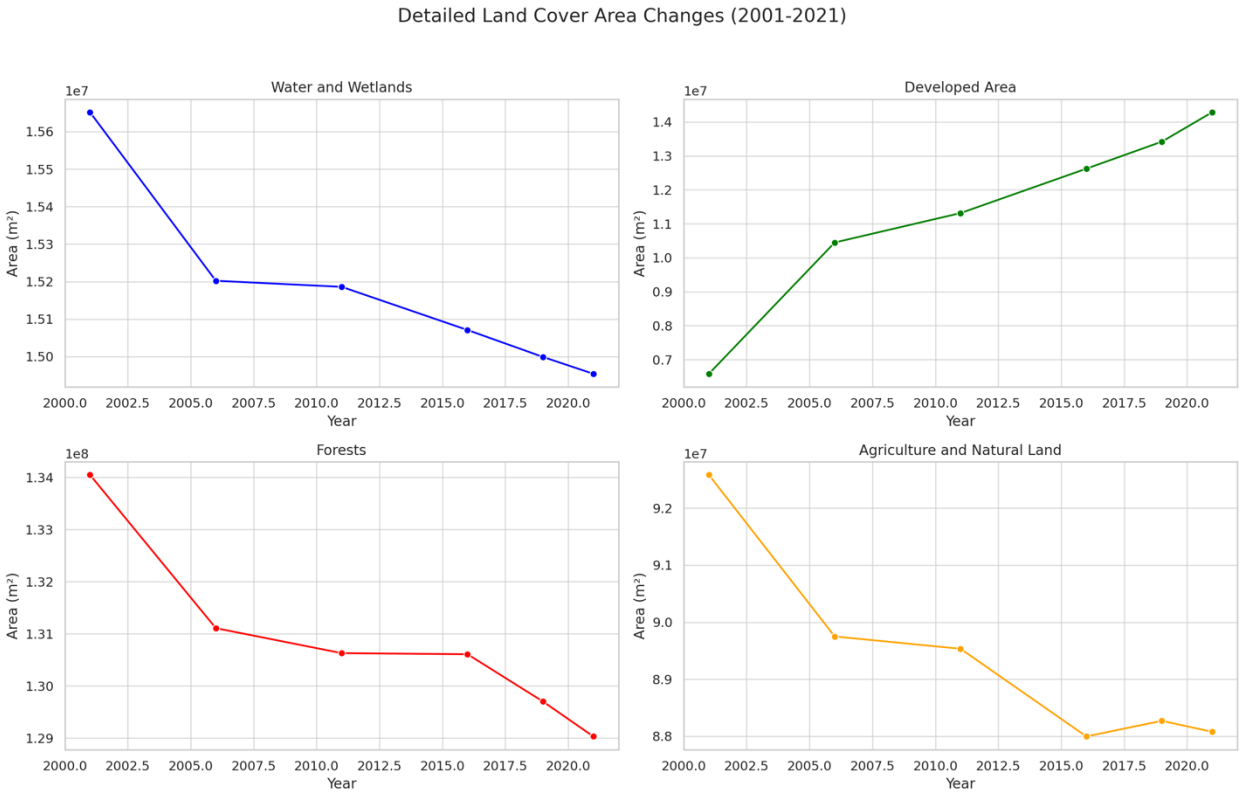

Fig 4. 20 years change are displayed across four categories: Water and Wetlands, Developed Aera, Forests, and Agriculture and Natural Land. Only the developed areas experienced a net increase. Notably, the y-axises are not in the same scale.

4.3 Carbon storage

	Area(he)	*Carbon(MT)*	*Forest Density*	*Area Proportion*	*Carbon Proportion*
total easement	10005.2	393211.1	48%	37%	39.82%
total conservation lands	1124.7	71483.5	95%	4%	7.24%
Others (developed and potential development area)	15948.1	522693.2	44%	59%	52.94%
Total Study Area	27078.0	987387.8	48%	1.00	1

Table 2 This table summarizes the area, carbon storage, forest density, and respective proportions of total easement, conservation lands, and other areas within a study zone, indicating the significant role of total easement and developed areas in carbon sequestration and land distribution.

In our comprehensive analysis of different land categories within the Total Study Area of 27,078 hectares, we observed varying patterns of carbon storage and forest density. The Total Easement, covering 10,005.2 hectares, constitutes 37% of the study area and holds 393,211.1 metric tons (MT) of carbon, representing 39.82% of the total carbon storage, with a forest density of 48%. In contrast, Total Conservation Lands, though only encompassing 1,124.7 hectares (4% of the area), is significant for its high forest density of 95%. It stores 71,483.5 MT of carbon, accounting for 7.24% of the total carbon, highlighting its disproportionately high carbon density. The 'Others' category, which includes developed and potential development areas, spans 15,948.1 hectares, making up 59% of the study area. It contains 522,693.2 MT of carbon (52.94% of the total), with a forest density of 44%. These findings illustrate the critical role of each land category in carbon sequestration, with particular emphasis on the high carbon storage efficiency of conservation lands despite their smaller area.

5. Discussion

Our study highlights a worrying trend in the Bull Run Mountains region (BRMR), where deforestation rates surpass those in neighboring counties and the Virginia state average. This accelerated loss of forest cover in BRMR, as illustrated in Figure 4, suggests a particular vulnerability to urban encroachment and development pressures. It appears that local factors, such as zoning policies and economic pressures, could be intensifying this deforestation.

Furthermore, the decline in forests, which play a vital role in supporting biodiversity by providing habitat for various species, could lead to a loss in biodiversity. This, in turn, affects critical ecosystem services essential for human survival, including pollination, water purification, and soil preservation. On a human dimension, the reduction in forest cover could significantly impact local residents. Forests contribute immensely to both mental and physical health by offering recreational spaces and enhancing air quality. Their decline could lead to a reduced quality of life and heightened health risks. In summary, our findings underscore the urgent need for more robust conservation policies and sustainable land use practices in the BRMR region. However, the resilience shown in areas under conservation easements is a positive sign. It demonstrates the effectiveness of targeted conservation efforts in preserving forest cover. This not only helps in maintaining the ecological balance but also serves as a model for sustainable land management. Such efforts can be instrumental in maintaining the region's natural beauty and ecological health, which are essential for the well-being of local communities and the environment. Overall, these findings emphasize the need for more robust conservation policies and sustainable land use practices to balance urban development and conservation practices in the BRMR region.

Based on the interviews, it seems the landowners in the BRM region all have relatively similar preferences and values for their land use. They seem to be a very tight-knit community, and all have conservation as their top priority. This is why it did not surprise me that the landowners expressed significant interest in a family forest carbon program, which we mentioned as a way to get landowners involved who have relatively small property sizes compared to typical sizes sold on the carbon market. Although we did previous research on this type of program before the interviews, we wanted to look more into other aspects of the program and find other successful examples of its implementation. The program itself was set up by the Nature Conservancy and the American Forest Foundation and is unique in two ways. First, it allows small forest owners to mitigate climate change while earning an income to cover the cost of taking care of their land. It also is the first program to employ groundbreaking carbon accounting methodology to provide high-quality carbon credits while keeping upfront costs low for forest owners. The program works by paying family forest owners annually to carry out climate-smart forestry that increases the amount of carbon sequestered and stored by their forest. The program began enrolling landowners in 2021 and is already responsible for sequestering almost 700,000 tons of CO2, equivalent to 151,496 carbon emission offsets as of August 2022. If the program enrolls 20% of US family-owned forest acres, it can sequester about 50 million tons of CO2 every year. An example of a landowner benefiting significantly from this program is Karren DeSeve, who is committed to the 20-year contract with FFCP. She and her family have faced pressure to develop the land, being close to major cities in Pennsylvania, and bought the land in the first place to protect it. By joining the program, they are looking to not only preserve the trees but add new trees to increase their carbon offsets and financial gains. If they choose to implement target forest management practices, they can nearly double the carbon storage in their

forest (The Nature Conservancy, 2022). We found Karren's story and circumstances similar to the landowners we interviewed, which we found exciting.

A primary concern the landowners all had was related to the current political framework in Virginia. They stated that they have had multiple conservation projects fall through due to this framework, such as solar panel installation. This sparked us to do more research and found that at the time, Republicans had Governor control under Gov. Glenn Youngkin, as well as house control, while Democrats had control of the Senate. Throughout history, democrats typically have more favorable policies when it comes to conservation, and Virginia has not been an exception to this. On June 7th, 2023, Virginia voted to withdraw from the Regional Greenhouse Gas Initiative (RGGI), led by Youngkin. Virginia joined the RGGI in 2020 to trade carbon credits on the carbon market to reduce emissions by creating a marketplace where electricity generators can trade allowances for carbon emissions. Proceeds from the auctions are used to increase energy efficiency in low-income homes and mitigate the effects of rising sea levels. Since 2021, there has been about $589 million generated from this initiative. However, Youngkin claimed it increased costs to consumers without providing benefits. Dominion Energy, the state's largest utility, said that participating in RGGI adds about $2.39 to the average monthly residential electricity bill (Schneider, 2023). Virginia's removal from this initiative has not been well received by all, as four environmental and climate groups filed a petition in August challenging the authority of the withdrawal, stating it's "impermissible under the Virginia Administrative Process Act" (DiGangi, 2023). Also, in the recent November State election, Virginia Democrats flipped the state House to Democratic control, while maintaining control of the Senate. This legislation provides Democrats with an easier chance of pushing against the policy priorities of Youngkin, such as the RGGI removal.

Another concern the landowners had was not having a precise monetary value for the carbon sequestration values for the parcels of land. This is a valid concern, as it would not make sense to put land on the market without knowing what value you will be compensated for. Unfortunately, we were unable to calculate a monetary value based on the values we calculated. As mentioned previously, we attempted to gather monetary values using the ERT calculator found on the ACR website. In the interview with Chandler from GreenTrees, he stated that typical IFM projects have monetary values of around $10-14 per ERT. After plugging in the carbon sequestration values from the parcels into many different ERT calculators on the website, we were unable to receive a value close to that range. We believe the initial carbon sequestration values we calculated are accurate, but for an unknown reason, the values were not generating an accurate monetary value based on the tool we used. If we had more time, we could have attempted other tools to calculate a more accurate value. However, based on the estimated range Chandler shared, as well as the carbon sequestration values of the parcels we calculated, an extremely rough estimate of the monetary value for the parcels we researched could be anywhere from $5 to 7 million.

We have a couple of recommendations for the BRM conservancy and the landowners within the region. We believe that while entering the carbon market may not be feasible in the short term, it can be within the next 20 years or so. Due to the current political framework in Virginia, the long and expensive enrollment process, and the inaccuracies in calculating a current monetary value, enrolling in the market in the short term is not realistic. However, we do think the carbon market can be a useful NbS to protect the forests in the BRM region eventually, due to the expressed interest from the landowners, current successful similar projects, and the high potential the forests have for sequestering carbon. In the meantime, landowners should continue

to practice conservation activities to maintain the sequestration values, while also possibly adding more trees and implementing forest management practices that could increase these values.

We also believe that landowners should continue to try adding more conservation easements to their unprotected lands. They have proven to be an effective method of protection, and although they can be expensive and time-consuming to implement, the tax benefits can reverse some of the costs. To go along with conservation easements, we suggest additional protection and restoration of the region's wetlands. This was brought up by a couple of landowners as well, which prompted us to do more research into their effectiveness of sequestering carbon. Wetlands are more efficient than forests and sequester carbon through plant photosynthesis and by acting as sediment traps for runoff. The US Global Change Research Program estimates terrestrial wetlands in the US store a total of 13.5 billion metric tons of CO2, much of which is within souls deeper than 30 cm. The value of storage depends on wetland type and size, vegetation, pH, groundwater and nutrient levels, etc. The best practices for protecting and restoring wetlands include reducing wetland drainage, controlling fires, restoring diverse vegetation to prevent invasive species, and controlling peat and other harvesting that removes carbon (MN Board of Water, Soil, Resources). According to the management plan for the BRM natural area preserve created in April 2004, wetland restoration is already labeled as a high-priority unit for different management actions they have. These plans specifically prevent the beaver, road, and trail use impacts on seepage wetlands (BRM management plan, 2004).

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Appendix 1 Data layers

Data	Description	Format & Unit	Last Update	Data Source
Bull Run Mountains Region (BRMR)	Polygon of the BRMR was created in the ArcGIS pro under the instruction from the BRMC.	Shape file format of the polygon.	Mar 2023	BRMC
Conservation Land	Lands in public and private protective management (excludes conservation easements)	Shape file format of the polygons.	3/27/2023	Virginia Department of Conservation and Recreation (DCR) (https://www.dcr.virginia.gov/natural-heritage/cldownload)
Easements	Conservation Easements in Virginia	Shape file format of the polygons.	3/27/2023	Virginia Department of Conservation and Recreation (DCR) (https://www.dcr.virginia.gov/natural-heritage/cldownload)
NLCD Land Cover (CONUS)	Land cover database for 2001, 2006, 2011, 2016, 2019, and 2021 at a 30m resolution with a 16-class legend based on a modified Anderson Level II classification system.	TIFF format for raster data layer.	7/20/2023	United States Geological Survey (USGS) (https://www.usgs.gov/centers/eros/science/national-land-cover-database)
Forest Inventory and Analysis Above Ground Forest Carbon	Above ground forest Carbon	TIFF format for the raster data layer, MTC/hector	8/29/2022	USDA Forest Service Forest Inventory and Analysis (FIA) program (https://data-usfs.hub.arcgis.com/datasets/usfs::forest-inventory-and-analysis-above-ground-forest-carbon-image-service/about)