ABSTRACT

Title of Dissertation:	CONTEXT AND FUTURE POTENTIAL FOR STRATEGIC AFFORESTATION AND REFORESTATION TO MEET STATE CLIMATE MITIGATION GOALS
	Rachel Loraine Lamb, Doctor of Philosophy, 2021
Dissertation directed by:	Professor George Hurtt, Department of Geographical Sciences

The development of greenhouse gas reduction plans, climate initiatives, and other international efforts, such as the Bonn Challenge, has driven demand for improved carbon accounting practices in the land-use sector. Recent projects advanced by the NASA Carbon Monitoring System (CMS) and the NASA Global Ecosystem Dynamics Investigation (GEDI) Mission provide critical information on present and future forest carbon stocks through high-resolution remote sensing and ecosystem modeling technologies. A key remaining geospatial and computational challenge is to identify and map strategic land areas for reforestation, which move decision-makers from considering wall-to-wall carbon sequestration potentials to priority implementation. This research seeks to address this challenge at the U.S. state scale by situating and demonstrating the unique capability of high-resolution NASA CMS forest carbon products to inform strategic reforestation in support of multiple policy goals. This work began with a review of the broader science and policy context for integrating forest carbon estimates into state climate mitigation planning across eleven states in the Regional Greenhouse Gas Initiative (RGGI) domain (USA). Next, two specific and linked applications of CMS products were advanced in Maryland (USA) in support of state reforestation goals. First, a forest carbon rental model was developed and applied to determine whether and where potential revenues from reforestation would outcompete existing cropland profit at the hectare scale. Second, two reforestation scenarios that jointly maximized remaining carbon sequestration potential and unprotected biodiversity conservation areas were mapped and evaluated under several socio-economic factors. These results show that while most states in the region do not yet including forest carbon estimates within their climate mitigation planning, high-resolution CMS forest carbon products can be combined with socio-economic data to advance strategic reforestation in support of climate mitigation, as well as landowner livelihoods and expanded biodiversity protection. This research provides a framework for other states interested in strategic climate mitigation planning with high-resolution forest carbon products. Furthermore, the results directly advance carbon monitoring science applications to ecosystem management, environmental policy, and land-use planning, and address relevant issues in public and private sector decision-making, such as uncertainty, valuation, implications, costs, and benefits.

CONTEXT AND FUTURE POTENTIAL FOR STRATEGIC AFFORESTATION AND REFORESTATION TO MEET STATE CLIMATE MITIGATION GOALS

by

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Dissertation submitted to the Faculty of the Graduate School of the
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Dedication

To my Grandpa Eddie (1926-2014), who might not have understood everything written in these pages, but would have been proud knowing that this effort was out of love for the Lord.

Acknowledgements

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Jim, Hope and Tim, Annette, Sheri, Dana, Gia, Lauren, Carl, Matt, Stephanie, Fred and Linda – thank you!

Finally, I’m thankful for my parents, Dave and Brenda, who have walked with me through all the highs and lows of this process. You have always reminded me Whose I am, and redirected me back to the most important things when I needed it with love and patience.

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List of Abbreviations

AGB	Aboveground biomass
BioNet	Maryland Biodiversity Conservation Network
CDEEP	Connecticut Department of Energy and Environmental Protection
CDL	Cropland data layer
CEP	Comprehensive Energy Plan (Vermont)
CLCPA	New York Climate Leadership and Community Protection Act
CMS	Carbon Monitoring System
COLE	Carbon on-line estimator
CREP	Conservation Reserve Enhancement Program
CSNE	Carbon Solutions New England
CSP	Carbon sequestration potential
CSPG	Carbon sequestration potential gap
CSPTG	Carbon sequestration potential time gap
DDA	Delaware Department of Agriculture
DNREC	Delaware Department of Natural Resources and Environmental Control
DOE	United States Department of Energy
ED	Ecosystem Demography model
EWG	Environmental Working Group
FAO	Food and Agriculture Organization of the United Nations
FIA	Forest Inventory and Analysis
FOIA	Freedom of Information Act
GAP	Gap Analysis Project
GCCC	Governor's Council on Climate Change (Connecticut)
GEDI	Global Ecosystem Dynamics Investigation
GGRA	Maryland Greenhouse Gas Reduction Act
GHG	Greenhouse Gas
GIS	Geographical information systems
GWRA	Global Warming Response Act (New Jersey)
GWSA	Global Warming Solutions Act (Massachusetts)
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for Conservation of Nature
LiDAR	Light detection and ranging
LULCP	Land use and land cover projections
LULUCF	Land use, land use change, and forestry
MALPF	Maryland Agricultural Land Preservation Foundation
MICAWG	Maine Interagency Climate Adaptation Work Group
MCCC	Maryland Commission on Climate Change
MCECP	Massachusetts Clean Energy and Climate Plan
MDCR	Massachusetts Department of Conservation and Recreation
MDE	Maryland Department of the Environment
MDEP	Maine Department of Environmental Protection

MDNR	Maryland Department of Natural Resources
MDP	Maryland Department of Planning
MEEA	Massachusetts Executive Office of Energy and Environmental Affairs
MRV	Monitoring, reporting, and verification
MSWG	Multi-State Working Group
NASA	National Aeronautics and Space Administration
NASS	National Agricultural Statistics Service
NCASI	National Council for Air and Stream Improvement
NCCPI	National Commodity Crop Productivity Index
NDC	Nationally determined contributions
NHCPTF	New Hampshire Climate Policy Task Force
NHDES	New Hampshire Department of Environmental Services
NJDEP	New Jersey Department of Environmental Protection
NLCD	National Land Cover Database
NWL	Natural and working lands
NYSCAC	New York State Climate Action Council
NYSEPB	New York State Energy Planning Board
NYSERDA	New York State Energy Research and Development Authority
PA	Protected areas
PACT	Protecting against climate threats
PAD-US	Protected Areas Database of the United States
PCCA	Pennsylvania Climate Change Act
PDCNR	Pennsylvania Department of Conservation and Natural Resources
PDEP	Pennsylvania Department of Environmental Protection
REDD+	Reducing emissions from deforestation and forest degradation in developing countries
RGGI	Regional Greenhouse Gas Initiative
RIDEM	Rhode Island Department of Environmental Management
RIEC4	Rhode Island Executive Climate Change Coordinating Council
SIT	State Inventory Tool
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USCA	United States Climate Alliance
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USFS	United States Forest Service
USGS	United States Geological Survey
VDPS	Vermont Department of Public Service
VTDEC	Vermont Department of Environmental Conservation
WHS	Maryland Wildlife and Heritage Service
WRI	World Resources Institute

List of Publications

This work has resulted in several peer-reviewed publications and professional conference posters and presentations. Citations for these materials have been provided below by chapter order.

Chapter 2

Lamb, R., Hurtt, G., Boudreau, T.J., Campbell, E., Sepúlveda Carlo, E., Chu, H., de Mooy, J., Dubayah, R., Gonsalves, D., Guy, M., Hultman, N., Lehman, S., Leon, B., Lister, A., Lynch, C., Martin, C., Ma, L., Robbins, N., Rudee, A., Silva, C.E., Skoglund, C., & Tang, H. (2021). Context and future directions for integrating forest carbon into sub-national climate mitigation planning in the RGGI region of the U.S. *Environmental Research Letters*. In Press. https://doi.org/10.1088/1748-9326/abe6c2

Lamb, R., Hurtt, G., Campbell, E., Sepúlveda Carlo, E., Guy, M., Hultman, N., Lister, A., Rudee, A., & Silva, C.E. (2020, December 1-17). *Context and future directions for integrating forest carbon into sub-national climate mitigation planning in the RGGI region of the U.S.* [Poster session]. Annual Meeting of the American Geophysical Union (AGU), Virtual Platform. http://doi.org/10.1002/essoar.10505328.1

Chapter 3

Lamb, R., Ma, L., Sahajpal, R., Edmonds, J., Hultman, N., Dubayah, R., Kennedy, J., & Hurtt, G. (2021). Geospatial assessment of the economic opportunity for reforestation in Maryland (USA). *Environmental Research Letters*. In Review.

Lamb, R., Hurtt, G., Sepulveda, E., Campbell, E., & Hultman, N. (2019, December 9-13). *Socio-economic opportunities for afforestation across the RGGI domain using high-resolution NASA CMS products* [Conference presentation]. 2019 Annual Meeting of the American Geophysical Union (AGU), San Francisco, CA, United States.

Lamb, R., Hurtt, G.C., Sahajpal, R., Edmonds, J., Hultman, N., Dubayah, R., & Ma, L. (2019, September 23-25). *Geospatial assessment of the economic opportunity for forest restoration in MD (USA)* [Poster session]. NASA Terrestrial Ecology Science Team Meeting, College Park, MD, United States.

Lamb, R., Hurtt, G.C., Dubayah, R., Hultman, N., Sahajpal, R., & Edmonds, J. (2019, February 14-17). *Pricing forest carbon: economic opportunities for afforestation at landowner scales* [Poster session]. 2019 Annual Meeting of the American Association for the Advancement of Science (AAAS), Washington, DC, United States.

Lamb, R., Hurtt, G., Dubayah, R., Hultman, N., Sahajpal, R., & Edmonds, J. (2018, December 10-14). *Quantifying the economic opportunity of afforestation and reforestation in Maryland (USA) using high resolution carbon monitoring products* [Conference presentation]. 2018 Annual Meeting of the American Geophysical Union (AGU), Washington DC, United States.

Lamb, R. & Hurtt, G. (2018, October 2-5). *Application of remote sensing and ecosystem modeling products to inform land-use decisions* [Conference presentation]. 2018 Annual Meeting of the Association for Forest Spatial Analysis Technologies (ForestSAT), College Park, MD, United States.

Lamb, R. & Hurtt, G. (2018, April 10-14). *Geographies of management opportunity: Incorporating the co-benefits of afforestation into climate policy and planning* [Conference presentation]. 2018 Annual Meeting of the American Association of Geographers (AAG), New Orleans, LA, United States.

Chapter 4

Lamb, R., Hurtt, G., Spivy, A., Ma, L., Campbell, E., Dubayah, R., Goetz, S., Hoffman Delett, C., Jantz, P., Panday, F.M., & Tang, H. (2021). High-resolution geospatial framework for future forest carbon storage and protected area expansion in Maryland (USA). *Environmental Research Letters. In Review.*

Lamb, R., Spivy, A., Dubayah, R., Sahajpal, R., Hultman, N., Edmonds, J., & Hurtt, G**.** (2021, February 8-11). *Mapping optimized future carbon stock corridors for climate and biodiversity* [Poster session]. 2021 Annual Meeting of the American Association for the Advancement of Science (AAAS), Virtual Platform. http:/doi.org/10.1002/essoar.10506283.1

Chapter 1: Introduction

1.1 Motivation and background

Forests are important ecosystems that provide a broad range of ecosystem services, including carbon storage, climate change mitigation, and wildlife habitat (Costanza et al., 2014; Pan et al., 2013). Multiple national and international commitments have been launched to not only protect forests (e.g., REDD+) but also to restore them. For example, the Bonn Challenge represents an international effort to restore 350 million hectares by 2030 (IUCN, 2011), with large supporting commitments offered towards this goal across Latin America (e.g., Crouzeilles et al. 2019). In March 2019, the United Nations (UN) launched the "Decade of Ecosystem Restoration 2021-2030," recognizing a global window of opportunity for forest restoration to offset serious concerns around climate change and biodiversity loss (UNEP, 2019). Over the next decade, improved carbon accounting and land-use planning will be necessary for these and other reforestation initiatives' long-term success. Further, scientific approaches that utilize advances in earth system science to help decision-makers quantify and assess spatially explicit trade-offs in land-use decisions will be critical as countries simultaneously advance the UN's seventeen Sustainable Development Goals (Papadimitriou et al., 2019).

One of the largest and most recent motivators of improved carbon accounting comes from the 2015 Paris Agreement, currently signed or ratified by 191 nations party to the United Nations Framework Convention on Climate Change (UNFCCC) (UN, 2015). As a component of this Agreement, countries commit to giving their best effort to reduce greenhouse gas (GHG) emissions through “nationally determined contributions” (NDCs). Originally there were concerns about including forests within the Paris carbon accounting system due to large uncertainties in biological sinks and sources, procedural challenges, and fear of unearned credits corrupting the overall system (Krug, 2018). However, the Parties’ commitment “to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century” places an intentional emphasis on including land sector emissions as a fundamental component of NDCs (UN, 2015, Article 4). Quantifying and realizing the tremendous sequestration potential of current and restored forests is a critical component of global climate mitigation, but more transparent, reliable, and higher confidence estimates are required (Grassi et al., 2017).

Against this backdrop, sub-national actors such as U.S. states are evidencing high levels of ambition and often driving national emissions reductions across sectors in the absence of comprehensive, sufficient, or consistently applied national climate strategies and policies (Hultman et al., 2020). Many states have advanced tighter restrictions across emissions sectors, through mandatory and voluntary approaches (Goulder & Stavins, 2011), and demonstrated success in curbing emissions from high GHG emitters such as those in the power sector (Martin & Saikawa, 2017). Most recently, large coalitions of states such as the U.S. Climate Alliance (USCA), have made commitments to improve the land carbon estimates found within member state climate action plans and inventories. Through the recent Natural and Working Lands

Challenge, the USCA has also emphasized the need for maintaining and enhancing resilient carbon sinks in support of Paris Agreement goals (USCA, 2020a).

In parallel to increased demand for improved carbon accounting, new science and technologies over the past two decades have revolutionized our capabilities for high-resolution forest carbon mapping, modeling, and monitoring. The first element of such a system is an accurate assessment of current carbon stocks. In particular, 3-D structure information on vegetation acquired from lidar remote sensing has helped provide by far the most accurate forest estimates across broad geographical extents (e.g., Cook et al., 2014; Dubayah & Drake, 2000; Dubayah et al., 2010). High-resolution carbon maps (~30m) can be generated from airborne lidar data at the county or state level (Zolkos et al., 2013; Huang et al., 2015, 2017, 2019; Tang et al. 2021), while several coarser resolution (90m - 1km) continental-scale maps of vegetation height and biomass have been produced from spaceborne lidar (NASA's ICESat/GLAS) with the aid of many ancillary datasets (Simard et al., 2011; Saatchi et al., 2011). Advancing this work, NASA's Global Ecosystem Dynamics Investigation (GEDI) provides near-global 1km estimates of forest canopy height, canopy vertical structure, and surface elevation (Dubayah et al., 2020). This mission will improve our knowledge of global carbon stocks and provide insight into habitat structure and connectivity with benefits for both climate mitigation and conservation.

Moving from current conditions to reforestation potential, NASA Carbon Monitoring System (CMS) projects have used this remote sensing data (optical and lidar data), coupled with prognostic ecosystem modeling and existing field observation systems, to predict carbon fluxes and produce high-resolution estimates of forest carbon sequestration potential. While traditionally there are computational trade-offs between high-resolution modeling and execution over large spatial domains (e.g., Hurtt et al., 1998), this work has resulted in products that promote consistent applications at both local scales and across large, policy-relevant geographies. Since these products' resolution is 90m, more than 100,000 times that of many global vegetation models, it is now possible to project sequestration outcomes at fine spatial scales with potential applications for land-use planning. First available at the county and state scale (Hurtt et al., 2019), this work has since been expanded to the multi-state regional scale (Ma et al., 2021), with plans to cover the larger U.S. and global domains by utilizing GEDI and Landsat remote sensing data (Ma et al., 2019).

Given the availability of high-resolution data on both current carbon stocks and carbon sequestration potential, the next geospatial and computational challenge is to identify priority reforestation areas. Strategic reforestation activities that account for both carbon sequestration potential as well as co-benefits, such as biodiversity protection and economic opportunity, can provide particularly attractive options for policy-makers who must manage competing social and environmental goals (Jackson & Baker, 2010; Chazdon & Brancalion, 2019). To be most useful, the socio-economic potential of reforestation must be quantified with respect to land ownership, follow a multi-factor approach to better capture co-benefits and trade-offs in the planning process, and consider the role of landscape connectivity (Gilroy et al., 2014; Menz et al., 2013; Smith et al., 2013). While reforestation can provide considerable benefits to climate, biodiversity, and human livelihood, maximizing their intersection requires spatially-explicit analysis (Brancalion et al., 2019). Furthermore, to remain most relevant to sub-national jurisdictions, such as states, counties, and cities, high-resolution spatial data and analysis is critical.

1.2 Research framework and objectives

Responsive to these challenges, this dissertation seeks the answer the following overarching research question: How can high-resolution forest carbon modeling products be used to facilitate strategic reforestation at the sub-national scale? To answer this question, this work leverages the strengths of existing CMS science to fundamentally advance and jointly inform social, economic, and ecological goals with high-resolution (90m) forest carbon data. By targeting applications at the U.S. local, state, and regional scales, this work maximizes the use of mature carbon monitoring products while also signaling what is possible to achieve within NDCs and other carbon management frameworks at the national and global scales as data becomes available.

Figure 1-1 illustrates the conceptual framework for this research, which completes the arc of a three-step process to 1) quantify and map current carbon stocks with remote sensing data, 2) quantify and map the potential for future regrowth based on prognostic ecosystem modeling, and 3) identify and map land areas for priority restoration by combining these estimates with additional social, economic, and biophysical data. The use of this high-resolution data for strategic climate mitigation planning is also contextualized in the broader U.S. forest carbon science and policy landscape. While this framework allows for multiple variables of interest to inform priority reforestation, this work focused on advancing climate mitigation alongside two key additional factors: human livelihood benefits and biodiversity conservation (e.g., Di Sacco et al., 2021).

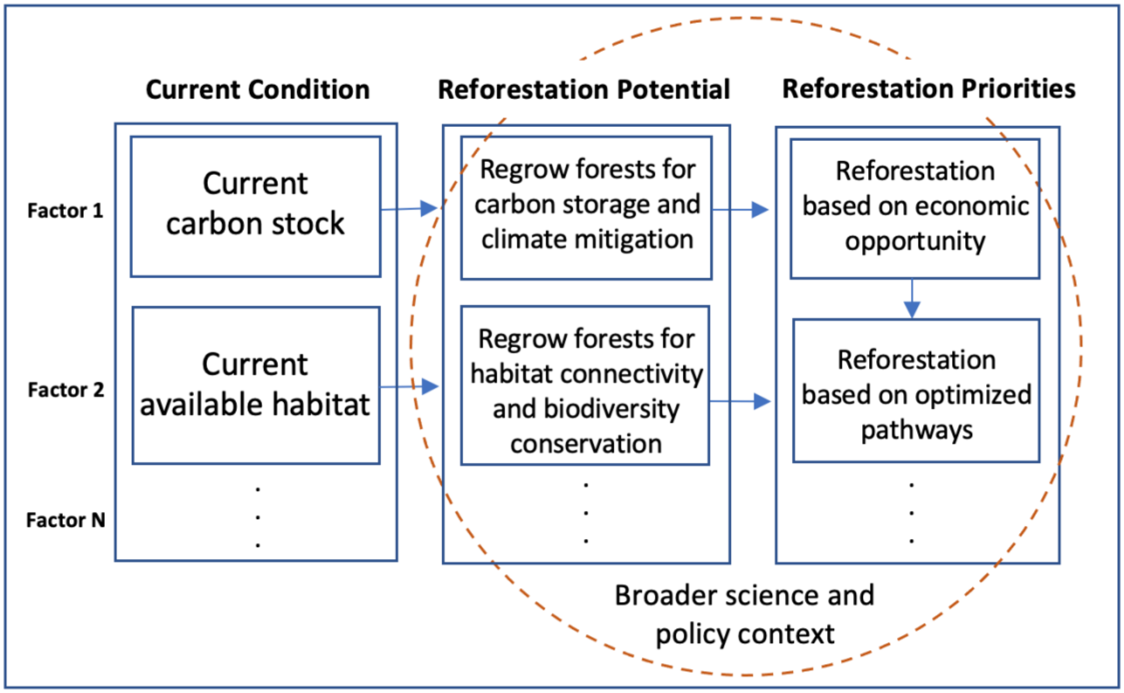


Figure 1-1: A conceptual framework showing the process of scientific advancement. This work focuses on two prominent factors informing strategic reforestation, but "n" number of factors are possible with this approach relative to decision-makers' goals and priorities.

In Chapters 2-4, this conceptual framework is subsequently applied to answer three supporting and related research questions:

- Question 1: What is the scientific and policy context for integrating forest carbon into state climate mitigation planning across the Regional Greenhouse Gas Initiative (RGGI) region?
- Question 2: What is the economic potential of reforestation in Maryland relative to cropland profit under a forest carbon rental model?
- Question 3: Where are viable future carbon stock corridors for jointly maximizing climate mitigation and biodiversity protection in Maryland?

A central goal of this work is to demonstrate the policy-relevance of recent high-resolution remote sensing and modeling products for strategic reforestation. Making such analyses "policy-relevant" requires that resulting knowledge and problem framings are well aligned. Consequently, this process "involves choices about the preferred audiences of knowledge and the types of policy actions that may follow from this knowledge" (Turnhout et al., 2016, p. 67). While this research is not policy prescriptive, it does provide a framework for strategic reforestation with explicit consideration of current state climate mitigation policy and other stated policy goals. It also demonstrates how spatially-explicit analysis could help states advance these goals in new ways and towards new applications--potentially raising current ambitions for increased natural carbon storage. Foundational to this effort has been the inclusion of state agency staff who have provided vital insight into emergent problems, science needs, and existing policy structures.

1.3 Dissertation outline

This work is presented across three core chapters (2-4), with a final chapter (5) offering additional synthesis and conclusions. Specifically, Chapter 2 provides a review of the broader science and policy context for integrating forest carbon estimates into state climate mitigation planning across eleven states in the Regional Greenhouse Gas Initiative (RGGI) domain. Chapter 3 develops and applies a forest carbon rental model in Maryland to determine whether and where potential revenues from reforestation would outcompete existing cropland profit at the hectare scale. Chapter 4 maps and analyses two potential reforestation scenarios in Maryland that can jointly maximize remaining carbon sequestration potential and unprotected biodiversity conservation areas, and evaluates both under several socio-economic considerations, including a price on forest carbon. Chapter 5 concludes with an overview of the main findings, limitations, and areas of future research. Additional supporting analysis, figures, and data for each chapter can be found in the Appendices.

Chapter 2: Context and future directions for integrating forest carbon into sub-national climate mitigation planning in the RGGI region of the U.S.

Abstract

International frameworks for climate mitigation that build from national actions have been developed under the United National Framework Convention on Climate Change and advanced most recently through the Paris Climate Agreement. In parallel, sub-national actors have set greenhouse gas (GHG) reduction goals and developed corresponding climate mitigation plans. Within the U.S., multi-state coalitions have formed to facilitate coordination of related science and policy. Here, utilizing the forum of the NASA Carbon Monitoring System's Multi-State Working Group (MSWG), we collected and reviewed climate mitigation plans for 11 states in the Regional Greenhouse Gas Initiative (RGGI) region of the Eastern U.S. For each state we reviewed the 1) policy framework for climate mitigation, 2) GHG reduction goals, 3) inclusion of forest activities in the state's climate action plan, 4) existing science used to quantify forest carbon estimates, and 5) stated needs for forest carbon monitoring science. Across the region, we found important differences across all categories. While all states have GHG reduction goals and framework documents, nearly three-quarters of all states do not account for forest carbon when planning GHG reductions; those that do account for forest carbon use a variety of scientific methods with various levels of planning detail and guidance. We suggest that a common, efficient, standardized forest carbon monitoring system would provide

important benefits to states and the geographic region as a whole. In addition, such a system would allow for more effective transparency and progress tracking to support state, national, and international efforts to increase ambition and implementation of climate goals.

2.1 Introduction

The Paris Climate Agreement represents the latest global effort to curb greenhouse gas (GHG) emissions with cross-sector planning and bottom-up leadership (Castro, 2020). Since the Paris Agreement entered into force in 2016, more than 187 countries around the world have worked to detail their respective contributions towards limiting global warming to 1.5° and 2°C by 2050 and 2100. For more than 100 countries, such pledges have included a range of mitigation options to reduce net emissions from the land use, land use change and forest (LULUCF) sector (Forsell et al., 2016). Much of the methodological guidance for these estimates has come from the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories (IPCC, 2008, 2019).

In the United States, sub-national actors (states, cities, businesses, and others) are driving climate change mitigation through policies and actions that collectively generate significant contributions to GHG reductions at a more local scale (Hultman et al., 2019, 2020). For nearly three decades, many state governments have not only implemented policies affecting their electricity, land, and transportation systems (to name a few), but have also set explicit GHG emissions reduction targets via legislation or gubernatorial directives. In doing this they have also charged state agencies and commissions to develop robust climate action plans to achieve these goals, and have developed monitoring strategies to quantify progress. To be most successful, a common scientific framework for estimating and comparing emissions reductions should be employed (Hsu et al., 2019). This is particularly true for accurately measuring the contributions of land-based carbon to climate mitigation. Previous climate planning efforts have a mixed record of LULUCF inclusion due to the complexities of available techniques, a lack of available data, limited technical capacity, and budget constraints, among other issues (e.g., Ellison et al., 2013; Krug, 2018).

The first generation of climate action plans at the state and municipal levels across the eastern U.S. arose in the late 1990s in response to growing global climate awareness and action. These plans were largely focused on providing a review of the issue of climate change or targeting a more select set of GHG emissions (Wheeler, 2008). In 2001, the New England Governors and Eastern Canadian Premiers began coordinating climate action planning through adoption of a Regional Climate Change Action Plan to reduce GHG emissions to 1990 levels by 2010 (NEGECP, 2001, 2017). Jurisdictional level inventories of existing emissions have frequently served as the basis for subsequent climate planning, establishing a benchmark against which proposed GHG emissions reduction measures could be assessed (Kennedy et al., 2010).

Many climate mitigation efforts in the U.S. have involved reducing emissions from sources tracked by the U.S. Environmental Protection Agency (USEPA) in fulfillment of national commitments under the United Nations Framework Convention on Climate Change (UNFCCC). The USEPA assembles an annual, national GHG inventory by compiling information from various sectors that emit and sequester GHGs, including the electric power, transportation, industrial, residential, commercial, waste, agriculture, and forestry sectors (USEPA, 2018). USEPA has also developed a State Inventory Tool (SIT) to provide a common method for states to calculate direct and indirect GHG emissions for state-specific GHG reduction accounting. Within the SIT, states have the option to utilize pre-loaded default data compiled by the USEPA in consultation with other federal agencies like the U.S. Department of Agriculture (USDA) Forest Service (USFS) or apply their own state-specific data (USEPA, 2019). Although the SIT does have a module for tracking emissions from LULUCF (USEPA, 2020), many state governments opt not to use this module in their GHG inventories. Given the potentially large LULUCF contribution to state-level carbon budgets, many states have expressed an interest in better quantifying the role of forests within their GHG inventories and climate action plans. Specifically, there is interest in scientific approaches that go beyond the current form of the SIT and offer more consistent, accurate, and regularly updated geo-referenced data.

In 2017, a coalition of U.S. states formed the United States Climate Alliance (USCA) to accelerate and implement policies that advance the goals of the Paris Agreement (USCA, 2020b). The 25 member states and territories of the USCA represent 55% of the U.S. population and collectively manage an economy larger than all other countries in the world except China and the United States (USCA, 2019). The USCA has focused on a suite of GHG emissions sectors including “Natural and Working Lands” (NWL). In 2018, 17 member states signed onto the “NWL

Challenge," which commits states to improving their inventory methods for land-based carbon flux, undertaking actions to support a collective alliance-wide goal to maintain NWL as a net carbon sink, and integrating priority actions and pathways into state GHG mitigation plans by 2020 (USCA, 2020b).

Regional coalitions have also paved the way for GHG reduction programs and trading schemes. Notably, ten USCA members are also part of the Regional Greenhouse Gas Initiative (RGGI), which includes eleven Northeastern and Mid-Atlantic states (Figure 2-1). As the first mandated cap-and-trade program in the United States, RGGI has capped CO_2 emissions from electric power plants and auctioned CO_2 allowances. Established in 2009, RGGI has a ten-year track record of coordinating GHG emissions reductions across the region, with other USCA members like Pennsylvania targeting participating in RGGI by 2022. Although land-based carbon is not traded on the RGGI market, a small number of offset allowances, 3.3% of a power plant's CO_2 compliance obligation, attempt to provide limited flexibility in achieving reduction goals via reforestation, improvements in forest management, and other approved sequestration projects (RGGI, 2020). Most member states have reinvested auction proceeds in state programs promoting energy efficiency, renewable energy, and a broader clean energy economy. However, depending on state law, there is potential to utilize a portion of auction proceeds to advance carbon sequestration on NWLs that is complimentary to regional USCA goals and individual state legislative agendas (e.g., NJDEP, 2020).

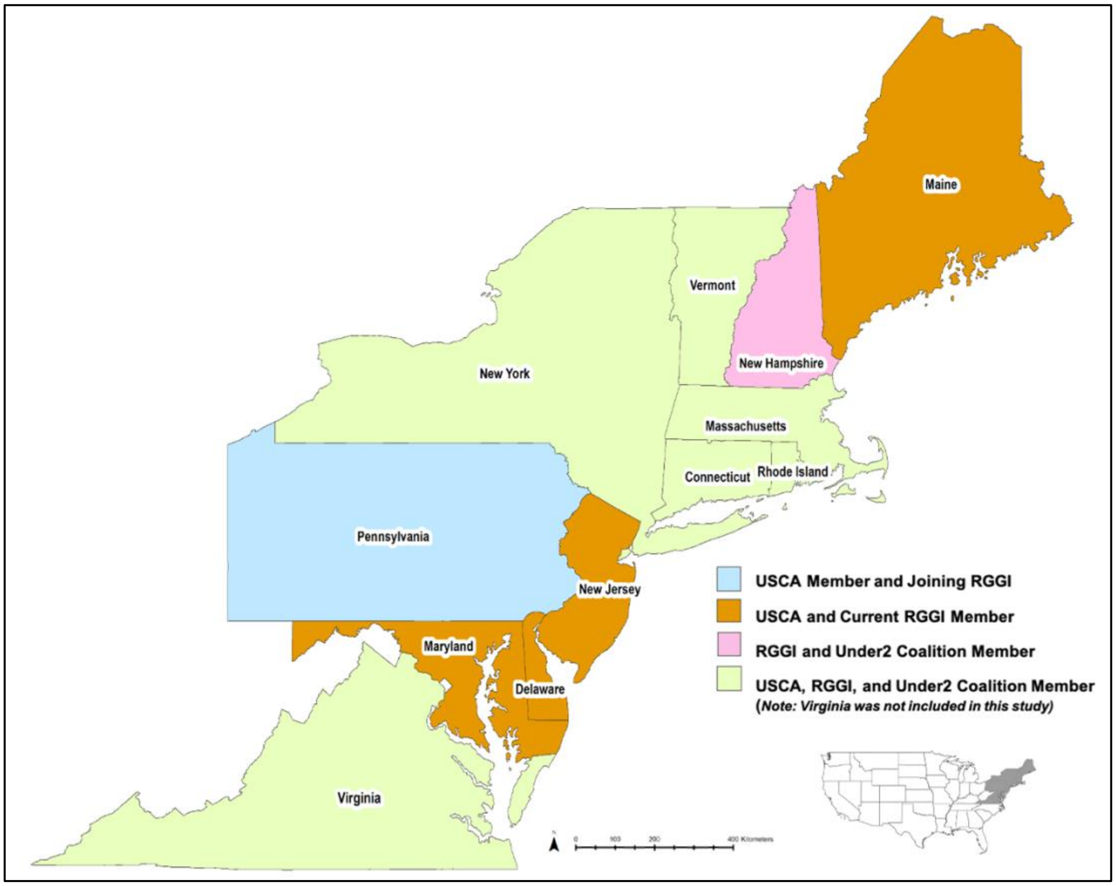


Figure 2-1: All states in the region belong to one or more multi-state coalitions, including the United States Climate Alliance (USCA), Regional Greenhouse Gas Initiative (RGGI), and the Under 2 Coalition of state and regional governments. Note that while Virginia has recently become a member of RGGI, it was not included in this study.

In this paper, we review the climate mitigation plans for 11 states in the RGGI region (all current RGGI members except Virginia, plus Pennsylvania) and identify opportunities for enhancing action through more systematic development and application of new forest carbon monitoring strategies. We focus particularly on the degree to which forest activities are included in this planning and the primary science approaches used to quantify expected forest carbon sequestration. After synthesizing state efforts, we discuss options and next steps toward a shared carbon monitoring system for the region.

2.2 Methods

2.2.1 Data collection

Data and other inputs for this study were collected from governmental documents published by or before April 30, 2020, including legislation, executive orders, climate mitigation plans and appendices, and state GHG inventories. To identify, supplement, and discuss these documents, a series of teleconferences were jointly hosted by the University of Maryland, College Park and the NASA Carbon Monitoring System (CMS) Applications Team between March 2019 and February 2020. All eleven states in the region were invited to join all three MSWG calls. Summary reports and presentation slides were shared with participants and published on NASA's Carbon Monitoring System website (Hurtt et al., 2014, NASA CMS, 2020a).

2.2.2 Data categories for state-level review

Presentations and published documents were reviewed for information relative to seven overarching data categories including: 1) legislation and executive orders, 2) established GHG reduction goals, 3) climate planning documents, 4) forest activities mentioned within the planning documents, 5) the extent to which forest activities count towards state GHG reduction goals, 6) existing science (tools, methods, approaches) used to generate forest carbon estimates, and 7) identified needs for forest carbon monitoring science (Figure 2-2).

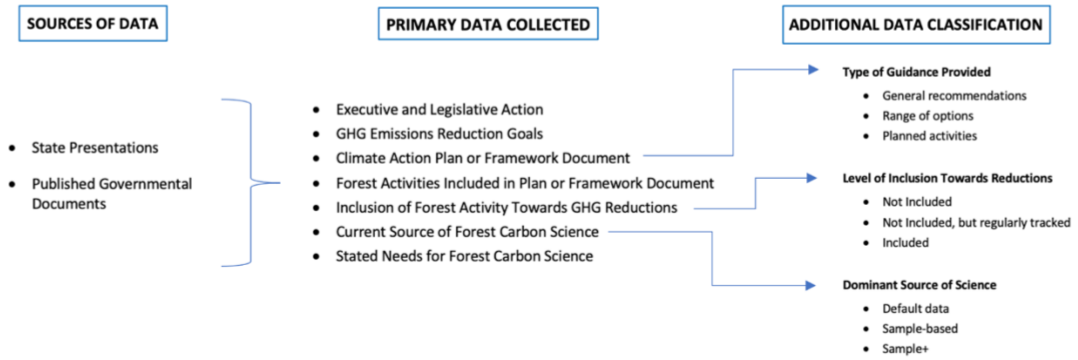


Figure 2-2: Flow chart of methodological steps for data collection, review, and additional classification of three data categories.

First, we reviewed executive orders and legislation that mandated GHG emissions goals, the creation of GHG inventories, climate change committees, and/or climate action plans. Many states have additional climate change legislation focused on clean energy, energy efficiency, electric vehicles, and other related topics. We did not include this legislation within the scope of our review, unless it mandated the development of the state's primary climate mitigation planning document (e.g., in the case of Vermont). Additionally, while many states have separate forestry legislation, we did not include it in our review unless the provisions were included in the core climate mitigation policy (e.g., in the case of New York). We also reported active GHG emissions reduction goals for each state. Most GHG targets were outlined within the executive orders or legislation, or otherwise summarized in state presentations during the MSWG calls.

Next, we reviewed core state climate action plans and climate mitigation framework documents. We defined Climate Action Plans as the primary governmental document outlining specific strategies for measuring, planning, and reducing GHG emissions and related climate change impacts. Some states have not published a climate action plan but have published either guidance documents that outline general recommendations for mitigation or interim reports that signal ongoing efforts to reduce GHG emissions via existing policies. We included these documents as part of a state's core climate mitigation framework. While separate forestry legislation and planning can result in co-benefits for climate mitigation, one goal of this work was to explicitly evaluate how well forest carbon goals and GHG reduction planning are currently integrated.

We reviewed the current version of each planning document for specific climate mitigation activities, options and/or terms that included forests or trees. Relevant forest activities were broadly classified as forestry management practices, reforestation/afforestation, urban tree planting and retention, and forest conservation, including preventing deforestation. As these terms are not often defined within the plans themselves, all activities have been categorized according to the term used by the plans' authors. Each state has utilized a range of stakeholder engagement processes to define, scope, and select forest activities with respect to the laws and policies of that state. For example, many states work with stakeholder advisory groups or a policy task force, with diverse membership across the private and public sectors, to generate and evaluate activity recommendations.

We subsequently recorded the data sources used to generate forest carbon estimates within the state's GHG inventory or associated with the forestry activities outlined in the plan. Finally, we documented the forest carbon science needs of states as provided to us via the NASA CMS presentations, including key tools (e.g., lidar and modeling) and monitoring requirements (e.g., annual, consistent, reliable, etc.).

2.2.3 Data classification for regional analysis

We synthesized the state-level analysis across the eleven-state region to identify emergent patterns across all seven data categories. Given the range of data collected across three data categories (plans, inclusion, and current science), we further classified states with three additional variables (Figure 2-2). Specifically, we evaluated the 1) type of planning guidance for forest activities provided within the climate mitigation framework document, 2) level of inclusion of forest activities towards the state GHG emission reduction target, and 3) the dominant source of forest carbon science used to estimate emissions and planned sequestration outcomes.

First, we classified framework documents according to the type of planning guidance provided for identified forest activities. One class of documents provides general activity recommendations, often originating in gubernatorial committees or working groups, but does not provide specific activities or quantitative carbon estimates ("general recommendations"). A second class recommends specific best practices or options for agency consideration but does not represent planned activity ("range of options"). These documents often highlight ongoing efforts or qualitatively describe areas for expanded GHG reductions but stop short of quantitative estimates. The third class details specific planned activities that state agencies and partners will implement and the expected carbon benefits of these activities ("planned activities").

Next, we evaluated whether identified forest activities counted towards the state's GHG reduction goals. Under the first category, states do not include forest activities towards achieving GHG goals (“not included”). There could be multiple reasons for this, including a lack of reliable data or concerns about inappropriately using a forest carbon sink to offset growing GHG emissions across other sectors. Under a second category, states do not include forest activities towards GHG reductions, but describe forests as an important component of overall climate mitigation within their plans and track net forest emissions separately within their inventories, in an appendix or supplementary analysis (“not included, tracked”). States utilizing this strategy may also share similar concerns to those in the first category but remain interested in reporting the magnitude of their carbon sink relative to total GHG emissions. Under the final category, the state does include forest activities towards overall GHG reductions (“included”), but inventories only emissions and sequestration terms for which they have data.

Third, we categorized states by the dominant source of scientific information used to generate forest carbon estimates related to forest activities in their plans and inventories. The first category includes states using default data directly from SIT, static literature values or regional rather than state-specific sample-based estimates (“default”). A second category involves methods and approaches which utilize USFS FIA field data or state-level data summarized in USFS technical reports (“sample”). A third category uses USFS FIA data in addition to either high-resolution modeling or the state’s own continuous forest inventory (“sample+”).

2.2.4 Forest carbon science and policy relationship analysis

Finally, we evaluated whether a state's primary scientific strategy was related to higher levels of inclusion in climate policy. We compared the type of guidance provided in the plans (in ascending order of detail provided) to the dominant science used to estimate forest carbon emissions and sequestration (in ascending order of methodological sophistication). We separated and assigned scores to planning documents providing general recommendations for further agency development (score of 1), from those outlining a suite of options and best-practices (score of 2) and those with specific planned activities (score of 3). Regarding the primary scientific strategy, we separated and assigned scores to default approaches (score of 1), from sample-based approaches (score of 2), and sample+ approaches (score of 3).

2.3 Results

Data collected and reviewed for each state across all seven data categories have been summarized in Table 2-1 and described in more detail by state in the supplementary file (Appendix A). Regional patterns have been summarized below by data category.

Table 2-1: Summary of state-level data collected across seven data categories

State	Executive and legislative action (year)	GHG emissions reduction goals	Climate action plan or framework document (year)	Forest activities included in plan or framework document	Inclusion of forest activities towards GHG reductions	Current source of forest carbon science	Stated needs for forest carbon science
Connecticut	CT Global Warming Solutions Act (2008) Executive Order 46 (2015) An Act Concerning Climate Change Planning and Resiliency (2018) Executive Order 3 (2019)	10% below 1990 levels by 2020 45% below 2001 levels by 2030 80% below 2001 levels by 2050	Building a Low Carbon Future Recommendations Report (2018)	- Forestry management practices - Urban tree planting - Afforestation on marginal agricultural land	Not included towards GHG reductions	Literature values	More reliable LULUCF data
Delaware	Executive Order 41 (2013)	26-28% below 2005 levels by 2030	Climate Framework for Delaware (2014) *Plan under development*	- Forest conservation and restoration (slow loss) - Restoring riparian buffers	Not included, but separately tracked within inventory	USEPA SIT/GHG Inventory USFS FIA data DE Forest Service analysis NASA CMS products	Annual carbon flux monitoring

continued

Table 2-1 continued

Maine	Act to Provide Leadership in Addressing the Threat of Climate Change (2003) Executive Order 10 (2019)	10% below 1990 levels by 2020 45% below 1990 levels by 2030 On track to achieve 80% by 2040 80% below 1990 levels by 2050, and carbon neutrality by 2045	Climate Action Plan (2004, update forthcoming 2020)	- Forestry management practices - Forest conservation (prevent conversion)	Not included, but separately tracked within inventory	USFS FIA data USFS ForGATE tool	Integration of remote sensing; improved forest monitoring; and integrated modeling
Maryland	Greenhouse Gas Emissions Reduction Act (2009, updated 2016)	25% below 2006 levels by 2020[a] 40% below 2006 levels by 2030 80 to 95% below 1990 levels by 2050[b]	Greenhouse Gas Emissions Reduction Act Plan (2013, 2015, draft update 2019)	- Forestry management practices - Reforestation/afforestation - Urban tree planting - Forest conservation (avoided emissions) - Planting forested stream buffers - Preservation/restoration of forested areas on agricultural land	Included towards GHG reductions	NASA-CMS products USFS FIA data NASA-USDA-DOE study MDNR RAS field study MD Forest Service analysis USEPA SIT WRI-TNC-USCA analysis	Annual carbon flux monitoring

continued

Table 2-1 continued

Massachusetts	The Global Warming Solutions Act (2008)	25% below 1990 levels by 2020 At least 80% below 1990 levels by 2050, and net zero emissions by 2050 *2030 reduction goal under development*	Clean Energy and Climate Plan for 2020 (2010, 2015) *2030 plan under development*	- Urban tree planting and retention	Not included towards GHG reductions, but tracking in inventory appendix	Harvard Forest Ecosystem modeling MassGIS analysis State Continuous Forest Field Inventory USFS FIA data/USFS reports Literature values	Enhanced lidar capabilities to improve estimates of urban tree/forest carbon
New Hampshire	Executive Order 3 (2007)	20% below 1990 levels by 2025 80% below 1990 levels by 2050	Climate Action Plan (2009)	- Forestry management practices - Forest conservation (prevent conversion)	Not included, but separately tracked within inventory	USEPA SIT USFS FIA data Hubbard Brook and Bartlett Forest field studies Integrated forest model	Potential valuation of forest ecosystem services, inclusive of forest carbon estimates

continued

Table 2-1 continued

New Jersey	Global Warming Response Act (2007, updated 2019) Clean Energy Act (2018) Executive Order 89 (2019) Executive Order 100 (2020)	At or below 1990 levels by 2020, 80% below 2006 levels by 2050	Global Warming Response Act Limit Recommendations Report (2009, update forthcoming 2020)	- Forest conservation (no net forest loss)	Included towards GHG reductions	USEPA SIT NCASI Carbon Online Tool USFS FIA data Default IPCC estimates	Improved estimates of land carbon flux; soil carbon data; and improved monitoring, measurement and verification methods
New York	Executive Order 24 (2009) Executive Order 166 (2017) Climate Leadership and Community Protection Act (2019)	40% below 1990 levels by 2030 85% below 1990 levels by 2050, and net zero emissions by 2050 or as soon as practicable	Forest Action Plan (2020) *Climate Scoping Plan under development*	- Forest management practices - Forest restoration - Urban forestry - Reforestation - Forest conservation (conserve open space, no forest loss)	Not included, but tracked separately as part of forest sector planning	USFS Technical Report USFS FIA data	High-resolution estimates of forest carbon; biogenic emissions

continued

Table 2-1 continued

Pennsylvania	Pennsylvania Climate Change Act (2008) Executive Order 1 (2019)	26% below 2005 levels by 2025 80% below 2005 levels by 2050	Climate Change Action Plan (2009, 2015, 2019)	- Forest conservation - Reforestation - Urban tree canopy expansion	Included towards GHG reductions	USFS Technical Reports State Continuous Forest Field Inventory NASA CMS products	Carbon sequestration potential; canopy change detection for monitoring; and lidar applications
Rhode Island	Resilient Rhode Island Act (2014)	10% below 1990 levels by 2020[a] 45% below 1990 levels by 2035 80% below 1990 levels by 2050	Rhode Island Greenhouse Gas Emissions Reduction Plan (2016)	- Forestry management practices - Urban tree planting	Not included towards GHG reductions	USFS Forest Carbon Budget model Grey literature values	More reliable land carbon data; and to fully understand mitigation potential of urban forests
Vermont	Vermont Statue, 30 V.S.A. § 578 (2005) Under2MOU (2015)	50% below 1990 levels by 2028 80 to 95% below 1990 levels by 2050	Comprehensive Energy Plan (2016)	- Forestry management practices	Not included towards GHG reductions, but biogenic emissions tracked	USFS FIA data	Annual flux monitoring; and high resolution, higher confidence forest carbon sequestration estimates

[a] Goal already achieved

[b] Goal included in plan as an ambition but not formal goal

2.3.1. Executive and legislative mandates

All eleven states in the RGGI region have climate mitigation policy mandates, directed by either the executive branch or their respective legislative bodies. The earliest statute comes from the State of Maine in 2003, with new and updated mandates continuing across the region for the following seventeen years. Eight states in the region have had their original climate mitigation goals established via state legislation, with the remaining three (New Hampshire, Delaware and New York) by Gubernatorial Executive Order, with Delaware’s and New Hampshire’s goals recommended by a Governor-established Cabinet Committee (DE) and Task Force (NH). Three states (Maine, New York, and Pennsylvania) have had their climate mitigation goals strengthened or expanded over time via the other branch of government (either state legislature or governor). Delaware’s goals were functionally updated in 2017 upon joining the U.S. Climate Alliance.

2.3.2 Greenhouse gas reduction goals

All states have greenhouse gas reduction goals (Figures 2-3 and 2-4). Five of eleven states in the region have short-term goals established for the year 2020, with the remaining states setting their first set of reductions for the years 2025 (Pennsylvania and New Hampshire), 2028 (Vermont), and 2030 (New York and Delaware), respectively. Two states, Maryland and Rhode Island, appeared to meet their 2020 reduction goals early, as identified via their respective 2017 and 2016 inventories, and have moved forward with medium-term reduction planning. Short-term reduction goals range between 10-50% relative to a ranging baseline year. Seven states have established short-term goals relative to 1990 emissions levels, with three other states at 2005 (Pennsylvania and Delaware) and 2006 (Maryland) levels, respectively. One state, New Jersey, has set short-term reductions for “at or below” 1990 levels.

Ten states in the region (excepting Delaware) have established long-term planning goals to be met by 2050. Of those states, seven have pledged to reduce emissions by 80% from a ranging baseline year, with Massachusetts specifying a long-term reduction goal of reducing emissions by “at least” 80%. One state, New York, has pledged an 85% reduction by 2050. Two states, Vermont and Maryland, mention in their plans the long-term goal of reducing carbon emissions between 80-95% below 1990 levels in accordance with IPCC recommendations for developed countries, but only Vermont has signed the Under2MOU formally committing to this goal.

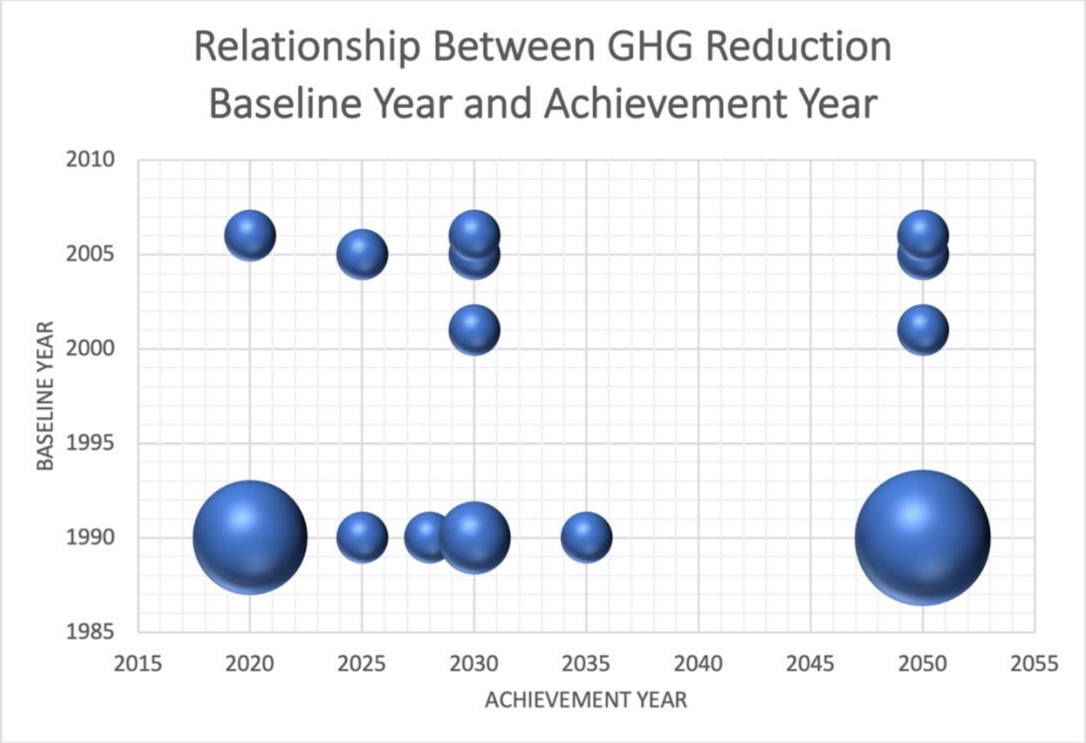


Figure 2-3: Baseline year of emissions and corresponding emission reduction achievement year for state greenhouse gas (GHG) targets across the RGGI region. The larger the circle, the more frequent the combination of baseline and achievement years. There are a variety of combinations. The most frequent goal sets are short-term goals for 2020 greenhouse gas (GHG) reductions relative to 1990 levels (5 states), and long-term goals for 2050 reductions relative to 1990 levels (7 states).

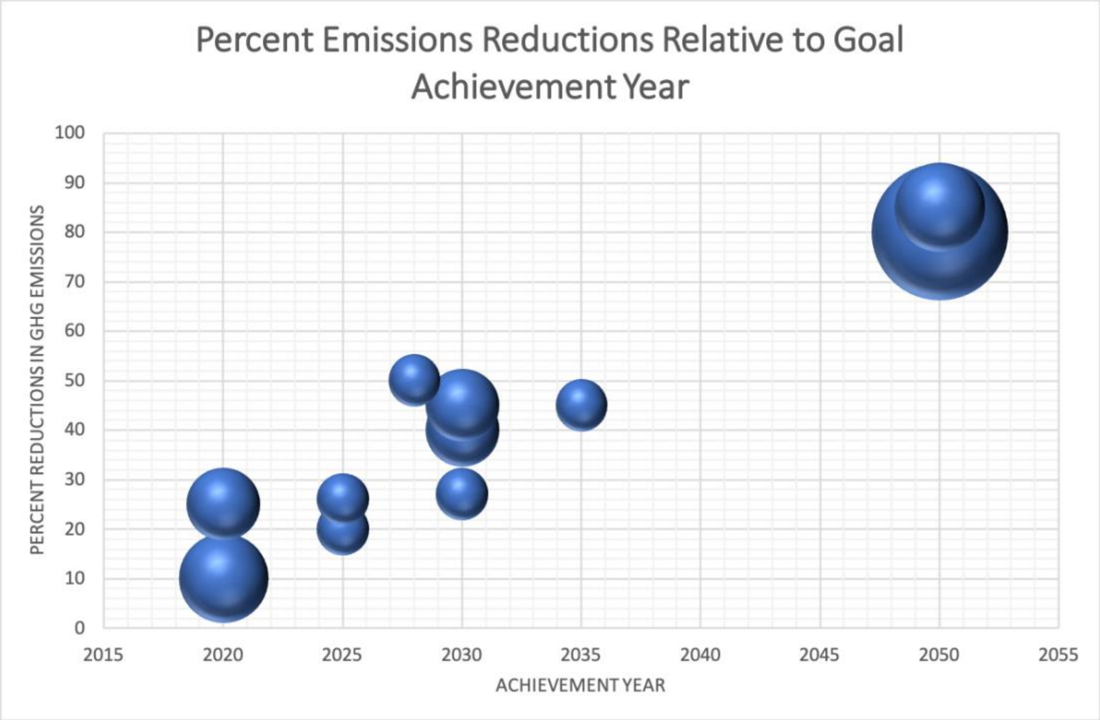


Figure 2-4: Emission reduction pledges and corresponding target year of achievement for states across the RGGI region. The larger the circle, the more frequent the combination of pledged greenhouse gas (GHG) emissions reductions by year. The most common goal set is 80% GHG emissions reductions by 2050 (seven states), with three more states pledging between 80-95% emissions reductions by 2050. Even with common pledges, the actual amount of emissions reduction will vary considerably by state depending, in part, on the target's baseline year (see Figure 2-3).

Three states (Connecticut, Maine and Rhode Island) have separate medium-term GHG reduction goals, falling between their established short and long-term goals. All three of these states have established 45% reductions by either 2030 or 2035. Maine has also established an interim emissions goal, such that the state must show they are on track to achieve their long-term 2050 reduction goal by 2040. One additional state, Massachusetts, is currently in the process of setting a 2030 emissions limit, with expected completion by December 2020. The vast majority of states in the region (81%) have the same baseline year (1990) for all of their established GHG goals, but two states (Connecticut and New Jersey) have more recent baselines for their medium to long term goals (2001 and 2006, respectively). Finally, three states have established additional climate neutrality goals. Massachusetts and New York have pledged to achieve net-zero greenhouse emissions by 2050, and Maine by 2045.

2.3.3 Climate action plans and type of guidance

All eleven states have a guiding climate action plan or framework document for GHG reductions. State agencies are on the frontlines of policy implementation, sometimes with the support of external climate change committees, and often with directives to achieve ambitious emission reductions across all sectors of the economy relative to established goals. Seven states have final Climate Action Plans, and two (Connecticut and New Jersey) have interim reports relative to the status of planned or accomplished activities. One state, New York, currently utilizes its Forest Action Plan, rather than a Climate Action Plan, to outline planned forest management and restoration strategies with co-benefits for climate change. One state, Delaware, is in the process of developing a Climate Action Plan, moving beyond the initial guidance provided in their 2014 framework report.

The type of planning guidance provided for forest activities varies across climate mitigation documents (Figure 2-5). Only two of eleven states (Maryland and Massachusetts) have outlined specific planned activities that are to be directly implemented by state agencies, with corresponding quantitative estimates relative to expected carbon sequestration goals (see Appendix A, sections A.4 and A.5). Five states provide a range of activity options for potential agency implementation, sometimes with corresponding carbon sequestration estimates, but more often qualitatively outlined with a high level of detail. The four remaining states

(Connecticut, Delaware, New Jersey, and Vermont) provide general overarching and qualitative recommendations for improving the carbon sink and direct the agencies to further design or determine further activity options or details.

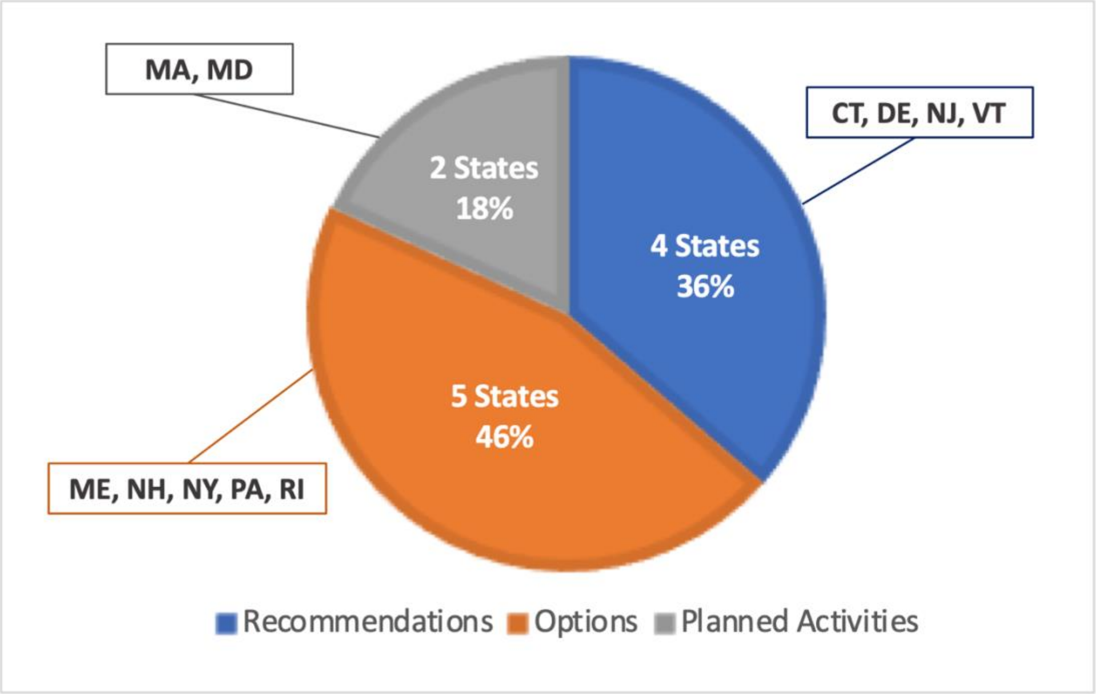


Figure 2-5: Level of planning guidance for forest activities provided across existing climate mitigation framework documents, including documents providing general and qualitative recommendations for agency consideration (Recommendations); documents providing an array of best-practices and options for potential adoption by agencies (Options); and documents outlining specific, quantitative activities, for planned implementation by agencies (Planned Activities).

2.3.4 Forest activities within framework document

Within each state's climate mitigation document, there are a range of forest activities mentioned in the context of planning. All framework documents mention the importance of trees and forests in the context of maintaining or increasing the respective state's carbon sink. Among the seven distinct terms mentioned across plans (Figure 2-6), "forest conservation" and "forestry management practices" were mentioned most frequently, by seven of the eleven states. In the case of forest conservation, there was some variety in application with at least one state (Maryland) estimating avoided emissions, and another four describing their efforts to further prevent loss, slow loss, or maintain no net forest loss. One state, New York, specifically mentioned the importance of forest conservation in broader efforts to conserve open space. Two states (New York and Delaware) also mentioned forest restoration as a separate practice from either forest conservation or improved forestry management practices.

Four states mentioned reforestation or afforestation as overarching strategies for growing the carbon sink. One state, Pennsylvania, only mentions reforestation, while another, Connecticut, only describes afforestation on marginal agricultural land. Preserving or restoring forested agricultural land is mentioned as a separate activity within Maryland’s plan, and Maryland and Delaware further specify a potentially related goal to plant forested stream buffers and/or riparian buffers. Finally, six states have explicitly outlined urban tree planting efforts, with at least one state, Massachusetts, additionally emphasizing the retention of existing urban canopy cover.

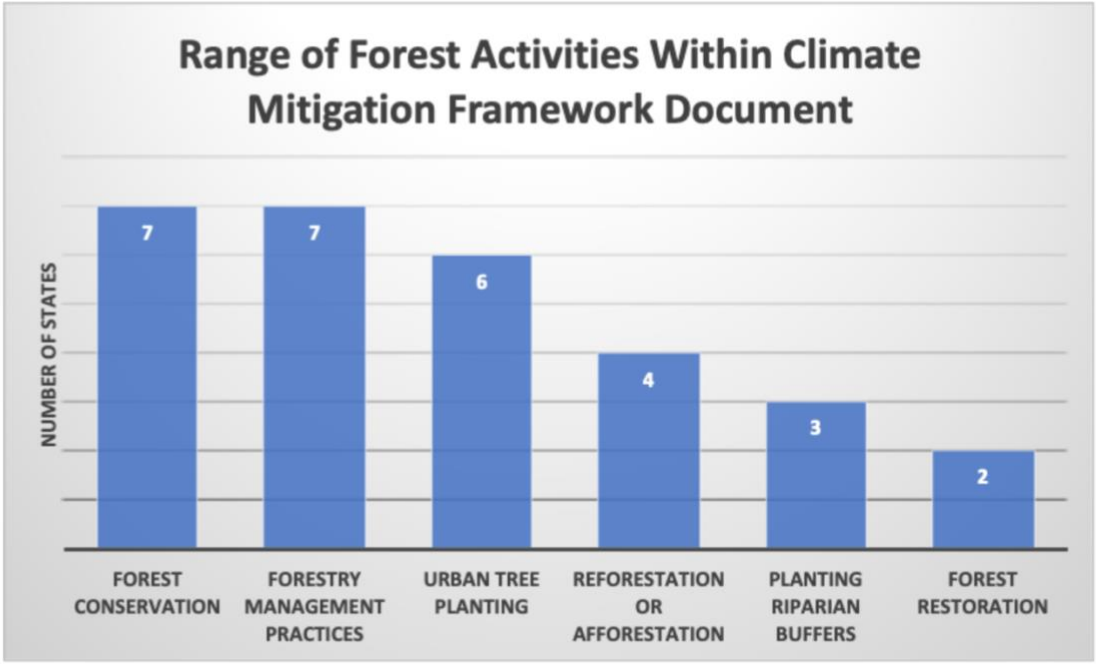


Figure 2-6: Range and frequency of activities, options, and/or terms within the state’s climate mitigation framework document that included forests or trees.

2.3.5 Inclusion of forest activities towards GHG reduction goals

The degree to which forest carbon estimates are tracked and included towards GHG reductions varies across the region (Figure 2-7). Three states (Pennsylvania, New Jersey, and Maryland) include emissions and/or sequestration from forest activity as a component of their state GHG inventory and consequently count them as reductions towards their GHG goals. Six states (Delaware, Massachusetts, Maine, New Hampshire, New York, and Vermont), do not count forest activities towards established GHG goals but have put effort into tracking related forest carbon estimates outside of their existing carbon budget or inventory. The final two states, Connecticut and Rhode Island, do not include forest activities towards GHG reductions, nor do they regularly track changes to their forest carbon stocks.

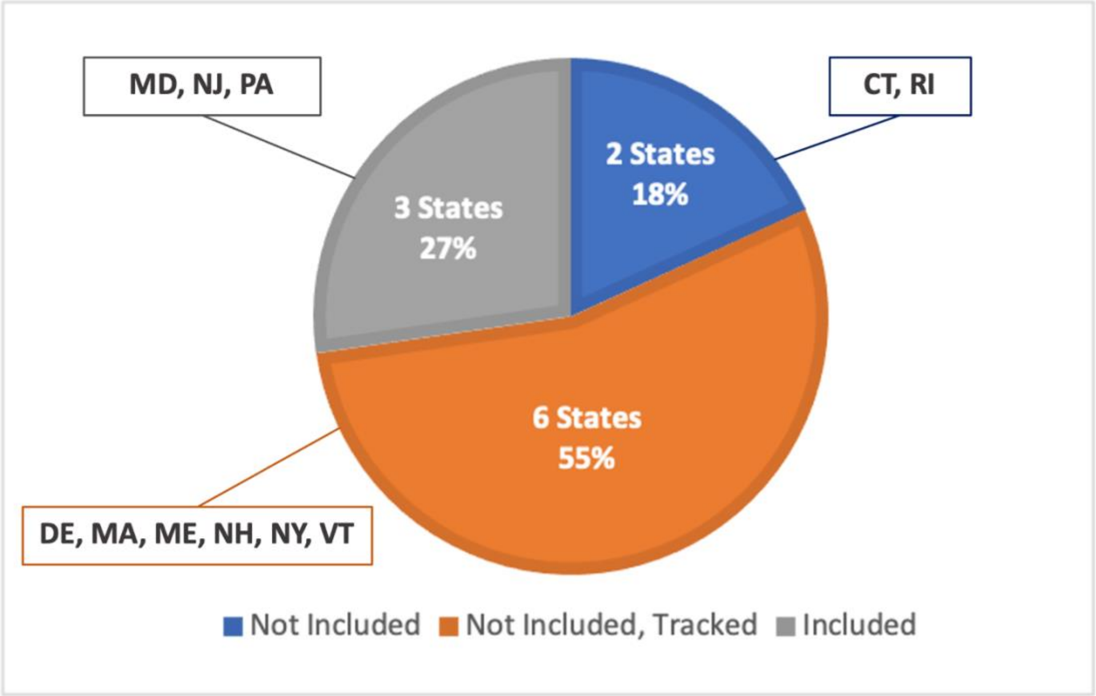


Figure 2-7. Degree to which forest activities are included towards greenhouse gas (GHG) reduction goals. States may not include forest activities relative to goal completion (not included), states may not include forest activities, but track changes independently of the GHG inventory (not include, tracked), or they may include them directly within their inventories as a component of overall GHG reductions (tracked).

2.3.6 Existing forest carbon science and dominant strategy

Despite the various scientific sources referenced across the region, states generally evidenced a primary or dominant strategy for generating forest carbon estimates across their plans and inventories (Figure 2-8). Four states (Connecticut, Rhode Island, New Hampshire, and New Jersey) are predominately using default data from the literature, SIT or default data directly from the IPCC. Four more states (Delaware, Maine, New York and Vermont) are using primarily sample-based methods from USFS FIA program or related USFS Technical reports. The final three states are utilizing USFS FIA data in addition to either a statewide ecosystem model (Maryland) or is otherwise utilizing continuous forest field inventory data from their state forest service (Massachusetts and Pennsylvania).

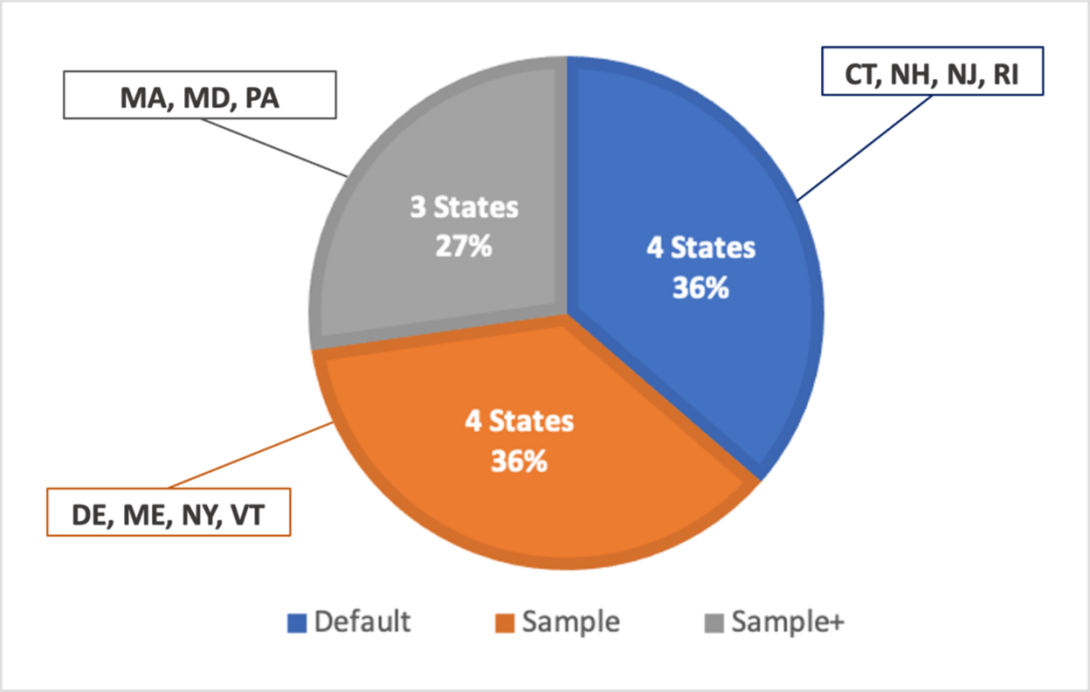


Figure 2-8: Primary scientific strategy employed by the states to estimate forest carbon stocks and fluxes within their climate mitigation plans or greenhouse gas (GHG) inventories. Four states use default data directly from SIT, static literature values or sample-based estimates from their region rather than their state (default). Four states utilize USFS FIA field data directly or via USFS technical reports as updated and made available to the states (sample). The final three states use USFS FIA data in addition to either high-resolution modeling or field data from the state's own continuous forest field inventory (sample+).

Looking across all science referenced, ten of eleven states in the region use data or tools produced by the USFS, often analysis derived from Forest Inventory and Analysis (FIA) plots in the form of state or regional technical reports. It is unclear from the documents how many of these states are working in direct partnership with the USFS to utilize spatially explicit estimates of forest carbon within their domain rather than state-wide averages. At least one state (Maine) has utilized the USFS

ForGATE, a Forest Sector Greenhouse Gas Assessment Tool, designed primarily to communicate information relevant to the evaluation of projected net GHG exchange in the context of Maine's forests (Henninger et al., 2013). At least two states (Massachusetts and Pennsylvania) mention the use of state-specific continuous forest field inventory data, with three more states (Maryland, Delaware, Massachusetts) utilizing data more generally from either their state forest service or state-based long-term ecological research areas.

One state (Maryland) currently utilizes data and analysis available via the NASA Carbon Monitoring System (CMS), which offers high-resolution statewide (wall-to-wall) coverage of annual carbon stocks and fluxes via remote sensing and dynamic ecosystem modeling (Hurtt et al., 2019). Two more states, Delaware and Pennsylvania, are in the process of reviewing existing CMS products for potential inclusion in state planning (e.g., Tang et al., 2021, Ma et al., 2021). One state, Maryland, also has a partnership with World Resources Institute (WRI) in the use of their tool to estimate avoided carbon emissions due to forest conservation and has formed relationships with USDA and the U.S. Department of Energy (DOE) relative to an ongoing climate impacts study.

At least four states (Maryland, New Hampshire, New Jersey, and Delaware) use LULUCF data derived from the SIT in either their plans or inventories. One state, New Jersey, uses default IPCC estimates in addition to those from SIT. Three states (Rhode Island, Connecticut and Massachusetts) utilize literature values that are either prepared by third party contractors (grey literature) or published in peer-reviewed journals. New Hampshire, while utilizing ecosystem modeling and field data within their Climate Action Plan, has since returned to using SIT as their primary science approach.

2.3.7 Forest carbon science needs

All states expressed a need for more data and/or tools to advance their forest carbon science relative to climate mitigation planning (Figure 2-9). Four states (Vermont, Connecticut, Rhode Island, New Jersey) have explicitly asked for more reliable and higher confidence LULUCF data across the spectrum of use. New Jersey has also asked for improved measurement and verification methods. Four other states have explicitly noted the need for higher resolution data on forest carbon sequestration (New York and Vermont) and carbon sequestration potential (Pennsylvania and Rhode Island). Four states (Maryland, Delaware, Vermont and New Jersey) have asked for improved annual carbon flux monitoring capabilities. Maine and Pennsylvania are also interested in improved monitoring capabilities to better detect tree canopy changes. Three states (Maine, Massachusetts and Connecticut) have also indicated a specific interest in better utilizing remote sensing technologies to improve forest carbon estimates (including lidar); especially with reference to capturing urban trees (sometimes also referred to as “trees outside of forests”). One state, New Hampshire, is interested in improved valuation of ecosystem services, inclusive of forest carbon. And, one other state, Maine, is interested in harnessing integrated ecosystem modeling.

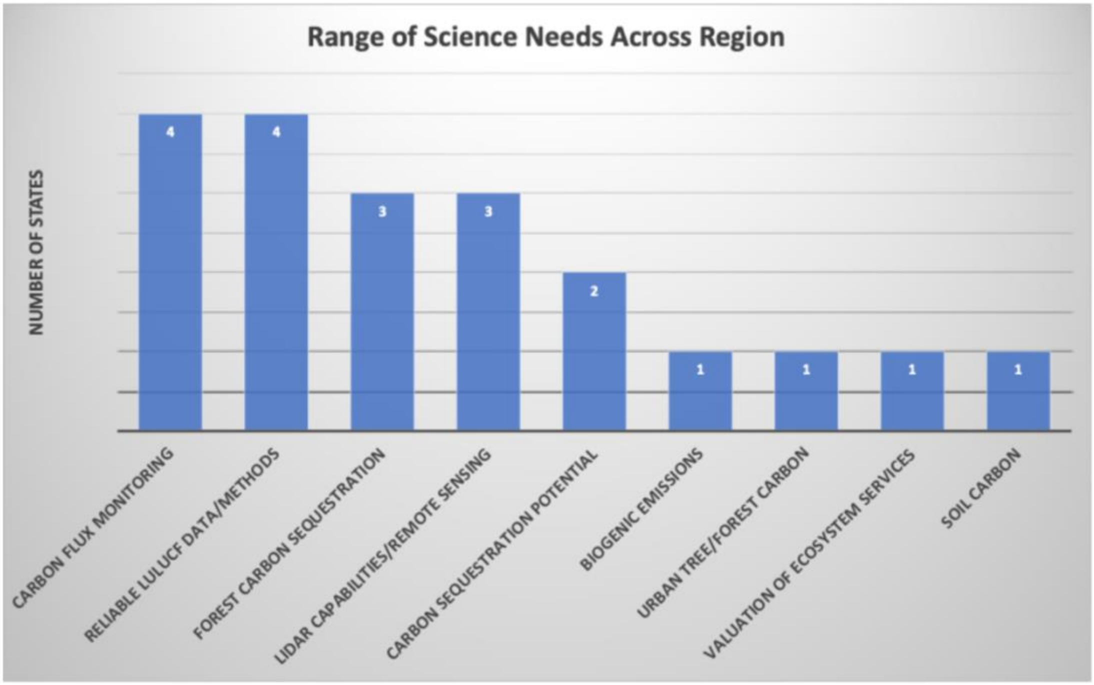


Figure 2-9: Frequency of reported science needs by states. Reported attributes of such science includes reliable, annual, and consistent data and methods.

2.3.8 Forest carbon science and policy relationships

Eight out of eleven states show commensurate levels of policy inclusion (section 2.3.5) and scientific support for forest carbon estimates (section 2.3.6) (Figure 2-10). For example, Connecticut and Rhode Island do not currently include or regularly track forest carbon estimates relative to achieving their GHG reduction goals and also maintain a default scientific strategy for estimating their current carbon sink. Similarly, Maine, New York, Delaware heavily utilize USFS FIA sample-based data to track forest carbon stocks and fluxes across their states, but do not include forest activities within their GHG inventories. Maryland and Pennsylvania include forest carbon activities towards their GHG goals and utilize sample+ scientific strategies such as high-resolution models and continuous statewide field inventories.

Two states functioning with higher levels of policy inclusion relative to existing scientific support include New Jersey, which fully includes forest activities towards established GHG goals, but primarily utilizes default data, and New Hampshire, which did include sample+ methods in their climate action plan but has since reverted to using default methods via SIT to track, but not include, forest activity towards their GHG goals. The final state, Massachusetts, utilizes sample+ scientific strategies, but currently tracks forest carbon estimates separately rather than directly within their GHG inventory.

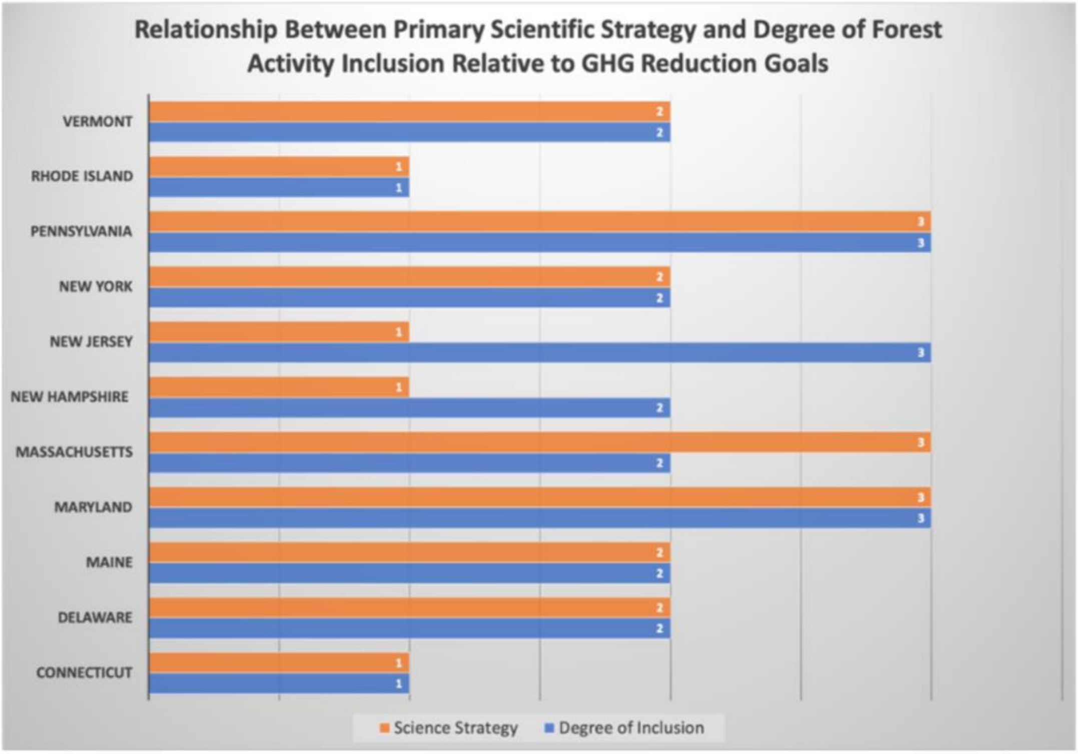


Figure 2-10: State-by-state relationships between the degree to which forest activities are included towards greenhouse gas (GHG) emissions reduction goals and the primary scientific strategy employed to generate related forest carbon estimates. Science Strategies (1-Default, 2-Sample, 3-Sample+). Degree of Inclusion (1-Not Included, 2-Not Included, Tracked, 3-Included). Where levels are the same, scientific and policy support are considered to be commensurate.

2.4 Discussion and conclusions

In this paper, we evaluated the current context for integrating forest carbon into state climate mitigation planning and identified opportunities for more systematic development and application of new forest carbon monitoring strategies. Our review showed that all states in the RGGI region have developed core climate mitigation planning documents relative to mandated GHG emissions goals, even as some states like New York and Delaware are still developing comprehensive climate action plans. Further, all such planning documents provide at least one reference to maintaining or increasing forest carbon benefits in recognition of its value to overall climate mitigation efforts. These references, coupled with active participation in the NASA CMS MSWG and USCA NWL Challenge, demonstrate the region's commitment towards including and improving estimates of land sector carbon in their planning. However, our results also emphasize considerable variability across the region. Notably, three-quarters of all states in this region do not count forest activities towards their GHG reductions goals, with the most common reason for exclusion surrounding ongoing data needs that extend beyond current national inventory tools. Furthermore, those that do attempt to quantify and track forest carbon estimates, utilize a range of scientific tools and data. Given the pattern of increasing variability in the region, we suggest that an enhanced common forest carbon monitoring system would provide important benefits for states already poised for ongoing regional collaboration.

2.4.1 Similarities, differences, and remaining challenges

Our regional analysis highlights several important patterns. First, most states provide general guidance on the importance of forest protection and restoration relative to climate mitigation but do not offer specific and quantitative forest carbon goals. Of the eleven states, only Maryland and Massachusetts have outlined specific planned activities that are to be directly implemented by state agencies. These activities, such as expanded urban tree planting, have correlating estimates of expected carbon sequestration in the years between plan implementation and GHG goal achievement. The remaining states are split near evenly between those that provide an array of options for potential adoption from those that provide general recommendations for future agency consideration. While this lack of detail may be reflective of perceived uncertainties in the available data, it also presents a challenge for anticipating the full emissions impacts of integrating forest and tree activities into climate mitigation planning.

Second, while all planning documents mention the importance of forest conservation and restoration for climate mitigation, nearly three-quarters of all states do not currently count forest carbon towards their GHG reduction goals. The relationship between plans and inventories can be complicated. Planning documents and inventories across the region are often completed on different time intervals, sometimes based on legislative or executive mandate, sometimes simply based on how much time the responsible agency requires to complete them. In some cases, a state may have a GHG inventory but no established or regularly updated climate action plan. In others, a state may have climate action plans with forest carbon goals, but not directly track forest carbon changes within their inventory. However, the number of states in the region who do not fully integrate net forest carbon emissions relative to GHG goals underscores concerns about access to reliable and regularly updated forest carbon data and how such data can be used to plan for and secure verifiable reductions in carbon emissions.

Third, most states are still using default factors and sampling-based methods to generate current forest carbon estimates. The referenced resources within state plans are often reflective of the type of scientific information made available to the state at the time the documents were created. Some plans have not been updated since the early-to-mid 2000s, and there may be scientific strategies being advanced by state agencies and their partners that are not currently represented in official government documentation. Only one state in the region (Maryland) currently utilizes high-resolution forest carbon modeling to inform their climate mitigation planning, suggesting more opportunity for expanded capacity in this area. This is especially important as current sample-based inventory methods used across the region (i.e., USFS FIA or State Continuous Forest Inventories) are not consistently used for spatially-explicit projections of future ecosystem dynamics over the full range of scales that are relevant to decisionmakers. Many sample-based methods that cover broad areas also tend to focus more on forests and to exclude trees outside of forests, leading to incomplete assessment of current and projected forest carbon stocks and fluxes across a heterogeneous landscape.

The pressure to better couple policy drivers and science solutions has been bi-directional. In some cases, policy mandates require agencies to develop improved scientific and technological strategies in order to achieve compliance, such as in New Jersey. On the other hand, improvements in scientific capabilities may spur greater inclusion of forest carbon within existing mitigation and planning frameworks, such as in Maryland. Commensurate levels of science sophistication and policy support within most states in the region suggests a general awareness of current capabilities and regular coordination across state governmental agencies and offices. Further, all states in the region have GHG reduction goals and have indicated an interest in improving their forest carbon science relative to climate mitigation planning, as evidenced by the range of data, tools, and methods requested by states; specifically, higher resolution and spatially explicit forest carbon estimates. However, the pace at which new science and technologies are embraced by individual states, is and likely will remain variable if primarily dependent on state resources.

2.4.2 Implications of current patchwork of approaches

Given the variety of approaches across the region, a default option would clearly be for each state to continue developing its own separate forest carbon planning and monitoring strategies. This strategy retains flexibility in terms of design and implementation across a diverse coalition of states and does not require additional resources or coordination. Some states which are more heavily urbanized, such as Rhode Island, may wish to focus extensively on science which allows for improved estimates of urban tree canopy and related carbon impacts, while more heavily forested states, like Maine, may wish to focus on forest carbon estimates which reflect the lifecycle of carbon related to biomass production or include the carbon storage implications of durable wood products. Maintaining the current patchwork of approaches also allows states with higher levels of access to improved science and technologies to integrate such tools into their own climate planning regardless of other state positions or policies. Further, diverse approaches to forest carbon integration across the region could result in more experimentation and potentially, innovation—and thus could also provide an increasing suite of options and choices for states to selectively implement based on perceived need, and on their own policy timetables.

Maintaining the current, uncoordinated approach, however, has significant limitations. First, those states who do not track forest carbon as part of their GHG reduction strategies cannot adequately plan for forest carbon activities, as it is unworkable to manage well what you do not measure. This means that even if states engage in separate forestry or reforestation planning, strategic afforestation and reforestation initiatives will remain decoupled from larger climate mitigation goals without quantified carbon estimates. While federal investment in the USFS's FIA program and its inclusion within USEPA SIT has sought to provide states with a common basis for LULUCF inclusion within inventories, many states have chosen not to use this data to inform their planning, let alone within their inventories. Second, the splitting of individual state efforts has also resulted in regional scale inefficiencies, with each state investing time and money into building their own carbon monitoring systems with varying levels of scientific quality, institutional robustness, and direct applicability to planning. Such a mix of methods and approaches also makes it difficult to compare or combine carbon estimates across the region, restricting opportunities to include forest carbon into broader carbon trading efforts, especially among states already invested in such collaboration via RGGI.

2.4.3 Future directions towards a shared forest carbon monitoring system

A common carbon monitoring system that more heavily relies upon the detailed information content of high-resolution imagery and lidar could address some of these limitations. It would also provide important benefits to states, and also eventually to national planning processes within the U.S. and in other countries. A common system would allow for a direct comparison of forest carbon strategies across the region, provide for the scientific needs of all states, and operate more efficiently than multiple systems. The specific attributes of such a shared system need to be further developed by the states, but several aspects of such a system are evident. The attributes of such a system need to meet state needs for baseline reporting, future planning, and annual monitoring. Specifically, our analysis shows that states have already identified a need for high spatial resolution georeferenced capabilities, transparent methods, reliable and consistent data updates, streamlined integration with GHG baseline years, and an ability to capture trees outside of forests. Any proposed system should also endeavor to remain consistent with the IPCC's methodological guidelines for inventory accounting (IPCC 2008, 2019).

Coalitions like MSWG, RGGI, and USCA have provided a forum for states to share best practices and pursue joint research in support of finding or supporting the best technology and science available. With at least four ongoing USCA NWL research projects in the region, this collaboration will remain important for supporting improved carbon sequestration planning on natural and working lands, which are still excluded from half of all current GHG inventories in the region. However, individual projects must ultimately be leveraged towards a shared system to maximize the policy-relevance of scientific improvements. Ongoing collaboration among federal and state agencies, non-governmental organizations, and academic institutions is critical to this process and together, these institutions can provide the components needed for a shared regional approach to forest carbon planning and monitoring.

Chapter 3: Geospatial assessment of the economic opportunity for reforestation in Maryland, USA

Abstract

Afforestation and reforestation have the potential to provide effective climate mitigation through forest carbon sequestration. Strategic reforestation activities, which account for both carbon sequestration potential (CSP) and economic opportunity, can provide attractive options for policymakers who must manage competing social and environmental goals. In particular, forest carbon pricing can incentivize afforestation on private land, but this may require landholders to forego other profits. Here, we utilize an ambitious geospatial approach to quantify economic opportunities for reforestation in the state of Maryland (USA) based on high-resolution remoting sensing, ecosystem modeling, and economic analysis. Our results identify spatially-explicit areas of economic opportunity where the potential revenue from forest carbon outcompetes the expected profit of existing cropland at the hectare scale. Specifically, we find that under a baseline economic scenario of $20 per ton of carbon (5% rental rate) and decadal average crop profitability, a transition to forest on agricultural land would be more profitable than 23.2% of cropland in Maryland under a 20-year land-use commitment. Accounting for variations in carbon and crop pricing, 5.5% to 55.4% of cropland would be immediately outcompeted by expected forest carbon revenue, with the potential for an additional 0.5% to 10.6% of outcompeted cropland within 20 years. Under the baseline economic scenario, an annual allocation of $5.8 million towards a carbon rental program could protect 6.93

Tg C (3.4% of the state's remaining CSP) on reforested croplands. This moderate yearly cost is equal to 9.7% of Maryland's average annual auction proceeds from participation in the Regional Greenhouse Gas Initiative (between 2014-2018), and 19.3% of the average annual subsidy payments for corn, soy, and wheat allocated over the same period. This methodological approach may be useful for state governments, not-for-profit organizations, or regional climate initiatives interested in identifying strategic areas for reforestation.

3.1 Introduction

Forests are important ecosystems that provide a broad range of ecosystem services, including carbon storage and climate change mitigation. In this context, multiple national and international commitments have been launched to not only protect forests (e.g., REDD+) but also to restore them. In early 2019, the UNEP and FAO launched the "Decade of Ecosystem Restoration 2021-2030" recognizing a global window of opportunity for forest restoration to offset serious concerns around climate change and biodiversity loss (UNEP, 2019). In mid-2020, the World Economic Forum launched the One Trillion Trees initiative (1t.org), designed to support the UN Decade on Ecosystem Restoration with a platform for connecting leading governments, businesses, civil society, and ecopreneurs committed to conserving, restoring, and growing one trillion trees globally.

Over the next decade, improved carbon accounting and land-use planning will be critical for the long-term success of these and other afforestation initiatives. The first step to forming a cohesive carbon monitoring, reporting, and verification (MRV) system is an accurate assessment of current carbon stocks. In particular, 3-D structure information on vegetation acquired from lidar remote sensing has helped provide by far the most accurate forest estimates across broad geographical extents (e.g., Dubayah & Drake, 2000; Dubayah et al., 2010). High-resolution carbon maps (~30m) can be generated from airborne lidar data at county, state, and regional levels (Huang et al., 2015, 2019; Tang et al. 2021), while several coarser resolution (90 m - 1km) continental-scale maps of vegetation height and biomass have been produced from spaceborne lidar (NASA's ICESat/GLAS) with the aid of many ancillary datasets (Simard et al., 2011; Saatchi et al., 2011). NASA's Global Ecosystem Dynamics Investigation (GEDI) advances this work by providing near-global 1km gridded estimates of forest canopy height, vertical canopy structure, and surface elevation to improve our knowledge of global carbon stocks (Dubayah et al., 2020).

Moving from current conditions to carbon sequestration potential, NASA Carbon Monitoring System (CMS) projects are utilizing this remote sensing data (optical and lidar), coupled with prognostic ecosystem modeling and existing field observation systems, to predict carbon fluxes and produce high-resolution estimates of forest carbon sequestration potential (e.g., Hurtt et al., 2019, Ma et al., 2021). Since the resolution of these products is 90m, more than 100,000 times that of many global vegetation models, it is now possible to project sequestration outcomes at fine spatial scales with potential applications for land-use planning. In particular, these science products help us understand the spatial heterogeneity of carbon sequestration potential and clarify the time in years to achieve such potential.

Given the availability of high-resolution data on both current carbon stocks and sequestration potential, the next geospatial and computational challenge is to identify priority areas for afforestation/reforestation. Strategic reforestation activities, which account for both carbon sequestration potential and co-benefits, such as economic opportunity, can provide attractive options for policymakers who must manage competing social and environmental goals (Jackson & Baker 2010). To be most useful, the socio-economic potential of reforestation must be quantified with respect to land ownership and follow a multi-factor approach to better capture co-benefits and trade-offs in the planning process (Smith et al., 2013). For example, decision-making around sustainable land allocation, particularly between forest and cropland, would benefit from spatially explicit information on the land-use implications of a price on forest carbon. Such analysis could inform private landowners, in how they might manage their property, as well as policymakers, who may establish policies and programs to financially incentivize particular land-use changes.

In the United States, the most mature carbon pricing schemes, such as the Regional Greenhouse Gas Initiative (RGGI), have focused exclusively on CO_2 emissions from coal-fired power plants. Between 2015-2020, RGGI allowances have generally traded between $4-$6 per ton of CO_2e, with efforts to decrease overall emissions by reducing the total number of permits allocated over time (RGGI, 2020). The mechanics of including land-based carbon within existing cap-and-trade systems may be complicated, but current high-resolution carbon monitoring and modeling products provide an unprecedented opportunity for doing so at policy-relevant scales.

In lei of a regional forest carbon trading scheme, individual states could utilize other pricing frameworks such as direct carbon payments to incentive reforestation as a nature-based climate solution (Fargione et al., 2018).

Unlike cap-and-trade programs, forest carbon payments have traditionally been envisioned and applied either in the form of carbon rental policies or policies where carbon compensations are based on subsidies and taxes (Nepal et al., 2013, Lintunen et al., 2016). While there are benefits to both models, rental models are considered more politically and economically expedient as the money transfers are always from the administrator to the forest owner (Lintunen et al., 2016). Carbon rental fees provide an opportunity to compensate individual landowners for the social benefits of carbon sequestration while incentivizing landowners to maximize standing biomass and avoid intentional reversal of tree cover throughout a long-term renewable contract. While many land-use types may remain economically competitive with a price on forest carbon, agricultural land will be of particular interest (e.g., Smith et al., 2013). While some US states have worked to prevent the conversion of prime agricultural land to other land-uses (particularly development), there may also be a unique potential to maximize the afforestation of marginal lands, areas where field crops maintain low productivity due to erosion or other environmental risks when cultivated (e.g., Gelfand et al., 2013; Kang et al., 2013).

Here, using high-resolution NASA Carbon Monitoring System (CMS) forest carbon products for Maryland (USA), we quantify and map the economic potential of afforestation/reforestation relative to cropland profit under a carbon pricing system. To estimate the economic opportunity provided by reforestation, we use a rental economic model, which includes an annual rental rate as a function of carbon price. To understand the land-use implications of this system, we evaluate 1) where the economic opportunity for reforestation is highest across the state, 2) how carbon price and rental rate influence the amount of cropland area that becomes outcompeted by expected forest carbon revenue, 3) the year at which projected forest carbon revenue outcompetes expected cropland profit at the landowner scale, and 4) the impact of agreement length on overall competition. Under a range of economic scenarios, we also consider the amount of carbon likely to be sequestered and the cost to implement such a program via individual land-use agreements. We demonstrate with an ambitious geospatial approach that the spatial and temporal heterogeneity of carbon sequestration potentials can be combined with economic data to support strategic land-use planning at the state and county levels.

3.2 Data and methods

3.2.1 Study Area

The state of Maryland (USA) provides an excellent study area for this prototype project due to its land-use history and strong climate mitigation goals. The dominant potential vegetation type for the state is deciduous forest (Ramankutty & Foley, 1999). Due to widespread human-induced land cover and land-use change, the landscape is characterized by fragmented forests with considerable opportunity for restoration. Depending on forest definition and method, forest covers 33-41%, and croplands account for 32% of the land area (Jin et al., 2013; Lister & Widann, 2016). As with the majority of the US Eastern seaboard, 90% of Maryland was cleared of forest and converted to agriculture by the mid-19th century. These lands were converted partially back to forest in the early 20th century as agriculture's economic importance declined in the state. Significant quantities of forest were subsequently lost to development in the mid to late 20th century.

Currently, Maryland has legislation related to forestry and climate mitigation that actively inform land-use planning. The Forest Conservation Act was enacted in 1992 and strengthened in 2013 with the intent for “no-net-loss” of forests and to maintain forest cover above 40% in Maryland. The Greenhouse Gas Reduction Act (GGRA) was passed in 2009, directing the state to reduce climate pollution 25% by 2020 and create a Greenhouse Gas Reduction Plan. In 2016, the GGRA was reauthorized and strengthened to a 40% reduction by 2030, requiring an updated plan with improved afforestation goals. The draft plan was released in October 2019, focusing, among other things, on improving the carbon management of farms and forests. As a member of the US Climate Alliance, Maryland has also participated in the Natural and Working Lands (NWL) Challenge, which commits states to maintain NWLs as a net carbon sink (USCA, 2020a).

3.2.2 NASA Carbon Monitoring System products

The foundational forest carbon sequestration products for this study were derived from the Ecosystem Demography model (ED) (Moorcroft et al., 2001; Hurtt et al., 2004), and previously published in Hurtt et. al 2019 as part of the NASA Carbon Monitoring System (CMS). Here, the forested fraction of every 90m grid cell is estimated circa 2011 using statewide airborne lidar and NAIP optical imagery (O’Neil-Dunne, 2019). The forested fraction is then held constant throughout the model projection such that the biomass density in any 90m grid cell over time is the area-weighted sum of carbon accumulated on contemporary forest area, and forest carbon accumulated on previously non-forested areas (e.g., via new plantings). Following definitions in Hurtt et al. 2019, carbon sequestration potential (CSP) is defined as 95% of the maximum aboveground biomass a site reaches during forest succession. In computing these potentials, all non-forest area could theoretically be reforested, excluding wetland and impervious surface. The carbon sequestration potential gap (CSPG) is defined as the difference between CSP and current carbon stocks (aboveground biomass or ABG). The carbon sequestration potential time gap (CSPTG) is defined as the number of years it takes to go from AGB to CSP.

3.2.3 Land cover and ownership

To understand existing spatial patterns of land-use, all 90m carbon sequestration data layers were stratified by land use classifications to identify those with the largest carbon stocks and highest CSP. The Maryland Department of Planning provided spatial polygon data (2015/16 edition data) for all property parcels in the state, including attribute data such as zoning and land-use designations (MDP, 2020). Zoned agricultural areas can include both annual crops as well as woodland that is either associated with a farm, part of an approved forest plan, or protected within a forest conservation management agreement. Zoned agricultural areas are also classified as private land areas, as they are distinct from tax “exempt” government-owned properties.

3.2.4 Crop productivity and profitability

We established a baseline case for crop profitability in Maryland, assuming no annual change in crop productivity (yield), revenue, profit, or spatial distribution of crop type through 2100. First, the grid cell fraction of soybean, wheat, and corn was estimated using the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) Cropland Data Layer (CDL) (USDA, 2011). We used 2011 CDL data to match the date of the NASA CMS tree canopy cover product. In this year, wheat, soybean, and corn collectively represented 13.3% (330,031 ha) of Maryland's land area. As CDL categorically assigns crop types at 30m, we estimated the crop fraction by counting the number of 30m pixels of soybean, corn, and wheat within the 90m grid; no 30m pixel had more than one crop identification. The tree canopy fraction layer was considered dominant, such that in any case where the sum of the tree canopy fraction and the crop cover fraction was greater than one (e.g., greater than 100%), the total crop fraction for each 90m pixel was reproportioned to equal the difference between the tree canopy fraction and one.

The average productivity of three focus Maryland crops (corn, soy, and wheat), were calculated using information on agricultural yield provided by USDA NASS and Maryland Department of Agriculture (USDA, 2019). Average annual yield data was reported from 2010 to 2019 for all three crop types across 23 counties in Maryland (excepting Baltimore City) in bushels per acre. For each county, we calculated the average decadal yield per crop type. Crop yield was subsequently multiplied by the respective crop fraction within each 90m pixel and converted from acres to hectares to estimate the total number of bushels per hectare over cropland area. To better account for property-scale variation, the yield in each 90m pixel was multiplied by the National Commodity Crop Productivity Index (NCCPI) value (range from 0-1) in that same grid cell and subsequently divided by the average NCCPI value calculated for the county; yields that were greater than the county average were multiplied by a factor greater than one and yields that were less than the county average were multiplied by a factor less than one.

Crop revenue was calculated as a function of crop yield and crop price. Crop pricing data was obtained from the USDA NASS and State of Maryland Annual Agricultural Overview, which provides a single annual market price for corn, soybeans, and wheat in USD per bushel from 2010-2019 (USDA, 2019). Similar to crop yield data, we calculated the decadal average price for each crop type. Crop revenue was estimated for each 90m pixel by multiplying the respective crop yield value by the average market price.

Crop profit is equal to crop revenue minus production costs, plus crop subsidies. For all three crops, the total cost per hectare was estimated using the University of Maryland Crop Extension Budgets for 2018 (Dill et al., 2017). Extension budgets include a range of variable and fixed costs to estimate economic returns at a given yield and market price (Tables B1, B3 and B3). We held most crop costs constant across space using the Extension Office's default budgets for Roundup Ready Soybeans, Conventional Corn Grain, and Soft Red Winter Wheat. Only yield-dependent variables, such as hauling charges, were adjusted for each grid cell relative to NCCPI-adjusted 90m yield estimates. Custom charges for field operation costs include charges for equipment, labor, repairs and maintenance, and fuel/lube for that practice**.**

Average county-level crop subsidies were obtained via the Environmental Working Group (EWG) Farm Subsidy Database (EWG, 2018). The EWG is a non-profit organization that utilizes Freedom of Information Act (FOIA) requests to obtain data on farm subsidies directly from the USDA. Subsidy data was reported by crop type and county and comprised four elements: commodity programs, crop insurance subsidies, conservation programs, and disaster programs. We used 2018 data to reflect recent payments under the 2014 Farm Bill (Agricultural Act of 2014). The first year of payments under the 2018 Farm Bill had not yet been released at time of publication. For each crop type, we generated 90m subsidy payments by first dividing total crop subsidies (USD) in each county over the total number of hectares in production and then multiplying that number by the crop fraction.

3.2.5 Rental model for forest carbon

The rental model for forest carbon included a carbon price and rental rate that remained temporally constant. The carbon price was set at \$20/Mg C in the baseline rental scenario, which is broadly consistent with recent trading prices within the Regional Greenhouse Gas Initiative (i.e., \$4.50 per short ton of CO_2 in 2018). The rental rate, which represents the proportion of the total forest carbon stock value rented in any given year, was set for 5 percent. Between 2011 and 2100, annual carbon revenue was quantified and mapped for each 90m grid cell (e.g., USD/Mg C/ha/year) by multiplying modeled forest AGB by the rental model. We considered all forest carbon as eligible for rental, including both trees that existed on the 90m grid as of 2011 and trees that could potentially be planted on the remaining non-forest area between 2011 and 2100.

3.2.6 Land-use competition

Finally, we estimated the locations and years at which projected forest carbon revenue outcompeted expected cropland profit. For each year between 2011 and 2100, we compared the cumulative forest carbon revenue of every 90m pixel against the cumulative cropland profit expected on that same 90m pixel. If there was more than one crop type within the same 90m grid cell, all crop profits were summed to report a single crop profit value. Where forest carbon revenue exceeded cropland profit, we flagged the pixel as outcompeted and recorded the year this occurred. In instances where cropland was immediately outcompeted by forest carbon revenue in 2011, we expected relatively low crop profit and existing trees (e.g., non-zero AGB) within the same 90m grid. Where forest carbon revenue never outcompeted cropland, we expected very high crop profit such that even as trees grew to maximum potential, total forest carbon revenue would never exceed crop profit under the current rental scenario.

3.2.7 Sensitivity analysis

We tested the sensitivity of these results using multiple carbon rental and crop pricing scenarios. First, we generated twenty rental factors between 0.5 and 10 to represent the product of multiplying a given carbon price by the rental rate (e.g., a rental factor of 1 represents our baseline carbon rental scenario at $20/Mg C multiplied by the 0.05 rental rate). Second, we identified the minimum and maximum market price (USD/bushel) for all crop types over the past decade (2010-2019). We then generated twenty crop pricing scenarios between these bounds with the price of all three crop types increasing or decreasing in the same direction (e.g., with $4.90/$10.04/$5.27 per bushel representing our baseline crop pricing scenario for corn, soybeans, and wheat, respectively). We subsequently re-ran our competition analysis across all 400 economic scenarios (e.g., 20 rental and 20 crop pricing scenarios). Finally, we tested the sensitivity of changing crop subsidies on overall competition in the baseline economic scenario using two bounding cases. In case one, we removed all subsidies, and in case two, we doubled all subsidies.

3.3 Results

3.3.1 Land cover and land use

Across 24 counties in Maryland, there are approximately 2.35 million distinct land parcels, with an average property size of 4.2 ha. Nearly three-quarters of the state's land area is zoned as either agricultural (48.1%) or residential (25.7%). Statewide, 38.2% of current aboveground biomass and 55.5% of the carbon sequestration potential gap (CSPG) is found on agricultural land, at 42.38 Tg C and 113.37 Tg C, respectively (Figure 3-1). Agricultural land has the highest CSPG of any zoned land-use classification in the state.

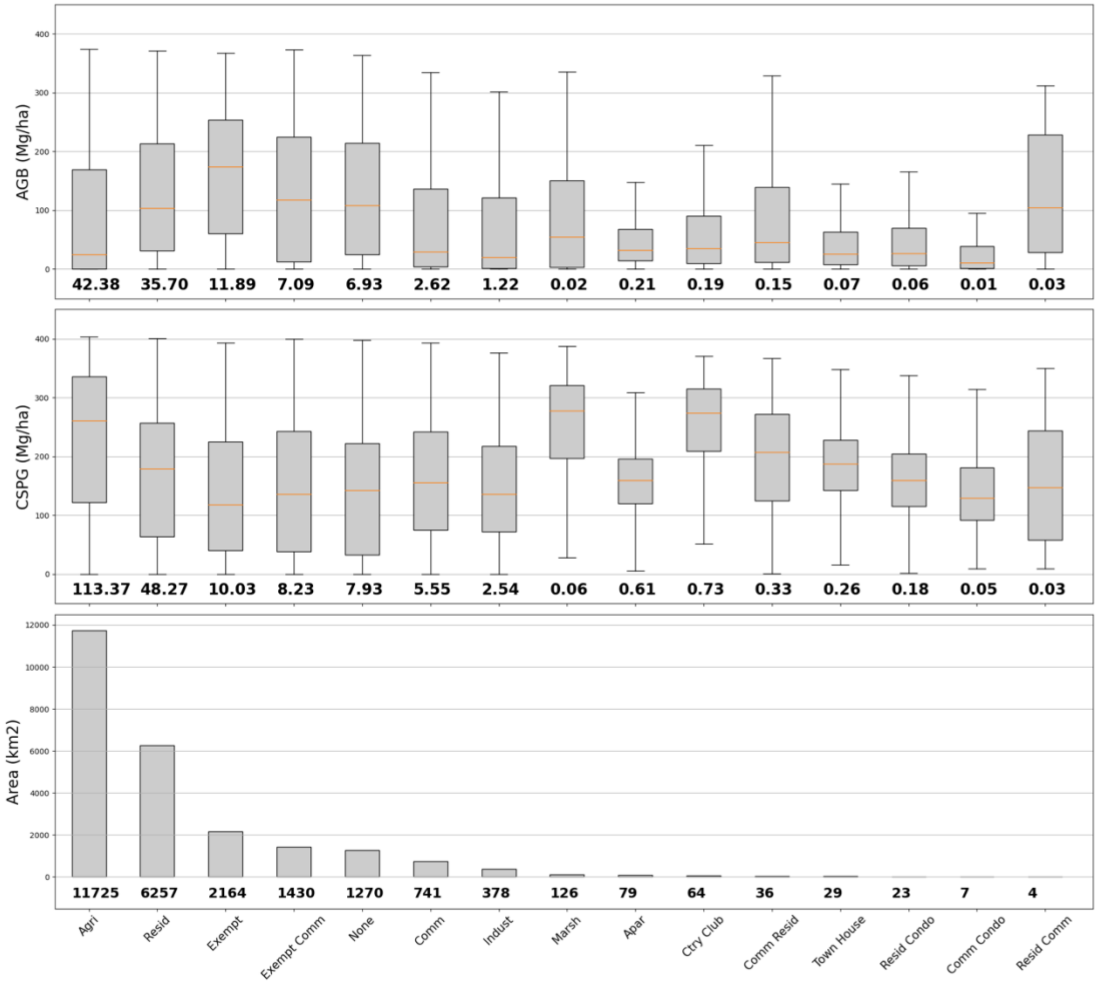


Figure 3-1: Total land area (km2) by land-use classification statewide, with corresponding box-and-whisker plots of contemporary aboveground biomass (AGB, Mg/ha) and estimated carbon sequestration potential gap (CSPG, Mg/ha). Total AGB and CSPG in Tg C are listed in bold under each respective classification.

3.3.2 Crop productivity and profitability

Under the baseline crop pricing scenario, crop yield, revenue, and profitability varied spatially and by crop type. Crop yield, scaled by soil productivity and adjusted by crop fraction, ranged from 0.39-562.03 bushels per 90m for corn (Figure B-1), 0.12-172.93 bushels for soy (Figure B-2), and 0.26-273.32 bushels for wheat (Figure

B-3). Crop revenue varied with yield, ranging from \$0 to \$2690 per 90m for corn, \$0 to \$1734 for soy, and \$0 to \$988 for wheat (Figure 3-2a). Geographically, high revenue areas were distributed across the state, with concentrations along the eastern seaboard and Frederick, Carroll, and Washington Counties in north-central Maryland (Figures B-4a, B-5a, and B-6a). Average crop subsidies ranged from \$0 to \$100 per 90m for corn, \$0 to \$194 for soy, and \$0 to \$19536 for wheat (Figure 3-2b). The highest wheat subsidies were concentrated in Talbot County, located in southeastern Maryland, while the highest corn and soy subsidies were found in Frederick and Kent Counties, respectively (Figures B-4b, B-5b, and B-6b). The cost of crop production ranged from \$10 to \$1340 per 90m for corn, \$7 to \$730 for soy, and \$11 to \$886 for wheat (Figure 3-2c), with production costs generally following the spatial pattern of crop revenue (Figures B-4c, B-5c, and B-6c). Finally, crop profit, a function of revenue, cost, and subsidies, ranged from \$-623 to \$1350 per 90m for corn, \$-526 to \$1005 for soy, and \$-635 to \$211 for wheat (Figure 3-2d). While crop profits were overwhelmingly positive and widely distributed across the state, negative profits were also found throughout, with the highest concentrations in Wicomico (corn), Charles (soy), and Frederick Counties (wheat) (Figures B-4d, B-5d, and B-6d).

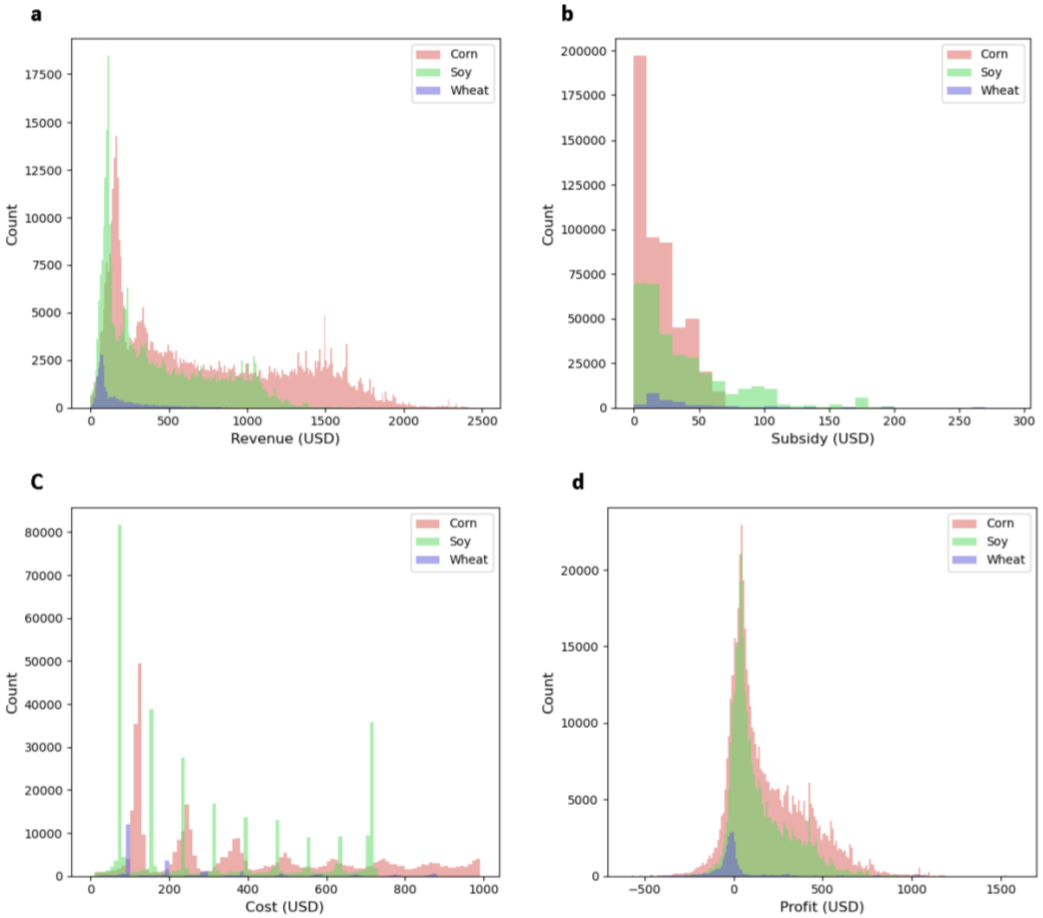


Figure 3-2: Statewide crop revenue (a), subsidies (b), costs (c) and profit (d) in USD per 90m under the baseline crop pricing scenario.

3.3.3 Forest carbon revenue

With a baseline carbon rental scenario of $20 per ton of carbon and a 5% rental rate, annual revenue from forest conservation and reforestation ranged from $0 to $151 (avg. $43.63) per 90m over twenty years, with the most profitable land areas representing areas with the highest AGB in any given year. In this way, the spatial pattern of forest carbon revenue followed the spatial heterogeneity of modeled AGB and annual carbon sequestration published in Hurtt et al. 2019 (Figure B-7). After 20 years, projected revenue increased to average annual payments of \$65 by 2050, \$73 by 2070, and \$80 by 2090 (Figure 3-3).

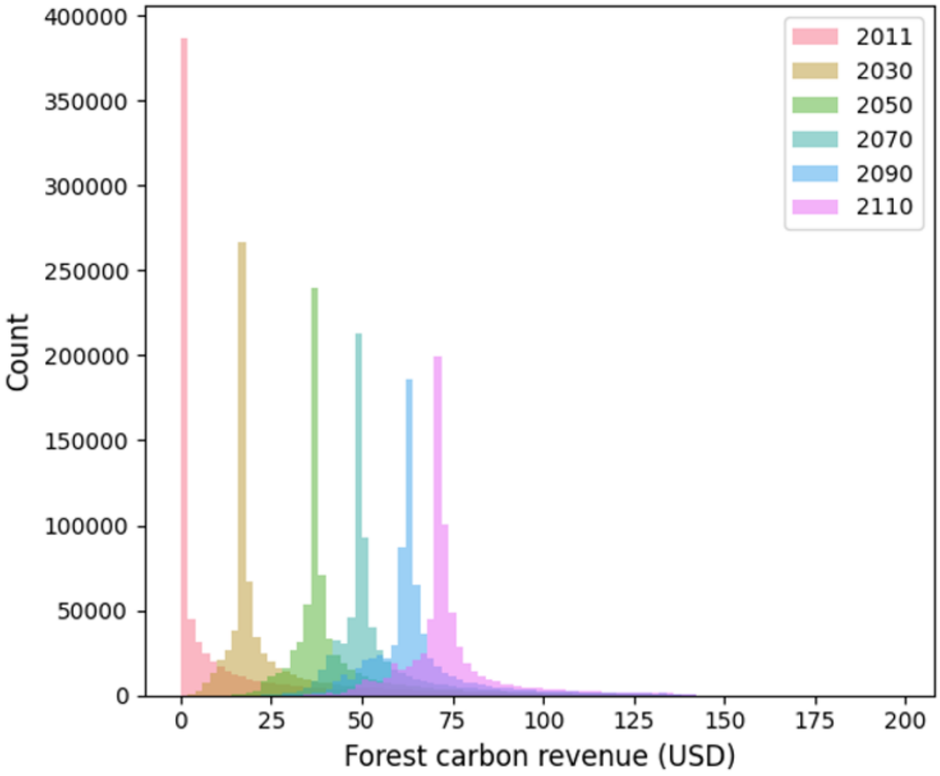


Figure 3-3: Statewide forest carbon revenue (USD per 90m) between 2011 and 2110 under the baseline carbon rental scenario.

3.3.4 Land-use competition and sensitivity analysis

Under the baseline economic scenario, 22.2% (1273 km^2) of cropland was immediately outcompeted by forest carbon revenue (Figure 3-4). With ongoing forest biomass accumulation, outcompeted cropland increased by 1% (52.2 km^2) to a total of 23.2% by 2030. Geographically, outcompeted lands were found in every county with the highest concentrations of immediately outcompeted cropland located in southeastern and south-central Maryland (Figure 3-5). If all outcompeted lands were reforested under a 20-year rental agreement, the state could expect to protect 6.9 Tg C at an average annual cost of $5.8 million.

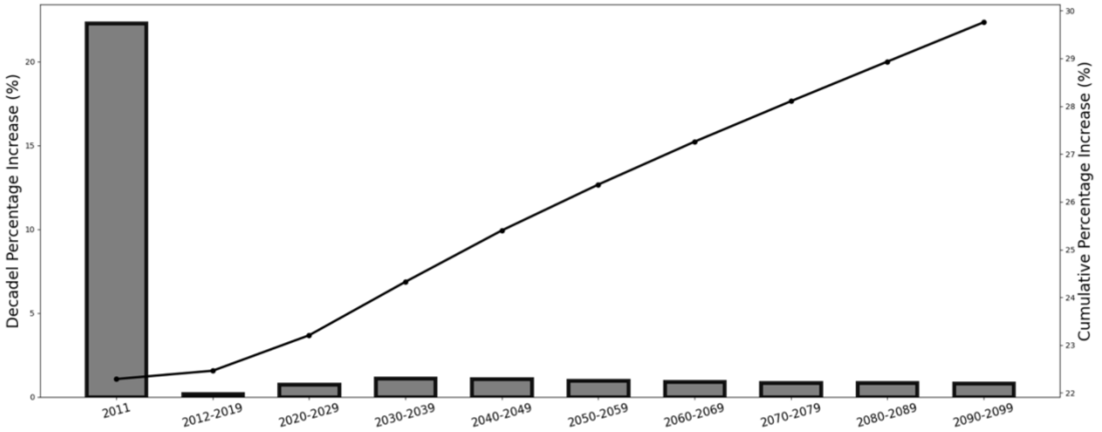


Figure 3-4: Proportion of Maryland cropland area outcompeted by forest carbon revenue under the baseline economic scenario immediately in 2011, and over each following decade from 2012 to 2100. Cumulative percentage increase is shown as the solid line, while the bars represent the percentage increase over the previous decade.

When the carbon rental scenario was fixed at the baseline, but crop prices were higher than the decadal average, the percentage of immediately outcompeted cropland declined to between 7.3-20.3%. Conversely, when crop prices were lower than the decadal average, immediately outcompeted cropland increased to between 24.6-44.1% (Figure 3-6). Under lower crop prices, the state could sequester an additional 0.5-4.4 Tg C over the 20-year rental period due to the increase in outcompeted cropland eligible for profitable reforestation. The cost to rent all outcompeted lands increased to between $6.2-8.9 million annually (Figure 3-7).

When crop prices were fixed, but the carbon rental factor was higher than the baseline scenario, the percentage of immediately outcompeted cropland increased to between 24.2-36.6% (Figure 3-6). An additional 1.9-7.1% of cropland was outcompeted by 2030. Correspondingly, the increase in outcompeted cropland could result in 7.8-12.1 Tg C sequestered by 2030 (between 12.5-175% higher than the baseline scenario), with the total annual cost of such payments increasing to between $9.9-98 million (Figure 3-7).

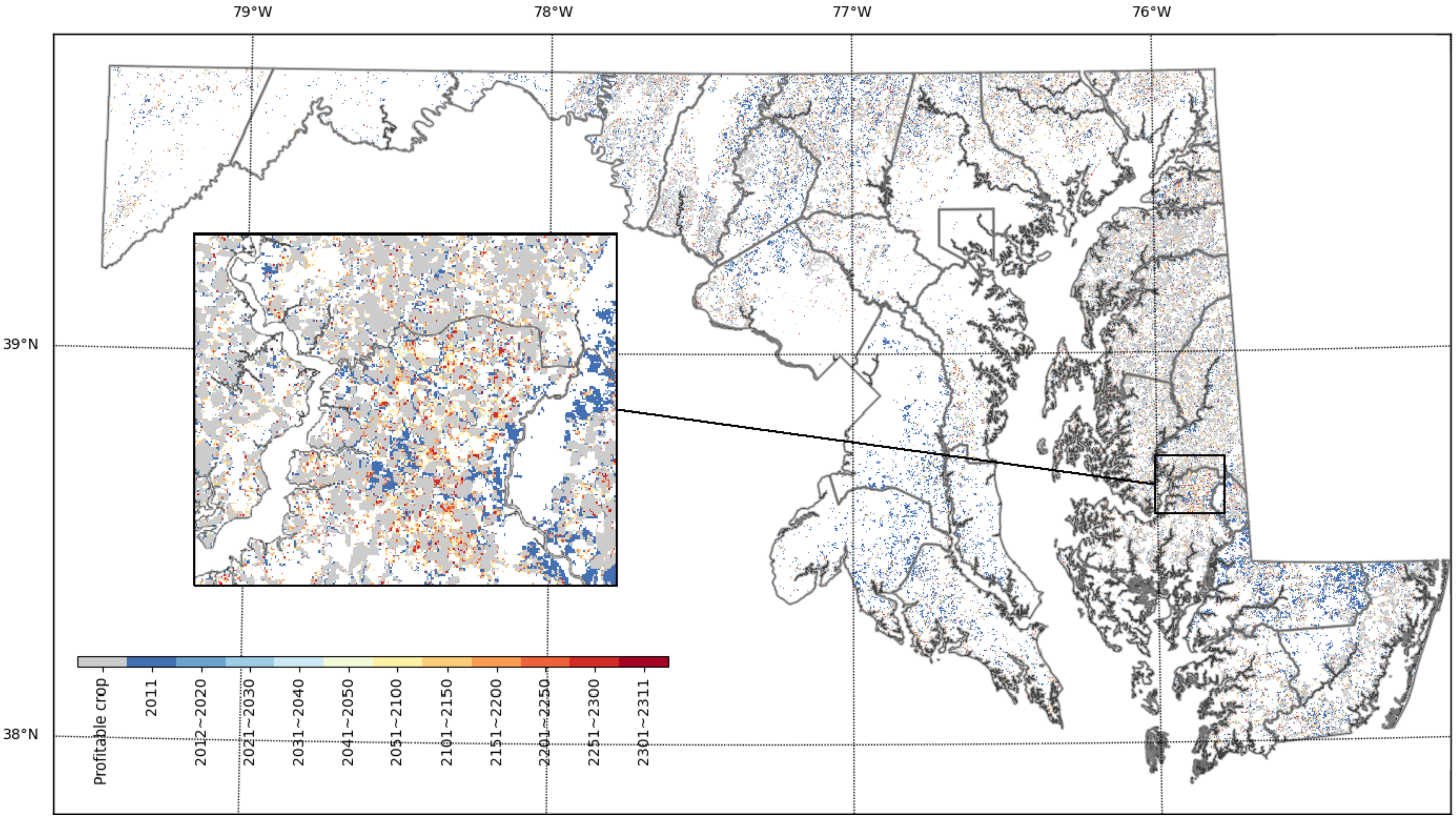
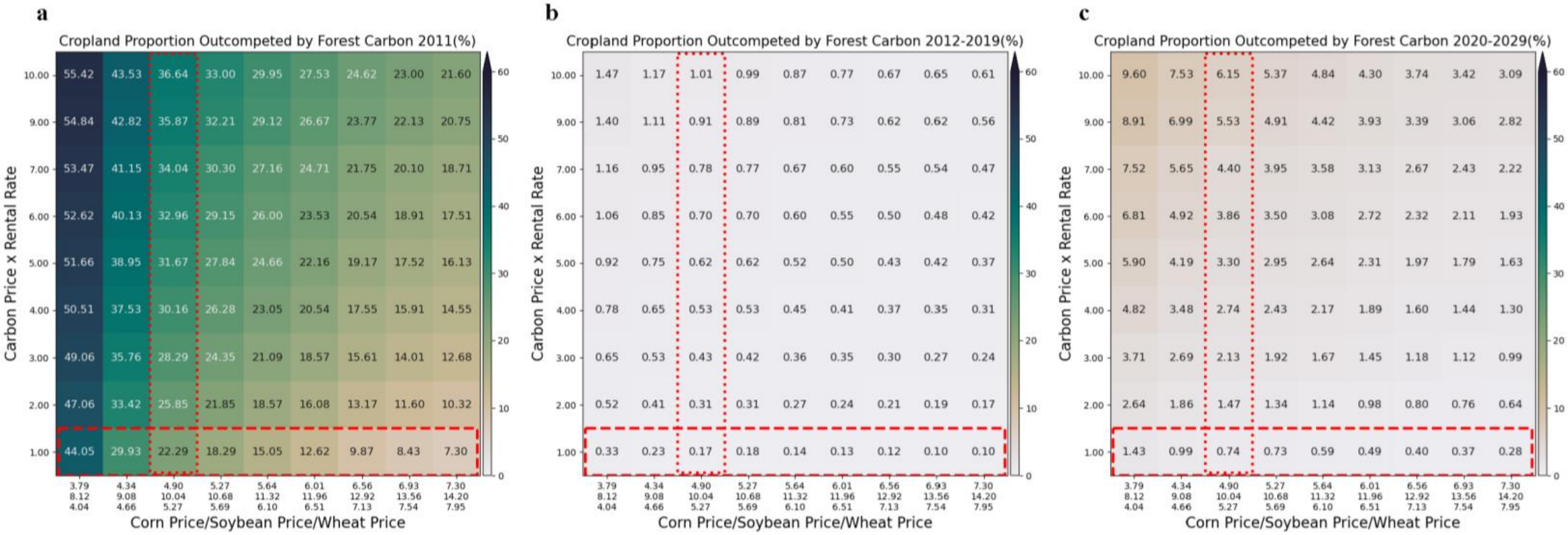


Figure 3-5: Spatial distribution of outcompeted cropland between 2011-2311 under the baseline economic scenario. Dark blue areas show where cropland is immediately outcompeted. Gray areas highlight cropland areas that remain profitable through 2311 under the baseline scenario. All other colored areas respectively represent the decade within which forest carbon revenue exceeds expected crop profit. The inset provides a closer view of the spatial heterogeneity provided at 90m resolution.



Cropland Proportion Outcompeted by Forest Carbon 2011(%)

Carbon Price x Rental Rate	3.79 8.12 4.04	4.34 9.08 4.66	4.90 10.04 5.27	5.27 10.68 5.69	5.64 11.32 6.10	6.01 11.96 6.51	6.56 12.92 7.13	6.93 13.56 7.54	7.30 14.20 7.95
10.00	55.42	43.53	36.64	33.00	29.95	27.53	24.62	23.00	21.60
9.00	54.84	42.82	35.87	32.21	29.12	26.67	23.77	22.13	20.75
7.00	53.47	41.15	34.04	30.30	27.16	24.71	21.75	20.10	18.71
6.00	52.62	40.13	32.96	29.15	26.00	23.53	20.54	18.91	17.51
5.00	51.66	38.95	31.67	27.84	24.66	22.16	19.17	17.52	16.13
4.00	50.51	37.53	30.16	26.28	23.05	20.54	17.55	15.91	14.55
3.00	49.06	35.76	28.29	24.35	21.09	18.57	15.61	14.01	12.68
2.00	47.06	33.42	25.85	21.85	18.57	16.08	13.17	11.60	10.32
1.00	44.05	29.93	22.29	18.29	15.05	12.62	9.87	8.43	7.30

Cropland Proportion Outcompeted by Forest Carbon 2012-2019(%)

Carbon Price x Rental Rate	3.79 8.12 4.04	4.34 9.08 4.66	4.90 10.04 5.27	5.27 10.68 5.69	5.64 11.32 6.10	6.01 11.96 6.51	6.56 12.92 7.13	6.93 13.56 7.54	7.30 14.20 7.95
10.00	1.47	1.17	1.01	0.99	0.87	0.77	0.67	0.65	0.61
9.00	1.40	1.11	0.91	0.89	0.81	0.73	0.62	0.62	0.56
7.00	1.16	0.95	0.78	0.77	0.67	0.60	0.55	0.54	0.47
6.00	1.06	0.85	0.70	0.70	0.60	0.55	0.50	0.48	0.42
5.00	0.92	0.75	0.62	0.62	0.52	0.50	0.43	0.42	0.37
4.00	0.78	0.65	0.53	0.53	0.45	0.41	0.37	0.35	0.31
3.00	0.65	0.53	0.43	0.42	0.36	0.35	0.30	0.27	0.24
2.00	0.52	0.41	0.31	0.31	0.27	0.24	0.21	0.19	0.17
1.00	0.33	0.23	0.17	0.18	0.14	0.13	0.12	0.10	0.10

Cropland Proportion Outcompeted by Forest Carbon 2020-2029(%)

Carbon Price x Rental Rate	3.79 8.12 4.04	4.34 9.08 4.66	4.90 10.04 5.27	5.27 10.68 5.69	5.64 11.32 6.10	6.01 11.96 6.51	6.56 12.92 7.13	6.93 13.56 7.54	7.30 14.20 7.95
10.00	9.60	7.53	6.15	5.37	4.84	4.30	3.74	3.42	3.09
9.00	8.91	6.99	5.53	4.91	4.42	3.93	3.39	3.06	2.82
7.00	7.52	5.65	4.40	3.95	3.58	3.13	2.67	2.43	2.22
6.00	6.81	4.92	3.86	3.50	3.08	2.72	2.32	2.11	1.93
5.00	5.90	4.19	3.30	2.95	2.64	2.31	1.97	1.79	1.63
4.00	4.82	3.48	2.74	2.43	2.17	1.89	1.60	1.44	1.30
3.00	3.71	2.69	2.13	1.92	1.67	1.45	1.18	1.12	0.99
2.00	2.64	1.86	1.47	1.34	1.14	0.98	0.80	0.76	0.64
1.00	1.43	0.99	0.74	0.73	0.59	0.49	0.40	0.37	0.28

Figure 3-6: Proportion of Maryland cropland area outcompeted by forest carbon revenue immediately in 2011 (a) and additionally between 2012-2019 (b) and 2020-2029 (c) under a select range of economic scenarios. Where both red boxes intersect is the baseline economic scenario. The vertical dotted box highlights the impact of maintaining the baseline crop pricing scenario but changing the carbon rental scenario. The horizontal dashed box highlights the impact of maintaining the carbon pricing scenario under changing crop pricing scenarios.

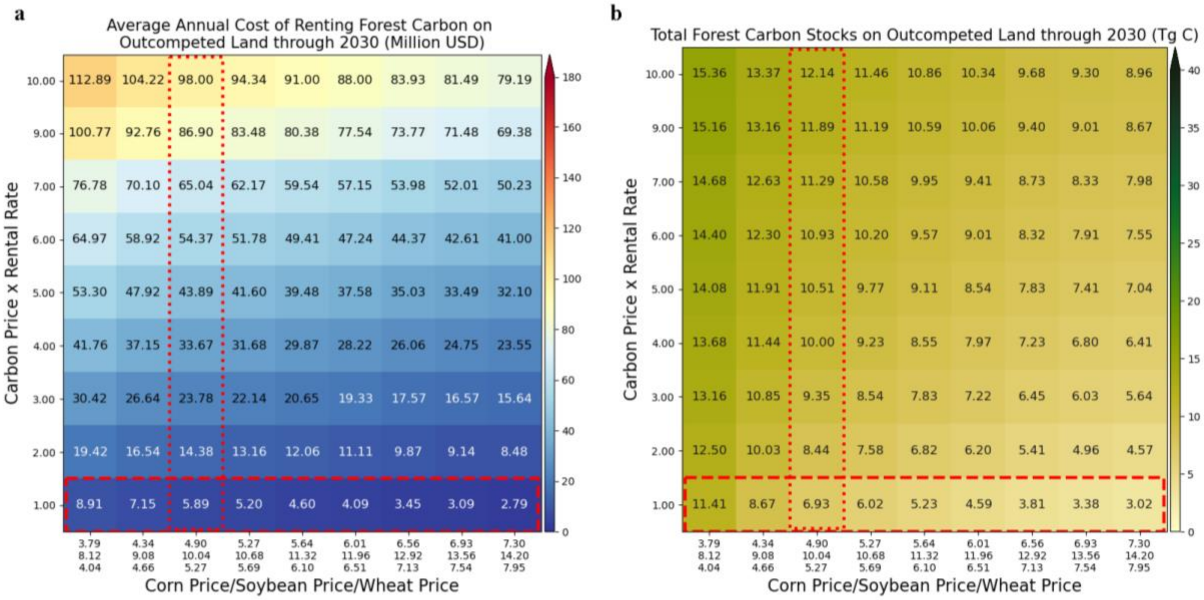


Figure 3-7: Average annual rental payments for all lands outcompeted by 2030 (Million USD) (a) and the corresponding amount of forest carbon on such lands (Tg C) (b), including the ongoing growth of existing trees and regrowth from new plantings. Where both red boxes intersect is the baseline economic scenario. The vertical dotted box highlights the impact of maintaining the baseline crop pricing scenario but changing the carbon rental scenario. The horizontal dashed box highlights the impact of maintaining the carbon pricing scenario under changing crop pricing scenarios.

Changing the economic scenario under a 20-year rental agreement produced a wide range of outcomes. The percentage of immediately outcompeted cropland ranged from 5.5-55.4%. The cumulative outcompeted cropland ranged from 5.7-66.5%. The total amount of carbon sequestered ranged from 2-15.3 Tg C at an annual average cost between $910,000 and $112.8 million. Lengthening the rental agreement increased cumulative outcompeted cropland by an additional 0.2-10.6% (30 years), 0.4-17.8% (40 years), and 0.6-23% (50 years) depending on the economic scenario (Figure B-8). Such a change correspondingly increased the total amount of carbon sequestered and cost to rent it to 2.3-21.4 Tg C by 2040 at an average annual cost of $990,000-143.2 million, 2.6-27.4 Tg C by 2050 at $1-175.2 million annually, and 2.9-32.3 Tg C by 2060 at $1.1- 206.4 million annually (Figure B-9).

Under the baseline economic scenario, removing subsidies had a marginal effect on the proportion of outcompeted cropland. Immediately outcompeted lands increased 3.7%, from 22.6% to 26.3%, with cumulative outcompeted lands increasing an additional 0.9% by 2030 (relative to 0.7% with subsidies) (Figure B-10). The total amount of carbon protected increased to 7.74 Tg C due to the increase in outcompeted lands and raised the average annual payment cost to $6.4 million (Figure B-11). Doubling total subsidies decreased immediately outcompeted cropland by a similar magnitude (3.8%), reaching 19.6% of cropland over 20 years (Figure B-12). The amount of carbon protected declined to 6.23 Tg C with an average annual rental cost of $5.39 million (Figure B-13).

3.4 Discussion and conclusions

We demonstrate with an ambitious geospatial approach that the spatial and temporal heterogeneity of carbon sequestration potentials can be combined with economic data to support strategic land-use planning at the state and county levels. Specifically, we find that economic opportunities for forest restoration on cropland do exist across the state, even under a conservative baseline economic scenario. Increasing the carbon rental scenario can make more cropland in the state eligible for profitable reforestation, both immediately and by the end of the rental agreement. However, not all cropland is outcompeted under any economic scenario presented, highlighting the importance of representing economic opportunity as spatially-explicit. Utilizing this information, individual landowners can project potential economic profit relative to the carbon rental scenario proposed. Policymakers, interested in incentivizing reforestation to meet state goals, may also be able to use this information to estimate projected program costs and the total amount of forest carbon they are likely to sequester relative to the cropland amount under agreement.

3.4.1 Impact of economic model variables

Under the baseline economic scenario, the total proportion of cropland outcompeted under a twenty-year rental agreement was relatively modest (23.2%), with the vast majority of this cropland immediately outcompeted in 2011 (22.2%). Existing mature trees that surround cropland areas as well as negative profits in some regions largely account for this immediate economic benefit (Figure B-14). This finding suggests that forest conservation is essential for securing competitive revenues at the start of the rental agreement. At the same time, minimal increases in additional outcompeted cropland (~1%) through the end of the rental period show that for the vast majority of cropland under this pricing scenario, biomass accumulation from newly planted trees does not produce enough additional revenue to outcompete expected crop profit by 2030.

The cost of renting forest carbon on all outcompeted land area under the baseline economic scenario is also relatively modest at $5.89 million annually. However, this is an average annual cost with rental payments generally increasing each year as trees grow. For comparison, these annual rental payments are equivalent to 9.7% of Maryland's average annual auction proceeds ($60.7 million) from participation in the Regional Greenhouse Gas Initiative between 2014-2018 (RGGI, 2020), and 19.3% of the average annual subsidy payments for corn, soy, and wheat ($30.5 million) distributed over the same time period (EWG, 2020). The total amount of carbon protected under the baseline scenario (6.93 Tg C) is 6.2% of the state's current AGB (110.8 Tg C) and 3.4% of the state's remaining carbon sequestration potential (204.1 Tg C) (Hurtt et al., 2019). While a small fraction of the state's total CSP, 6.93 Tg C is 16 times the amount of carbon (1.5 MMtCO2e) expected to be sequestered by 2030 via state forest management and reforestation activities listed within the 2019 draft Greenhouse Gas Emissions Reduction Act plan (MDE, 2019a).

Changing the rental scenario under a twenty-year rental agreement does impact overall competition. Since the market generally influences crop prices, program managers could strategically select a competitive carbon rental scenario to estimate the total amount of outcompeted cropland as well the upper bound of expected carbon sequestration relative to the cost. For example, under decadal low crop prices, revenues generated from a carbon price of $100 per Mg C with a rental rate of 10% (e.g., a rental factor of 10) could immediately outcompete 55.4% (3166 km^2) of cropland area (a 32.2% increase from the baseline scenario). Correspondingly, the carbon sequestered could increase to upwards of 12.1 Tg C (almost double that of the baseline scenario). For any scenario, the projected amount of carbon sequestered and the corresponding cost to protect it is contingent on all outcompeted land being reforested under rental agreements. If only a subsection of this land is enrolled, the corresponding amount of carbon and related rental costs will be smaller. Because the NASA CMS forest carbon products used in this study are spatially explicit, it is possible to estimate the projected rental payments and carbon sequestered for any subset of cropland selected.

Changing the agreement's length had a greater effect on the total amount of carbon stored than the percentage of cropland outcompeted. For example, under the baseline scenario, the percentage of outcompeted cropland increased an additional ~1% each decade from 2030 to 2060, but the total amount of carbon increased ~17% over the same time period. Under a very high carbon rental factor, outcompeted cropland would increase an additional ~7.6% per decade from 2030 to 2060, with the total amount of carbon sequestered increasing an average of 28% per decade. These trajectories suggest that a longer land-use agreement, especially under a higher rental scenario, may make the transition to forestland more economically advantageous for a small percentage of farmers. However, the real benefit of a longer rental agreement may be the amount of carbon likely to be sequestered.

Finally, while crop subsidies are assumed to influence greatly overall crop profitability in the United States, our results suggest they have only a small effect on overall competition. When subsidies were eliminated, the proportion of outcompeted cropland only increased by 3.7% under a twenty-year rental agreement. This suggests that overall crop revenue under the baseline crop pricing scenario is still relatively competitive compared to expected forest carbon revenue. Doubling the subsidy decreased the proportion of outcompeted cropland by a similar magnitude. While our analysis assumed subsidy payments were distributed proportionally across all cropland, we know that subsidy payments are often distributed to a small number of recipients. For example, according to the 2017 USDA Census of Agriculture, only 28.7% of all Maryland farms received government subsidies with the average farm receiving $12,471 annually (USDA, 2019). While the USDA does not report the number of cropland hectares owned or managed by subsidy recipients, they do report the average farm size in Maryland (160 acres). For comparison, a 160-acre farm receiving $77.94 per acre ($192.75/ha) in annual subsidy payments (based on a $12,471 total) would fall in the middle of our baseline estimates, where subsidy payments reach nearly $350/ha in some parts of the state (as shown in Figure 3-3b). This suggests that there may be a small portion of cropland that we identified as "outcompeted" that may never be competitive under the baseline carbon rental scenario due to very high subsidy payments. Conversely, with ~71% of all farms not receiving subsidies, there are likely to be gains in the proportion of outcompeted cropland due to lower crop profit (as demonstrated in the zero subsidies case). One of the greatest influences on crop subsidies is the impact of the Farm Bill. Subsidy payments and eligible programs can vary widely as new legislation is passed every five years. Thus, the specific spatial locations of some outcompeted cropland may depend on farmer participation in governmental subsidy programs (EWG 2020).

3.4.2 Challenges and opportunities for program implementation

As a member state of RGGI, Maryland has earned more than $725 million in auction proceeds since 2008 (~$54 million in 2019) (RGGI, 2020). Each member state must use auction proceeds to invest in "strategic energy and consumer programs" that further reduce harmful CO_2 pollution while spurring local economic growth and job creation (RGGI, 2021). While such investment has primarily included an emphasis on energy efficiency and renewable energy technologies, it is possible that this money could be used to pay landowners for avoided forest conversion, afforestation, and improved forest management practices to enhance carbon sequestration (as was done in New Jersey; NJDEP, 2020). While current RGGI carbon pricing, as reflected in our baseline scenario, does not compete with the vast majority of cropland, auction proceeds could be used to back-cast competitive pricing. For example, under decadal average crop prices, a $14.3 million annual allocation for forest carbon payments could be used to protect upwards of 8.4 Tg C on outcompeted cropland with a carbon rental scenario of $40/Mg C and 5% rental rate (rental factor of 2) (Figure 3-7). As a RGGI member, any forest carbon pricing programs instituted by the State of Maryland could influence other member states' strategies.

Although the proposed research offers an independent economic assessment of forest carbon sequestration potential on cropland, the results could also be used alongside existing agricultural programs to increase carbon accounting of conservation activities. There is a suite of government-sponsored activities cooperatively managed by the Maryland Department of Agriculture (MDA) and the USDA that are designed to incentivize conservation on agricultural lands (e.g., the Conservation Reserve Enhancement Program (CREP)). While these programs may indirectly increase carbon stocks, any carbon sequestration benefits realized through conservation activities are not measured as an objective of enrollment. Instead, payments are distributed relative to specific practices and generally require a minimum percentage of land to be retained under contract. CREP was retained in the 2018 Farm Bill, but national caps on land enrollments mean that not all eligible land can receive payments for conservation practices. Increasing the funding available for CREP to cover forest carbon sequestration payments and maximizing the national cap of eligible hectares could increase enrollments.

While there is considerable opportunity to design and implement a forest carbon rental program for the economic benefit of landowners, our work also suggests some additional design considerations. For example, in our analysis, the carbon rental and crop pricing scenarios are fixed throughout the rental period, regardless of length. While helpful for providing a bounding case, it may be that crop prices increase dramatically over the rental period. If the carbon rental scenario remains fixed, this may decrease the total amount of additional revenue the farmer can realize over this time period relative to initial projections (e.g., forest carbon still outcompetes expected cropland profit but by a smaller margin). Designing a carbon rental scenario and program that is responsive to crop market adjustments could ensure farmers earn as much as if not more than what they would have earned with annual crops over the length of the agreement. However, such flexibility would also have a dynamic impact on program cost.

Additionally, estimated rental payments are based on expected growth rates of native tree species. While our model projections account for average rates of natural disturbance across the landscape, the rented property's actual disturbance rate could be much higher or lower. As is often done for annual crops, instituting a carbon insurance program may help protect landowners from circumstances outside of their control. Furthermore, a system for annualized forest carbon monitoring must be established to ensure annual payments are within an acceptable margin of error. While field-based assessments are standard practice within many forest carbon offset protocols, a move towards remote sensing-based methods may decrease the cost of ensuring compliance for both the program and landowner. As annual high-resolution lidar collection is currently not practicable, hybrid methods that utilize a combination of GEDI data, Landsat data, and ecosystem modeling data, coupled with periodic ground assessments, may be more economically feasible over broad spatial domains (Hurtt et al., 2021).

Finally, reforestation and afforestation on cropland can be viewed as an economic opportunity rather than livelihood displacement, with trees being viewed as another type of crop. However, there is an ongoing need for sensitivity regarding landowner and cultural choices around farming. Voluntary programs for forest carbon payments must be considered alongside other state priorities and programs such as the Maryland Agricultural Land Preservation Foundation (MALPF). Housed within the MDA, MALPF identifies and protects eligible agricultural lands through perpetual easements. MALPF's primary purpose is to preserve productive agricultural land and woodland to provide for the continuing production of food and fiber for Maryland citizens. While reforesting agricultural land would generally fall within the provisions of MALPF (MALPF 2015), it may be strategic to look for outcompeted cropland that is not otherwise protected or is otherwise considered to be marginal cropland (Kang et al., 2013; Gelfand et al., 2013). In general, consistent carbon rental payments over the length of the rental agreement may provide more economic stability for farmers than is currently experienced with crop market volatility.

3.4.3 Limitations and future directions

Our analysis explicitly considered the impact of different economic scenarios on the competitive advantage of reforestation on agricultural land. With this focus, we were able to test an ambitious range of pricing scenarios focusing on spatially-explicit opportunities for profitable reforestation. Future work could expand the range of scenarios tested. First, while we did include variations in crop yield and forest growth rate based on contemporary environmental conditions, we did not explicitly propagate climate change projections through our model. Growth rates and yield are likely to be altered under future climate conditions although the direction of impact is still very uncertain (e.g., Long et al., 2006; McMahon et al., 2010; Zhao & Running, 2010). More work should be done to test the effects of such variability on forest carbon competition. Second, to test the impact of price variability on competition, we held constant the relative statewide distribution of corn, soybeans, and wheat. In practice, what a farmer may choose to plant in any given year can vary depending on market projections (Plourde et al., 2013). Since the competitive value of crop profit varies by crop type, more work could be done to test the spatial distribution of outcompeted cropland under different crop rotation patterns. Third, given the variability in operational costs for individual farmers, we elected to utilize a standard crop budget that provided a per-acre cost for each crop type. While such an approach does provide a baseline estimate of profitability, each farmer would likely need to determine the economic advantage of enrolling their land in a forest carbon rental program based on actual costs. Finally, we do not include the cost of tree planting in our competition analysis as this is a one-time cost that can be highly variable depending on the number of hectares and size of trees planted. Further, our results assume unassisted natural forest succession and regeneration. Planting more mature trees may accelerate the competitive value of forest carbon relative to cropland profit, but also require associated planting and short-term maintenance costs (Brancalion et al., 2019a).

Chapter 4: High-resolution geospatial framework for future forest carbon storage and protected area expansion in Maryland, USA

Abstract

Global initiatives to advance nature-based climate solutions and increase the amount of protected area for biodiversity have proliferated in recent years. Many of these efforts have centered on preserving existing forests with high carbon stocks. This study advances a high-resolution geospatial framework to identify strategic areas for reforestation in order to increase future carbon sequestration in support of climate mitigation goals while simultaneously increasing the amount of protected area to reach area-based targets. Using this framework, we analyze two potential reforestation scenarios in the State of Maryland using high-resolution (90m) NASA Carbon Monitoring System forest carbon modeling products and the Maryland Biodiversity Conservation Network (BioNet) dataset. Specifically, we map, quantify, and compare future optimized carbon habitat corridors that connect existing protected areas with an alternative of increasing the size of existing protected areas via extended buffers. To identify priority geographies and strategies for implementation, both scenarios are evaluated under several socio-economic factors including land-ownership, land-use, and economic opportunity. Finally, for each reforestation scenario, we estimate the potential risk to future development under several IPCC emissions scenarios. The application of this high-resolution framework provides

insights into current opportunities and potential liabilities for reforestation statewide and county-by-county, where these strategies must ultimately be implemented at land-owner scales. We also emphasize the importance of iterating these scenarios to remain adaptive as land-use decisions are made over time.

4.1 Introduction

Recent global initiatives, such as the UN Decade on Ecosystem Restoration, Bonn Challenge, and 1 Trillion Trees Initiative, have called for increasing ecosystem restoration and reforestation as a nature-based solution for climate change and other social and environmental challenges (IUCN & State of Germany, 2011; UN, 2019; WEF, 2020). Under the 2015 Paris Climate Agreement, nature-based climate solutions are estimated to provide over one-third of the cost-effective climate mitigation needed between now and 2030 to stabilize warming to below 2 degrees C (Griscom et al., 2017). Further, the climate mitigation potential of reforestation suggests that even with conservative estimates of carbon uptake, regrowth of natural forests presents the single largest natural climate solution globally and within the United States (Fargione et al., 2018, Cook-Patton et al., 2020), provided considerations of forest permanence are properly accounted for (Anderegg et al., 2020).

In parallel, the International Union for Conservation of Nature (IUCN), and other advocates under the Convention on Biodiversity Diversity, have argued for more protected area to bend the curve on biodiversity loss (UN, 2020). Currently, about 15% of the earth’s land surface is formally protected with calls to increase this area to between 30-50% (e.g., Dudley et al., 2018; UN, 2020). While improved management and protection of current protected areas is vital (e.g., Adams et al., 2019; Golden Kroner et al., 2019), such increases in land area could also provide important benefits for biodiversity. Area-based approaches have traditionally included the expansion of existing protected areas (de la Fuente et al., 2020), the creation of new protected areas in priority geographies (Maxwell et al., 2020), the management of human-modified lands as “working lands” with biodiversity-based land-management techniques (Kremen & Merenlender, 2018), and the identification and protection of wildlife corridors to improve habitat connectivity (Jantz et al., 2014) and guard against harmful land-use change across the landscape (Blanco et al., 2020). In the context of climate change, maintaining habitat connectivity has remained particularly important for facilitating species persistance and movement across a rapidly changing landscape (Hodgson et al., 2011, Van Dyke & Lamb, 2020a).

Recent perspectives have suggested tackling the dual crises of biodiversity loss and climate change require interdependent strategies (e.g., Dinerstein et al., 2019, 2020). However, joint climate mitigation and biodiversity protection are not always assumed due to historically siloed approaches. For example, recent work has documented the risks to endemic species when biodiversity is not well accounted for in carbon management (Reside et al., 2017). Furthermore, while climate stabilization approaches have focused on protecting areas with high contemporary carbon stocks (Hansen et al., 2020; Walker et al.; 2020), there are still questions about the ability to better promote biodiversity through reforestation, where habitat structure and species diversity are paramount considerations, but sometimes overlooked in efforts to achieve rapid carbon mitigation (Bremer & Farley 2010; Chazdon et al., 2016). As more nations, and regional actors like states and provinces, seek to simultaneously achieve their goals of climate mitigation and biodiversity protection, more work must be done to advance spatially-explicit areas of opportunity for reforestation where the co-benefits can be better quantified and mapped (Brancalion et al., 2019; Stickler et al., 2009; Strassburg et al., 2020).

In this study, we offer a high-resolution geospatial framework for identifying strategic areas for reforestation in order to meet the growing need for climate mitigation and biodiversity protection (Figure 4-1). Specifically, we seek to simultaneously maximize future carbon storage as well as increase the total amount of protected area using the State of Maryland (USA) as a case-study. We first provide a detailed overview of the state's contemporary protected areas and priority biodiversity conservation areas as identified by the Maryland Biodiversity Conservation Network, including their related aboveground biomass and carbon sequestration potential. Second, we map two potential reforestation scenarios that include optimized future carbon habitat corridors to improve connectivity and extended protected area buffers to increase the amount of core habitat. We then evaluate the resulting scenarios using several socio-economic criteria to identify the most strategic policy pathways towards implementation. Finally, we consider the future risk of urbanization across both scenarios using four IPCC emissions scenarios. We conclude by offering several observations about what we can learn from these scenarios, as well as the importance of iterating this analysis over time to advance strategic land-use planning.

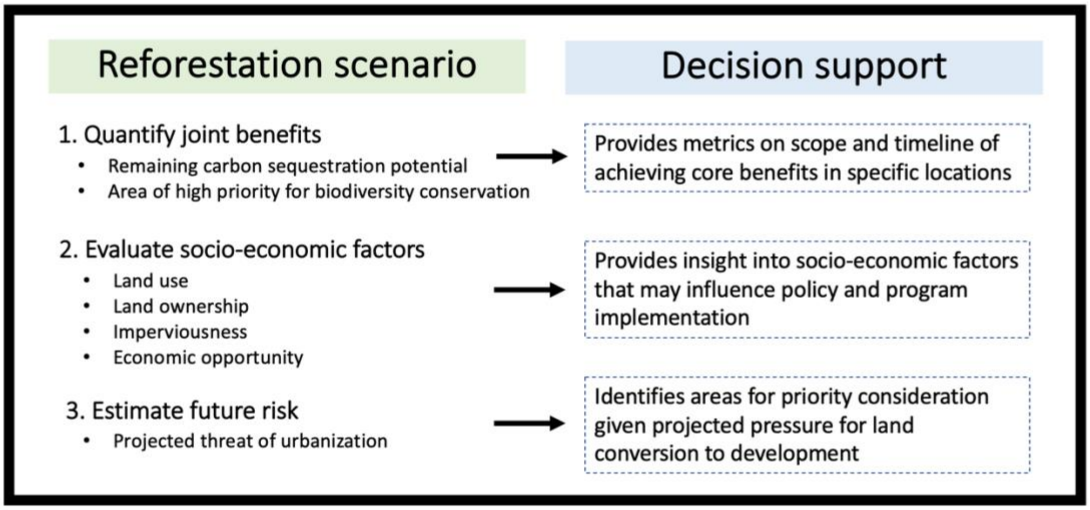


Figure 4-1: High-resolution geospatial framework for advancing climate mitigation and biodiversity protection through strategic reforestation, where spatially-explicit reforestation scenarios undergo several rounds of review and evaluation. In this study, we illustrate the application of this framework using two potential reforestation scenarios, including optimized carbon habitat corridors and expanded protected area buffers.

4.2 Data and methods

4.2.1 Study area

The state of Maryland (USA) covers over 25,255 km^2 of land area, with deciduous forest as the dominant potential vegetation type (Ramankutty & Foley, 1999). Due to widespread human-induced land cover and land-use change, the landscape is characterized by fragmented forests with significant restoration potential. Depending on forest definition and method, forest covers 33-41%, and croplands account for 32% of state land area (Jin et al., 2013; Lister & Widmann, 2016). As with much of the US Eastern seaboard, 90% of Maryland was cleared of forest and converted to agriculture by the mid-19th century. These lands were converted partially back to forest in the early 20th century as agriculture's economic importance declined in the state. Then significant quantities of forest were lost to development in the mid to late 20th century.

Currently, Maryland has legislation related to forestry and climate mitigation that actively inform land-use planning. The Forest Conservation Act (Annotated Code of Maryland 5-1601-1612) was enacted in 1992 and strengthened in 2013 with the intent for “no-net-loss” of forests and to maintain forest cover above 40% in Maryland. The Greenhouse Gas Reduction Act (GGRA) was passed in 2009, directing the state to reduce climate pollution by 25% by 2020 and create a Greenhouse Gas Reduction Plan. In 2016, the GGRA was reauthorized and strengthened to a 40% reduction by 2030, requiring an updated plan with improved afforestation goals. The draft plan was released in October 2019, focusing, among other things, on improving the carbon management of farms and forests. As a member of the US Climate Alliance (USCA), Maryland has also participated in the Natural and Working Lands (NWL) Challenge, which commits states to maintain NWLs as a net carbon sink (USCA, 2020a).

The State of Maryland is also strongly committed to biodiversity protection. The Wildlife and Heritage Service (WHS), located within the Maryland Department of Natural Resources (MDNR) is charged with the listing, management, and recovery of all rare, threatened, endangered or extirpated species. The primary law that governs this process is the 1975 Nongame and Endangered Species Conservation Act (Annotated Code of Maryland 10-2A-01). The State is home to an estimated 90 species of mammals, 93 species and subspecies of reptiles and amphibians, more than 400 species of birds, and several hundred species of marine and freshwater fishes

(MDNR, 2021a). Despite its small size, Maryland is also home to a disproportionately large number (over 3000) of native plant species, 1,250 of which are tracked by the WHS as among the rarest in the state (MDNR, 2021b).

In Maryland, lands acquired by the state for conservation are scored across different priorities, including presence of rare or threatened species or habitats, degree of connectivity to other habitat parcels, climate resiliency, and proximity to existing protected lands. Secondary considerations are the ecosystem services being provided by the parcel, including carbon sequestration (Campbell et al., 2020), and the suitability of the land for ecological restoration. While tree planting is a key tool for climate mitigation, it is typically pursued in Maryland for the purposes of meeting water quality goals, with the accompanying carbon uptake and other ecosystem services being largely unquantified co-benefits. Systematically considering the potential of tree planting or natural regeneration to expand upon or connect important areas for wildlife habitat would allow these co-benefits to be maximized more regularly. Maryland's regulatory structure and existing process for data integration into decision making for land conservation and climate mitigation suggests that information developed in this analysis is likely to be utilized by the state.

4.2.2 Primary data

4.2.2.1 Forest aboveground biomass and carbon sequestration

The fundamental forest carbon products used to inform this analysis were derived from the Ecosystem Demography model (ED) (Moorcroft et al., 2001; Hurtt et al., 2004), and previously published in Hurtt et al. 2019 as part of the NASA

Carbon Monitoring System (CMS) (Hurtt et al., 2014). Here, the forested fraction of every 90m grid cell is estimated circa 2011 using statewide airborne lidar and NAIP optical imagery (O’Neil-Dunne, 2019). Following definitions in Hurtt et al. 2019, the aboveground carbon sequestration potential (CSP) is defined as 95% of the maximum aboveground biomass a site reaches during natural forest succession. In computing these potentials, all non-forest area could theoretically be reforested, excluding wetland and impervious surface. The aboveground carbon sequestration potential gap (CSPG) is defined as the difference between CSP and current carbon stocks (aboveground biomass or AGB). The aboveground carbon sequestration potential time gap (CSPTG) is defined as the number of years it takes to go from AGB to CSP. While other carbon pools do impact climate mitigation and biodiversity, this analysis focuses specifically on aboveground carbon because it is the observable component of forest carbon from lidar remote sensing. Further, aboveground carbon is where carbon management is currently focused and most feasible, and where anthropogenic and natural disturbances are dominant.

4.2.2.2 Protected areas

Existing protected areas in the state were identified using the Protected Areas Database of the U.S. (PAD-US) developed by the United States Geological Survey (USGS) (Version 2.1, Prior-Magee et al., 2020). This dataset provides a compilation of lands owned and managed by the federal and state governments, as well as the boundaries of American Indian reservations and off-reservation trust lands, private local land trusts, city parks, and national marine protected areas. In this study, all lands have been classified by land management type and designated Gap Analysis

Project (GAP) Status (Maxwell et al., 2009). Here, the land management type is separated into five primary categories including Federal, State, Local Government, Non-Governmental Organization, and Unknown. The Protected Area's GAP Status, a measure of management intent to conserve biodiversity, falls within one of four categories where GAP Status 1 refers to areas that are managed for biodiversity and disturbance events proceed or are mimicked, GAP Status 2 areas are managed for biodiversity but disturbance events are suppressed, GAP Status 3 areas are managed for multiple uses and subject to extractive (e.g., mining or logging) or off-highway vehicle (OHV) use, and GAP Status 4 areas have no known mandate for biodiversity protection. A fuller description of these classifications can be found on the USGS PAD-US website (USGS, 2021).

4.2.2.3 Areas of conservation priority

The Maryland Biodiversity Conservation Network (BioNet) dataset was developed by the MDNR WHS to identify areas of conservation priority within Maryland. This BioNet spatial dataset systematically identifies and prioritizes ecologically important lands necessary to conserve Maryland's biodiversity, including plants, animals, habitats, and landscapes, by generating a five-tiered system based on a continuum of rarity, diversity, and quality (MDNR, 2020). Tier 1 areas are considered "critically significant" for biodiversity conservation, Tier 2 are "extremely significant", Tier 3 are "highly significant", Tier 4 are moderately significant", and Tier 5 are "significant" for biodiversity conservation. Included in this prioritization process are nine key factors including, only known occurrences of species and habitats in the State; globally rare species and habitats; state rare species and habitats;

high quality examples of common habitats; Animals of Greatest Conservation Need; Watch List plants, as indicators of high-quality habitats; animal assemblages (e.g., colonial nesting waterbirds, forest interior species); “hotspots” for rare species and habitats; and wildlife corridors and concentration areas. All mapped terrestrial BioNet areas in the state were included in this analysis. More information on specific data included within each BioNet tier can be found on MDNR’s website (MDNR, 2020).

4.2.3 Statewide context and reforestation scenarios

Using these primary datasets, we first quantified several statewide and county-level metrics for all PAD-US and BioNet areas, including total land area, AGB, CSPG, CSPTG, average AGB density, and contemporary tree cover fraction. We also quantified each of these metrics by protected area land management type and GAP status, as well as by BioNet tier. We further estimated the degree of overlap between PAD-US and BioNet area to identify BioNet area, including by tier, that remained unprotected. Where some PAD-US polygons extend into the Chesapeake Bay or Atlantic Ocean, we clipped their boundaries to provide metrics for only the land area portion of the protected area.

Next, we mapped two reforestation scenarios relative to all PAD-US protected areas in the state regardless of their size or type, one focusing on corridors and the other on protected area buffers (Figure 4-2). For our first scenario, we mapped optimized corridors that maximize the remaining carbon sequestration potential (CSPG) and overlap with existing BioNet area. Here, we use Linkage Mapper 2.0 tools in ArcGIS 10.6 (Dickson et al., 2019; McRae et al., 2016; McRae & Kavanagh 2011) to identify least-cost pathways. To do this, we first created a cost-resistance map at 90m resolution statewide, which included two equally weighted factors, including the CSPG layer from Hurtt et al. 2019 and the BioNet map from MDNR 2020. Each layer was scaled from 0 to 10 with areas of highest CSPG (exponential scaling) and highest Tier (linear scaling) allocated the lowest resistance scores. In the case of BioNet, we allocated all lands with no Tier a score of 10. As the CSPG layer masks impervious surface, land areas with low CSPG and high fractional imperviousness will generally have the highest resistance scores. However, in some cases, when no other viable pathways are found, mapped corridors will contain significant impervious surfaces. We then use the Linkage Mapper tool to connect each protected area to its four nearest neighbors using cost-weighted distance to identify the lowest cost routes, and added in additional pathways to otherwise isolated constellations of protected areas. Finally, we increased the width of mapped pathways to a maximum of 1km, which is broadly consistent with the approach used in Jantz et al. (2014) for mapping high AGB corridors connecting protected areas across tropical forests at a continental scale.

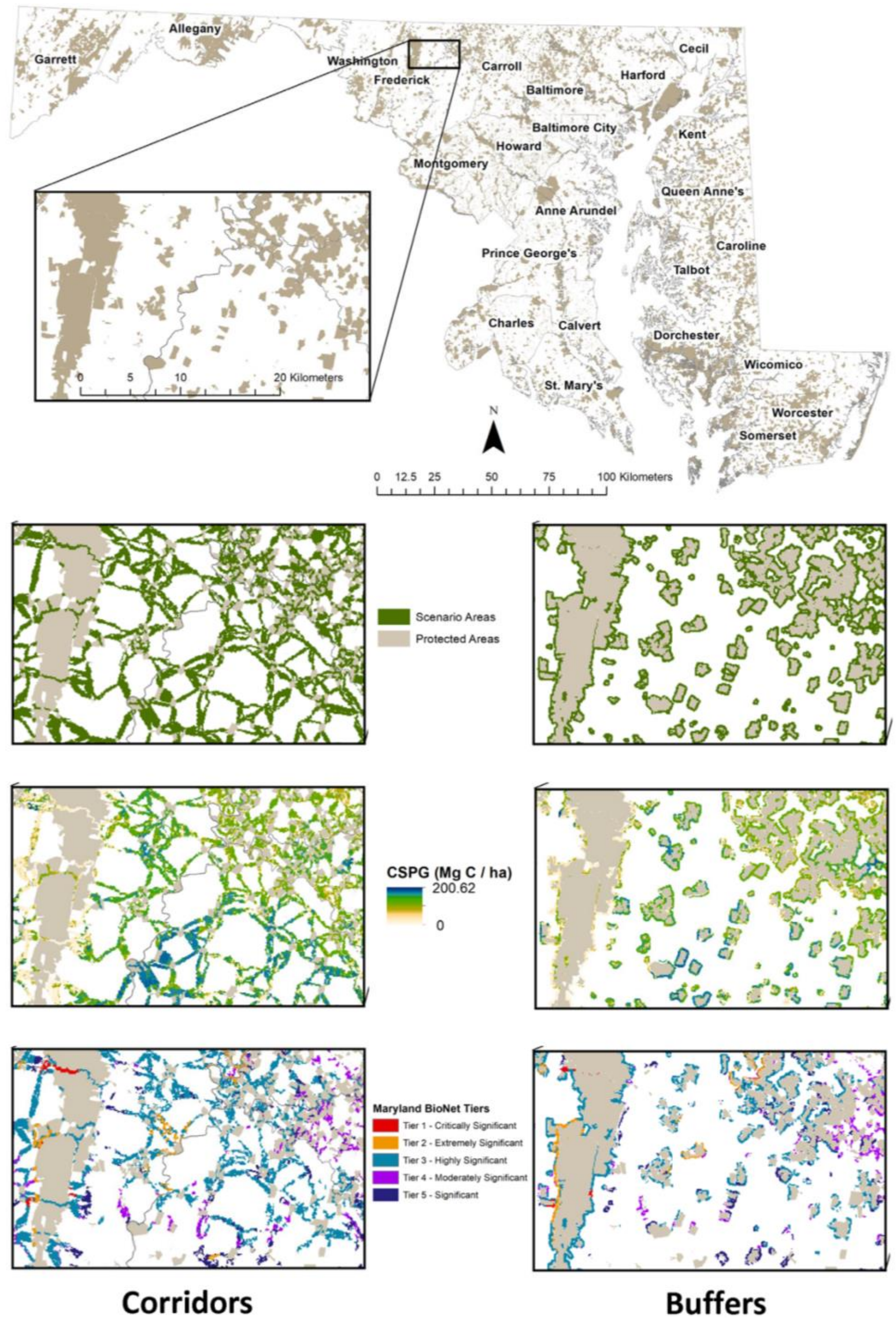


Figure 4-2: Primary attributes of each reforestation scenario in Maryland where optimized corridors connect existing protected areas by jointly maximizing the carbon sequestration potential gap (CSPG) and highest tiers of Maryland Biodiversity Conservation Network (BioNet) area. The CSPG and portion of BioNet land area by tier is also quantified for mapped protected area buffers. The inset from Frederick County highlights the high spatial resolution of this approach.

Resulting corridors were summarized statewide and by county in terms of total land area required, AGB, CSPG, CSPTG, average AGB density, contemporary tree cover fraction, and total percentage of BioNet area included by Tier. Finally, we estimated the time that it would take in years for the average density of corridors to reach the average density of current protected areas at the state and county scales (hereafter referred to as the AGB density time gap).

As a second reforestation scenario, we uniformly increased the boundary of all protected areas such that the total land area included matched the magnitude of that in the first least-cost corridor scenario. All resulting 225m protected area buffers were merged together to ensure no overlapping boundaries. These buffers were then summarized statewide and by county using the same metrics as the corridors, including AGB, CSPG, CSPTG, average AGB density, AGB density time gap, contemporary tree cover fraction, and total percentage of BioNet area included by Tier.

Finally, we compared both scenarios across all above metrics. Additionally, we quantified and mapped overlap in land area between both reforestation scenarios. While corridors intentionally maximize connectivity, we also compared the relative connectivity of buffers by quantifying that fraction of protected area units (e.g., non-adjacent protected area polygons) that become newly connected given overlapping buffers.

4.2.4 Socio-economic considerations

Both reforestation scenarios were subsequently evaluated under several socio-economic factors, including percent imperviousness, land ownership, and land-use.

For the agricultural land use areas, we further considered contemporary crop profitability, and potential competition with forest carbon revenues under a hypothetical forest carbon rental model. All data were then mapped and summarized statewide and by county.

4.2.4.1 Percent impervious

The percent imperviousness of all corridors and buffers was estimated using the NLCD's 2011 Percent Developed Imperviousness layer (Jin et al., 2013; Xian et al., 2011). This layer, aggregated from 30m to 90m by averaging the 30m fraction, matches the imperviousness mask used within the NASA CMS forest carbon products.

4.2.4.2 Land ownership and land use

The designated land-ownership classification of each 90m pixel was determined using the Maryland Department of Planning's (MDP) MdProperty View dataset, which classifies all property parcels in the state with one of seven classifications (MDP, 2020). Here, we calculated the proportion of corridors and buffers that traversed public owned real property or USA federal property (Federal), state owned real property (State), county or Baltimore city owned real property (County), town or municipality owned real property (Town/Municipal), privately owned real property (Private), non-profit or charitable organizations (Non-profit), and all other classes (Other) (as identified within the dataset's "EXCLASS" and "DESCEXCL" columns).

The MDP MdProperty View dataset also provided the land-use class of each 90m pixel using one of fifteen categories (derived from the dataset's "DESCLU" column) (MDP, 2020). Here, we use nine simplified land-use categories including Agricultural, Residential, Commercial, Other Housing, Industry, Marsh Land, Country Clubs, Tax-Exempt, and None, which refers to no provided classification. The "Other Housing" category is inclusive of Apartments, Commercial Condominium, Commercial Residential, Residential Commercial, Residential Condominium, and Town House land-use categories. Since the zoned Agricultural land identified within the buffers and corridors is not already designated a "protected area" within the PAD-US database, it is not otherwise protected by the Maryland Agricultural Land Preservation Foundation (MALPF). Located within the Maryland Department of Agriculture, MALPF identifies and protects eligible agricultural lands through perpetual easements to preserve productive agricultural land and woodland across the state (MALPF, 2015).

4.2.4.3 Crop profitability and competition

Given the significant portion of zoned agricultural land in the state, we further analyzed the economic profitability of cropland in Maryland buffers and corridors using data from Lamb et al. 2021. Here, the fraction of statewide corn, soy, and wheat cropland was estimated for the year 2011, using the United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) Cropland Data Layer (CDL) (USDA, 2011). This data year was used to match the NASA CMS tree canopy cover product. Baseline crop profitability under decadal average crop prices was established using data provided by USDA NASS and Maryland Department of Agriculture (USDA, 2019a). A rental economic model for forest carbon was then developed to estimate the locations and years at which projected forest carbon revenue under a given carbon price and rental rate would outcompete expected crop profit over the same time period. The baseline rental scenario includes a forest carbon price of $20/Mg C and rental rate of 5%. Competition scenarios assume the ongoing growth of existing trees plus the regrowth of new trees on all non-impervious areas. The baseline scenario included in this study evaluates competition over a twenty-year time period (e.g., through 2030). Other scenarios are provided in detail within Lamb et al. 2021.

4.2.5 Impact of projected land-use change

Finally, we evaluated the projected impact of land-use and land-cover change on the identified corridors and buffers utilizing the USGS Land Cover Projections for the Conterminous United States (LULCP) (Sohl et al., 2014, 2018). These projections, running from 2006 to 2100, are provided at 250m resolution, and include similar classifications to the USGS NLCD dataset (Jin et al., 2013). Four scenarios were modeled based on the IPCC Special Report on Emissions Scenarios (SRES) including A1B, A2, B1, and B2 (IPCC, 2000). While the IPCC now focuses on use of Representative Concentration Pathways (RCP) for climate change projections, related land-use projections for this geographic area have not yet been provided at sufficiently high resolution.

Here, we calculated the fraction and total area of mapped corridors and buffers projected to convert to development by 2030 across each IPCC scenario by calculating the difference between the NLCD 2011 land-use class (aggregated from 30m) of each 90m pixel to the projected USGS LULCP land-use class (downscaled from 250 to 90m). As the USGS LULCP only uses a single "development" land cover classification, we first combined all four NLCD development classes into a single "development" class before comparing the two datasets. These combined NLCD categories include: Developed, open space; Developed, low intensity; Developed, medium intensity; and Developed, high intensity. Differences in development over time were mapped and summarized for both reforestation scenarios at the state and county levels. For each scenario, we also estimated the fraction of projected development occurring on agricultural land areas.

4.3 Results

Here we provide the current statewide context for contemporary protected areas, priority biodiversity conservation areas, and related forest carbon stocks and carbon sequestration potential across the state of Maryland. We first compare each scenario to the statewide context to estimate relative improvements. Then we compare each scenario to each other, including potential areas of overlap, and subsequently evaluate both scenarios under several socio-economic considerations. We conclude with a review of the projected risk of development under four IPCC emissions scenarios. Additional county-level analyses can be found in Appendix C.

4.3.1 Statewide context

According to our analysis of the USGS PAD-US dataset, 22.3% of Maryland's land area currently falls within established protected areas (PA) (Table 4-

1). These statewide PAs vary in terms of size and management type, with the largest fractions managed by the state government (59.5%), local governments (15.3%) and the U.S. federal government (14.2%) (Figure C-1, Table C-1). However, the vast majority of PAs are not explicitly managed for biodiversity, falling in either the GAP Status 3 (42.9%) and GAP Status 4 (44.4%) categories (Table C-2). Those that are managed for biodiversity (GAP Status 1 and 2), primarily include conservation easements administered by the State, private land trusts and conservation areas, state parks and conservation areas managed by the Maryland Department of Natural Resources (MDNR), several National Wildlife Refuges, and local parks. Geographically, GAP Status 1 areas are clustered in Somerset County in southeastern Maryland and primarily include State Wildlife Management areas (Figure C-2).

Table 4-1: Protected areas in Maryland divided by area management type and GAP status category, which is a measure of management intent to conserve biodiversity

Layer	**Size (km2)**	**Land area fraction (%)**	**AGB (Tg C)**	**CSPG (Tg C)**	**Tree canopy fraction (%)[a]**	**Avg AGB density (Mg C /ha)[a]**
Statewide		*% of state*	*(% of state)*	*(% of state)*		
State of Maryland[b]	25255.77	--	110.79	204.11	49.5	51.83
Protected Areas (PA-MD)	5782.55	22.3	28.32 (25.6)	36.37 (17.8)	56.7	65.73
Management Type		*% of PA-MD*	*(% of PA-MD)*	*(% of PA-MD)*		
Federal	819.19	14.2	2.83 (9.9)	2.83 (7.8)	48.2	70.11
Local	884.85	15.3	5.93 (20.9)	6.30 (17.2)	65.9	76.31
NGO	635.98	11.0	2.58 (9.1)	5.09 (14.0)	50.7	54.78
State	3441.18	59.5	16.99 (60.0)	22.18 (60.0)	57.4	63.91
Unknown	1.35	<1.0	0.01 (<1.0)	0.01 (<1.0)	81.5	104.06
GAP Status[c]		*% of PA-MD*	*(% of PA-MD)*	*(% of PA-MD)*		
Status 1	16.85	<1.0	0.00 (<1.0)*	0.00 (<1.0)*	<1.0	76.63
Status 2	720.63	12.5	4.75 (16.8)	2.38 (6.5)	76.5	102.04
Status 3	2479.64	42.9	15.01 (53.2)	11.47 (31.6)	69.8	82.74
Status 4	2565.43	44.4	8.52 (30.0)	22.51 (61.9)	39.7	42.07

*these areas have low AGB/CSPG in part because much of this marshland has been masked out in our CSP data layers

[a] based on contemporary metrics (circa 2011); due to the marshland/impervious surface mask, some of this land area does not have AGB/CSPG estimates

[b] derived from Hurtt et al. 2019

[c] GAP Status 1 areas are managed for biodiversity and disturbance proceeds; GAP Status 2 areas are managed for biodiversity but disturbance is suppressed; GAP Status 3 areas are managed for multiple uses; and GAP Status 4 areas have no known mandate for biodiversity protection

More than 25% of the state's contemporary AGB can be found within PAs, which is slightly higher than proportional relative to the amount of land area they protect (22.3%) (Tables 4-1, C-3). The CSPG is less proportional, with 36.4 Tg C (or only 17.8%) of the state's total CSPG falling within protected areas. The tree canopy fraction is slightly higher than the statewide average at 59.7% and the average biomass density is also higher at 65.7 Mg C/ha in PAs. Across PA management types, 60% of both PA AGB and PA CSPG can be found on state managed areas (Tables C-4 and C-5). Locally managed lands represent the second largest group at 20.9% of PA AGB and 17.2% of PA CSPG. While GAP Status 3 PAs currently have the largest AGB stocks (53.2% of PA AGB), GAP Status 4 PAs boast the largest CSPG (61.9% of PA CSPG). In contrast, GAP Status 1 and 2 PAs together provide only ~7% of PA CSPG (Tables C-6 and C-7).

The MDNR WHS has classified 55.9% of Maryland's land area as significant for conserving Maryland's biodiversity (Table C-8). Ranked according to five tiers of increasing significance, 9.1% of all BioNet land is considered Tier 1, or of *critical* significance for biodiversity conservation, with another 8.1% falling within Tier 2 areas considered *extremely* significant for biodiversity conservation. The rest of the BioNet land area is divided rather evenly among Tier designations (Table C-8). Geographically, Tier 1 and Tier 2 areas can be found in every county except Baltimore City, with high fractions of statewide Tier 1 data located in Garrett county in northwestern Maryland, and in Worchester county in southeastern Maryland (Figure C-3).

BioNet lands include 83% of the state’s contemporary AGB (91.9 Tg C) but only 32.8% of the state’s CSPG (66.9 Tg C) (Table C-10). This high AGB is partially related to a high tree cover fraction (72%) and high average biomass density (85.9 Mg C/ha). When reviewed by tier, we find Tier 4 and Tier 5 land areas contribute the most to both BioNet AGB at 28.7% and 31.7%, respectively, and to BioNet CSPG at 31.6% and 33.4%, respectively. As the largest BioNet categories, these carbon contributions are relatively proportional to the amount of land area within each tier. The tree canopy fractions (65-76%) and average biomass densities (158.1-177 Mg/ha) for all Tiers are higher than the statewide average (Table C-8).

Finally, there is considerable overlap between the PA and BioNet datasets (Figure 4-3). Nearly 69% of all protected lands falls into one of the five BioNet tiers, including 43.5% of Tier 1 and 38.4% of Tier 2 classified land in the state (Tables C-10). Furthermore, 92.5% of PA AGB comes from these BioNet areas. However, 71.8% of all BioNet land remains unprotected, including majorities of all Tiers. In addition, the vast majority (78.1%) of BioNet CSPG can be found on land outside of existing PAs.

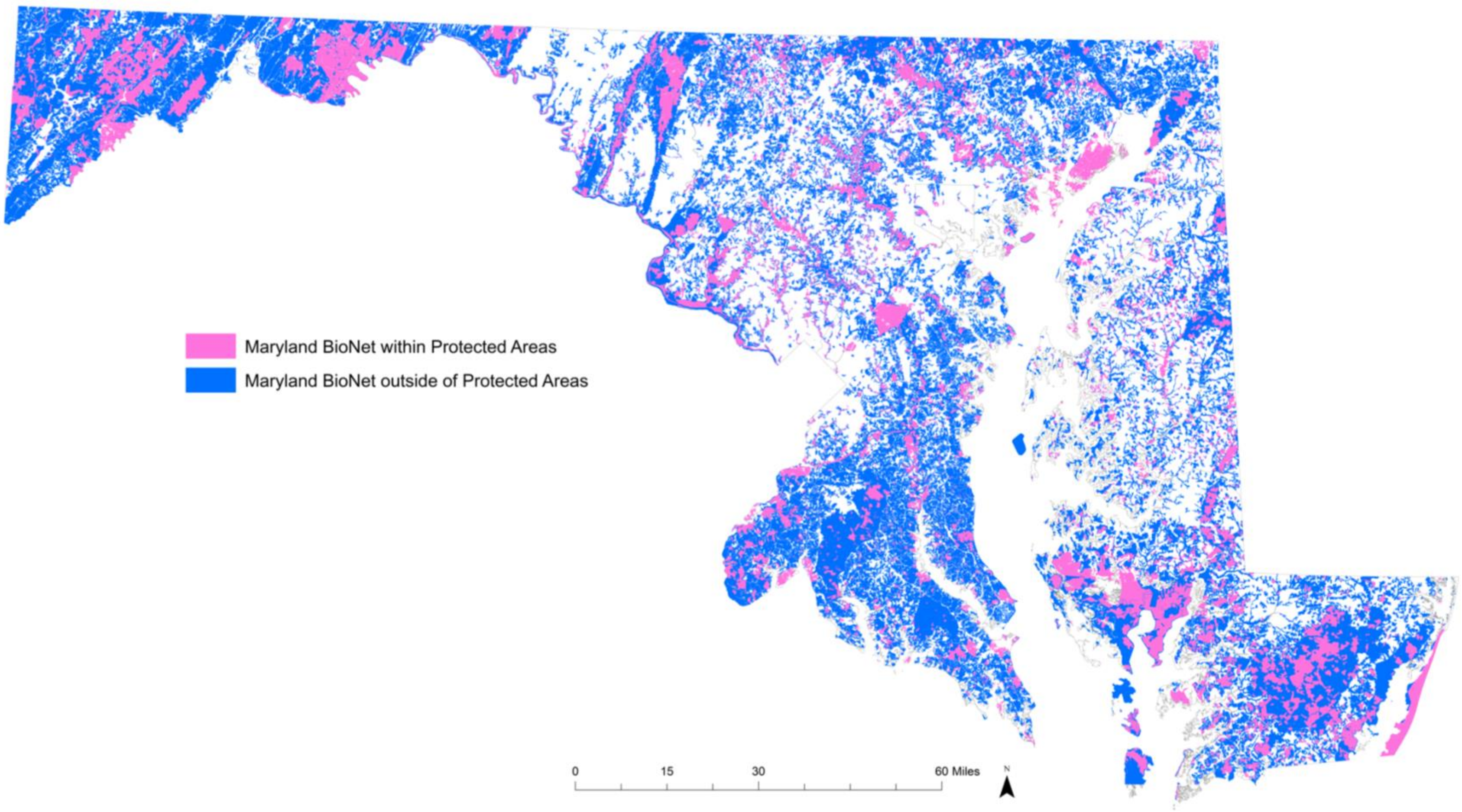


Figure 4-3: Identified Maryland Biodiversity Conservation Network (BioNet) areas for priority biodiversity conservation both inside and outside of existing protected areas.

4.3.2 Reforestation scenarios

4.3.2.1 Comparison to current protected areas

Together with existing protected areas, both optimized corridors and protected area buffers would increase protected lands to 45% of the state (Figure 4-4, Table 4-2). Both reforestation scenarios also provide similar increases in total BioNet area protected, at 67.1% for corridors and 70.4% for buffers. Corridors would add slightly higher AGB than buffers (3.9%), and with current protected areas, increase the total AGB protected to 53.8 Tg C. Corridors also provide moderately higher increases in CSPG (37.6%) relative to buffers, increasing the remaining carbon sequestration potential included in protected areas to 92.8 Tg C. While corridors maximize connectivity relative to existing protected areas, statewide buffers also increase connectivity by about 75%, and provided a range of benefits at the county level with between 38% and 95% of protected area units newly connected due to overlapping buffers (Table C-12).

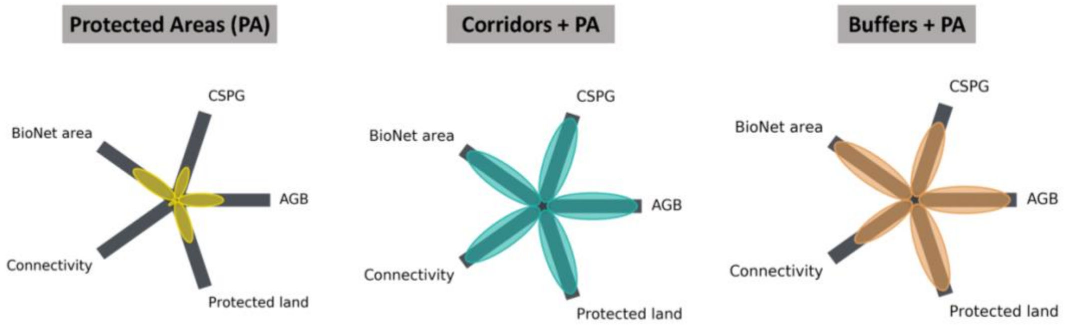


Figure 4-4. Key metrics of existing protected areas and the relative improvements provided by both reforestation scenarios statewide, including optimized corridors and protected area buffers, where *BioNet area* is the proportion of priority area for biodiversity conservation newly protected; *CSPG* is remaining carbon sequestration potential included; *AGB* is the contemporary aboveground biomass included; *Protected land* is the total area included; and *Connectivity* is the number of protected area units newly connected. A shorter ellipse represents lower values.

Table 4-2. Carbon and Maryland Biodiversity Conservation Network (BioNet) metrics for optimized 1km corridors and 225m protected area buffers across Maryland, including current aboveground biomass (AGB), carbon sequestration potential gap (CSPG), fraction of statewide BioNet area newly protected, contemporary average AGB density, and the time in years required for each reforestation scenario to achieve the average AGB density of existing protected areas.

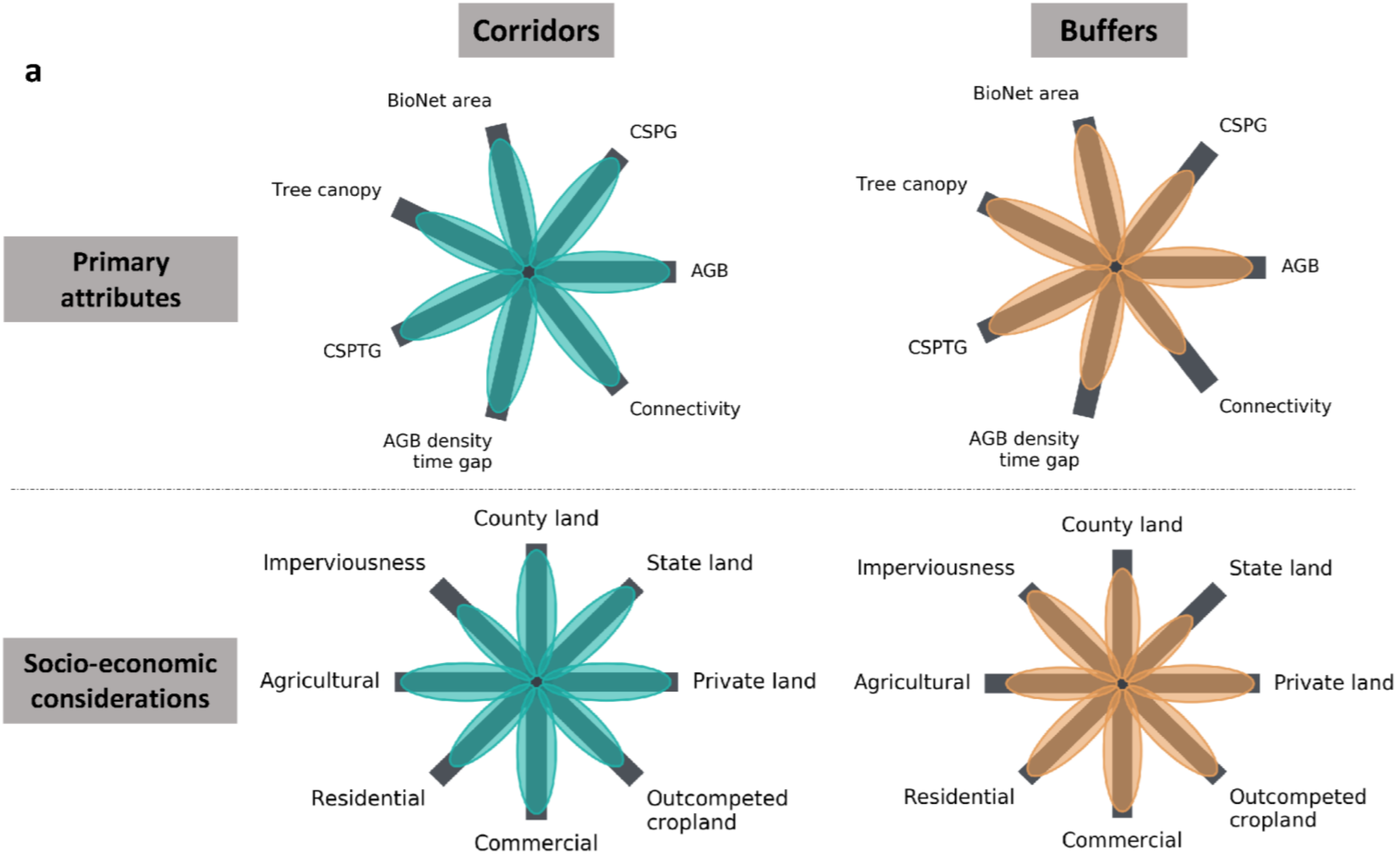
Layer	**Size (km2)**	**Land area fraction (%)**	**AGB (Tg C)**	**CSPG (Tg C)**	**Fraction of BioNet Area (%)**	**Tree canopy fraction (%)[a]**	**Avg AGB density (Mg C /ha)[a]**	**AGB density time gap (years)**
Statewide		*% of state*	*(% of state)*	*(% of state)*				
State of Maryland	25255.77	--	110.79	204.11	--	49.5	51.83	--
Protected Areas	5782.55	22.3	28.32 (25.6)	36.37 (17.8)	28.2	56.7	65.74	--
Reforestation Scenario			*(% of state)*	*(% of state)*				
Optimized Corridors	5625.26	22.3	25.48 (23.0)	56.42 (27.6)	19.3	43.5	46.35	28
Protected Area Buffers	5588.27	22.1	24.37 (22.0)	47.39 (23.2)	20.4	49.5	49.93	24

[a] based on contemporary metrics (circa 2011); due to the marshland/impervious surface mask, some of this land area does not have AGB/CSPG estimates

4.3.2.2 Optimized corridors

Optimized future carbon habitat corridors cover 22.3% of the state's land area (Figure C-4a), ranging at the county scale from 9.8% of Somerset County to 37.4% of Carroll County (Table C-14). Corridors range from 0.01 to 33.3 km^2 in length statewide (avg. 0.7 km^2). The contemporary tree cover fraction (43.5%) and average biomass density (46.4 Mg C/ha) are slightly lower than the statewide numbers. Corridors include 23% of statewide AGB (25.9 Tg C) and 27.6% of statewide CSPG (56.4 Tg C) (Table 4-3, Figures 4-4 and 4-5). As a fraction of total county-level AGB, corridors range from 14.5% in Allegany County to 33.6% in Howard and Charles counties (Table C-15, Figure C-5a). Relative to county-level CSPG, these proportions increase from 19.3% in Allegany County to 40% in Carroll County (Table C-16). To achieve the maximum carbon sequestration potential of these corridors would take approximately 298 years (Table C-17). However, it would take approximately 28 years for statewide corridors to achieve the average biomass density of statewide protected areas, at which point corridors would have gained an additional 11 Tg C relative to contemporary AGB (Table C-18). This average AGB density time gap ranges considerably at the county level with no remaining gap in five counties, including Allegany, Calvert, Charles, Garrett, and St. Mary's, and over 100 years in Baltimore City (Table C-18). Statewide, mapped corridors include 28.2% of statewide BioNet area, including 20.4% of Tier 1 and 16.8% of Tier 2 areas. Geographically, the highest fractions of Tier 1 area within corridors can be found in Garrett and Harford counties at 13.2% and 13.4%, respectively (Table C-19).

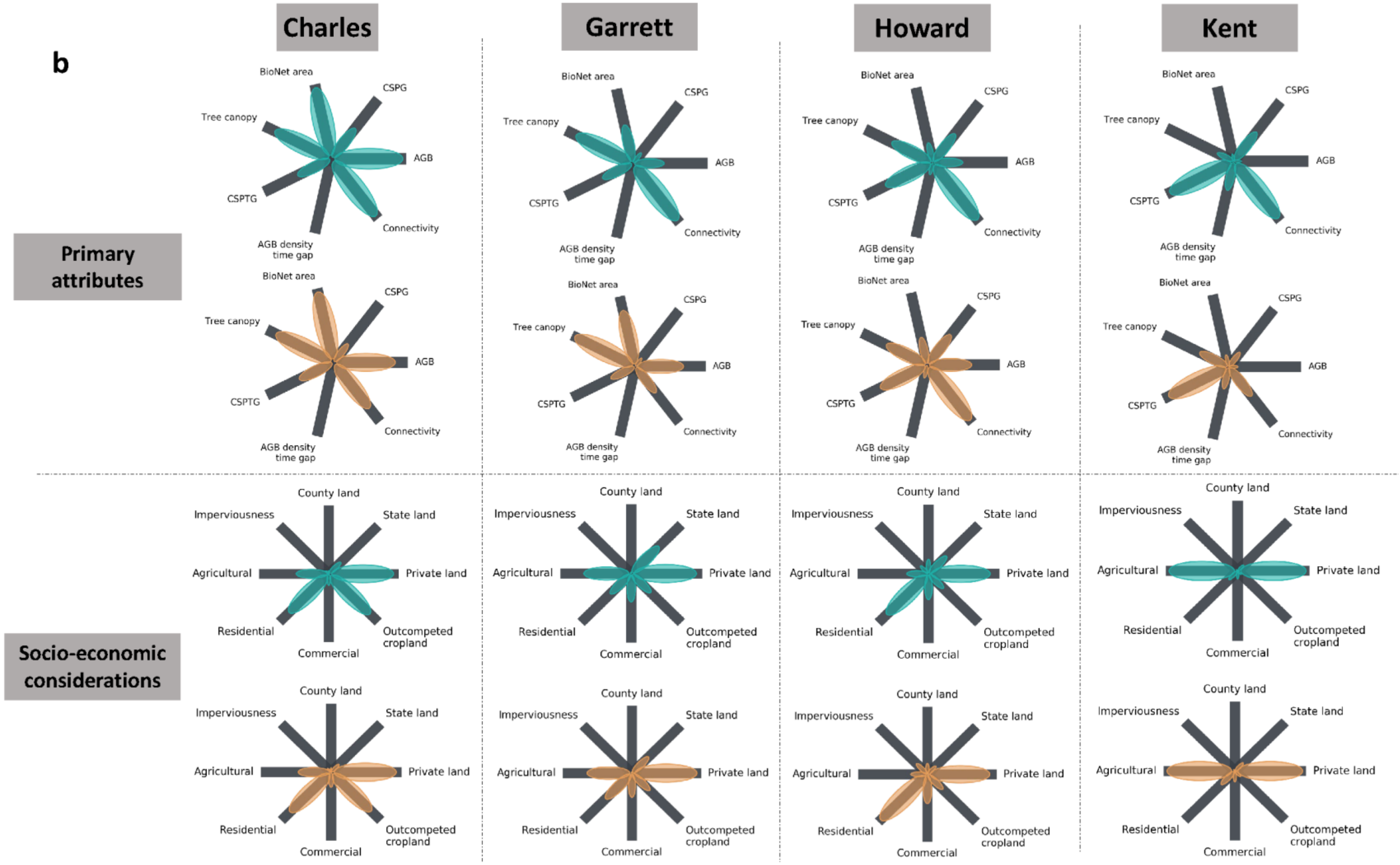
However, Charles County protects the most additional BioNet area regardless of specific tier (Figure 4-6).



continued

Figure 4-5. Relative difference between each reforestation scenario statewide (a) for several primary attributes and socio-economic considerations, where a shorter ellipse represents lower values. While values are fairly similar at the state scale, there is wide variability at the county scale. Panel (b) highlights this variability using four counties located across the state as examples.

Figure 4-5 continued



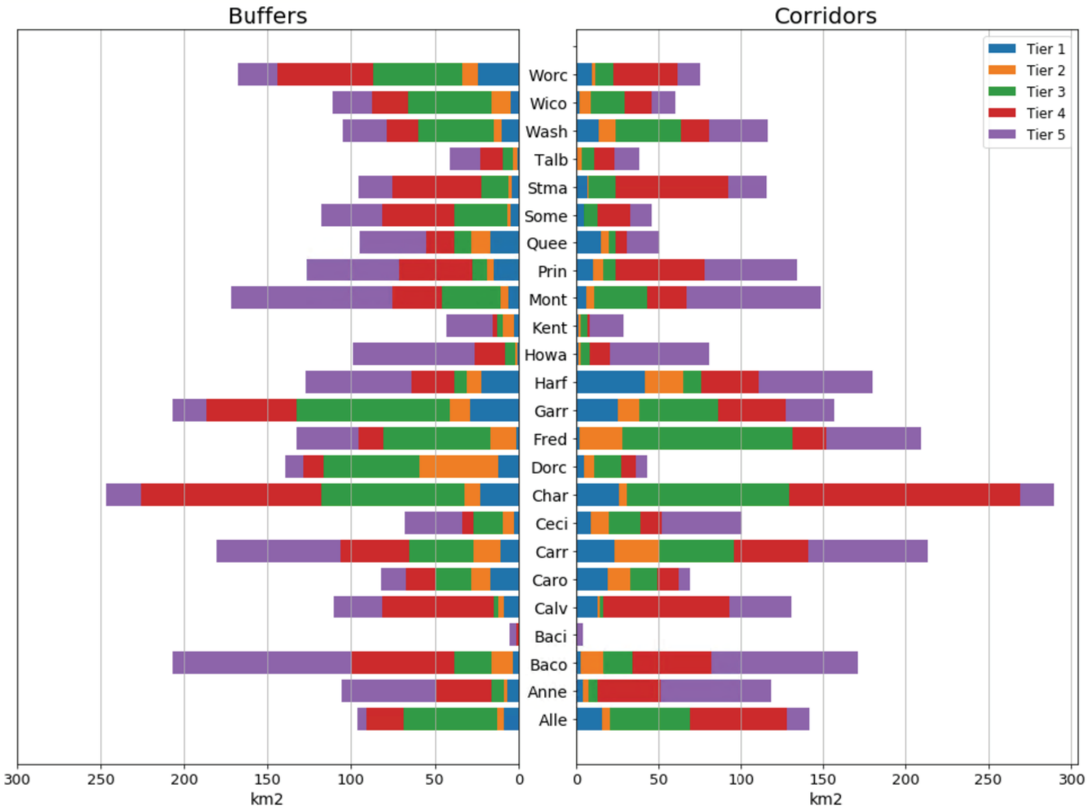


Figure 4-6: Maryland Biodiversity Conservation Network (BioNet) area by tier within both buffers and corridors at the county scale. The total amount of BioNet area and relative contribution of each tier of significance varies considerably across counties and between reforestation scenarios.

4.3.2.3 Protected area buffers

By design, protected area (PA) buffers cover a similar land area fraction (22.1%) as the corridor scenario (Table 4-2, Figure 4-4b). The total fraction of county land area covered by protected area buffers ranges from 11% in Allegany County to 49.7% of Howard County (Table C-14). Relative to corridors, mapped buffers include a similar tree canopy fraction (49.5%) and proportion of statewide AGB (24.4 Tg C). The CSPG, however, is lower than the optimized corridors at 47.4 Tg C or 23.2% of statewide CSPG (Figure C-6a). The contemporary statewide average biomass density of buffers (49.9 Mg C /ha) is lower than the state but slightly higher than that of the corridors. To achieve the maximum carbon sequestration potential of these buffers would take approximately 294 years (Table C-17). However, it would take approximately 24 years for statewide buffers to achieve the average biomass density of statewide protected areas, at which point buffers would have gained an additional 7.9 Tg C relative to contemporary AGB. As with corridors, the time gap ranges considerably at the county level (Table C-18). In addition, the AGB density time gap is lower for buffers than for corridors in fifteen of the twenty-three counties. PA buffers include 20.4% of all mapped BioNet area, including 18.4% of Tier 1 and 18.4% of Tier 2 area (Figure C-6b, Table C-19). The portion of each BioNet tier included within buffers varies among counties (Figure 4-6).

4.3.2.4 Scenario overlap

Geographically, there is some level of overlap between these two scenarios, especially where protected areas are clustered and mapped buffers and corridors utilize similar land area (Figure C-7). Both scenarios share 1876 km^2 of land area, or roughly 33% of mapped corridors and buffers at the state level. The specific portion of shared land area varies by county, with some counties such as Allegany in northwestern Maryland, showing very little overlap at 12.8% of corridors and 18% of buffers, and others, such as Howard, in Central Maryland, with high levels of overlap at 61.4% of corridors and 44.2% of buffers (Table C-14).

4.3.3 Socio-economic considerations

4.3.3.1 Impervious surface

The statewide impervious surface fraction of mapped corridors is 5.9%, with a county-level range between 46.4% in Baltimore City and 0.6% in Garrett County (Tables 4-3, C-16). Within protected area buffers, the impervious surface fraction increases to 7.3% (Table 4-4), with a similar range among counties between 50.4% in Baltimore City and 0.8% in Garrett County (Table C-16).

4.3.3.2 Land ownership

The vast majority of land within both corridors and buffers statewide is privately owned (88% for corridors, 88.8% for buffers) (Figure 4-5a). For both reforestation scenarios, counties (including Baltimore City) represent the second largest land owner at 3.9% of corridor land area and 3.5% of buffer land area. This pattern is relatively consistent across counties, except for Baltimore City where the portion of private (39.5%) and county/city ownership (35.7%) within corridors is more equitable (Figure C-8).

The portion of total scenario CSPG is relatively proportional to land ownership, with 89.9% of corridor CSPG (50.7 Tg C) and 90.1% of Buffer CSPG (42.7 Tg C) located on private land, and 3.3% of corridor CSPG (1.9 Tg C) and 3.5% of buffer CSPG (0.9 Tg C) located on county land. As the third largest land owner in both mapped scenarios, state land makes up a slightly larger portion of mapped corridors (2.3%) than buffers (1.7%), and contributes about 1.4% of corridor CSPG (0.8 Tg C) and 1% of buffer CSPG (0.5 Tg C). Regarding the potential for additional biodiversity conservation, 88.1% of corridor BioNet area and 90% of buffer BioNet area is found on private land. Within corridors, county and state land include relative equal portions of corridor BioNet area at 3.8% and 3.7%, respectively. For buffers, county land includes 3.2% of buffer BioNet area, while state land includes 2.3%.

Table 4-3: Socio-economic considerations for optimized corridors

Layer	**Size (km2)**	**Land Area Fraction (%)**	**AGB (Tg C)**	**CSPG (Tg C)**	**BioNet Fraction (%)**	**Impervious Fraction (%)**
Reforestation Scenario		*% of state*	*(% of state)*	*(% of state)*		
Optimized Corridors (Corr-MD)	5625.26	22.3	25.48 (23.0)	56.42 (27.6)	19.3	5.9
Land Ownership		*% of Corr-MD*	*(% of Corr-MD)*	*(% of Corr-MD)*	*Corr-MD-BN*[a]	
Private	4947.39	88.0	21.96 (86.2)	50.7 (89.9)	88.1	5.0
Federal	27.65	0.5	0.16 (0.6)	0.20 (0.4)	0.6	11.0
State	127.77	2.3	1.01 (4.0)	0.80 (1.4)	3.7	4.0
County	218.04	3.9	1.17 (4.6)	1.87 (3.3)	3.8	11.8
Town/Municipal	35.81	0.6	0.17 (0.7)	0.31 (0.6)	0.6	8.1
Non-profit	42.90	0.8	0.24 (0.9)	0.35 (0.6)	0.9	10.6
Other	44.06	0.8	0.25 (1.0)	0.43 (1.0)	0.9	2.0
Land Use		*% of Corr-MD*	*(% of Corr-MD)*	*(% of Corr-MD)*	*Corr-MD-BN*[a]	
Agricultural	2694.38	47.9	10.24 (40.2)	30.63 (54.3)	49.0	0.6
Residential	1666.46	29.6	9.62 (37.8)	14.94 (26.5)	31.8	6.4
Commercial	183.58	3.3	1.59 (6.2)	3.49 (6.2)	2.1	23.5
Other Housing	53.30	0.9	0.38 (1.5)	1.04 (1.8)	0.4	26.9
Industry	77.60	1.4	0.25 (1.0)	0.63 (1.0)	1.0	28.6
Marsh Land	0.67	0.0	0.00 (<1.0)	0.01 (<1.0)	0.0	0.4
Exempt	282.72	5.0	1.93 (7.6)	2.07 (3.7)	6.8	7.3
County Club	16.80	0.3	0.04 (0.2)	0.22 (0.4)	0.2	5.7
No Class	250.18	4.4	1.04 (4.1)	2.26 (4.0)	3.3	14.3

[a] Fraction of BioNet land within optimized corridor

Table 4-4: Socio-economic considerations for protected area buffers

Layer	**Size (km2)**	**Land Area Fraction (%)**	**AGB (Tg C)**	**CSPG (Tg C)**	**BioNet (BN) Fraction (%)**	**Impervious Fraction (%)**
Reforestation Scenario		*% of state*	*(% of state)*	*(% of state)*		
Protected Area Buffers (Buff-MD)	5588.27	22.1	24.37 (22.0)	47.39 (23.2)	20.4	7.3
Land Ownership		*% of Buff-MD*	*(% of Buff-MD)*	*(% of Buff-MD)*	*Buff-MD-BN*[a]	
Private	4962.34	88.8	21.90 (89.8)	42.73 (90.2)	90.9	19.6
Federal	24.71	0.4	0.15 (0.6)	0.14 (0.3)	0.5	10.4
State	93.43	1.7	0.44 (1.8)	0.46 (1.0)	2.3	8.2
County	198.10	3.5	0.86 (3.5)	1.51 (3.2)	3.2	15.2
Town/Municipal	26.41	0.5	0.11 (0.5)	0.20 (0.4)	0.4	10.9
Non-profit	38.30	0.7	0.20 (0.8)	0.29 (0.6)	0.7	12.9
Other	44.06	0.4	0.25 (1.0)	0.43 (<1.0)	0.5	4.0
Land Use		*% of Buff-MD*	*(% of Buff-MD)*	*(% of Buff-MD)*	*Buff-MD-BN*[a]	
Agricultural	2362.54	42.3	9.18 (37.7)	21.77 (45.9)	47.4	0.7
Residential	1864.52	33.4	10.07 (41.3)	15.37 (32.4)	33.6	7.0
Commercial	184.50	3.3	1.47 (6.0)	3.05 (6.4)	2.3	24.9
Other Housing	69.51	1.2	0.40 (1.6)	1.10 (2.3)	0.5	27.4
Industry	77.60	1.4	0.25 (1.0)	0.63 (1.0)	0.9	32.2
Marsh Land	25.86	0.5	0.01 (<1.0)	0.02 (<1.0)	0.6	4.6
Exempt	284.43	5.1	1.43 (5.9)	1.88 (4.0)	6.0	10.4
County Club	13.88	0.2	0.04 (0.2)	0.16 (0.3)	0.2	5.6
No Class	278.79	5.0	1.12 (4.5)	2.30 (4.9)	3.4	15.9

[a] Fraction of BioNet land within protected area buffer

4.3.3.3 Land use

The dominant land-use class across both corridors and buffers is agricultural, including 49% of statewide corridors and 47.4% of buffers (Table 4-6, Table 4-7). Residential area is the second highest land-use class, representing 31.8% and 33.6% of mapped corridors and buffers, respectively. For at least three counties, the proportion of agricultural land within buffers is more than 70%, including Caroline, Kent and Talbot along Maryland’s eastern shore (Figure C-9). For corridors, an additional county, Dorchester is further included at 73.2% agricultural.

Along corridors, agricultural lands include slightly higher AGB (40.2 Tg C) than residential lands (37.8 Tg C). For protected area buffers, this AGB pattern is reversed with 41.3 Tg C on residential lands and 37.7 Tg C on agricultural land. Regarding their remaining carbon sequestration potential, agricultural land includes 54.3% of corridor CSPG (30.6 Tg C) and 45.9% of buffer CSPG (21.8 Tg C), while residential lands include 26.5% of corridor CSPG (14.9 Tg C) and 32.4% of buffer CSPG (15.4 Tg C). Similar fractions of BioNet area are found along agricultural and residential land areas for both corridors (49% and 31.8%, respectively) and buffers (47.4% and 33.6%, respectively).

4.3.3.4 Cropland profitability

Just over half of all zoned agricultural land in both corridors (57.6%) and buffers (54.3%) included cultivated corn, soy, or wheat in the baseline year of analysis. Under the baseline carbon rental scenario, 17.5% of corridor cropland would be immediately outcompeted by expected forest carbon revenues, with an additional

0.8% of cropland outcompeted by 2030 under a 20-year land-use agreement (Table C-21). In comparison, 19.7% of buffer cropland would be immediately outcompeted under the baseline rental scenario, with an additional 0.9% of cropland outcompeted by 2030. At the county-scale, the fraction of outcompeted cropland varies widely along corridors from 3.8% in Talbot county to 65.1% in Prince George's county. Within buffers, outcompeted cropland ranges from 6.3% in Talbot county to 67.2% in Allegany county.

4.3.4 Risk to future development

Both corridors and buffers show projected increases in development across all four IPCC emissions scenarios (Table C-22). While both reforestation scenarios show a similar magnitude of total development by 2030 (~30%), optimized corridors are projected to experience slightly higher increases relative to their contemporary development fraction. Some counties are more affected by these projected increases, such as Prince George's County along the Baltimore-Washington DC corridor, where upwards of 26.9% of corridors and 25.6% of buffers face additional urbanization (Figure 4-7). Other counties, such as Garrett county in northwestern Maryland, face little projected development at less than 1% of corridors and buffers. At the state scale, between 42.7-49.2% of projected development within corridors, and 14.3-15.5% of projected development within buffers is expected to occur on agricultural land (Table C-23). Along Maryland's eastern shore, including in Talbot and Queen Anne's counties, the fraction of agricultural land facing projected urbanization is upwards of 68.8% along corridors and 60.9% within buffers.

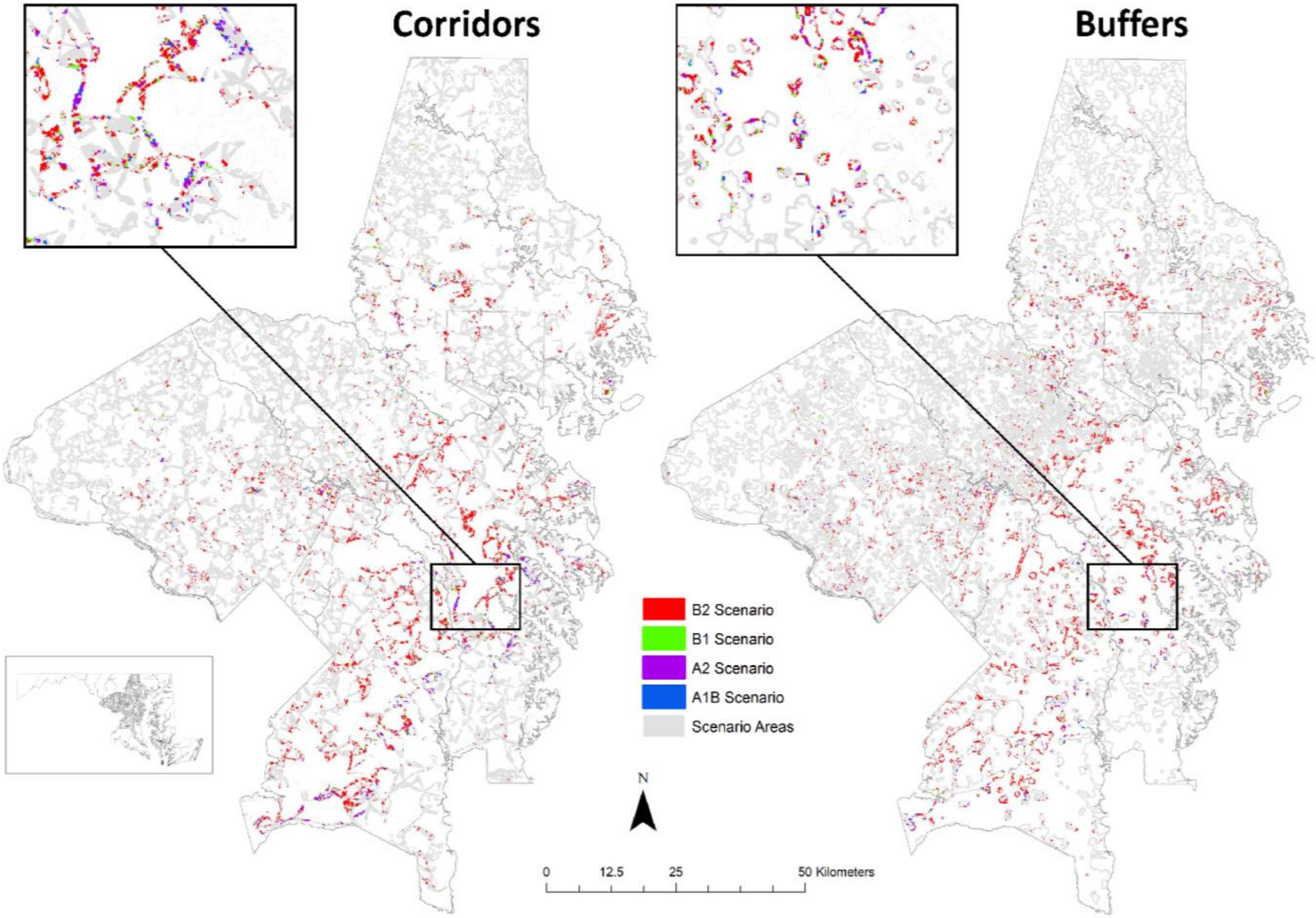


Figure 4-7: Projected development along scenario areas (optimized corridors and protected area buffers) within the Baltimore-Washington corridor, where IPCC scenario results are layered such that anything shown as development under the B2 scenario is also developed in subsequent scenarios. The inset highlights additional development identified at 90m resolution as scenarios change.

4.4 Discussion and conclusions

In this study we advance a high-resolution geospatial framework to identify strategic areas for reforestation that can increase the amount of carbon stored for climate mitigation and advance goals for expanded protected area in support of biodiversity protection. We found that optimized future corridors can sequester significant amounts of additional carbon (11 Tg C) over short time scales (<30 years), reconnect nearly all currently fragmented protected areas statewide, and promote economically profitable restoration, including on at least 17.5% of traversed cropland under modest forest carbon pricing. Our second reforestation scenario expanded protected area buffers to analyze potential benefits and tradeoffs of implementation relative to corridors. While state level results highlight similar portions of Maryland BioNet area protected relative to corridors (~20%), these buffers include less CSPG and provide lower levels of connectivity in counties across the state. Neither scenario would achieve a 50% target of area-based land protection, suggesting the importance of combining these strategies as part of an iterative process at the state and county scales. Innovative policies and programs that engage private landowners on agricultural and residential land will be critical for creating such a landscape matrix. Below we discuss the major findings from our scenarios and consider the implications of leveraging this approach in ongoing land-use planning.

4.4.1 Scenario observations and implications

4.4.1.1 Carbon

The carbon benefits of reforestation are not the same over space. Our analysis shows that the expected carbon sequestration potential gap (CSPG) of corridors is

19% higher than protected area buffers, sequestering an additional 56.4 Tg C. Given that both scenarios included a similar magnitude of overall land area, prioritizing areas with high CSPG in our least-cost corridor model was successful in securing higher carbon benefits. While achieving the full carbon sequestration potential of buffers and corridors would take well over 200 years, these scenarios would add between 7.9-11 Tg C by 2030, which is still twenty-three times the amount of forest carbon the state expects to sequester by 2030 from planned reforestation activities outlined within the 2019 Greenhouse Gas Reduction Act Plan (~1.5 MMtCO2e).

As the state considers potential legislation to increase reforestation efforts (e.g., MD HB 1133, 2021 Reg. Sess), the expected benefits of carbon sequestration should be quantified across space to prioritize areas where additional climate mitigation through reforestation can be maximized. All carbon sequestration estimates here are based on natural regeneration rates and native plant species. Therefore, planting non-native species or engaging in active planting and management approaches will likely alter expected outcomes. While forest restoration through natural regeneration is expected to be cost-effective at landscape scales (e.g., Crouzeilles et al., 2020), this approach may require adaptation in highly urbanized areas such as cities and residential areas with high levels of imperviousness and tendencies towards non-native species selection. Finally, while our analysis prioritizes remaining the CSPG in order to store more carbon, this approach relies on current forests remaining protected. Existing forests in the state provide many ongoing benefits including climate mitigation, and if converted would likely negate the related sequestration benefits of reforestation over policy-relevant time periods.

4.4.1.2 Habitat

Habitat corridors and protected area buffers offer opportunities for advancing biodiversity protection using different approaches. As mapped here, future habitat corridors would facilitate high levels of habitat connectivity across a fragmented and heterogeneous landscape as well as increase overall habitat area. Our approach identified more than 31,000 unique least-cost pathways that together connect existing protected areas in a new network while prioritizing the inclusion of Maryland BioNet land area that remains unprotected. Due to our least-cost model, corridors did protect slightly higher proportions of Tier 1 or “critically significant” habitat for biodiversity conservation than buffers statewide. However, the portion of BioNet area included in each scenario varied widely at the county level. For example, corridors included between 6.6-69.4% of county-level Tier 1 land area suggesting that these scenarios may not completely protect all unique species assemblages in a given county. Further, corridors protected more BioNet area than buffers in only half the counties (Figure 4-6). However, habitat corridors do provide important benefits on a landscape scale.

While corridor use is undoubtedly species-specific, recent meta-analysis show that corridors can increase movement between habitat patches by approximately 50% compared to patches that are otherwise not connected, and are more important for the movement of invertebrates, non-avian vertebrates, and plants than for birds (Gilbert-Norton et al., 2009; Keeley et al., 2019). Further, reducing human development pressure by increasing forest cover may have benefits for a range of taxa whose movements are acutely affected by a growing human footprint (Tucker et al., 2018). While some have raised the potential negative effects of corridors on target species, specifically the creation of edge and its effects on species population size and persistence (Simberloff & Cox 1987; Simberloff et al., 1992), wider corridors (at or greater than 1km) as well as the reduction of contrast between corridors and the surrounding land-use matrix may strongly mitigate these edge effects (Haddad et al., 2014). Restoring corridors is also critical for facilitating species migration in the context of ongoing climate change, where the velocity and directionality of such change is likely to shift species outside of current protected area boundaries (Burrows et al., 2014; Loarie et al., 2009; McGuire et al., 2016).

Our alternative reforestation strategy highlighted the value of strategic land-use management around current protected area boundaries. Mapped future buffers are intended to ultimately increase the amount of core habitat and reduce harmful land-use change around sensitive ecological areas (de la Fuente et al., 2020). As protected areas in the state range from very small local conservation easements (~100m^2) to large State Resource Management Areas (212km^2), the benefits of a standard 225m forest buffer will vary considerably. However, edge-effect magnitude and extent are not necessarily correlated (Ewers & Didham, 2006) and even small buffers may provide significant benefits for certain taxa (e.g., Marsh et al., 2018; Terraube et al., 2016). We also found that buffers can advance connectivity by structurally connecting protected areas within 450m of each other (Table C-12). In some counties, such as Howard, buffers provided about 95% of the connectivity otherwise offered by corridors.

Similar to national-level trends (Simmons et al., 2021), most of the protected areas in the state are not explicitly managed for biodiversity, and many easements are specifically designed to meet a variety of land-management objectives (e.g., Farr et al., 2018). Further, while the average contemporary AGB density of these protected areas is higher than the state average, they may not necessarily include core forest habitat across their entire domains, especially those which contain higher levels of impervious surface and fragmentation via roads (e.g., Goetz et al., 2009). This suggests an additional opportunity for reengaging or reimagining the management approaches utilized within these protected areas so that reforested buffers can provide maximum value for forest species. However, 69% of protected area also has a Maryland BioNet tier of significance, reflecting the priority the state places on these areas for protection regardless of the current management intent of the protected area unit. Since the State of Maryland is the dominant manager of statewide protected areas, there is higher potential for coordinated and targeted management relative to state wildlife and biodiversity goals.

Both reforestation scenarios require further engagement by conservation managers to identify potential benefits for specific species. While the time to achieve the AGB density time gap across counties is much quicker than the time required to achieve the CSPG, there is still considerable variability at the county-scale (Table C-18). At least five counties have average corridor and buffer AGB densities that are as high if not higher than current protected areas, suggesting that reforestation would immediately increase the value of these areas for current forest species. Most other counties range from 12-45 years, with Baltimore City requiring more than 100 years to develop AGB densities that may meet the needs of species within neighboring protected areas. This should be considered a minimum time estimate of viability, given AGB density is not the only indicator of habitat suitability and use (e.g., Rappaport et al., 2018). As these buffers and corridors regrow, they may over time provide habitat for different species which have different forest structure and age requirements (e.g., Sanjuan de Medeiros-Sarmento et al., 2021).

4.4.1.3 Socio-economic considerations for policy and planning

Private land-owners are critical to the implementation of either reforestation scenario. Specifically, the largest fraction of statewide optimized corridors (47.9%) and protected area buffers (42.3%) includes agricultural land. At the county scale, this fraction increases to upwards of 83.2% in corridors and 75% in buffers across Maryland's eastern shore. Many counties in the state are dominated by agriculture, highlighting the importance of engaging famers in reforestation implementation of corridors and buffers. Promoting carbon sequestration and wildlife habitat on agricultural lands supports existing policies and programing such as the USDA Agricultural Conservation Easement Program (USDA, 2021). Further, a heterogeneous landscape with agroforestry has been shown to yield increased carbon benefits and facilitate species movement while mitigating negative edge effects (Arroyo-Rodriquez et al., 2017). However, many forest species are unable to persist within such systems without the preservation or restoration of forest cover across the landscape (Schroth et al., 2015). Therefore, while partial reforestation of agricultural land can be helpful, financial incentives to support the full conversion of some cropland to forest land may be required.

Comparing to recent work by Lamb et al. 2021, we find 17.5% of cropland within mapped corridors could be immediately outcompeted by forest carbon rental revenue generated from a low-to-moderate carbon price ($20/Mg C) and rental rate (5%). This proportion increases to 19.7% of cropland along mapped buffers. With appropriate economic incentives, farmers may choose to convert current cropland to forests, which could increase forest cover and related carbon benefits. However, as securing farmers' livelihood benefits is paramount, a higher carbon price or rental rate could increase the proportion of eligible cropland, and farmland that lies within priority corridors or buffers could be prioritized for funding.

Finally, since this work focuses on creating new habitat corridors rather than protecting existing ones, the time scale of acquired habitat benefits, including AGB density requirements and carbon sequestration rates, must be compared to the pace of projected land-use change. While the statewide fraction of corridors and buffers expected to experience additional land-use change from development pressure is relatively low across scenarios (5.6-7.4%), some counties such as Howard and Baltimore City show disproportionate impacts given current high levels of development. Given high levels of risk and current impervious surface, these urban areas will require refined strategies for corridor mapping and management to ensure long term species viability and reduce human-wildlife conflict (e.g., Apfelbeck et al., 2020). As urban tree planting initiatives increase across Maryland, Washington DC, and elsewhere along the East Coast (e.g., MDNR, 2021c), proactive engagement at this intersection will be critical. Further, identifying priority corridors and buffers at highest risk to future development can guide contemporary land-use planning by proactively incentivizing their protection and reforestation.

4.4.2 Iterative development and implementation

Our high-resolution geospatial framework advances several key design elements for optimizing carbon sequestration, biodiversity recovery, and livelihood benefits (Di Sacco et al., 2021). Specifically, our approach encourages the protection of existing forests even as it expands forest area for more carbon; depends on and benefits from ongoing collaboration with stakeholders from across state agencies, non-governmental organizations, private land-owners and universities; jointly maximizes biodiversity recovery to meet multiple state goals rather that maintaining siloed approaches; identifies specific, strategic, and appropriate areas for reforestation using natural regeneration; supports a model of "learning by doing" where some corridors and buffers can be reforested in phases based on priority, rather than all reforestation happening at once; and encourages sensitivity to economic opportunity by supporting local land owners under a carbon pricing program. This work must also be adaptive.

Adaptive management is not only a hallmark of ecosystem management (Van Dyke & Lamb, 2020b), but is also important for securing carbon and habitat benefits from reforestation that may accrue over decades and depend on larger patterns of global environmental change (Liu & Taylor, 2010). For example, not only are there a large number of variables that could be used to map strategic carbon habitat corridors, implemented routes across the landscape will ultimately be influenced by land-owner participation and engagement as well as changes in larger carbon markets (Brancalion et al., 2017). Operating as a planning tool, this framework should be applied iteratively to explore the tradeoffs that exist across space and over time and updated regularly as new land-use data, including of baseline forest carbon stocks, is acquired.

Another important consideration moving forward is the impact of ongoing climate change on forest growth rates, disturbance rates, species movements, and general viability of farming under increase climatic variability (e.g., Bonan et al. 2008, Long et al. 2006, Parmesan & Yohe 2003). Predicting these effects was beyond the scope of this work, as the relevant global climate change scenarios were not available or harmonized at the resolutions required, and the links between future climate change and disturbance rates are not well understood. However, it is clear that future climate conditions could either raise (e.g., through faster growth rates and/or reduced disturbance) or lower (e.g., through depressed growth rates and/or increased disturbance) the default estimates for CSP, related CSPTG, and the AGB density time gap (Dolan et al., 2017; Fisk et al., 2013; Le Page et al., 2013; McMahon et al., 2010; Murray-Tortarolo et al., 2016; Zhao & Running, 2010). For example, Hurtt et al. show that on one extreme, higher rates of net primary productivity (NPP) and lower disturbance rates could quadruple the statewide average CSP and increase the related CSPTG in Maryland by 132 years (2019). Faster growth rates and lower disturbance rates over the next few decades may help reforested corridors and buffers close the AGB density time gap more quickly, but long-term trends must be more well understood to clarify the magnitude of ongoing carbon sequestration benefits and their impacts on forest competition with alternative land uses also affected by climate change (e.g., crop yield and profitability).

Finally, high-resolution ecosystem mapping and modeling, initialized by remote sensing data, is foundational to the extension of this work (e.g., Ma et al., 2021; Tang et al., 2021). As space-borne lidar-based missions, such as the Global Ecosystem Dynamics Investigation (Dubayah et al., 2020), continue to collect and disseminate lidar data over extensive areas, this approach can be leveraged to other geographies. Having a high-resolution framework for advancing climate mitigation and biodiversity is critical because reforestation must ultimately take place at local land-owner scales. The most successful connectivity conservation plans are those which support enduring partnerships among stakeholders and provide continuity of commitment over space and time (Keeley et al., 2019). Consequently, this framework must be ultimately applied outside of academia and alongside state agencies, non-profits, and land managers who can only together implement the work.

Chapter 5: Conclusions

5.1 Summary of contributions

While most states in the Regional Greenhouse Gas Initiative (RGGI) region are not yet utilizing high-resolution forest carbon products to inform climate mitigation planning, this research has demonstrated the products' tremendous value for identifying spatially-explicit areas for strategic reforestation that advance multiple policy goals. Afforestation, reforestation, and urban tree planting are increasingly popular nature-based climate solutions; however, the most successful efforts will be based on the best geospatial science and maintain a strong commitment to local ownership and management (Chazdon et al., 2017; Lamb & Schmidt, 2021). This research directly engaged complex issues in potential reforestation efforts, including land ownership and management, compensation, policy supports, and ecological co-benefits (e.g., César et al., 2021). The results emphasized the opportunity that states have individually and collectively to strategically advance climate mitigation with carbon smart land-use planning, provided that the spatial heterogeneity of related benefits is quantified and mapped.

Chapter 2 evaluated the current context for integrating forest carbon into state climate mitigation planning and identified opportunities for more systematic development and application of new forest carbon monitoring strategies. Of the eleven states reviewed, only Maryland and Massachusetts have outlined specific forest activities to be directly implemented by state agencies within their climate mitigation planning. Further, only one state in the region (Maryland) currently utilizes high-resolution forest carbon modeling to quantify the carbon outcomes of these activities, suggesting more opportunity for expanded capacity in this area. However, this work also showed that most states (eight) in the region evidence commensurate levels of science support and policy inclusion, suggesting that greater access to and uptake of advance high-resolution forest carbon science may drive ambition towards fuller inclusion of forest carbon within greenhouse gas reduction planning. By forming the basis of a shared carbon monitoring system across the U.S., high-resolution products may also spur new regional collaborations and facilitate the development of carbon markets for forests.

Chapter 3 specifically demonstrated the usefulness of this high-resolution data within a forest carbon rental model, where the potential revenue from forest carbon was found to outcompete the expected profit of existing cropland across the state of Maryland. Even under a conservative baseline economic scenario, this work identified economic opportunities for reforestation on almost a quarter of cropland across the state. Further, increasing the carbon rental scenario's competitive value made more cropland in the state eligible for profitable reforestation, both immediately and by the end of a long-term rental agreement. However, not all cropland was outcompeted under any economic scenario presented, highlighting the importance of representing economic opportunity as spatially-explicit. Further, this work can guide the development of a competitive forest carbon price within state policy and programming and better clarify the time it takes to realize related economic and carbon benefits.

Chapter 4 expanded the notion of strategic reforestation to explicitly consider the joint goals of climate mitigation and biodiversity conservation using a new high-resolution framework. Using two potential reforestation scenarios across Maryland, this work identified future landscape connectivity pathways that expanded protected area while maximizing the remaining statewide carbon sequestration potential. Neither corridors nor buffers would independently achieve a 50% target of area-based land protection, suggesting the importance of combining these strategies as part of an iterative process at the state and county scales. As much of the land area within these scenarios is agricultural, a price on forest carbon, as demonstrated in Chapter 3, could incentivize partial or full reforestation of these land areas to advance implementation. Given state-wide projections of urbanization through 2030, this work additionally identified county-level corridors and buffers at highest risk to future development, and suggests that proactive land-use planning could incentivize their protection and reforestation.

This research began with a review of states in the RGGI domain given their influential participation in the first mandatory market-based program in the United States. Although forest carbon is not yet traded within this market, annual auction revenues provide member states such as Maryland new opportunities to strategically re-invest proceeds in reforestation and forest restoration. For example, this body of work suggests that access to and use of high-resolution forest carbon science can effectively guide program dollars to land areas with high potential climate mitigation value and quantifiable co-benefits to local livelihoods and biodiversity conservation. Not only can auction proceeds fund economically viable reforestation at land owner scales (Chapter 3), but they can be used to facilitate strategic planning at coordinated landscape scales (Chapter 4). While one other state in RGGI, New Jersey, has signaled an interest in using RGGI auction proceeds to fund strategic tree planting (NJDEP, 2020), they currently have a large mismatch between their current level of policy integration and the sophistication of the science guiding this work (e.g., they fully include forest carbon towards greenhouse gas reduction goals using primarily default methods from the IPCC) (Chapter 1). Moving forward, the confluence of high-resolution forest carbon products, high levels of inclusion within climate mitigation planning, and targeted re-investment of auction proceeds could strategically advance the climate mitigation goals of RGGI member states.

5.2 Potential improvements and future research

All of this research represents a single snapshot of opportunity. As land-use decisions are made over time and carbon markets continue to develop, spatially strategic areas for reforestation may change. This reality emphasizes the importance of iterating the presented framework (Figure 1-1) to improve and adapt related findings. Specifically, ongoing climate change is likely to alter forest growth rates and long-term carbon storage by affecting net primary productivity (NPP) and disturbance rates (Körner, 2017; Norby & Zak, 2011; Walker et al., 2019). As the direction and extent of this impact on future forest carbon stocks are still unknown, and will likely vary across broad spatial domains (e.g., regional and national scales), more work should be done to include climate projection information as soon as they are available at sufficiently high resolutions.

There are a large number of variables that could be used to define “strategic” reforestation, and this work highlighted two of key interest to land-use planning (economic livelihood and biodiversity protection). However, as a framework, this work can and should also be extended to other variables of interest, including riparian restoration to improve surface water quality. Water security is one of the major co-benefits of forest restoration identified globally (Filoso et al., 2017), and spatially-explicit impacts on watershed services will be of particular interest across governance scales (Murcia et al., 2016). Selected variables will likely vary across geographies given heterogenous biophysical and socio-economic factors. However, different analyses should be combined as much as possible to reinforce layered benefits across space (e.g., as was done in Chapters 3 and 4).

Each chapter also has specific opportunities for future work and improvement. Chapter 2 could be expanded to include other states in the U.S. Climate Alliance that may represent different patterns of state need and opportunity for forest carbon science and policy. More work should also be done to explicitly consider the linkages between climate mitigation plans and GHG inventories, which are highly variable across the RGGI domain. These policy connections are particularly important for forest carbon monitoring, where high spatial resolution approaches will be required to assess and validate local reforestation activities, and to evaluate progress relative to the goals outlined in the climate mitigation plan (e.g., Harris et al., 2021, Hurtt et al., 2021). Key questions remain about the attribution of forest stock changes identified in the annual inventory (e.g., anthropogenic vs. natural) and whether all changes should count towards pledged GHG reduction goals (Hurtt et al., 2020).

Chapter 3 considers potential economic competition of reforestation with cropland, a large fraction of current land-use in Maryland, but this competition analysis should be expanded to other land-uses. Additionally, while the competition analysis with Maryland cropland provides insight for the average farmer, actual economic costs vary at the landowner scale. Consequently, more work could be done to make the analysis more sensitive to local heterogeneity in crop budgets. As interest in “carbon farming,” and related agricultural methods aimed at increasing carbon sequestration in the soil and crops grows (e.g., Dumbrell et al., 2016), this work might also benefit from expanded analysis to other carbon pools. For example, the level of economic and the carbon benefit of reforestation on cropland may change if markets or other financial incentives expand for climate-friendly farming practices.

Chapter 4 utilizes existing maps of priority biodiversity conservation areas as developed by the State of Maryland. However, as this work is expanded and applied to other regions where such maps are not available, more work will be needed to identify potential habitat using spatially-explicit variables that match the temporal and spatial dynamism of the carbon sequestration estimates used here. Furthermore, while this work targets native forest species, habitat requirements for such species are still variable. Further research is necessary to clarify the relationship between the structural characteristics of future corridors/buffers and species-specific habitat use (e.g., Farwell et al., 2021; Nagendra et al., 2013).

Now available wall-to-wall in eight states across the RGGI region (Ma et al., 2021), NASA CMS forest carbon products can be used to advance similar strategic analyses in other member states. Additionally, forthcoming national scale modeling products (e.g., Ma et al., 2019), as informed by recent GEDI data, will also provide the fundamental forest carbon products necessary for facilitating these analyses at national and global scales. Such efforts may directly guide the implementation of high-level commitments such as the One Trillion Trees Initiative and Nationally Determined Contributions under the Paris Agreement, while remaining sensitive to state-level policy drivers. However, as forthcoming national and global products may be coarser than 90m, their relevance for strategic reforestation at landowner scales may require further exploration, such as across suburban and urban areas where smaller average property sizes often exist. This may be especially pertinent to ongoing questions about the "price of precision" and related tradeoffs involved in technology cost and the social and economic benefits derived from remote sensing data use (Galik, 2016).

Finally, while this research demonstrates that high-resolution forest carbon products can directly inform strategic reforestation at policy-relevant scales, states are critical partners in implementation. While Chapter 1 provided a shared understanding of the current science and policy landscape for forest carbon across the RGGI region, some states have reiterated that they do not always have the technical capabilities to perform high-resolution analyses and integrate these estimates into planning tools. Therefore, ongoing partnerships between universities and state agencies, and continued collaboration between national agencies such as NASA and the USFS, will be critical. Further, recent analysis suggests that the most effective forest and landscape restoration will be based on working frameworks that prioritize transparency, feedback, communication, assessment, and adaptive management

(Chazdon et al., 2020). This work contributes to the growing literature on reforestation potentials and priorities, but its greatest contributions will be realized as the science becomes operationalized and functionally guides implementation.

Appendix A: Supplementary material for Chapter 2

Detailed state-level summaries

A.1. Connecticut

The Global Warming Solutions Act (PA 08-98) and An Act Concerning Climate Change Planning and Resiliency (PA 18-82) together set forth Connecticut's GHG emissions reduction requirements to 10% below 1990 levels by 2020, 45% below 2001 levels by 2030, and 80% below 2001 levels by 2050 (CDEEP, 2019a, NASA CMS, 2019a). In 2015, Executive Order 46 established the Governor's Council on Climate Change (GCCC), charging it with recommending strategies to achieve GHG reductions relative to 2030 targets. In 2019, Executive Order 3 expanded the GCCC's oversight role to include monitoring and reporting on progress toward implementing the state's strategy.

Connecticut's Department of Energy and Environmental Protection (DEEP) is the lead agency charged with creating a baseline GHG emission inventory and reporting on progress toward reducing statewide GHG emissions against a reference emissions case. DEEP utilizes the USEPA's State Inventory Tool (SIT) to calculate sector-by-sector GHG emissions based on state-level data sets (USEPA, 2019). However, the state has explicitly chosen not to use LULUCF default data from SIT due to concerns about its reliability. The state does not account for LULUCF emissions in its GHG inventory, nor does it include natural carbon sinks (CDEEP, 2017).

While Connecticut does not have a Climate Action Plan, the GCCC has recommended the state continue its work with the USCA NWL to improve forest carbon tracking. The state intends to integrate priority actions into GHG plans by 2020 (GCCC). In their 2018 report, the GCCC included an appendix with potential LULUCF measures to reduce further CO_2, emissions including forestry best management practices, urban tree planting, and conversion of marginal agricultural land to forest. However, none of these practices are accompanied by specific policy options or related estimates of carbon sequestration potential (GCCC, 2018). As required by the US Farm Bill, Connecticut does have a separate Forest Action Plan (2010, 2015) with a rewrite set for 2020. Under this plan, the state commits to conserving working forest landscapes, protecting forests from harm, and enhancing the public benefits from trees and forests (CDEEP, 2019b; NASA CMS, 2019a). The state has previously supported research to assess carbon sequestration in the Connecticut forestry sector (e.g., Duveneck & Thompson, 2019; Silver et al., 2015; Tomasso & Leighton, 2014). The state is also an active participant in the USCA NWL Challenge, with pending research to improve the land carbon sector's integration into its GHG budget with attention to its forest sector.

A.2. Delaware

Governor Jack Markell signed Executive Order 41 in 2013, creating a cabinet committee to "oversee development of an implementation plan to maintain and build upon Delaware's leadership in responsibly reducing greenhouse gas emissions, including identifying appropriate interim goals." In turn, the Cabinet Committee on Climate and Resiliency recommended a goal to reduce Delaware's GHG emissions 30% from 2008 levels by 2030. Outlining plans to achieve this goal, the Delaware

Department of Natural Resources and Environmental Control (DNREC) developed the Climate Framework for Delaware in 2014 and led the coordination of climate mitigation activities across agencies (DNREC, 2014). Broadly, DNREC was charged with designing and implementing restoration activities to slow forest habitat loss and restore forested riparian buffers. The estimated carbon sequestration of planted forest buffers was derived from the USEPA's carbon sequestration factor outlined in the national GHG inventory (USEPA, 2018). The state's 2016 GHG inventory, published in 2019, includes historical and projected LULUCF emissions estimates from the USFS FIA and Delaware Forest Service (Albright et al., 2017; DNREC, 2019; Woodall et al., 2015). While not included in calculating GHG reductions, net LULUCF emissions are tracked as a co-benefit and climate sink within the state's inventory.

A climate action progress report published in 2016 highlights the implementation of recommendations identified in the Framework Document. Specifically, this report notes the contribution of the state's Forest Stewardship and Urban and Community Forestry Programs to increasing forest protection (DDA, 2020a, 2020b; DNREC, 2016); however, the specific carbon impact of such programs was not quantified.

Delaware is in the process of drafting its first Climate Action Plan, which will allow the public to "provide their thoughts on choices the state can make to more effectively take action on climate change" (DNREC, 2020). When the state joined the USCA in 2017, Governor Carney functionally changed Delaware's 2030 emissions reduction goals to 26-28% below 2005 levels by 2030 to better align with the Paris

Agreement. The new Climate Action Plan is expected to reflect this GHG goal. Additionally, as an active member of the USCA NWL group, the state is partnering with the State of Maryland, World Resources Institute (WRI), and the University of Maryland on research to utilize NASA CMS science for annual forest carbon monitoring.

A.3. Maine

In 2003, the Maine legislature established three statewide GHG reduction goals, including a reduction to 1990 emissions levels by 2010, a 10% reduction below 1990 levels by 2020, and if necessary, a 75-80% reduction below 2003 levels to "eliminate any dangerous threat to the climate" (PL 2003 c. 237, 38 MRSA §574-579). In 2004, the Department of Environmental Protection (DEP) developed a Climate Action Plan to establish the 1990s emission baseline and develop strategies to make additional GHG reductions (MDEP, 2004). This plan included seven options for carbon-friendly forest management, six of which focused extensively on voluntary forestry management practices and policy incentives for sustainably managed woodlands. One option emphasized increased forest protection from development, utilizing existing forest conservation programs, such as Land for Maine's Future, the Tree Growth Tax Law, and the USDA Forest Legacy Program (MDEP, 2004). Another option considers the expanded use of wood products, where durable wood products used in the construction of furnishings or as a replacement for steel and concrete in buildings can reduce emissions and sequester carbon for long periods of time (MDEP, 2004).

In 2019, the legislature tasked the Maine Climate Council to create an updated Climate Action Plan to reduce emissions 45% below 1990 levels by 2030 and 80% below by 2050. By 2040, the state must also demonstrate they are on track to achieve their long-term GHG reduction goal of 80% below 1990 levels (PL 2019 c 476 §8). Additionally, Governor Janet Mills signed Executive Order 10-2019, tasking the Maine Climate Council with making recommendations to achieve carbon neutrality by 2045. An updated Climate Action Plan is due by December 1, 2020. The Maine Interagency Climate Adaptation Work Group published a 2019 inventory of existing climate mitigation and adaptation programs, highlighting the technical capacity available in the Bureau of Forestry and its Healthy Forests Program and Woodswise Incentives Programs. The document also described a new program, Project Canopy, to support well-managed urban and community forests in public spaces (MICAWG, 2019).

With forest covering 83% of the state, Maine has estimated that its forest carbon sink offsets at least 55% of the state's annual GHG emissions (NASA CMS, 2020b). Maine's Climate Action Plan was the first in the United States to fully consider the forest carbon cycle and forest carbon management as a significant component of the overall GHG mitigation effort. The state has subsequently invested in forest research and modeling (MDEP, 2004). Currently, forest carbon is not included in the state's GHG inventory. Still, it is tracked separately by the Maine Forest Service and the University of Maine ("Maine's Carbon Budget") using USFS FIA data and the USFS ForGATE Tool (Hennigar et al., 2013; MDEP, 2020; UM et al., 2020). As the 2019 legislation directs the Maine DEP to report both gross and net emissions, forest carbon will likely be reported in the next biennial report to the Maine Legislature in 2022.

As an active member of the USCA NWL group, Maine is committed to including net forest carbon emissions in its state carbon budget and improving forest carbon sequestration estimates as research becomes available. In addition to maximizing capacities in-state, such as technical support provided by the University of Maine Center for Research on Sustainable Forests, Maine has identified improved forest monitoring via remote sensing and modeling as priority information needs (NASA CMS, 2020b).

A.4. Maryland

In 2007, the Maryland Commission on Climate Change (MCCC) was established by Executive Order (01.01.2007.07) to develop a plan and timetable for climate mitigation in the state. With support from the MCCC, the Greenhouse Gas Emissions Reduction Act of 2009 (GGRA) established state goals to reduce GHG emissions 25% below 2006 levels by 2020 while ensuring a positive impact on Maryland's economy (MD Env Code § 2-1205 (2016)). Reauthorized and enhanced in 2016, the GGRA now includes a 40% reduction of baseline emissions by 2030 relative to a reference emissions scenario, as the 2020 GHG goals were met early. Further, the 2016 GGRA specifies that the state must position itself to achieve longer-term goals, such as reducing GHG emissions between 80-95% from 1990 levels by 2050, as recommended by the IPCC for developed countries. The GHG inventory, which is updated triennially and most recently in 2017, includes LULUCF estimates from SIT (MDE, 2019b). The Maryland Department of Environment has developed and updated a Climate Action Plan in support of GGRA emissions goals (2012, 2015), with the most recent plan update drafted in 2019 in response to the 2016 legislative updates to the GGRA (MDE, 2019a). The 2019 draft plan addresses actions on state-owned and/or managed lands or via state-sponsored programs while outlining a range of voluntary actions by non-state partners to meet the 2030 reduction goals.

Maryland forests are expected to persist as a net carbon sink through 2030, offsetting at least 6.5-7 MMtCO_2e annually (MDE, 2019a). The 2019 draft GGRA plan outlines three primary forest carbon mitigation programs, which account for approximately 4.5% of the 2020-2030 planned emissions reductions and are expected to increase the carbon sink ~1.5 MMtCO_2e by 2030. The first program aims to incorporate carbon-friendly management practices on state and private forests where the MDNR provides management services to increase carbon sequestration. Joint research with NASA, USDA, and the DOE, is expected to assess the carbon consequences of alternative forest management practices. In addition, a field study led by MDNR's Resource Assessment Service is expected to improve estimates of aboveground carbon sequestration rates in Maryland forests. The second program aims to increase the forested area in Maryland, with 2030 carbon benefits coming from the growth of new trees and ongoing carbon accumulation from trees planted in support of the 2020 reduction goals. The primary scientific support for these projected estimates comes from high-resolution NASA CMS projects, where a statewide average growth rate is assumed for all project areas (Hurtt et al., 2019).

The third program aims to increase urban tree planting. The goal is to plant an additional 265,000 trees per year in urban and suburban areas. The MD Forest Service has estimated the carbon sequestration expected from this tree planting. Finally, using the USCA NWL Opportunity Assessment, completed by The Nature Conservancy and WRI, the state is also estimating avoided emissions due to forest conservation within its Climate Action Plan (assessment follows methodology derived from Fargione et al., 2018). The state projects that avoided deforestation of 500 - 1,300 acres through 2030 would avoid emissions of 0.1 - 0.24 MMtCO$_2$e per year (MDE, 2019a). As an active member of the USCA NWL group, the state is partnering with Delaware, WRI, and the University of Maryland to utilize NASA CMS science in support of annual forest carbon monitoring (Hurtt et al., 2020). Maryland has also committed to use these yearly estimates in their 2020 update to the GHG inventory and to track progress towards the forest carbon goals outlined in their GHG reduction plan.

A.5. Massachusetts

In 2008, the Global Warming Solutions Act (GWSA) established a statewide goal of reducing emissions 25% below 1990 levels by 2020 and at least 80% below by 2050 (Chapter 298 of the Acts of 2008, as codified in Massachusetts General Law Chapter 21N). The Massachusetts Department of Environmental Protection conducted a GHG inventory to track emissions resulting from fossil fuels, natural gas infrastructure, industry, agriculture, and waste (MDEP, 2016; NASA CMS, 2019b). While not included in the inventory nor counted towards the emissions reduction targets, the state seeks to improve its methodologies for estimating net LULUCF emissions (MDEP, 2016). Currently, the Massachusetts Executive Office of Energy and Environmental Affairs calculates forest carbon estimates using USFS FIA data and a range of literature values (e.g., Jenkins et al., 2003; Urbanksi et al., 2007; Wienert, 2006).

The 2015 Massachusetts Clean Energy and Climate Plan (MCECP) for 2020, which updates the state's original 2010 Climate Action Plan, specifies tree planting and retention as a way of achieving emissions reductions beyond 2020. The plan also establishes an objective to improve estimates of the state's net carbon sink (MEEA 2015), with initial carbon estimates (11.2 MMTCO2e in 2012) derived from USFS reporting and studies by Harvest Forest (Butler, 2014; Thompson et al., 2014). Although the plan calls for more research to reduce uncertainty in estimates of net forest emissions, Massachusetts has several forest programs to increase tree planting, including an urban tree planting program, the Working Forest Initiative, and a proposed Forest Carbon Incentive Program (MDCR, 2021; MDCR & MWI, 2020). The MCECP suggests that while many of the carbon benefits provided by these existing and proposed policies and programs will accrue after 2020, the goal is to bolster these programs in service of future climate mitigation. The long-term goal is to increase the terrestrial carbon stock by approximately 2 million metric tons of carbon from 2011 levels by 2040. The urban tree planting program, in particular, is projected to sequester 473,500 metric tons of CO2e per year by 2050.

In a recent 80x50 decarbonization study and new MCECP for 2030, the state has signaled increased interest in the potential for carbon sequestration on NWLs to reduce emissions beyond the 80% target, despite population and economic growth (Executive Order 569-2016; MEEA, 2020a). In April 2020, the Secretary of Energy and Environmental Affairs issued a determination letter establishing a statewide emissions limit of net-zero greenhouse gas emissions by 2050 (MEEA, 2020b). The state is also expected to set an interim 2030 emissions reduction target to be reflected in the new MCECP for 2030. The MA Continuous Forest Inventory plots on state and water supply forests, covering approximately 415,000 acres, provide necessary data for achieving this goal (NASA CMS, 2019b). The state is increasingly interested in utilizing lidar observations to improve carbon estimates in urban trees and forests (NASA CMS, 2019b).

A.6. New Hampshire

Under Executive Order 2007-3, New Hampshire Governor John Lynch initiated a Climate Change Policy Task Force, chaired by the New Hampshire Department of Environmental Services, to establish greenhouse gas emission reduction goals and recommend specific actions to achieve them. The resulting Climate Action Plan in 2009 outlined two aspirational GHG goals: reducing emissions 20% below 1990 levels by 2025 and 80% below 1990 levels by 2050 (NHCPTF, 2009a). One essential strategy for achieving these goals includes protecting natural resources to maintain the amount of carbon sequestered without taking credit for secondary regrowth. Recommended actions include investing in forests to maximize carbon storage and avoid net forest loss due to conversion, optimizing biomass use and harvest within sustainable limits, and promoting a market for durable wood products that may result in longer-term carbon storage (NHDES 2009a, 2009b). Implementation of such activities will be at the discretion of the relevant agency.

New Hampshire is roughly 83% forested, and using SIT, the Task Force established that the state's forests take up the equivalent of 25% of the state's anthropogenic CO_2 emissions annually (NHDES, 2009a). Interested in maintaining this sink, the plan included supplementary analysis by Carbon Solutions New England (CSNE), using USFS FIA data and an integrated forest model, to explicitly evaluate the potential for wood resources to contribute to carbon reductions (Aber & Frades, 2009; NHDES, 2009b; Wake et al., 2009). Field data from experimental forests such as Hubbard Brook and Bartlett also served as a mechanism for validation. As a result of this analysis, the state has made more substantial commitments towards increasing the timber harvest rate without changing wood use, maximizing the avoidance of existing forested land loss, and adopting sustainable forest management techniques that maximize harvested tree size (NASA CMS, 2020b).

New Hampshire does not include LULUCF as a carbon sink within their GHG inventory, but notes that forests are critical to the success of the Climate Action Plan (NASA CMS, 2020b; NHDES, 2015). Since the creation of the 2009 Climate Action Plan, New Hampshire has defaulted to using USEPA SIT data to track forest carbon changes outside of the inventory. Moving forward, the state is potentially interested in developing mechanisms to fully value forest ecosystem services, inclusive of more precise forest carbon estimates (NASA CMS, 2020b).

A.7. New Jersey

Under the Global Warming Response Act (GWRA) (2007), New Jersey has pledged to reduce economy-wide GHG emissions at or below 1990 levels by 2020 and 80% below 2006 levels by 2050 relative to a business-as-usual emissions case (NASA CMS 2019a, NJSA 26:2C-37). Updated in 2019, the Act includes mandates for interim benchmarks and annual reporting, tasking the New Jersey Department of Environmental Protection (NJDEP) with adopting rules and regulations that establish a GHG emission monitoring and reporting program by December 2020. The state does not currently have a Climate Action Plan, but under the GWRA, it is required to develop two recommendation reports, one for each GHG reduction goal. New Jersey’s 2020 GHG Limit Report was published in 2009, and the “The Global Warming Response Act 2050 Recommendations Report” is due by July 2020 (NJDEP, 2009). The report's high-level recommendations include creating new natural carbon sinks, enhancing sinks on existing forest land, and maintaining no net loss of forested area (NJDEP, 2009).

In October 2019, Executive Order No. 89 established new requirements for an interagency Council on Climate Resilience to develop a Statewide Climate Change Resilience Strategy, including mitigation and adaptation actions regarding natural resources. In 2020, Governor Philip Murphy signed Executive Order 100, directing the NJDEP to make sweeping regulatory reforms, branded as Protecting Against Climate Threats (PACT), to reduce emissions relative to established goals.

The state does track LULUCF emissions within its GHG inventory (NJDEP, 2019a). Currently, New Jersey estimates its terrestrial carbon sequestration capacity at 8.1 $MMTCO_2e$ per year (8% of gross statewide GHG emissions) utilizing a combination of default and state-specific data methodologies from SIT (NASA CMS, 2019a). In their 2008 GHG Inventory and Reference guide, NJDEP specifies that the agency utilized multiple methods to estimate LULUCF. One method utilizes a Carbon On-Line Estimator (COLE) produced by the National Council for Air and Stream Improvement (NCASI) to determine statewide estimates of land cover to develop an average carbon sequestration rate per hectare on forested lands. To estimate changes in carbon stocks based on land cover changes over time, the agency utilized data from USFS FIA, NJDEP GIS, and default assumptions adapted from the IPCC (NJDEP, 2008).

As of 2015, 31% of New Jersey is considered forested, and the state has a broad range of natural resources legislation that indirectly supports forest sink management, including the NJ Forest Service's *No Net Loss* program, the NJ Forest Stewardship Program, and Open Space Preservation Funding Amendment (NJDEP, 2017, 2018, 2019b). In response to recent legislation for improved monitoring, New Jersey needs updated and improved MRV methodologies that better account for land carbon fluxes within their GHG budget, including methane emissions from wetlands and soil carbon data (NASA CMS, 2019a).

A.8. New York

In 2009, Governor Patterson signed Executive Order No. 24, establishing a goal to reduce GHG emissions 80% by 2050 from 1990 levels, based on UNFCCC guidance. Patterson's EO-14 also established the New York State Climate Action

Council (CAC) and charged them with preparing a Climate Action Plan. In 2010, the CAC published a Climate Action Plan Interim Report, which broadly identified the state’s natural resources as terrestrial carbon sinks with opportunities for improved forest management, forest restoration, urban forestry, and reforestation (NYSCAC, 2010). Additionally, the state pledged to conserve open space, which included a commitment to maintain or increase forestland acreage without converting agricultural land to forest, unless the agricultural land would have higher carbon sequestration potential. Generally, the report called for more research and development in service of the recommended forest carbon strategies. With the change in administration, a final Climate Action Plan was never published.

In 2017, Governor Cuomo established new interim emissions reduction goals in support of the 2015 New York State Energy Plan, the state’s ongoing participation in the Regional Greenhouse Gas Initiative (RGGI), and commitments to the Paris Climate Agreement (Executive Order 2017-166; NYSEPB, 2015). In 2019, the Climate Leadership and Community Protection Act (CLCPA) was passed by the state legislature and signed into law by Governor Andrew Cuomo to establish statutory GHG reduction goals and achieve more ambitious energy targets, including a 40% GHG reduction from 1990 levels by 2030 and 85% reduction by 2050. The law also includes a state commitment to reach net-zero greenhouse gas emissions as soon as practical or by 2050 (A8429 2019, bill). In 2020, a new CAC was created and charged with preparing a Scoping Plan to achieve the state’s new clean energy and climate goals.

Although not explicitly a climate action plan, the state’s draft 2020 Forest Action Plan references the 2019 legislative GHG goals and emphasizes the value of forest carbon sequestration as an added benefit for climate mitigation. All states have a Forest Action Plan, as it is a requirement for funding from the federal government; however, New York considers this plan the primary policy regarding forests rather than the previous 2010 Climate Action Plan Interim Report. The plan broadly describes strategies for forest conservation and restoration, including maintaining and potentially increasing the percentage of forestland in the state, conserving or restoring landscape connections between fragmented and parceled forestland, establishing buffers for already protected forestland, improving forest regeneration on private forestland, and encouraging expanded green space in urban and suburban areas (NYSCAC, 2010). Some goals reference general estimates and carbon sequestration assessments based on USFS FIA data, but no strategy has a specific and quantified carbon sequestration estimate. One challenge for the state is to better integrate forest sector planning into its climate strategy and GHG goals (NASA CMS, 2019b).

Since 2005, New York has tracked GHG emissions as part of their State Greenhouse Gas Inventory (NYSERDA & NYDEC, 2019). The most recent inventory does not include emissions or sequestration estimates from LULUCF (NASA CMS, 2019b). However, the CLCPA requires improved measures to achieve long-term carbon sequestration and promote best management practices in land use, agriculture, and forestry, and will likely be included in the next inventory update. Further, as an active member of the USCA NWL group, New York is interested in improved estimates of carbon sequestration and biogenic emissions based on pending research with the State University of New York College of Environmental Science and Forestry. In particular, the state intends to develop its capacity to monitor and forecast net emissions from the forest sector and is considering opportunities for going beyond USFS FIA data to include more high-resolution estimates (NASA CMS, 2019b).

A.9. Pennsylvania

The Pennsylvania Climate Change Act (PCCA, Act 70 of 2008) requires the Pennsylvania Department of Environmental Protection (PDEP) to develop an annual GHG inventory, administer a Climate Change Advisory Committee, and prepare a Climate Change Action Plan. In 2019, Governor Wolf signed Executive Order 2019-01, establishing a goal of reducing GHG emissions 26% from 2005 levels by 2025 and 80% from 2005 levels by 2050. The Pennsylvania Climate Action Plan of 2018 reflects the charges of both the state legislature and the governor and is the third update of the plan pursuant to the PCCA (PDEP, 2019a). The plan indicates its intention to measure progress towards its GHG emissions goals using a net-net accounting approach. Currently, the state includes an estimate of LULUCF within its GHG inventory with data obtained from SIT (PDEP, 2019b).

Although not quantitatively analyzed as actions related to emission reductions, the state's Climate Action Plan recommends forest conservation, reforestation, and urban tree canopy expansion. The Plan also recommends establishing a statewide monitoring and research network to establish baseline ecosystem conditions (PDEP, 2019a). One of the key listed performance indicators of progress towards these strategies is the total forest ecosystem biomass and carbon pool, stratified by forest type, age class, and successional stage. However, as a qualitative goal, the state does not reference a specific source of forest carbon science.

Outside of the Climate Action Plan, the Pennsylvania Department of Conservation and Natural Resources (DCNR) has promoted carbon capture use and storage practices on state-owned lands (PDCNR, 2015). In 2018, the agency developed a Climate Change Adaptation and Mitigation Plan, which describes increasing forest carbon stocks by increasing forest coverage, avoiding forest conversion, and adjusting timber harvesting intensities and rotations. No specific source of forest carbon science is noted relative to quantifying the carbon impacts of these actions. However, the plan cites the USFS's Forest Adaptation Resources report as a scientific reference for conducting climate change vulnerability assessments. The state's Bureau of Forestry has developed a Continuous Forest Inventory that is used alongside USFS data to generate aboveground biomass estimates for each forest community type (NASA CMS, 2017).

Pennsylvania has indicated an interest in forest carbon science that can help them better estimate carbon sequestration potential, canopy changes for monitoring purposes, and the use of lidar for detecting change, particularly around natural gas developments (NASA CMS, 2017).

A.10. Rhode Island

Pursuant to the Resilient Rhode Island Act of 2014, the state has established three GHG reduction goals from 1990 levels to achieve 10% reductions by 2020, 45%

by 2035, and 80% by 2050 (RIGL §46-6.2-2; RIEC4, 2016). Progress under these goals is generally estimated relative to a baseline projection of GHG emissions out to 2050. While Rhode Island does utilize SIT data for other sectors in its GHG budget, it finds the land carbon data unreliable and does not include it as a calculated source or sink within the current inventory (NASA CMS, 2019a; RIDEM, 2019). To estimate the 1990 emissions baseline for the inventory and create a reference case projection of LULUCF fluxes, carbon stock estimates were derived from an analysis completed for Massachusetts (Abt Associates, 2015; Thompson et al., 2014), and from regional modeling on future forest carbon dynamics using the U.S. Forest Service's Forest Carbon Budget model (Heath et al., 2010; RIEC4, 2016).

The Rhode Island Greenhouse Gas Emissions Reduction Act Plan (2016) assumes no net loss of forest, wetlands, and pasture lands from 2011 to 2035. The Plan does mention a range of LULUCF mitigation options, including protecting existing forest acreage, reforestation, conservation of riparian buffers, enhanced forest management programs, and enhanced urban tree canopies. However, no specific scientific source is provided relative to each mitigation option, nor are there specific GHG emissions reductions projected relative to option implementation. The Plan notes that detailed aspects of program design and implementation have been delegated to appropriate working groups, agency initiatives, and stakeholder collaborations. The state identifies "major existing" land-use conservation policies as the primary avenue for supporting a growing land carbon sink, including the Forestry Legacy Program, the Forest Stewardship Program, and the Urban Community

Forestry Program, which offers trees directly to homeowners in cooperation with the US Forest Service (RIDEM 2020a, 2020b).

As an active participant in the USCA NWL group, Rhode Island is particularly interested in understanding their forests' carbon mitigation potential with increasing granularity to identify and include trees in heavily urbanized areas (NASA CMS, 2019a).

A.11. Vermont

Under a 2005 statute (30 VSA § 578), Vermont established goals of reducing GHG emissions 50% from 1990 levels by 2028 and 75% by 2050. With Executive Order 15 in 2012, Governor Shumlin created a state-level Climate Cabinet to lead planning for GHG reductions among government agencies focusing on transportation, energy efficiency, and renewable energy. In 2015, the state increased its 2050 goals to reduce emissions to 80-95% below 1990 levels via the Under2MOU for subnational governments, which supports keeping global warming under 2°C by the end of this century (Under2, 2020). Later that same year, Vermont joined the conference of New England Governors and Eastern Canadian Premiers in adopting a resolution to decrease emissions in the multi-state and provincial region 35-45% by 2030. The state also established additional renewable energy goals under the state’s Comprehensive Energy Plan (CEP) (VDPS, 2016).

Although the state has no separate Climate Action Plan, the CEP includes an overview of existing forest regulations and best practices. It emphasizes the role of sustainable forestry management for energy (e.g., wood and biofuels) and non-energy (e.g., habitat connectivity) related purposes (VDPS, 2016). Specific mitigation strategies with corresponding forest carbon measurements are not listed; however, Vermont does refer to the 2010 *Forest Resources Plan and State Assessment and Resources Strategy* as a source for specific strategies regarding the maintenance of sustainable forests. This discussion includes the possibility of boosting prospects for durable wood production. The state has noted a gap in clearly established carbon storage and sequestration goals (NASA CMS, 2019b).

The state does maintain an annual GHG emissions inventory which reports estimates of forest carbon emissions due to decomposition and wood combustion (VTDEC, 2015). The primary scientific source for this forest carbon information is the USFS FIA program, specifically the USFS State Inventory Report for Vermont (Domke et al., 2019; USFS, 2020). However, these LULUCF estimates are not counted towards meeting emission reduction goals (net emissions totals). Vermont is currently seeking higher-resolution, higher confidence estimates of forest carbon sequestration that can help prioritize forest activities in the absence of clearly established carbon storage and sequestration goals (NASA CMS, 2019b).

Appendix B: Supplementary material for Chapter 3

Table B-1: Sample corn crop budget from University of Maryland Extension where all quantity values followed by "(yield)" are replaced by 90m yield estimates

CORN GRAIN, CONVENTIONAL NON-IRRIGATED		**PER ACRE FOR**		**2018**
Item	**Unit**	**Quantity**	**Price**	**Total**
Gross income				
Corn grain	Bushel	150 *(yield)*	$3.93	$589.50
Variable costs				
Seed	1000 seeds	29	$1.68	$48.72
Soil test	Acre	1	$0.30	$0.30
Nitrogen	Pound	150 (*yield*)	$0.34	$51.00
Phosphate	Pound	30	$0.58	$17.40
Potash	Pound	60	$0.29	$17.40
Lime	Ton	0.5	$48.00	$24.00
Corvus	Ounce	4	$7.00	$28.00
Atrazine	Quart	0.5	$4.00	$2.00
Crop insurance (rp 75%)	Acre	1	$17.57	$17.57
Drying fuel	Bushel	150 (*yield*)	$0.36	$54.00
Interest on operating capital	$188.82	0.5	8.5%	$8.02
Total variable costs listed above				$268.41
Fixed/overhead costs (custom rates are used as a proxy for field operation costs)[1]				
Chisel plowing	Acre	1	$20.90	$20.90
Disking	Acre	1	$23.75	$23.75
Field cultivator/finisher	Acre	1	$23.50	$23.50
Fertilizer spreading	Acre	1	$9.22	$9.22
Planting with fertilizer	Acre	1	$19.92	$19.92
Nitrogen application	Acre	1	$10.59	$10.59
Pesticide applications	Acre	1	$9.86	$9.86
Harvesting	Acre	1	$33.89	$33.89
Hauling	Bushel	150 (*yield*)	$0.21	$31.50
Interest on spring custom charges	$117.74	0.5	8.5%	$5.00
Land charge	Acre	1	$98.00	$98.00
Total fixed cost listed above				$286.13
Total variable and fixed cost listed above				$554.55
Net income over variable & fixed costs listed above				$34.95

[1] Custom charges for field operation costs include charges for equipment, labor, repairs and maintenance and fuel/lube for that practice

Table B-2: Sample soybean crop budget from University of Maryland Extension where all quantity values followed by “(yield)” are replaced by 90m yield estimates

SOYBEANS RR READY		**PER ACRE FOR**		**2018**
Item	**Unit**	**Quantity**	**Price**	**Total**
Gross income				
Soybeans	Bushel	40 *(yield)*	$10.05	$402.00
Variable costs				
Seed	1000 seeds	150	$0.34	$51.00
Soil testing	Acre	1	$0.30	$0.30
Phosphate	Pound	45	$0.58	$26.10
Potash	Pound	40 (*yield*)	$0.29	$11.60
Lime	Ton	0.5	$48.00	$24.00
2 4-d	Quart	1	$5.25	$5.25
Roundup (x2 passes)	Quart	2	$5.00	$10.00
Warrior	Ounce	3	$2.20	$6.60
Crop insurance (rp 75%)	Acre	1	$10.17	$10.17
Interest on operating capital	$134.85	0.5	8.5%	$5.73
Total variable costs listed above				$150.75
Fixed/overhead costs (custom rates are used as a proxy for field operation costs) [1]				
Fertilizer application	Acre	1	$9.22	$9.22
Soybean - notill	Acre	1	$22.33	$22.33
Pesticide applications	Acre	3	$9.86	$29.58
Harvesting	Acre	1	$33.89	$33.89
Hauling	Bushel	40 (*yield*)	$0.21	$8.40
Interest on spring custom charges	$61.13	0.5	8.5%	$2.60
Land charge	Acre	1	$98.00	$98.00
Total fixed cost listed above				$204.02
Total variable and fixed cost listed above				$354.77
Net income over variable & fixed costs listed above				$47.23

[1] Custom charges for field operation costs include charges for equipment, labor, repairs and maintenance and fuel/lube for that practice

Table B-3: Sample wheat crop budget from University of Maryland Extension where all quantity values followed by "(yield)" are replaced by 90m yield estimates

WHEAT		**PER ACRE FOR**		**2018**
Item	**Unit**	**Quantity**	**Price**	**Total**
Gross income				
Wheat	Bushel	75 *(yield)*	$4.66	$349.50
Variable costs				
Seed	Pound	150	$0.33	$49.50
Soil testing	Acre	1	$0.30	$0.30
Nitrogen	Pound	70	$0.34	$23.80
Phosphate	Pound	40	$0.58	$23.20
Potash	Pound	40	$0.29	$11.60
Lime	Ton	0.5	$48.00	$24.00
Harmony total sol	Ounce	0.8	$10.00	$8.00
Tilt	Ounce	4	$1.00	$4.00
Zidua	Ounce	1.5	$9.16	$13.74
Prosaro	Ounce	8	$2.44	$19.52
Crop insurance (rp 75%)	Acre	1.00	$6.88	$6.88
Interest on operating capital	$177.66	0.5	8.5%	$7.55
Total variable costs listed above				$192.09
Fixed/overhead costs (custom rates are used as a proxy for field operation costs)[1]				
Spreading fertilizer	Acre	2	$9.22	$18.44
Vertical tillage	Acre	2	$18.05	$36.10
Broadcast seeding	Acre	1	$20.33	$20.33
Pesticide application	Acre	2	$9.86	$19.72
Harvesting	Acre	1	$34.13	$34.13
Hauling	Bushel	75 (*yield*)	$0.21	$15.75
Interest on fall custom charges	$94.59	0.5	8.5%	$4.02
Land charge	Acre	1	$98.00	$98.00
Total fixed cost listed above				$246.49
Total variable and fixed cost listed above				$438.58
Net income over variable & fixed costs listed above				($89.08)

[1] Custom charges for field operation costs include charges for equipment, labor, repairs and maintenance and fuel/lube for that practice

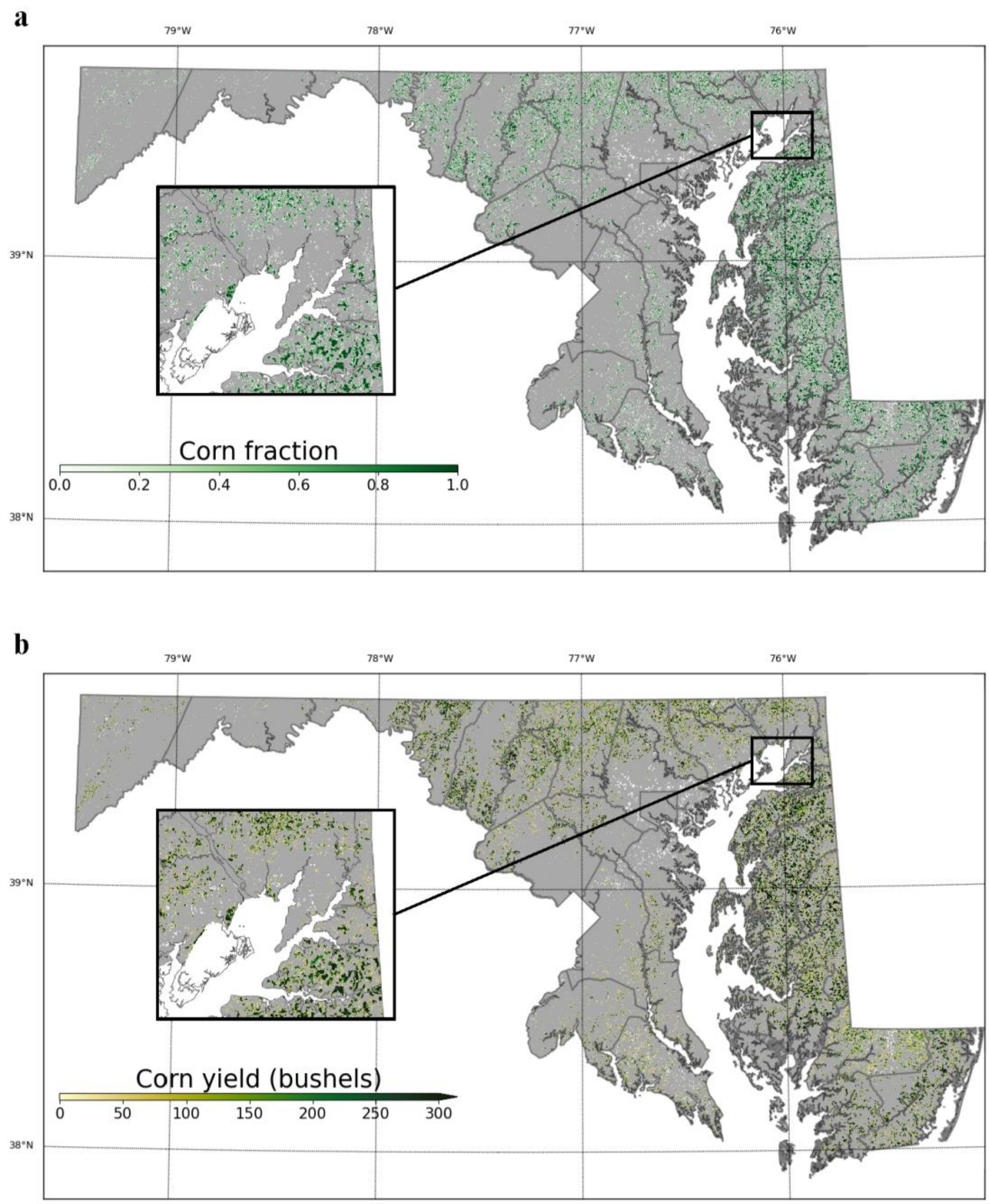


Figure B-1: Corn fraction (a) and productivity-scaled corn yield in bushels (b) at 90m resolution statewide. The inset provides a close view of the spatial heterogeneity provided at 90m resolution.

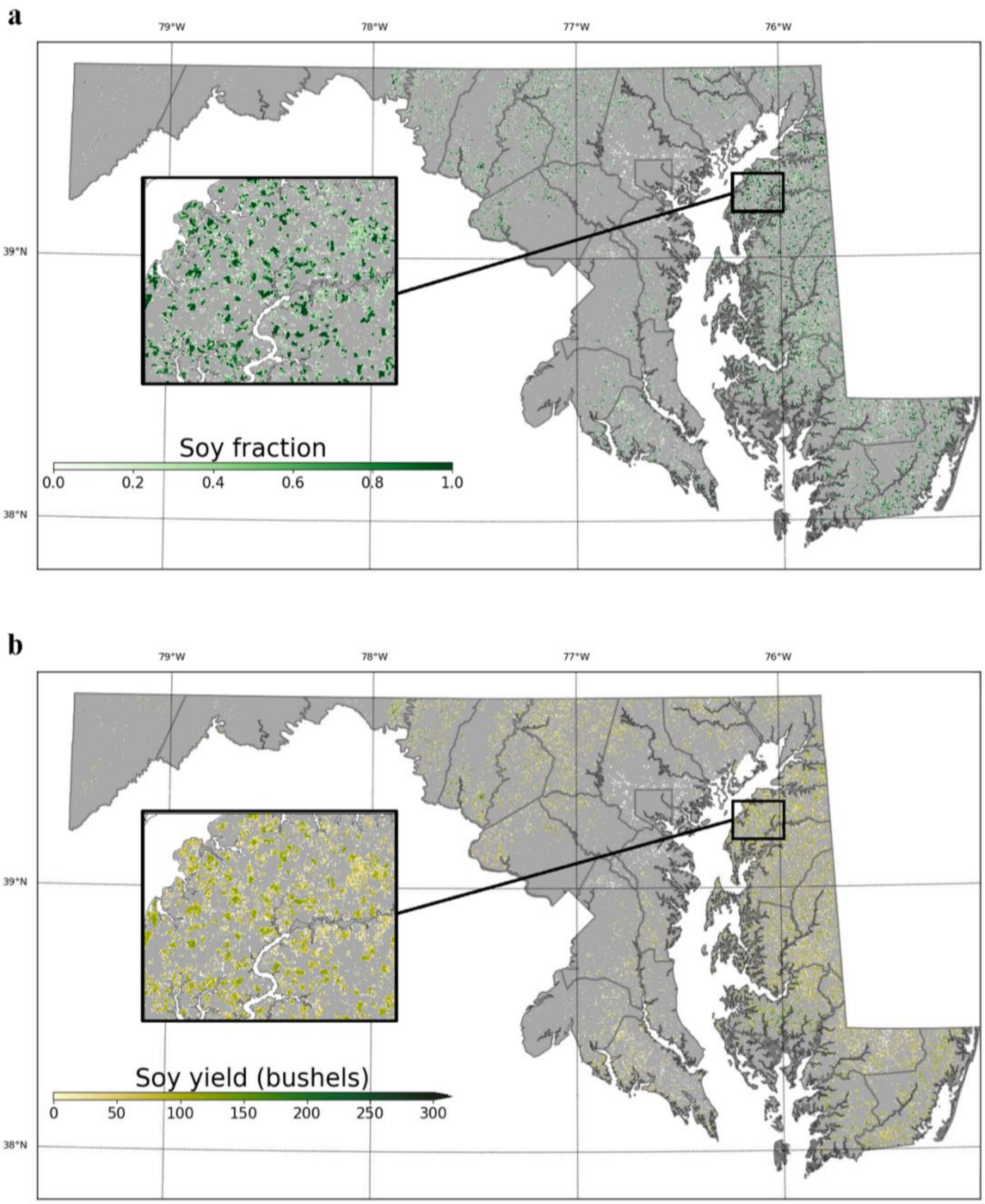


Figure B-2: Soy fraction (a) and productivity-scaled soy yield in bushels (b) at 90m resolution statewide. The inset provides a close view of the spatial heterogeneity provided at 90m resolution.

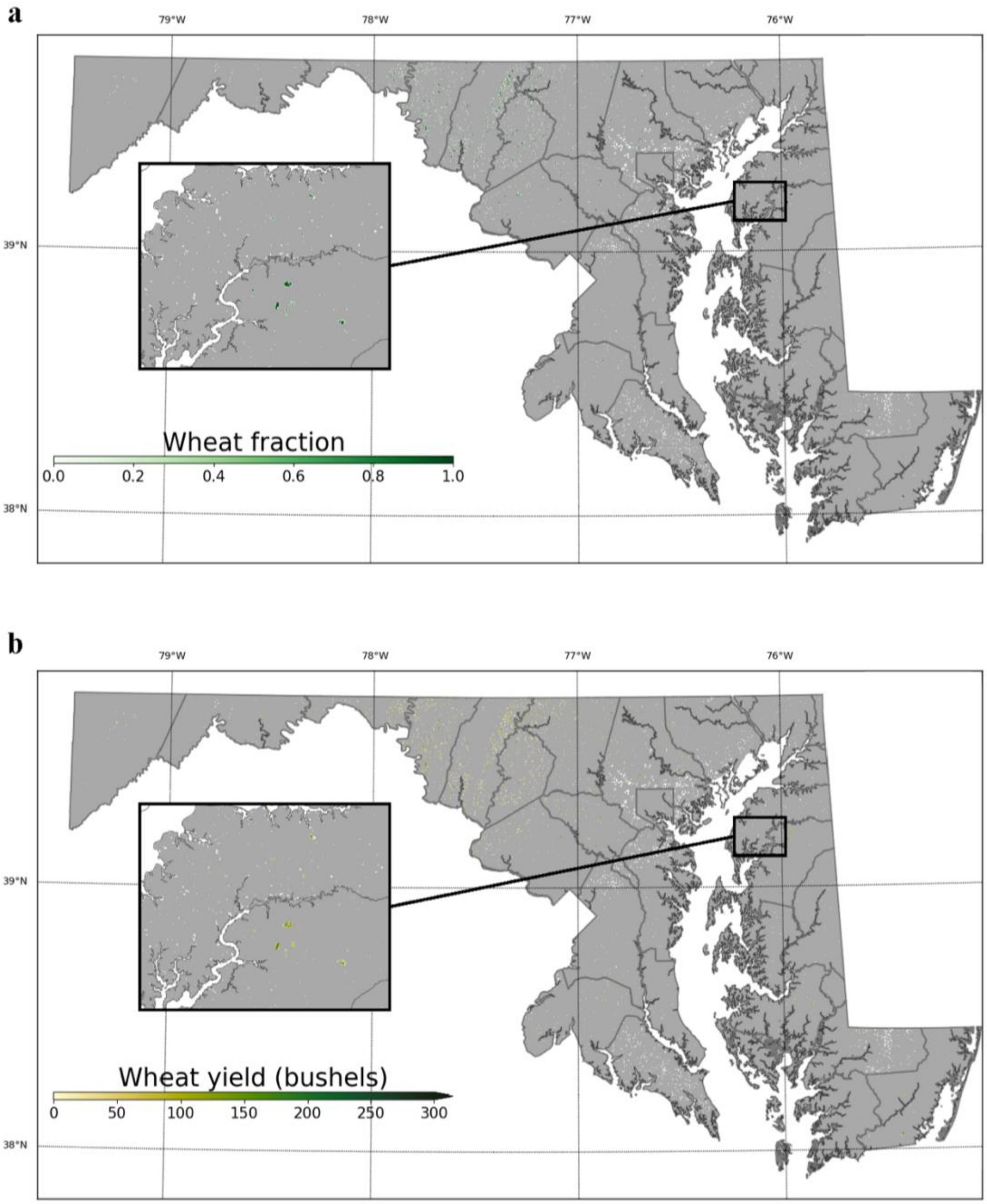


Figure B-3: Wheat fraction (a) and productivity-scaled wheat yield in bushels (b) at 90m resolution statewide. The inset provides a close view of the spatial heterogeneity provided at 90m resolution.

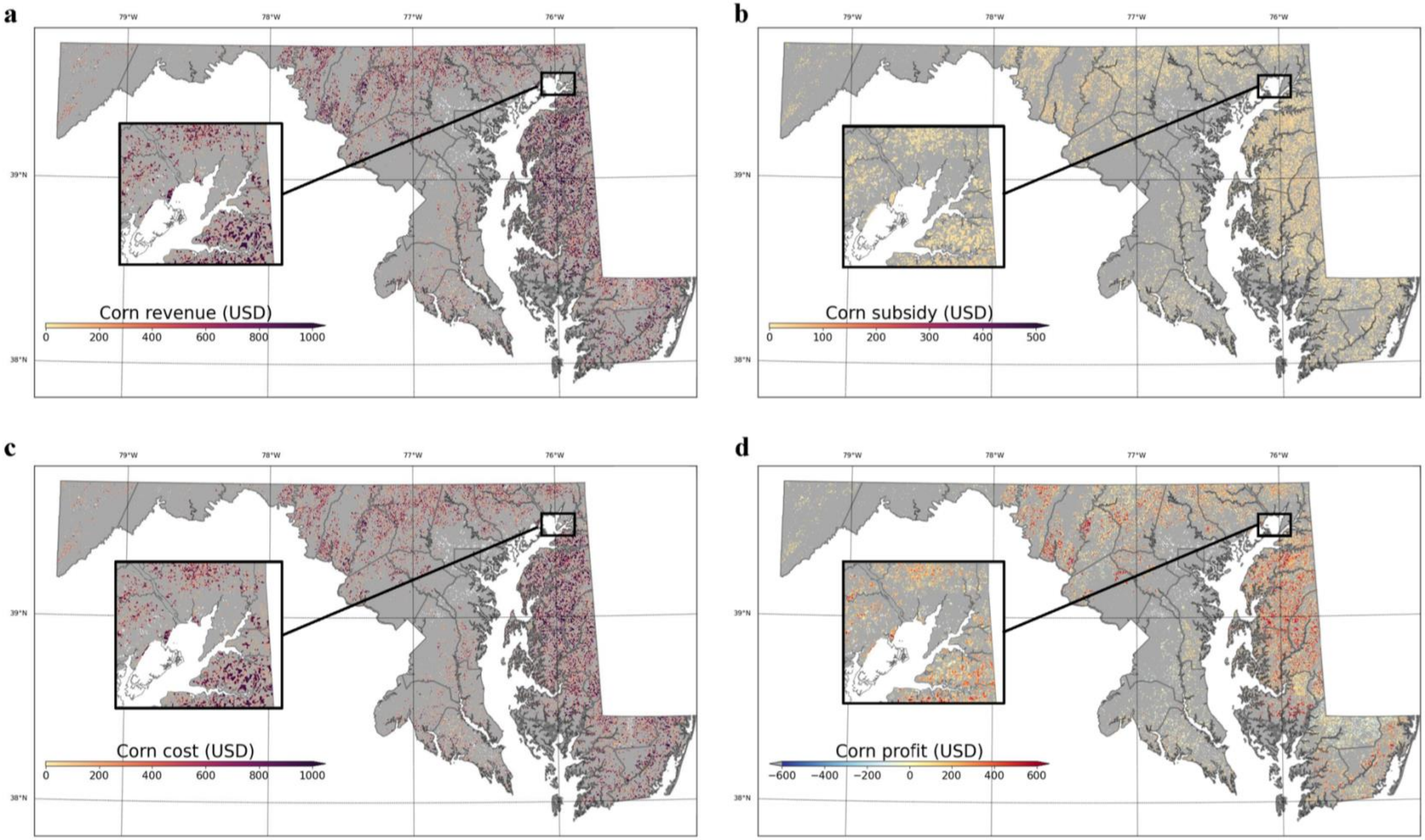


Figure B-4: Corn revenue (a), corn subsidies (b), corn costs (c), and corn profit (d) under the baseline crop pricing scenario at 90m statewide. The inset provides a close view of the spatial heterogeneity provided at 90m resolution.

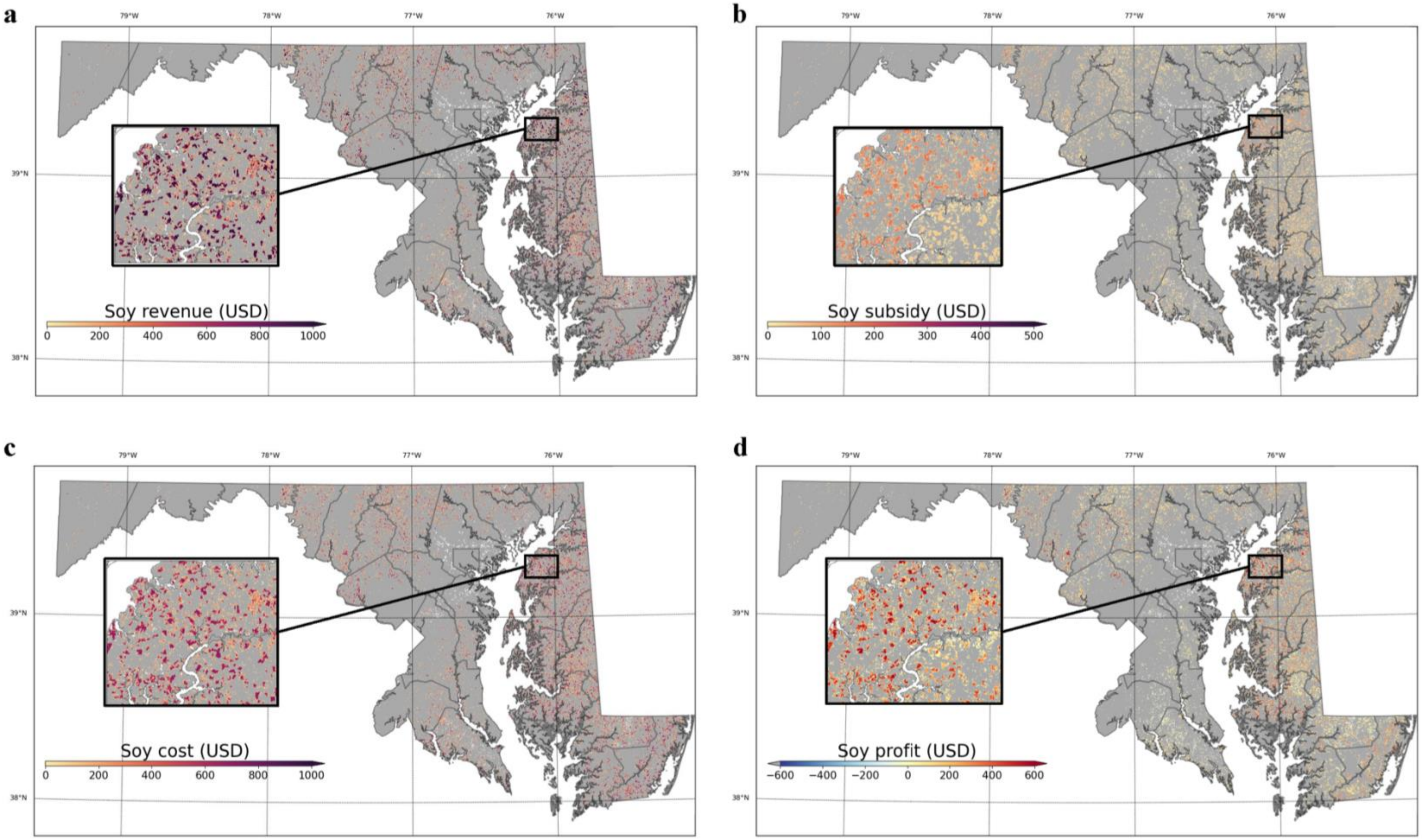


Figure B-5: Soy revenue (a), soy subsidies (b), soy costs (c), and soy profit (d) under the baseline crop pricing scenario at 90m statewide. The inset provides a close view of the spatial heterogeneity provided at 90m resolution.

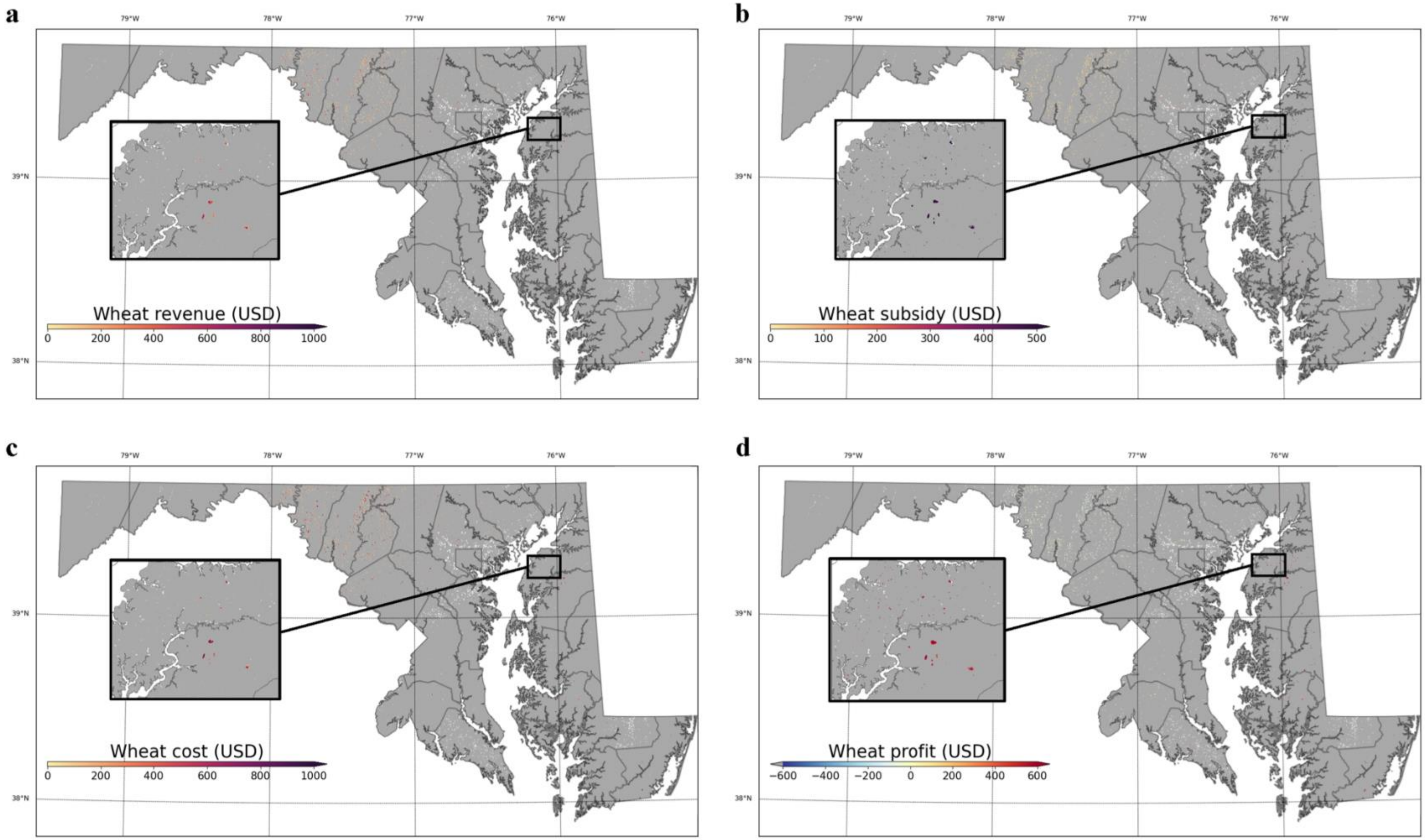


Figure B-6: Wheat revenue (a), wheat subsidies (b), wheat costs (c), and wheat profit (d) under the baseline crop pricing scenario at 90m statewide. The inset provides a close view of the spatial heterogeneity provided at 90m resolution.

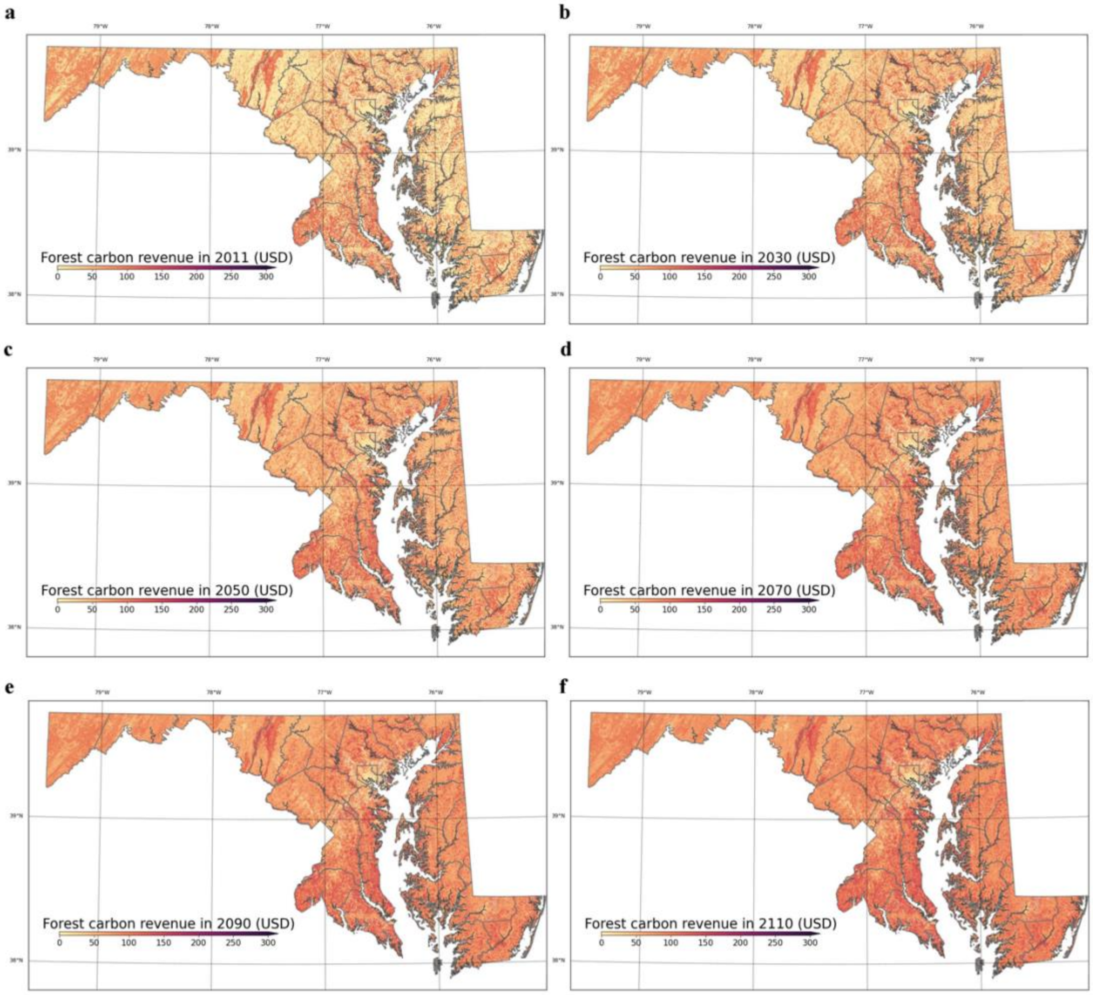
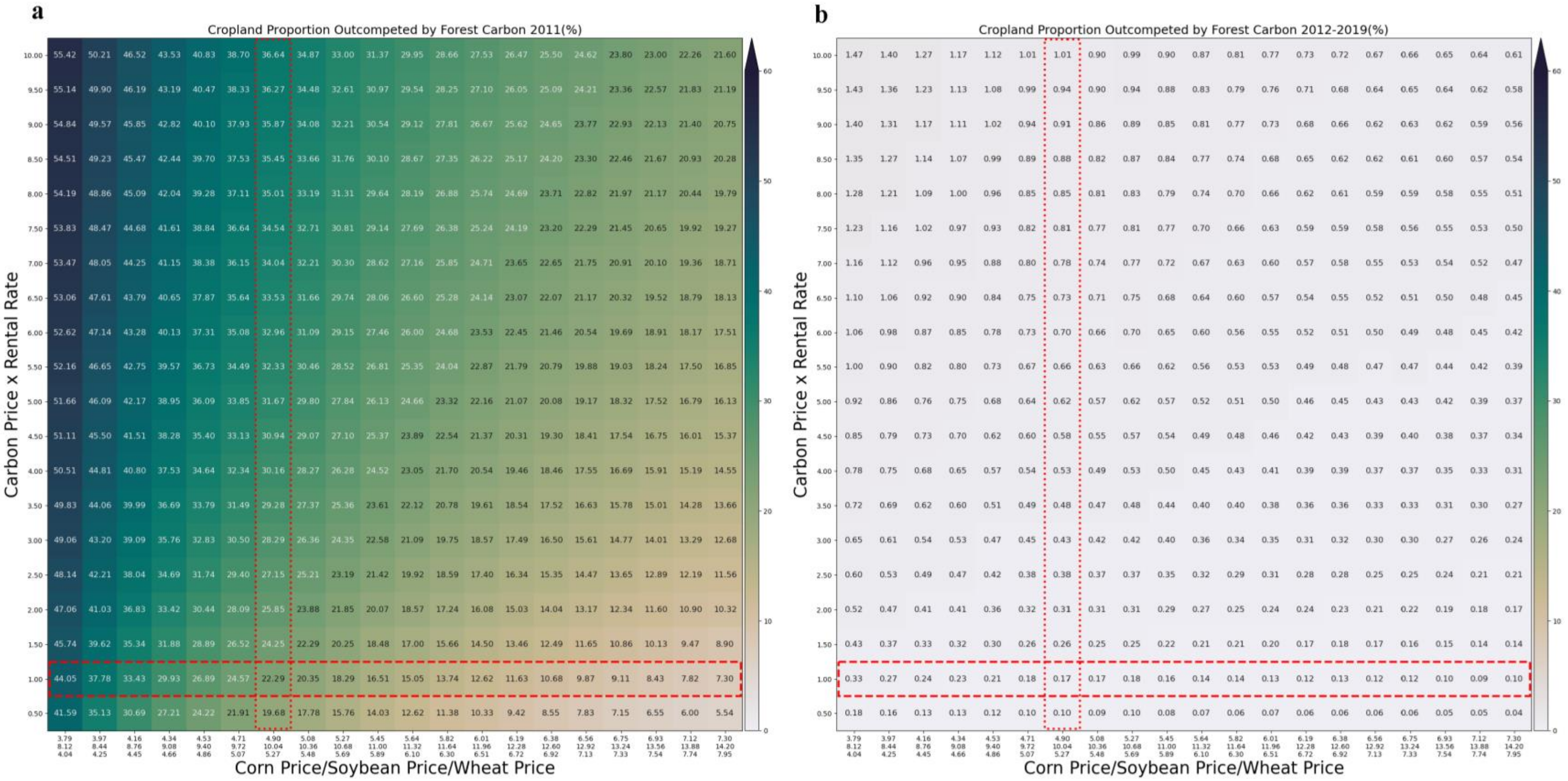


Figure B-7: Statewide spatial distribution of forest carbon revenue (USD per 90m) under the baseline rental scenario every 20 years from 2011-2100 (a-f).



a Cropland Proportion Outcompeted by Forest Carbon 2011(%)

	3.79 8.12 4.04	3.97 8.44 4.25	4.16 8.76 4.45	4.34 9.08 4.66	4.53 9.40 4.86	4.71 9.72 5.07	4.90 10.04 5.27	5.08 10.36 5.48	5.27 10.68 5.69	5.45 11.00 5.89	5.64 11.32 6.10	5.82 11.64 6.30	6.01 11.96 6.51	6.19 12.28 6.72	6.38 12.60 6.92	6.56 12.92 7.13	6.75 13.24 7.33	6.93 13.56 7.54	7.12 13.88 7.74	7.30 14.20 7.95
10.00	55.42	50.21	46.52	43.53	40.83	38.70	36.64	34.87	33.00	31.37	29.95	28.66	27.53	26.47	25.50	24.62	23.80	23.00	22.26	21.60
9.50	55.14	49.90	46.19	43.19	40.47	38.33	36.27	34.48	32.61	30.97	29.54	28.25	27.10	26.05	25.09	24.21	23.36	22.57	21.83	21.19
9.00	54.84	49.57	45.85	42.82	40.10	37.93	35.87	34.08	32.21	30.54	29.12	27.81	26.67	25.62	24.65	23.77	22.93	22.13	21.40	20.75
8.50	54.51	49.23	45.47	42.44	39.70	37.53	35.45	33.66	31.76	30.10	28.67	27.35	26.22	25.17	24.20	23.30	22.46	21.67	20.93	20.28
8.00	54.19	48.86	45.09	42.04	39.28	37.11	35.01	33.19	31.31	29.64	28.19	26.88	25.74	24.69	23.71	22.82	21.97	21.17	20.44	19.79
7.50	53.83	48.47	44.68	41.61	38.84	36.64	34.54	32.71	30.81	29.14	27.69	26.38	25.24	24.19	23.20	22.29	21.45	20.65	19.92	19.27
7.00	53.47	48.05	44.25	41.15	38.38	36.15	34.04	32.21	30.30	28.62	27.16	25.85	24.71	23.65	22.65	21.75	20.91	20.10	19.36	18.71
6.50	53.06	47.61	43.79	40.65	37.87	35.64	33.53	31.66	29.74	28.06	26.60	25.28	24.14	23.07	22.07	21.17	20.32	19.52	18.79	18.13
6.00	52.62	47.14	43.28	40.13	37.31	35.08	32.96	31.09	29.15	27.46	26.00	24.68	23.53	22.45	21.46	20.54	19.69	18.91	18.17	17.51
5.50	52.16	46.65	42.75	39.57	36.73	34.49	32.33	30.46	28.52	26.81	25.35	24.04	22.87	21.79	20.79	19.88	19.03	18.24	17.50	16.85
5.00	51.66	46.09	42.17	38.95	36.09	33.85	31.67	29.80	27.84	26.13	24.66	23.32	22.16	21.07	20.08	19.17	18.32	17.52	16.79	16.13
4.50	51.11	45.50	41.51	38.28	35.40	33.13	30.94	29.07	27.10	25.37	23.89	22.54	21.37	20.31	19.30	18.41	17.54	16.75	16.01	15.37
4.00	50.51	44.81	40.80	37.53	34.64	32.34	30.16	28.27	26.28	24.52	23.05	21.70	20.54	19.46	18.46	17.55	16.69	15.91	15.19	14.55
3.50	49.83	44.06	39.99	36.69	33.79	31.49	29.28	27.37	25.36	23.61	22.12	20.78	19.61	18.54	17.52	16.63	15.78	15.01	14.28	13.66
3.00	49.06	43.20	39.09	35.76	32.83	30.50	28.29	26.36	24.35	22.58	21.09	19.75	18.57	17.49	16.50	15.61	14.77	14.01	13.29	12.68
2.50	48.14	42.21	38.04	34.69	31.74	29.40	27.15	25.21	23.19	21.42	19.92	18.59	17.40	16.34	15.35	14.47	13.65	12.89	12.19	11.56
2.00	47.06	41.03	36.83	33.42	30.44	28.09	25.85	23.88	21.85	20.07	18.57	17.24	16.08	15.03	14.04	13.17	12.34	11.60	10.90	10.32
1.50	45.74	39.62	35.34	31.88	28.89	26.52	24.25	22.29	20.25	18.48	17.00	15.66	14.50	13.46	12.49	11.65	10.86	10.13	9.47	8.90
1.00	44.05	37.78	33.43	29.93	26.89	24.57	22.29	20.35	18.29	16.51	15.05	13.74	12.62	11.63	10.68	9.87	9.11	8.43	7.82	7.30
0.50	41.59	35.13	30.69	27.21	24.22	21.91	19.68	17.78	15.76	14.03	12.62	11.38	10.33	9.42	8.55	7.83	7.15	6.55	6.00	5.54

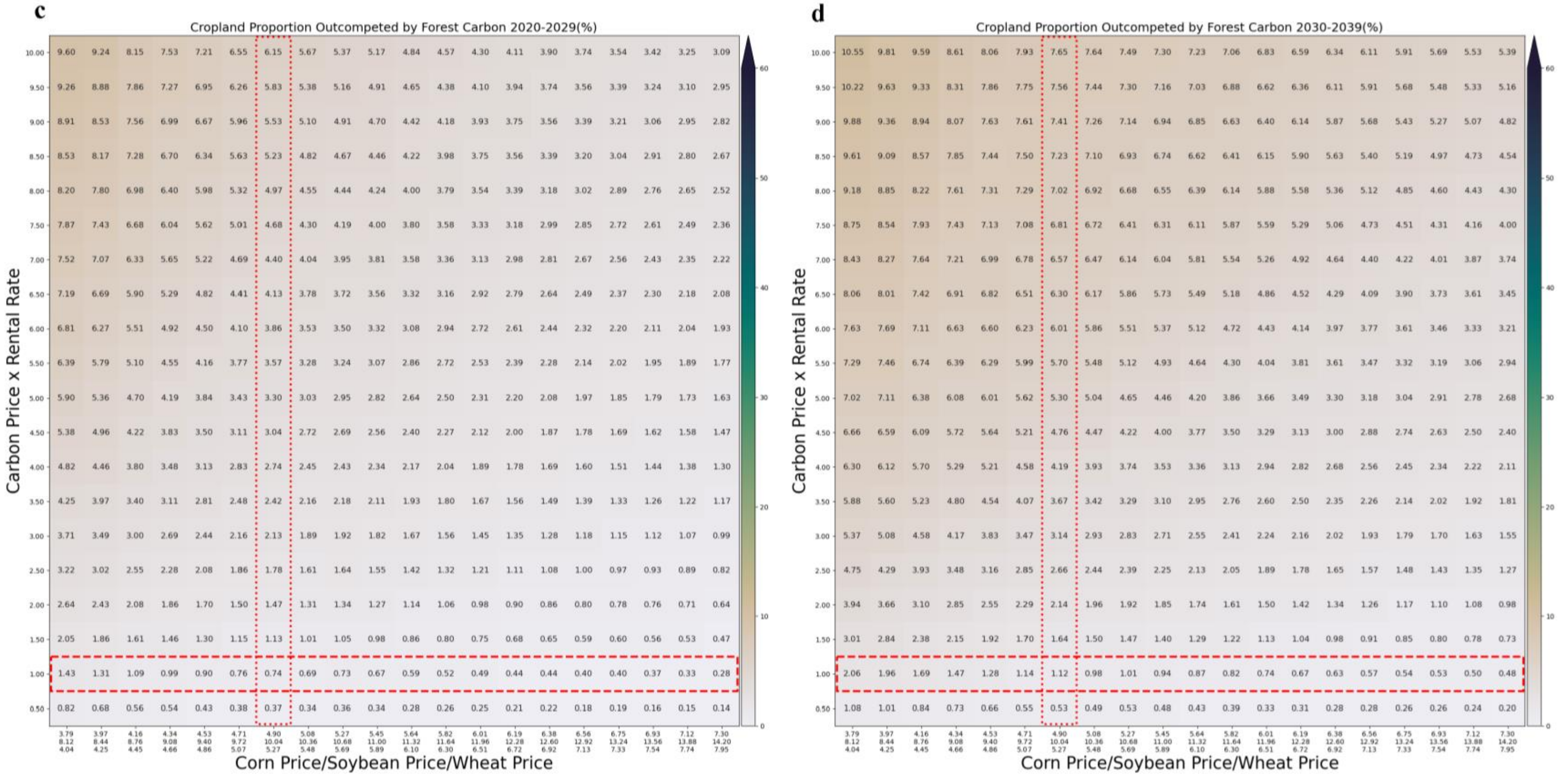
b Cropland Proportion Outcompeted by Forest Carbon 2012-2019(%)

	3.79 8.12 4.04	3.97 8.44 4.25	4.16 8.76 4.45	4.34 9.08 4.66	4.53 9.40 4.86	4.71 9.72 5.07	4.90 10.04 5.27	5.08 10.36 5.48	5.27 10.68 5.69	5.45 11.00 5.89	5.64 11.32 6.10	5.82 11.64 6.30	6.01 11.96 6.51	6.19 12.28 6.72	6.38 12.60 6.92	6.56 12.92 7.13	6.75 13.24 7.33	6.93 13.56 7.54	7.12 13.88 7.74	7.30 14.20 7.95
10.00	1.47	1.40	1.27	1.17	1.12	1.01	1.01	0.90	0.99	0.90	0.87	0.81	0.77	0.73	0.72	0.67	0.66	0.65	0.64	0.61
9.50	1.43	1.36	1.23	1.13	1.08	0.99	0.94	0.90	0.94	0.88	0.83	0.79	0.76	0.71	0.68	0.64	0.65	0.64	0.62	0.58
9.00	1.40	1.31	1.17	1.11	1.02	0.94	0.91	0.86	0.89	0.85	0.81	0.77	0.73	0.68	0.66	0.62	0.63	0.62	0.59	0.56
8.50	1.35	1.27	1.14	1.07	0.99	0.89	0.88	0.82	0.87	0.84	0.77	0.74	0.68	0.65	0.62	0.62	0.61	0.60	0.57	0.54
8.00	1.28	1.21	1.09	1.00	0.96	0.85	0.85	0.81	0.83	0.79	0.74	0.70	0.66	0.62	0.61	0.59	0.59	0.58	0.55	0.51
7.50	1.23	1.16	1.02	0.97	0.93	0.82	0.81	0.77	0.81	0.77	0.70	0.66	0.63	0.59	0.59	0.58	0.56	0.55	0.53	0.50
7.00	1.16	1.12	0.96	0.95	0.88	0.80	0.78	0.74	0.77	0.72	0.67	0.63	0.60	0.57	0.58	0.55	0.53	0.54	0.52	0.47
6.50	1.10	1.06	0.92	0.90	0.84	0.75	0.73	0.71	0.75	0.68	0.64	0.60	0.57	0.54	0.55	0.52	0.51	0.50	0.48	0.45
6.00	1.06	0.98	0.87	0.85	0.78	0.73	0.70	0.66	0.70	0.65	0.60	0.56	0.55	0.52	0.51	0.50	0.49	0.48	0.45	0.42
5.50	1.00	0.90	0.82	0.80	0.73	0.67	0.66	0.63	0.66	0.62	0.56	0.53	0.53	0.49	0.48	0.47	0.47	0.44	0.42	0.39
5.00	0.92	0.86	0.76	0.75	0.68	0.64	0.62	0.57	0.62	0.57	0.52	0.51	0.50	0.46	0.45	0.43	0.43	0.42	0.39	0.37
4.50	0.85	0.79	0.73	0.70	0.62	0.60	0.58	0.55	0.57	0.54	0.49	0.48	0.46	0.42	0.43	0.39	0.40	0.38	0.37	0.34
4.00	0.78	0.75	0.68	0.65	0.57	0.54	0.53	0.49	0.53	0.50	0.45	0.43	0.41	0.39	0.39	0.37	0.37	0.35	0.33	0.31
3.50	0.72	0.69	0.62	0.60	0.51	0.49	0.48	0.47	0.48	0.44	0.40	0.40	0.38	0.36	0.36	0.33	0.33	0.31	0.30	0.27
3.00	0.65	0.61	0.54	0.53	0.47	0.45	0.43	0.42	0.42	0.40	0.36	0.34	0.35	0.31	0.32	0.30	0.30	0.27	0.26	0.24
2.50	0.60	0.53	0.49	0.47	0.42	0.38	0.38	0.37	0.37	0.35	0.32	0.29	0.31	0.28	0.28	0.25	0.25	0.24	0.21	0.21
2.00	0.52	0.47	0.41	0.41	0.36	0.32	0.31	0.31	0.31	0.29	0.27	0.25	0.24	0.24	0.23	0.21	0.22	0.19	0.18	0.17
1.50	0.43	0.37	0.33	0.32	0.30	0.26	0.26	0.25	0.25	0.22	0.21	0.21	0.20	0.17	0.18	0.17	0.16	0.15	0.14	0.14
1.00	0.33	0.27	0.24	0.23	0.21	0.18	0.17	0.17	0.18	0.16	0.14	0.14	0.13	0.12	0.13	0.12	0.12	0.10	0.09	0.10
0.50	0.18	0.16	0.13	0.13	0.12	0.10	0.10	0.09	0.10	0.08	0.07	0.06	0.07	0.06	0.06	0.06	0.06	0.05	0.05	0.04

continued

Figure B-8: Proportion of Maryland cropland area outcompeted by forest carbon revenue immediately in 2011(a) and additionally between 2012-2019 (b), 2020-2029 (c), 2030-2039 (d), 2040-2049 (e), and 2050-2059 (f) under twenty economic scenarios. Where both red boxes intersect is the baseline economic scenario. The vertical dotted box highlights the impact of maintaining the baseline crop pricing scenario but changing the carbon rental scenario. The horizontal dashed box highlights the impact of maintaining the carbon pricing scenario under changing crop pricing scenarios.

Figure B-8 continued



c Cropland Proportion Outcompeted by Forest Carbon 2020-2029(%)

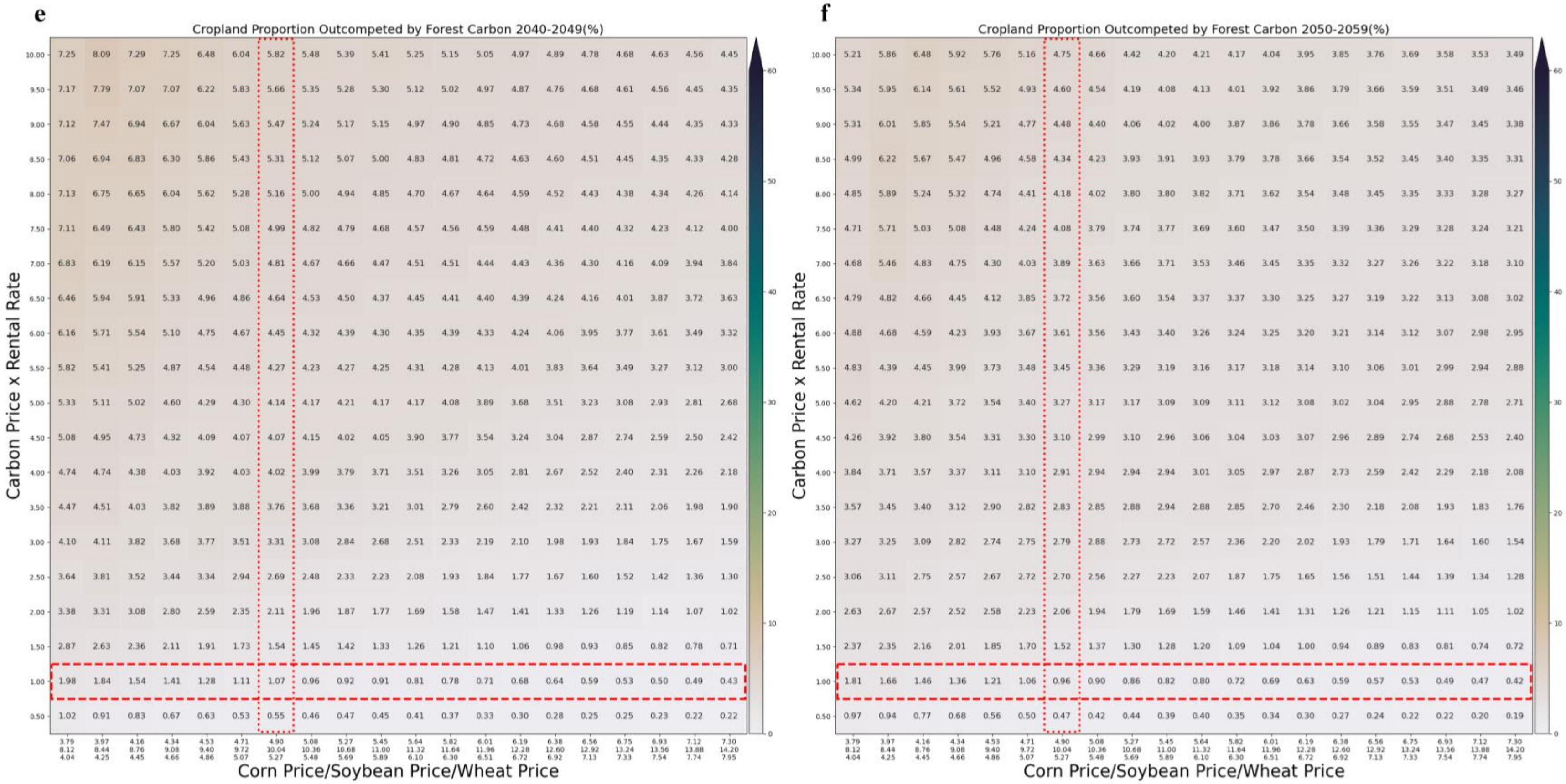
Carbon Price x Rental Rate	3.79 8.12 4.04	3.97 8.44 4.25	4.16 8.76 4.45	4.34 9.08 4.66	4.53 9.40 4.86	4.71 9.72 5.07	4.90 10.04 5.27	5.08 10.36 5.48	5.27 10.68 5.69	5.45 11.00 5.89	5.64 11.32 6.10	5.82 11.64 6.30	6.01 11.96 6.51	6.19 12.28 6.72	6.38 12.60 6.92	6.56 12.92 7.13	6.75 13.24 7.33	6.93 13.56 7.54	7.12 13.88 7.74	7.30 14.20 7.95
10.00	9.60	9.24	8.15	7.53	7.21	6.55	6.15	5.67	5.37	5.17	4.84	4.57	4.30	4.11	3.90	3.74	3.54	3.42	3.25	3.09
9.50	9.26	8.88	7.86	7.27	6.95	6.26	5.83	5.38	5.16	4.91	4.65	4.38	4.10	3.94	3.74	3.56	3.39	3.24	3.10	2.95
9.00	8.91	8.53	7.56	6.99	6.67	5.96	5.53	5.10	4.91	4.70	4.42	4.18	3.93	3.75	3.56	3.39	3.21	3.06	2.95	2.82
8.50	8.53	8.17	7.28	6.70	6.34	5.63	5.23	4.82	4.67	4.46	4.22	3.98	3.75	3.56	3.39	3.20	3.04	2.91	2.80	2.67
8.00	8.20	7.80	6.98	6.40	5.98	5.32	4.97	4.55	4.44	4.24	4.00	3.79	3.54	3.39	3.18	3.02	2.89	2.76	2.65	2.52
7.50	7.87	7.43	6.68	6.04	5.62	5.01	4.68	4.30	4.19	4.00	3.80	3.58	3.33	3.18	2.99	2.85	2.72	2.61	2.49	2.36
7.00	7.52	7.07	6.33	5.65	5.22	4.69	4.40	4.04	3.95	3.81	3.58	3.36	3.13	2.98	2.81	2.67	2.56	2.43	2.35	2.22
6.50	7.19	6.69	5.90	5.29	4.82	4.41	4.13	3.78	3.72	3.56	3.32	3.16	2.92	2.79	2.64	2.49	2.37	2.30	2.18	2.08
6.00	6.81	6.27	5.51	4.92	4.50	4.10	3.86	3.53	3.50	3.32	3.08	2.94	2.72	2.61	2.44	2.32	2.20	2.11	2.04	1.93
5.50	6.39	5.79	5.10	4.55	4.16	3.77	3.57	3.28	3.24	3.07	2.86	2.72	2.53	2.39	2.28	2.14	2.02	1.95	1.89	1.77
5.00	5.90	5.36	4.70	4.19	3.84	3.43	3.30	3.03	2.95	2.82	2.64	2.50	2.31	2.20	2.08	1.97	1.85	1.79	1.73	1.63
4.50	5.38	4.96	4.22	3.83	3.50	3.11	3.04	2.72	2.69	2.56	2.40	2.27	2.12	2.00	1.87	1.78	1.69	1.62	1.58	1.47
4.00	4.82	4.46	3.80	3.48	3.13	2.83	2.74	2.45	2.43	2.34	2.17	2.04	1.89	1.78	1.69	1.60	1.51	1.44	1.38	1.30
3.50	4.25	3.97	3.40	3.11	2.81	2.48	2.42	2.16	2.18	2.11	1.93	1.80	1.67	1.56	1.49	1.39	1.33	1.26	1.22	1.17
3.00	3.71	3.49	3.00	2.69	2.44	2.16	2.13	1.89	1.92	1.82	1.67	1.56	1.45	1.35	1.28	1.18	1.15	1.12	1.07	0.99
2.50	3.22	3.02	2.55	2.28	2.08	1.86	1.78	1.61	1.64	1.55	1.42	1.32	1.21	1.11	1.08	1.00	0.97	0.93	0.89	0.82
2.00	2.64	2.43	2.08	1.86	1.70	1.50	1.47	1.31	1.34	1.27	1.14	1.06	0.98	0.90	0.86	0.80	0.78	0.76	0.71	0.64
1.50	2.05	1.86	1.61	1.46	1.30	1.15	1.13	1.01	1.05	0.98	0.86	0.80	0.75	0.68	0.65	0.59	0.60	0.56	0.53	0.47
1.00	1.43	1.31	1.09	0.99	0.90	0.76	0.74	0.69	0.73	0.67	0.59	0.52	0.49	0.44	0.44	0.40	0.40	0.37	0.33	0.28
0.50	0.82	0.68	0.56	0.54	0.43	0.38	0.37	0.34	0.36	0.34	0.28	0.26	0.25	0.21	0.22	0.18	0.19	0.16	0.15	0.14

d Cropland Proportion Outcompeted by Forest Carbon 2030-2039(%)

Carbon Price x Rental Rate	3.79 8.12 4.04	3.97 8.44 4.25	4.16 8.76 4.45	4.34 9.08 4.66	4.53 9.40 4.86	4.71 9.72 5.07	4.90 10.04 5.27	5.08 10.36 5.48	5.27 10.68 5.69	5.45 11.00 5.89	5.64 11.32 6.10	5.82 11.64 6.30	6.01 11.96 6.51	6.19 12.28 6.72	6.38 12.60 6.92	6.56 12.92 7.13	6.75 13.24 7.33	6.93 13.56 7.54	7.12 13.88 7.74	7.30 14.20 7.95
10.00	10.55	9.81	9.59	8.61	8.06	7.93	7.65	7.64	7.49	7.30	7.23	7.06	6.83	6.59	6.34	6.11	5.91	5.69	5.53	5.39
9.50	10.22	9.63	9.33	8.31	7.86	7.75	7.56	7.44	7.30	7.16	7.03	6.88	6.62	6.36	6.11	5.91	5.68	5.48	5.33	5.16
9.00	9.88	9.36	8.94	8.07	7.63	7.61	7.41	7.26	7.14	6.94	6.85	6.63	6.40	6.14	5.87	5.68	5.43	5.27	5.07	4.82
8.50	9.61	9.09	8.57	7.85	7.44	7.50	7.23	7.10	6.93	6.74	6.62	6.41	6.15	5.90	5.63	5.40	5.19	4.97	4.73	4.54
8.00	9.18	8.85	8.22	7.61	7.31	7.29	7.02	6.92	6.68	6.55	6.39	6.14	5.88	5.58	5.36	5.12	4.85	4.60	4.43	4.30
7.50	8.75	8.54	7.93	7.43	7.13	7.08	6.81	6.72	6.41	6.31	6.11	5.87	5.59	5.29	5.06	4.73	4.51	4.31	4.16	4.00
7.00	8.43	8.27	7.64	7.21	6.99	6.78	6.57	6.47	6.14	6.04	5.81	5.54	5.26	4.92	4.64	4.40	4.22	4.01	3.87	3.74
6.50	8.06	8.01	7.42	6.91	6.82	6.51	6.30	6.17	5.86	5.73	5.49	5.18	4.86	4.52	4.29	4.09	3.90	3.73	3.61	3.45
6.00	7.63	7.69	7.11	6.63	6.60	6.23	6.01	5.86	5.51	5.37	5.12	4.72	4.43	4.14	3.97	3.77	3.61	3.46	3.33	3.21
5.50	7.29	7.46	6.74	6.39	6.29	5.99	5.70	5.48	5.12	4.93	4.64	4.30	4.04	3.81	3.61	3.47	3.32	3.19	3.06	2.94
5.00	7.02	7.11	6.38	6.08	6.01	5.62	5.30	5.04	4.65	4.46	4.20	3.86	3.66	3.49	3.30	3.18	3.04	2.91	2.78	2.68
4.50	6.66	6.59	6.09	5.72	5.64	5.21	4.76	4.47	4.22	4.00	3.77	3.50	3.29	3.13	3.00	2.88	2.74	2.63	2.50	2.40
4.00	6.30	6.12	5.70	5.29	5.21	4.58	4.19	3.93	3.74	3.53	3.36	3.13	2.94	2.82	2.68	2.56	2.45	2.34	2.22	2.11
3.50	5.88	5.60	5.23	4.80	4.54	4.07	3.67	3.42	3.29	3.10	2.95	2.76	2.60	2.50	2.35	2.26	2.14	2.02	1.92	1.81
3.00	5.37	5.08	4.58	4.17	3.83	3.47	3.14	2.93	2.83	2.71	2.55	2.41	2.24	2.16	2.02	1.93	1.79	1.70	1.63	1.55
2.50	4.75	4.29	3.93	3.48	3.16	2.85	2.66	2.44	2.39	2.25	2.13	2.05	1.89	1.78	1.65	1.57	1.48	1.43	1.35	1.27
2.00	3.94	3.66	3.10	2.85	2.55	2.29	2.14	1.96	1.92	1.85	1.74	1.61	1.50	1.42	1.34	1.26	1.17	1.10	1.08	0.98
1.50	3.01	2.84	2.38	2.15	1.92	1.70	1.64	1.50	1.47	1.40	1.29	1.22	1.13	1.04	0.98	0.91	0.85	0.80	0.78	0.73
1.00	2.06	1.96	1.69	1.47	1.28	1.14	1.12	0.98	1.01	0.94	0.87	0.82	0.74	0.67	0.63	0.57	0.54	0.53	0.50	0.48
0.50	1.08	1.01	0.84	0.73	0.66	0.55	0.53	0.49	0.53	0.48	0.43	0.39	0.33	0.31	0.28	0.28	0.26	0.26	0.24	0.20

Corn Price/Soybean Price/Wheat Price

Figure B-8 continued



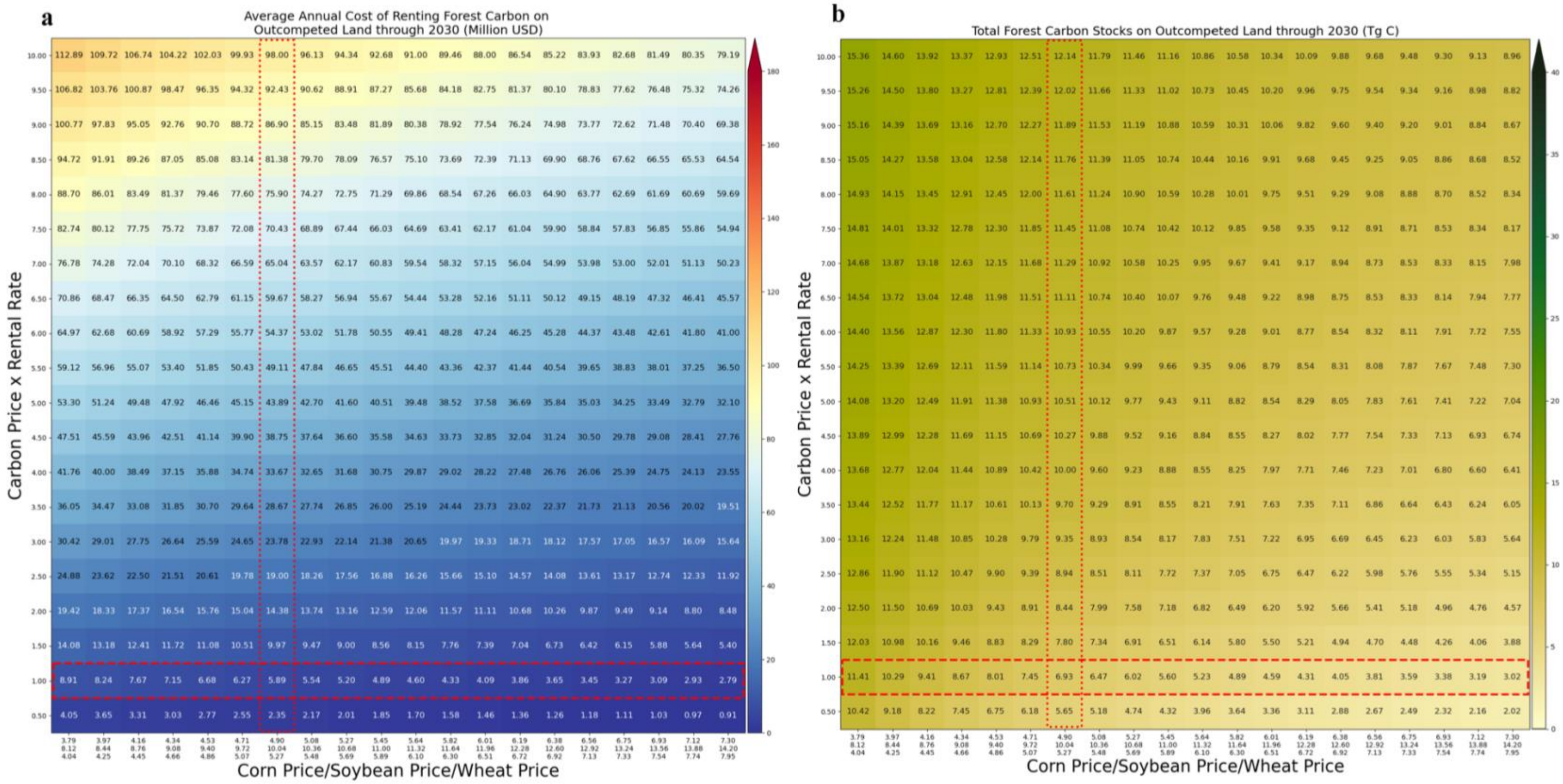
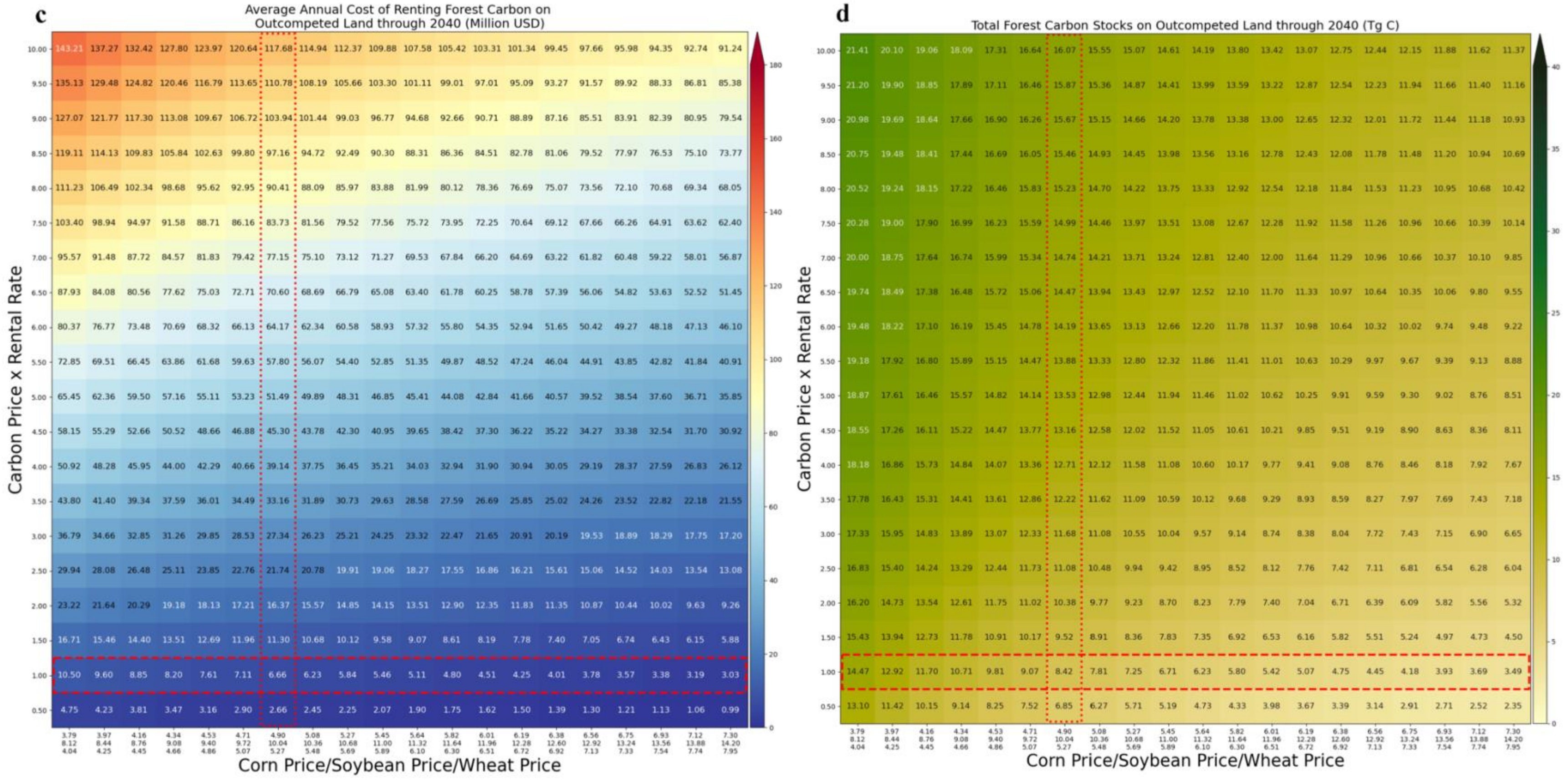


Figure B-9: Average annual rental payments for all lands outcompeted (million USD) and the corresponding amount of forest carbon accumulated on such lands (Tg C), including the ongoing growth of existing trees and regrowth from new plantings, by 2030 (a and b), 2040 (c and d), 2050 (e and f), and 2060 (g and h). Where both red boxes intersect is the baseline economic scenario. The vertical dotted box highlights the impact of maintaining the baseline crop pricing scenario but changing the carbon rental scenario. The horizontal dashed box highlights the impact of maintaining the carbon pricing scenario under changing crop pricing scenarios.

Figure B-9 continued



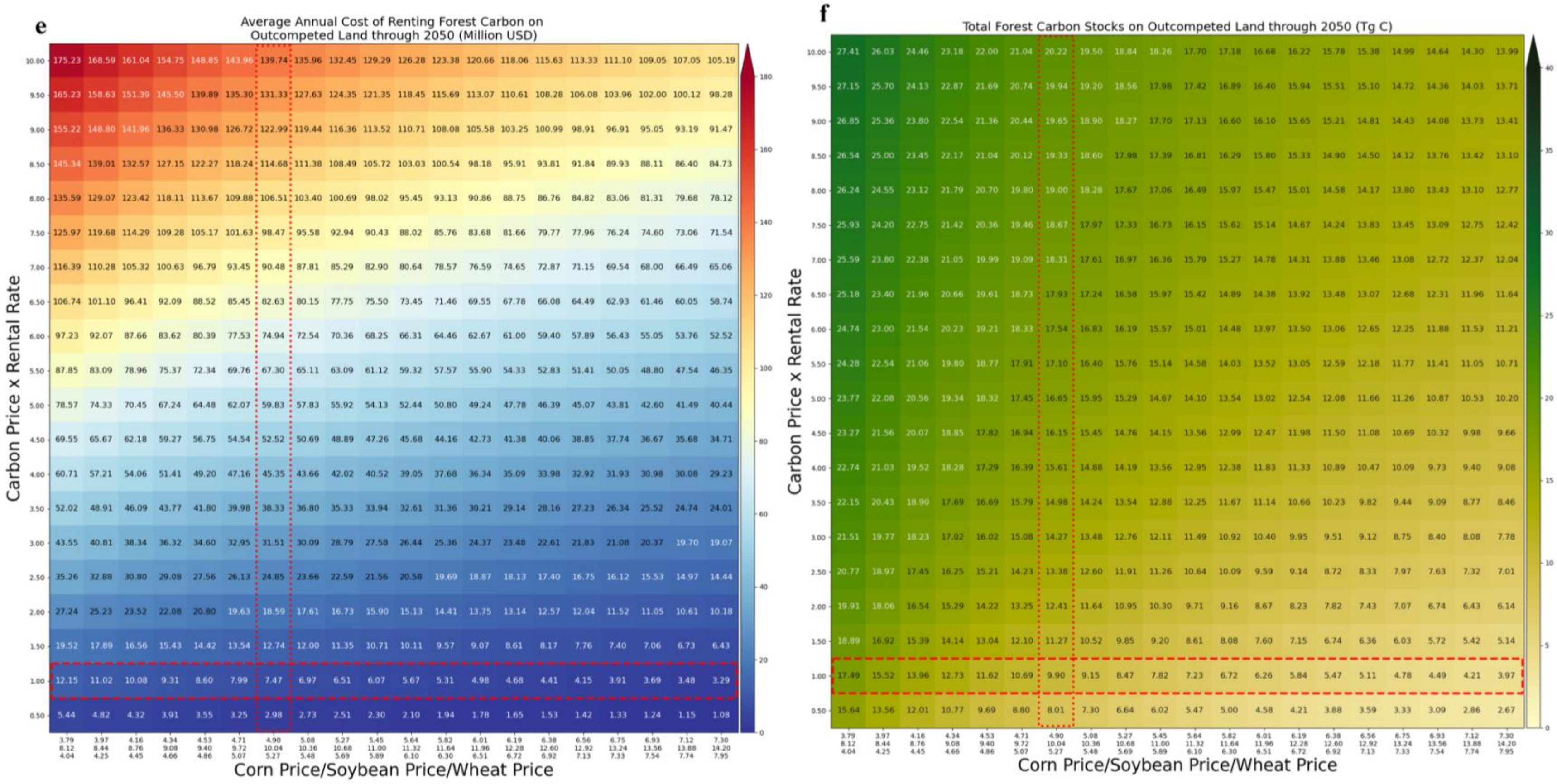
c Average Annual Cost of Renting Forest Carbon on Outcompeted Land through 2040 (Million USD)

Carbon Price x Rental Rate \ Corn Price/Soybean Price/Wheat Price	3.79/8.12/4.04	3.97/8.44/4.25	4.16/8.76/4.45	4.34/9.08/4.66	4.53/9.40/4.86	4.71/9.72/5.07	4.90/10.04/5.27	5.08/10.36/5.48	5.27/10.68/5.69	5.45/11.00/5.89	5.64/11.32/6.10	5.82/11.64/6.30	6.01/11.96/6.51	6.19/12.28/6.72	6.38/12.60/6.92	6.56/12.92/7.13	6.75/13.24/7.33	6.93/13.56/7.54	7.12/13.88/7.74	7.30/14.20/7.95
10.00	143.21	137.27	132.42	127.80	123.97	120.64	117.68	114.94	112.37	109.88	107.58	105.42	103.31	101.34	99.45	97.66	95.98	94.35	92.74	91.24
9.50	135.13	129.48	124.82	120.46	116.79	113.65	110.78	108.19	105.66	103.30	101.11	99.01	97.01	95.09	93.27	91.57	89.92	88.33	86.81	85.38
9.00	127.07	121.77	117.30	113.08	109.67	106.72	103.94	101.44	99.03	96.77	94.68	92.66	90.71	88.89	87.16	85.51	83.91	82.39	80.95	79.54
8.50	119.11	114.13	109.83	105.84	102.63	99.80	97.16	94.72	92.49	90.30	88.31	86.36	84.51	82.78	81.06	79.52	77.97	76.53	75.10	73.77
8.00	111.23	106.49	102.34	98.68	95.62	92.95	90.41	88.09	85.97	83.88	81.99	80.12	78.36	76.69	75.07	73.56	72.10	70.68	69.34	68.05
7.50	103.40	98.94	94.97	91.58	88.71	86.16	83.73	81.56	79.52	77.56	75.72	73.95	72.25	70.64	69.12	67.66	66.26	64.91	63.62	62.40
7.00	95.57	91.48	87.72	84.57	81.83	79.42	77.15	75.10	73.12	71.27	69.53	67.84	66.20	64.69	63.22	61.82	60.48	59.22	58.01	56.87
6.50	87.93	84.08	80.56	77.62	75.03	72.71	70.60	68.69	66.79	65.08	63.40	61.78	60.25	58.78	57.39	56.06	54.82	53.63	52.52	51.45
6.00	80.37	76.77	73.48	70.69	68.32	66.13	64.17	62.34	60.58	58.93	57.32	55.80	54.35	52.94	51.65	50.42	49.27	48.18	47.13	46.10
5.50	72.85	69.51	66.45	63.86	61.68	59.63	57.80	56.07	54.40	52.85	51.35	49.87	48.52	47.24	46.04	44.91	43.85	42.82	41.84	40.91
5.00	65.45	62.36	59.50	57.16	55.11	53.23	51.49	49.89	48.31	46.85	45.41	44.08	42.84	41.66	40.57	39.52	38.54	37.60	36.71	35.85
4.50	58.15	55.29	52.66	50.52	48.66	46.88	45.30	43.78	42.30	40.95	39.65	38.42	37.30	36.22	35.22	34.27	33.38	32.54	31.70	30.92
4.00	50.92	48.28	45.95	44.00	42.29	40.66	39.14	37.75	36.45	35.21	34.03	32.94	31.90	30.94	30.05	29.19	28.37	27.59	26.83	26.12
3.50	43.80	41.40	39.34	37.59	36.01	34.49	33.16	31.89	30.73	29.63	28.58	27.59	26.69	25.85	25.02	24.26	23.52	22.82	22.18	21.55
3.00	36.79	34.66	32.85	31.26	29.85	28.53	27.34	26.23	25.21	24.25	23.32	22.47	21.65	20.91	20.19	19.53	18.89	18.29	17.75	17.20
2.50	29.94	28.08	26.48	25.11	23.85	22.76	21.74	20.78	19.91	19.06	18.27	17.55	16.86	16.21	15.61	15.06	14.52	14.03	13.54	13.08
2.00	23.22	21.64	20.29	19.18	18.13	17.21	16.37	15.57	14.85	14.15	13.51	12.90	12.35	11.83	11.35	10.87	10.44	10.02	9.63	9.26
1.50	16.71	15.46	14.40	13.51	12.69	11.96	11.30	10.68	10.12	9.58	9.07	8.61	8.19	7.78	7.40	7.05	6.74	6.43	6.15	5.88
1.00	10.50	9.60	8.85	8.20	7.61	7.11	6.66	6.23	5.84	5.46	5.11	4.80	4.51	4.25	4.01	3.78	3.57	3.38	3.19	3.03
0.50	4.75	4.23	3.81	3.47	3.16	2.90	2.66	2.45	2.25	2.07	1.90	1.75	1.62	1.50	1.39	1.30	1.21	1.13	1.06	0.99

d Total Forest Carbon Stocks on Outcompeted Land through 2040 (Tg C)

Carbon Price x Rental Rate \ Corn Price/Soybean Price/Wheat Price	3.79/8.12/4.04	3.97/8.44/4.25	4.16/8.76/4.45	4.34/9.08/4.66	4.53/9.40/4.86	4.71/9.72/5.07	4.90/10.04/5.27	5.08/10.36/5.48	5.27/10.68/5.69	5.45/11.00/5.89	5.64/11.32/6.10	5.82/11.64/6.30	6.01/11.96/6.51	6.19/12.28/6.72	6.38/12.60/6.92	6.56/12.92/7.13	6.75/13.24/7.33	6.93/13.56/7.54	7.12/13.88/7.74	7.30/14.20/7.95
10.00	21.41	20.10	19.06	18.09	17.31	16.64	16.07	15.55	15.07	14.61	14.19	13.80	13.42	13.07	12.75	12.44	12.15	11.88	11.62	11.37
9.50	21.20	19.90	18.85	17.89	17.11	16.46	15.87	15.36	14.87	14.41	13.99	13.59	13.22	12.87	12.54	12.23	11.94	11.66	11.40	11.16
9.00	20.98	19.69	18.64	17.66	16.90	16.26	15.67	15.15	14.66	14.20	13.78	13.38	13.00	12.65	12.32	12.01	11.72	11.44	11.18	10.93
8.50	20.75	19.48	18.41	17.44	16.69	16.05	15.46	14.93	14.45	13.98	13.56	13.16	12.78	12.43	12.08	11.78	11.48	11.20	10.94	10.69
8.00	20.52	19.24	18.15	17.22	16.46	15.83	15.23	14.70	14.22	13.75	13.33	12.92	12.54	12.18	11.84	11.53	11.23	10.95	10.68	10.42
7.50	20.28	19.00	17.90	16.99	16.23	15.59	14.99	14.46	13.97	13.51	13.08	12.67	12.28	11.92	11.58	11.26	10.96	10.66	10.39	10.14
7.00	20.00	18.75	17.64	16.74	15.99	15.34	14.74	14.21	13.71	13.24	12.81	12.40	12.00	11.64	11.29	10.96	10.66	10.37	10.10	9.85
6.50	19.74	18.49	17.38	16.48	15.72	15.06	14.47	13.94	13.43	12.97	12.52	12.10	11.70	11.33	10.97	10.64	10.35	10.06	9.80	9.55
6.00	19.48	18.22	17.10	16.19	15.45	14.78	14.19	13.65	13.13	12.66	12.20	11.78	11.37	10.98	10.64	10.32	10.02	9.74	9.48	9.22
5.50	19.18	17.92	16.80	15.89	15.15	14.47	13.88	13.33	12.80	12.32	11.86	11.41	11.01	10.63	10.29	9.97	9.67	9.39	9.13	8.88
5.00	18.87	17.61	16.46	15.57	14.82	14.14	13.53	12.98	12.44	11.94	11.46	11.02	10.62	10.25	9.91	9.59	9.30	9.02	8.76	8.51
4.50	18.55	17.26	16.11	15.22	14.47	13.77	13.16	12.58	12.02	11.52	11.05	10.61	10.21	9.85	9.51	9.19	8.90	8.63	8.36	8.11
4.00	18.18	16.86	15.73	14.84	14.07	13.36	12.71	12.12	11.58	11.08	10.60	10.17	9.77	9.41	9.08	8.76	8.46	8.18	7.92	7.67
3.50	17.78	16.43	15.31	14.41	13.61	12.86	12.22	11.62	11.09	10.59	10.12	9.68	9.29	8.93	8.59	8.27	7.97	7.69	7.43	7.18
3.00	17.33	15.95	14.83	13.89	13.07	12.33	11.68	11.08	10.55	10.04	9.57	9.14	8.74	8.38	8.04	7.72	7.43	7.15	6.90	6.65
2.50	16.83	15.40	14.24	13.29	12.44	11.73	11.08	10.48	9.94	9.42	8.95	8.52	8.12	7.76	7.42	7.11	6.81	6.54	6.28	6.04
2.00	16.20	14.73	13.54	12.61	11.75	11.02	10.38	9.77	9.23	8.70	8.23	7.79	7.40	7.04	6.71	6.39	6.09	5.82	5.56	5.32
1.50	15.43	13.94	12.73	11.78	10.91	10.17	9.52	8.91	8.36	7.83	7.35	6.92	6.53	6.16	5.82	5.51	5.24	4.97	4.73	4.50
1.00	14.47	12.92	11.70	10.71	9.81	9.07	8.42	7.81	7.25	6.71	6.23	5.80	5.42	5.07	4.75	4.45	4.18	3.93	3.69	3.49
0.50	13.10	11.42	10.15	9.14	8.25	7.52	6.85	6.27	5.71	5.19	4.73	4.33	3.98	3.67	3.39	3.14	2.91	2.71	2.52	2.35

Figure B-9 continued



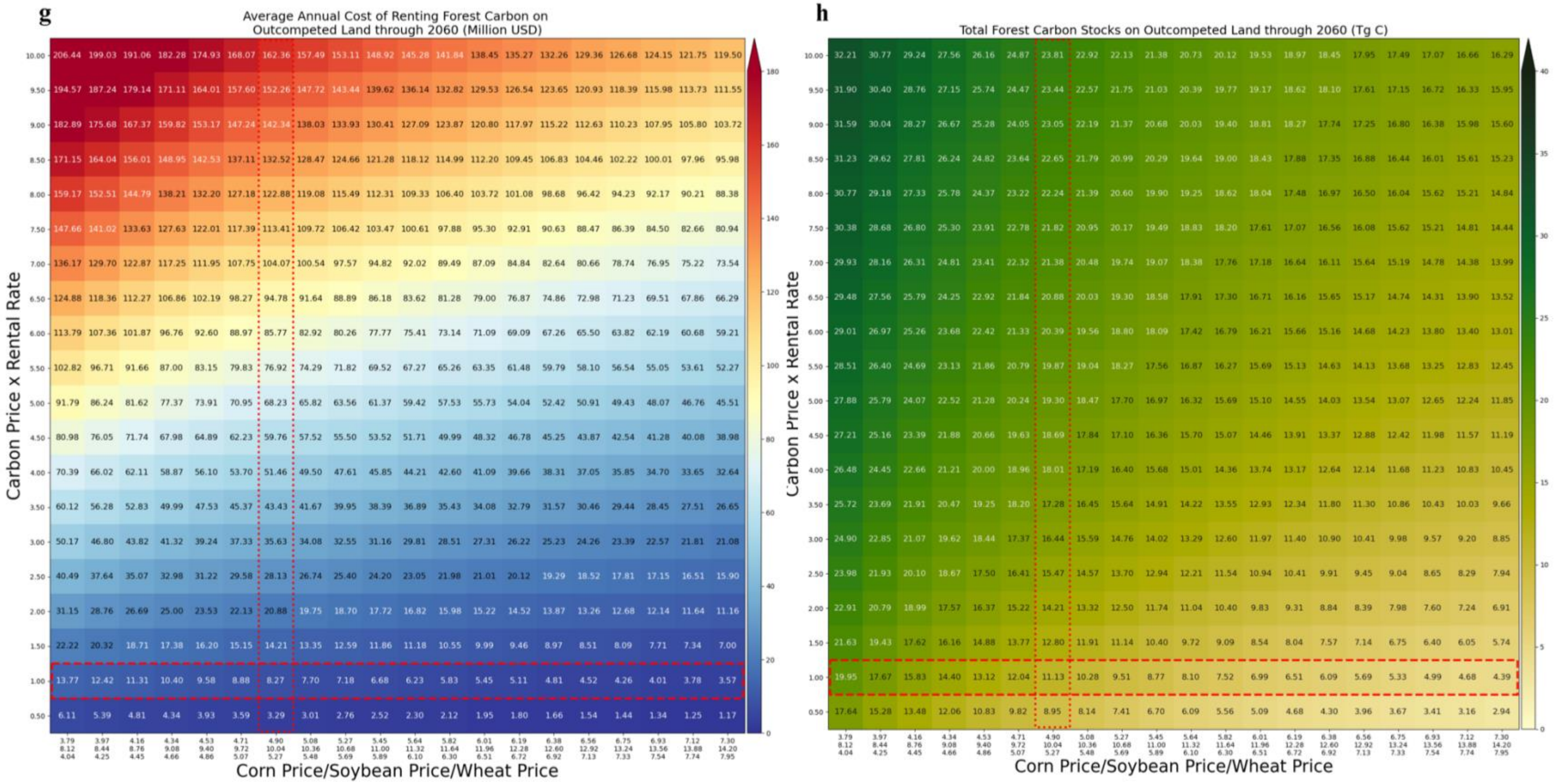
e Average Annual Cost of Renting Forest Carbon on Outcompeted Land through 2050 (Million USD)

Carbon Price x Rental Rate	3.79 8.12 4.04	3.97 8.44 4.25	4.16 8.76 4.45	4.34 9.08 4.66	4.53 9.40 4.86	4.71 9.72 5.07	4.90 10.04 5.27	5.08 10.36 5.48	5.27 10.68 5.69	5.45 11.00 5.89	5.64 11.32 6.10	5.82 11.64 6.30	6.01 11.96 6.51	6.19 12.28 6.72	6.38 12.60 6.92	6.56 12.92 7.13	6.75 13.24 7.33	6.93 13.56 7.54	7.12 13.88 7.74	7.30 14.20 7.95
10.00	175.23	168.59	161.04	154.75	148.85	143.96	139.74	135.96	132.45	129.29	126.28	123.38	120.66	118.06	115.63	113.33	111.10	109.05	107.05	105.19
9.50	165.23	158.63	151.39	145.50	139.89	135.30	131.33	127.63	124.35	121.35	118.45	115.69	113.07	110.61	108.28	106.08	103.96	102.00	100.12	98.28
9.00	155.22	148.80	141.96	136.33	130.98	126.72	122.99	119.44	116.36	113.52	110.71	108.08	105.58	103.25	100.99	98.91	96.91	95.05	93.19	91.47
8.50	145.34	139.01	132.57	127.15	122.27	118.24	114.68	111.38	108.49	105.72	103.03	100.54	98.18	95.91	93.81	91.84	89.93	88.11	86.40	84.73
8.00	135.59	129.07	123.42	118.11	113.67	109.88	106.51	103.40	100.69	98.02	95.45	93.13	90.86	88.75	86.76	84.82	83.06	81.31	79.68	78.12
7.50	125.97	119.68	114.29	109.28	105.17	101.63	98.47	95.58	92.94	90.43	88.02	85.76	83.68	81.66	79.77	77.96	76.24	74.60	73.06	71.54
7.00	116.39	110.28	105.32	100.63	96.79	93.45	90.48	87.81	85.29	82.90	80.64	78.57	76.59	74.65	72.87	71.15	69.54	68.00	66.49	65.06
6.50	106.74	101.10	96.41	92.09	88.52	85.45	82.63	80.15	77.75	75.50	73.45	71.46	69.55	67.78	66.08	64.49	62.93	61.46	60.05	58.74
6.00	97.23	92.07	87.66	83.62	80.39	77.53	74.94	72.54	70.36	68.25	66.31	64.46	62.67	61.00	59.40	57.89	56.43	55.05	53.76	52.52
5.50	87.85	83.09	78.96	75.37	72.34	69.76	67.30	65.11	63.09	61.12	59.32	57.57	55.90	54.33	52.83	51.41	50.05	48.80	47.54	46.35
5.00	78.57	74.33	70.45	67.24	64.48	62.07	59.83	57.83	55.92	54.13	52.44	50.80	49.24	47.78	46.39	45.07	43.81	42.60	41.49	40.44
4.50	69.55	65.67	62.18	59.27	56.75	54.54	52.52	50.69	48.89	47.26	45.68	44.16	42.73	41.38	40.06	38.85	37.74	36.67	35.68	34.71
4.00	60.71	57.21	54.06	51.41	49.20	47.16	45.35	43.66	42.02	40.52	39.05	37.68	36.34	35.09	33.98	32.92	31.93	30.98	30.08	29.23
3.50	52.02	48.91	46.09	43.77	41.80	39.98	38.33	36.80	35.33	33.94	32.61	31.36	30.21	29.14	28.16	27.23	26.34	25.52	24.74	24.01
3.00	43.55	40.81	38.34	36.32	34.60	32.95	31.51	30.09	28.79	27.58	26.44	25.36	24.37	23.48	22.61	21.83	21.08	20.37	19.70	19.07
2.50	35.26	32.88	30.80	29.08	27.56	26.13	24.85	23.66	22.59	21.56	20.58	19.69	18.87	18.13	17.40	16.75	16.12	15.53	14.97	14.44
2.00	27.24	25.23	23.52	22.08	20.80	19.63	18.59	17.61	16.73	15.90	15.13	14.41	13.75	13.14	12.57	12.04	11.52	11.05	10.61	10.18
1.50	19.52	17.89	16.56	15.43	14.42	13.54	12.74	12.00	11.35	10.71	10.11	9.57	9.07	8.61	8.17	7.76	7.40	7.06	6.73	6.43
1.00	12.15	11.02	10.08	9.31	8.60	7.99	7.47	6.97	6.51	6.07	5.67	5.31	4.98	4.68	4.41	4.15	3.91	3.69	3.48	3.29
0.50	5.44	4.82	4.32	3.91	3.55	3.25	2.98	2.73	2.51	2.30	2.10	1.94	1.78	1.65	1.53	1.42	1.33	1.24	1.15	1.08

f Total Forest Carbon Stocks on Outcompeted Land through 2050 (Tg C)

Carbon Price x Rental Rate	3.79 8.12 4.04	3.97 8.44 4.25	4.16 8.76 4.45	4.34 9.08 4.66	4.53 9.40 4.86	4.71 9.72 5.07	4.90 10.04 5.27	5.08 10.36 5.48	5.27 10.68 5.69	5.45 11.00 5.89	5.64 11.32 6.10	5.82 11.64 6.30	6.01 11.96 6.51	6.19 12.28 6.72	6.38 12.60 6.92	6.56 12.92 7.13	6.75 13.24 7.33	6.93 13.56 7.54	7.12 13.88 7.74	7.30 14.20 7.95
10.00	27.41	26.03	24.46	23.18	22.00	21.04	20.22	19.50	18.84	18.26	17.70	17.18	16.68	16.22	15.78	15.38	14.99	14.64	14.30	13.99
9.50	27.15	25.70	24.13	22.87	21.69	20.74	19.94	19.20	18.56	17.98	17.42	16.89	16.40	15.94	15.51	15.10	14.72	14.36	14.03	13.71
9.00	26.85	25.36	23.80	22.54	21.36	20.44	19.65	18.90	18.27	17.70	17.13	16.60	16.10	15.65	15.21	14.81	14.43	14.08	13.73	13.41
8.50	26.54	25.00	23.45	22.17	21.04	20.12	19.33	18.60	17.98	17.39	16.81	16.29	15.80	15.33	14.90	14.50	14.12	13.76	13.42	13.10
8.00	26.24	24.55	23.12	21.79	20.70	19.80	19.00	18.28	17.67	17.06	16.49	15.97	15.47	15.01	14.58	14.17	13.80	13.43	13.10	12.77
7.50	25.93	24.20	22.75	21.42	20.36	19.46	18.67	17.97	17.33	16.73	16.15	15.62	15.14	14.67	14.24	13.83	13.45	13.09	12.75	12.42
7.00	25.59	23.80	22.38	21.05	19.99	19.09	18.31	17.61	16.97	16.36	15.79	15.27	14.78	14.31	13.88	13.46	13.08	12.72	12.37	12.04
6.50	25.18	23.40	21.96	20.66	19.61	18.73	17.93	17.24	16.58	15.97	15.42	14.89	14.38	13.92	13.48	13.07	12.68	12.31	11.96	11.64
6.00	24.74	23.00	21.54	20.23	19.21	18.33	17.54	16.83	16.19	15.57	15.01	14.48	13.97	13.50	13.06	12.65	12.25	11.88	11.53	11.21
5.50	24.28	22.54	21.06	19.80	18.77	17.91	17.10	16.40	15.76	15.14	14.58	14.03	13.52	13.05	12.59	12.18	11.77	11.41	11.05	10.71
5.00	23.77	22.08	20.56	19.34	18.32	17.45	16.65	15.95	15.29	14.67	14.10	13.54	13.02	12.54	12.08	11.66	11.26	10.87	10.53	10.20
4.50	23.27	21.56	20.07	18.85	17.82	16.94	16.15	15.45	14.76	14.15	13.56	12.99	12.47	11.98	11.50	11.08	10.69	10.32	9.98	9.66
4.00	22.74	21.03	19.52	18.28	17.29	16.39	15.61	14.88	14.19	13.56	12.95	12.38	11.83	11.33	10.89	10.47	10.09	9.73	9.40	9.08
3.50	22.15	20.43	18.90	17.69	16.69	15.79	14.98	14.24	13.54	12.88	12.25	11.67	11.14	10.66	10.23	9.82	9.44	9.09	8.77	8.46
3.00	21.51	19.77	18.23	17.02	16.02	15.08	14.27	13.48	12.76	12.11	11.49	10.92	10.40	9.95	9.51	9.12	8.75	8.40	8.08	7.78
2.50	20.77	18.97	17.45	16.25	15.21	14.23	13.38	12.60	11.91	11.26	10.64	10.09	9.59	9.14	8.72	8.33	7.97	7.63	7.32	7.01
2.00	19.91	18.06	16.54	15.29	14.22	13.25	12.41	11.64	10.95	10.30	9.71	9.16	8.67	8.23	7.82	7.43	7.07	6.74	6.43	6.14
1.50	18.89	16.92	15.39	14.14	13.04	12.10	11.27	10.52	9.85	9.20	8.61	8.08	7.60	7.15	6.74	6.36	6.03	5.72	5.42	5.14
1.00	17.49	15.52	13.96	12.73	11.62	10.69	9.90	9.15	8.47	7.82	7.23	6.72	6.26	5.84	5.47	5.11	4.78	4.49	4.21	3.97
0.50	15.64	13.56	12.01	10.77	9.69	8.80	8.01	7.30	6.64	6.02	5.47	5.00	4.58	4.21	3.88	3.59	3.33	3.09	2.86	2.67

Figure B-9 continued



g

Average Annual Cost of Renting Forest Carbon on Outcompeted Land through 2060 (Million USD)

Carbon Price x Rental Rate	3.79 8.12 4.04	3.97 8.44 4.25	4.16 8.76 4.45	4.34 9.08 4.66	4.53 9.40 4.86	4.71 9.72 5.07	4.90 10.04 5.27	5.08 10.36 5.48	5.27 10.68 5.69	5.45 11.00 5.89	5.64 11.32 6.10	5.82 11.64 6.30	6.01 11.96 6.51	6.19 12.28 6.72	6.38 12.60 6.92	6.56 12.92 7.13	6.75 13.24 7.33	6.93 13.56 7.54	7.12 13.88 7.74	7.30 14.20 7.95
10.00	206.44	199.03	191.06	182.28	174.93	168.07	162.36	157.49	153.11	148.92	145.28	141.84	138.45	135.27	132.26	129.36	126.68	124.15	121.75	119.50
9.50	194.57	187.24	179.14	171.11	164.01	157.60	152.26	147.72	143.44	139.62	136.14	132.82	129.53	126.54	123.65	120.93	118.39	115.98	113.73	111.55
9.00	182.89	175.68	167.37	159.82	153.17	147.24	142.34	138.03	133.93	130.41	127.09	123.87	120.80	117.97	115.22	112.63	110.23	107.95	105.80	103.72
8.50	171.15	164.04	156.01	148.95	142.53	137.11	132.52	128.47	124.66	121.28	118.12	114.99	112.20	109.45	106.83	104.46	102.22	100.01	97.96	95.98
8.00	159.17	152.51	144.79	138.21	132.20	127.18	122.88	119.08	115.49	112.31	109.33	106.40	103.72	101.08	98.68	96.42	94.23	92.17	90.21	88.38
7.50	147.66	141.02	133.63	127.63	122.01	117.39	113.41	109.72	106.42	103.47	100.61	97.88	95.30	92.91	90.63	88.47	86.39	84.50	82.66	80.94
7.00	136.17	129.70	122.87	117.25	111.95	107.75	104.07	100.54	97.57	94.82	92.02	89.49	87.09	84.84	82.64	80.66	78.74	76.95	75.22	73.54
6.50	124.88	118.36	112.27	106.86	102.19	98.27	94.78	91.64	88.89	86.18	83.62	81.28	79.00	76.87	74.86	72.98	71.23	69.51	67.86	66.29
6.00	113.79	107.36	101.87	96.76	92.60	88.97	85.77	82.92	80.26	77.77	75.41	73.14	71.09	69.09	67.26	65.50	63.82	62.19	60.68	59.21
5.50	102.82	96.71	91.66	87.00	83.15	79.83	76.92	74.29	71.82	69.52	67.27	65.26	63.35	61.48	59.79	58.10	56.54	55.05	53.61	52.27
5.00	91.79	86.24	81.62	77.37	73.91	70.95	68.23	65.82	63.56	61.37	59.42	57.53	55.73	54.04	52.42	50.91	49.43	48.07	46.76	45.51
4.50	80.98	76.05	71.74	67.98	64.89	62.23	59.76	57.52	55.50	53.52	51.71	49.99	48.32	46.78	45.25	43.87	42.54	41.28	40.08	38.98
4.00	70.39	66.02	62.11	58.87	56.10	53.70	51.46	49.50	47.61	45.85	44.21	42.60	41.09	39.66	38.31	37.05	35.85	34.70	33.65	32.64
3.50	60.12	56.28	52.83	49.99	47.53	45.37	43.43	41.67	39.95	38.39	36.89	35.43	34.08	32.79	31.57	30.46	29.44	28.45	27.51	26.65
3.00	50.17	46.80	43.82	41.32	39.24	37.33	35.63	34.08	32.55	31.16	29.81	28.51	27.31	26.22	25.23	24.26	23.39	22.57	21.81	21.08
2.50	40.49	37.64	35.07	32.98	31.22	29.58	28.13	26.74	25.40	24.20	23.05	21.98	21.01	20.12	19.29	18.52	17.81	17.15	16.51	15.90
2.00	31.15	28.76	26.69	25.00	23.53	22.13	20.88	19.75	18.70	17.72	16.82	15.98	15.22	14.52	13.87	13.26	12.68	12.14	11.64	11.16
1.50	22.22	20.32	18.71	17.38	16.20	15.15	14.21	13.35	12.59	11.86	11.18	10.55	9.99	9.46	8.97	8.51	8.09	7.71	7.34	7.00
1.00	13.77	12.42	11.31	10.40	9.58	8.88	8.27	7.70	7.18	6.68	6.23	5.83	5.45	5.11	4.81	4.52	4.26	4.01	3.78	3.57
0.50	6.11	5.39	4.81	4.34	3.93	3.59	3.29	3.01	2.76	2.52	2.30	2.12	1.95	1.80	1.66	1.54	1.44	1.34	1.25	1.17

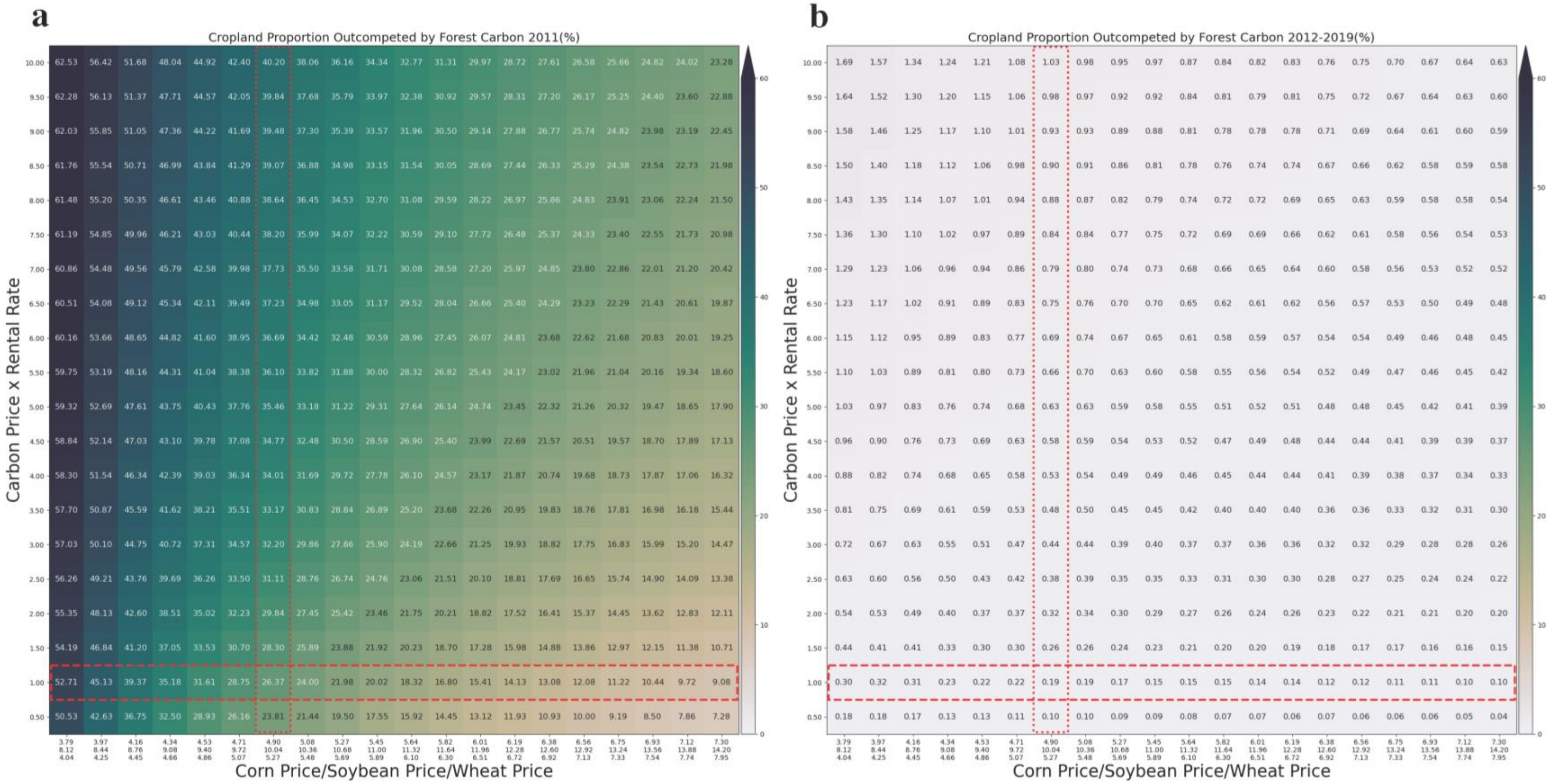
Corn Price/Soybean Price/Wheat Price

h

Total Forest Carbon Stocks on Outcompeted Land through 2060 (Tg C)

Carbon Price x Rental Rate	3.79 8.12 4.04	3.97 8.44 4.25	4.16 8.76 4.45	4.34 9.08 4.66	4.53 9.40 4.86	4.71 9.72 5.07	4.90 10.04 5.27	5.08 10.36 5.48	5.27 10.68 5.69	5.45 11.00 5.89	5.64 11.32 6.10	5.82 11.64 6.30	6.01 11.96 6.51	6.19 12.28 6.72	6.38 12.60 6.92	6.56 12.92 7.13	6.75 13.24 7.33	6.93 13.56 7.54	7.12 13.88 7.74	7.30 14.20 7.95
10.00	32.21	30.77	29.24	27.56	26.16	24.87	23.81	22.92	22.13	21.38	20.73	20.12	19.53	18.97	18.45	17.95	17.49	17.07	16.66	16.29
9.50	31.90	30.40	28.76	27.15	25.74	24.47	23.44	22.57	21.75	21.03	20.39	19.77	19.17	18.62	18.10	17.61	17.15	16.72	16.33	15.95
9.00	31.59	30.04	28.27	26.67	25.28	24.05	23.05	22.19	21.37	20.68	20.03	19.40	18.81	18.27	17.74	17.25	16.80	16.38	15.98	15.60
8.50	31.23	29.62	27.81	26.24	24.82	23.64	22.65	21.79	20.99	20.29	19.64	19.00	18.43	17.88	17.35	16.88	16.44	16.01	15.61	15.23
8.00	30.77	29.18	27.33	25.78	24.37	23.22	22.24	21.39	20.60	19.90	19.25	18.62	18.04	17.48	16.97	16.50	16.04	15.62	15.21	14.84
7.50	30.38	28.68	26.80	25.30	23.91	22.78	21.82	20.95	20.17	19.49	18.83	18.20	17.61	17.07	16.56	16.08	15.62	15.21	14.81	14.44
7.00	29.93	28.16	26.31	24.81	23.41	22.32	21.38	20.48	19.74	19.07	18.38	17.76	17.18	16.64	16.11	15.64	15.19	14.78	14.38	13.99
6.50	29.48	27.56	25.79	24.25	22.92	21.84	20.88	20.03	19.30	18.58	17.91	17.30	16.71	16.16	15.65	15.17	14.74	14.31	13.90	13.52
6.00	29.01	26.97	25.26	23.68	22.42	21.33	20.39	19.56	18.80	18.09	17.42	16.79	16.21	15.66	15.16	14.68	14.23	13.80	13.40	13.01
5.50	28.51	26.40	24.69	23.13	21.86	20.79	19.87	19.04	18.27	17.56	16.87	16.27	15.69	15.13	14.63	14.13	13.68	13.25	12.83	12.45
5.00	27.88	25.79	24.07	22.52	21.28	20.24	19.30	18.47	17.70	16.97	16.32	15.69	15.10	14.55	14.03	13.54	13.07	12.65	12.24	11.85
4.50	27.21	25.16	23.39	21.88	20.66	19.63	18.69	17.84	17.10	16.36	15.70	15.07	14.46	13.91	13.37	12.88	12.42	11.98	11.57	11.19
4.00	26.48	24.45	22.66	21.21	20.00	18.96	18.01	17.19	16.40	15.68	15.01	14.36	13.74	13.17	12.64	12.14	11.68	11.23	10.83	10.45
3.50	25.72	23.69	21.91	20.47	19.25	18.20	17.28	16.45	15.64	14.91	14.22	13.55	12.93	12.34	11.80	11.30	10.86	10.43	10.03	9.66
3.00	24.90	22.85	21.07	19.62	18.44	17.37	16.44	15.59	14.76	14.02	13.29	12.60	11.97	11.40	10.90	10.41	9.98	9.57	9.20	8.85
2.50	23.98	21.93	20.10	18.67	17.50	16.41	15.47	14.57	13.70	12.94	12.21	11.54	10.94	10.41	9.91	9.45	9.04	8.65	8.29	7.94
2.00	22.91	20.79	18.99	17.57	16.37	15.22	14.21	13.32	12.50	11.74	11.04	10.40	9.83	9.31	8.84	8.39	7.98	7.60	7.24	6.91
1.50	21.63	19.43	17.62	16.16	14.88	13.77	12.80	11.91	11.14	10.40	9.72	9.09	8.54	8.04	7.57	7.14	6.75	6.40	6.05	5.74
1.00	19.95	17.67	15.83	14.40	13.12	12.04	11.13	10.28	9.51	8.77	8.10	7.52	6.99	6.51	6.09	5.69	5.33	4.99	4.68	4.39
0.50	17.64	15.28	13.48	12.06	10.83	9.82	8.95	8.14	7.41	6.70	6.09	5.56	5.09	4.68	4.30	3.96	3.67	3.41	3.16	2.94

Corn Price/Soybean Price/Wheat Price



Cropland Proportion Outcompeted by Forest Carbon 2011(%)

Carbon Price x Rental Rate	3.79 8.12 4.04	3.97 8.44 4.25	4.16 8.76 4.45	4.34 9.08 4.66	4.53 9.40 4.86	4.71 9.72 5.07	4.90 10.04 5.27	5.08 10.36 5.48	5.27 10.68 5.69	5.45 11.00 5.89	5.64 11.32 6.10	5.82 11.64 6.30	6.01 11.96 6.51	6.19 12.28 6.72	6.38 12.60 6.92	6.56 12.92 7.13	6.75 13.24 7.33	6.93 13.56 7.54	7.12 13.88 7.74	7.30 14.20 7.95
10.00	62.53	56.42	51.68	48.04	44.92	42.40	40.20	38.06	36.16	34.34	32.77	31.31	29.97	28.72	27.61	26.58	25.66	24.82	24.02	23.28
9.50	62.28	56.13	51.37	47.71	44.57	42.05	39.84	37.68	35.79	33.97	32.38	30.92	29.57	28.31	27.20	26.17	25.25	24.40	23.60	22.88
9.00	62.03	55.85	51.05	47.36	44.22	41.69	39.48	37.30	35.39	33.57	31.96	30.50	29.14	27.88	26.77	25.74	24.82	23.98	23.19	22.45
8.50	61.76	55.54	50.71	46.99	43.84	41.29	39.07	36.88	34.98	33.15	31.54	30.05	28.69	27.44	26.33	25.29	24.38	23.54	22.73	21.98
8.00	61.48	55.20	50.35	46.61	43.46	40.88	38.64	36.45	34.53	32.70	31.08	29.59	28.22	26.97	25.86	24.83	23.91	23.06	22.24	21.50
7.50	61.19	54.85	49.96	46.21	43.03	40.44	38.20	35.99	34.07	32.22	30.59	29.10	27.72	26.48	25.37	24.33	23.40	22.55	21.73	20.98
7.00	60.86	54.48	49.56	45.79	42.58	39.98	37.73	35.50	33.58	31.71	30.08	28.58	27.20	25.97	24.85	23.80	22.86	22.01	21.20	20.42
6.50	60.51	54.08	49.12	45.34	42.11	39.49	37.23	34.98	33.05	31.17	29.52	28.04	26.66	25.40	24.29	23.23	22.29	21.43	20.61	19.87
6.00	60.16	53.66	48.65	44.82	41.60	38.95	36.69	34.42	32.48	30.59	28.96	27.45	26.07	24.81	23.68	22.62	21.68	20.83	20.01	19.25
5.50	59.75	53.19	48.16	44.31	41.04	38.38	36.10	33.82	31.88	30.00	28.32	26.82	25.43	24.17	23.02	21.96	21.04	20.16	19.34	18.60
5.00	59.32	52.69	47.61	43.75	40.43	37.76	35.46	33.18	31.22	29.31	27.64	26.14	24.74	23.45	22.32	21.26	20.32	19.47	18.65	17.90
4.50	58.84	52.14	47.03	43.10	39.78	37.08	34.77	32.48	30.50	28.59	26.90	25.40	23.99	22.69	21.57	20.51	19.57	18.70	17.89	17.13
4.00	58.30	51.54	46.34	42.39	39.03	36.34	34.01	31.69	29.72	27.78	26.10	24.57	23.17	21.87	20.74	19.68	18.73	17.87	17.06	16.32
3.50	57.70	50.87	45.59	41.62	38.21	35.51	33.17	30.83	28.84	26.89	25.20	23.68	22.26	20.95	19.83	18.76	17.81	16.98	16.18	15.44
3.00	57.03	50.10	44.75	40.72	37.31	34.57	32.20	29.86	27.86	25.90	24.19	22.66	21.25	19.93	18.82	17.75	16.83	15.99	15.20	14.47
2.50	56.26	49.21	43.76	39.69	36.26	33.50	31.11	28.76	26.74	24.76	23.06	21.51	20.10	18.81	17.69	16.65	15.74	14.90	14.09	13.38
2.00	55.35	48.13	42.60	38.51	35.02	32.23	29.84	27.45	25.42	23.46	21.75	20.21	18.82	17.52	16.41	15.37	14.45	13.62	12.83	12.11
1.50	54.19	46.84	41.20	37.05	33.53	30.70	28.30	25.89	23.88	21.92	20.23	18.70	17.28	15.98	14.88	13.86	12.97	12.15	11.38	10.71
1.00	52.71	45.13	39.37	35.18	31.61	28.75	26.37	24.00	21.98	20.02	18.32	16.80	15.41	14.13	13.08	12.08	11.22	10.44	9.72	9.08
0.50	50.53	42.63	36.75	32.50	28.93	26.16	23.81	21.44	19.50	17.55	15.92	14.45	13.12	11.93	10.93	10.00	9.19	8.50	7.86	7.28

Corn Price/Soybean Price/Wheat Price

Cropland Proportion Outcompeted by Forest Carbon 2012-2019(%)

Carbon Price x Rental Rate	3.79 8.12 4.04	3.97 8.44 4.25	4.16 8.76 4.45	4.34 9.08 4.66	4.53 9.40 4.86	4.71 9.72 5.07	4.90 10.04 5.27	5.08 10.36 5.48	5.27 10.68 5.69	5.45 11.00 5.89	5.64 11.32 6.10	5.82 11.64 6.30	6.01 11.96 6.51	6.19 12.28 6.72	6.38 12.60 6.92	6.56 12.92 7.13	6.75 13.24 7.33	6.93 13.56 7.54	7.12 13.88 7.74	7.30 14.20 7.95
10.00	1.69	1.57	1.34	1.24	1.21	1.08	1.03	0.98	0.95	0.97	0.87	0.84	0.82	0.83	0.76	0.75	0.70	0.67	0.64	0.63
9.50	1.64	1.52	1.30	1.20	1.15	1.06	0.98	0.97	0.92	0.92	0.84	0.81	0.79	0.81	0.75	0.72	0.67	0.64	0.63	0.60
9.00	1.58	1.46	1.25	1.17	1.10	1.01	0.93	0.93	0.89	0.88	0.81	0.78	0.78	0.78	0.71	0.69	0.64	0.61	0.60	0.59
8.50	1.50	1.40	1.18	1.12	1.06	0.98	0.90	0.91	0.86	0.81	0.78	0.76	0.74	0.74	0.67	0.66	0.62	0.58	0.59	0.58
8.00	1.43	1.35	1.14	1.07	1.01	0.94	0.88	0.87	0.82	0.79	0.74	0.72	0.72	0.69	0.65	0.63	0.59	0.58	0.58	0.54
7.50	1.36	1.30	1.10	1.02	0.97	0.89	0.84	0.84	0.77	0.75	0.72	0.69	0.69	0.66	0.62	0.61	0.58	0.56	0.54	0.53
7.00	1.29	1.23	1.06	0.96	0.94	0.86	0.79	0.80	0.74	0.73	0.68	0.66	0.65	0.64	0.60	0.58	0.56	0.53	0.52	0.52
6.50	1.23	1.17	1.02	0.91	0.89	0.83	0.75	0.76	0.70	0.70	0.65	0.62	0.61	0.62	0.56	0.57	0.53	0.50	0.49	0.48
6.00	1.15	1.12	0.95	0.89	0.83	0.77	0.69	0.74	0.67	0.65	0.61	0.58	0.59	0.57	0.54	0.54	0.49	0.46	0.48	0.45
5.50	1.10	1.03	0.89	0.81	0.80	0.73	0.66	0.70	0.63	0.60	0.58	0.55	0.56	0.54	0.52	0.49	0.47	0.46	0.45	0.42
5.00	1.03	0.97	0.83	0.76	0.74	0.68	0.63	0.63	0.59	0.58	0.55	0.51	0.52	0.51	0.48	0.48	0.45	0.42	0.41	0.39
4.50	0.96	0.90	0.76	0.73	0.69	0.63	0.58	0.59	0.54	0.53	0.52	0.47	0.49	0.48	0.44	0.44	0.41	0.39	0.39	0.37
4.00	0.88	0.82	0.74	0.68	0.65	0.58	0.53	0.54	0.49	0.49	0.46	0.45	0.44	0.44	0.41	0.39	0.38	0.37	0.34	0.33
3.50	0.81	0.75	0.69	0.61	0.59	0.53	0.48	0.50	0.45	0.45	0.42	0.40	0.40	0.40	0.36	0.36	0.33	0.32	0.31	0.30
3.00	0.72	0.67	0.63	0.55	0.51	0.47	0.44	0.44	0.39	0.40	0.37	0.37	0.36	0.36	0.32	0.32	0.29	0.28	0.28	0.26
2.50	0.63	0.60	0.56	0.50	0.43	0.42	0.38	0.39	0.35	0.35	0.33	0.31	0.30	0.30	0.28	0.27	0.25	0.24	0.24	0.22
2.00	0.54	0.53	0.49	0.40	0.37	0.37	0.32	0.34	0.30	0.29	0.27	0.26	0.24	0.26	0.23	0.22	0.21	0.21	0.20	0.20
1.50	0.44	0.41	0.41	0.33	0.30	0.30	0.26	0.26	0.24	0.23	0.21	0.20	0.20	0.19	0.18	0.17	0.17	0.16	0.16	0.15
1.00	0.30	0.32	0.31	0.23	0.22	0.22	0.19	0.19	0.17	0.15	0.15	0.15	0.14	0.14	0.12	0.12	0.11	0.11	0.10	0.10
0.50	0.18	0.18	0.17	0.13	0.13	0.11	0.10	0.10	0.09	0.09	0.08	0.07	0.07	0.06	0.07	0.06	0.06	0.06	0.05	0.04

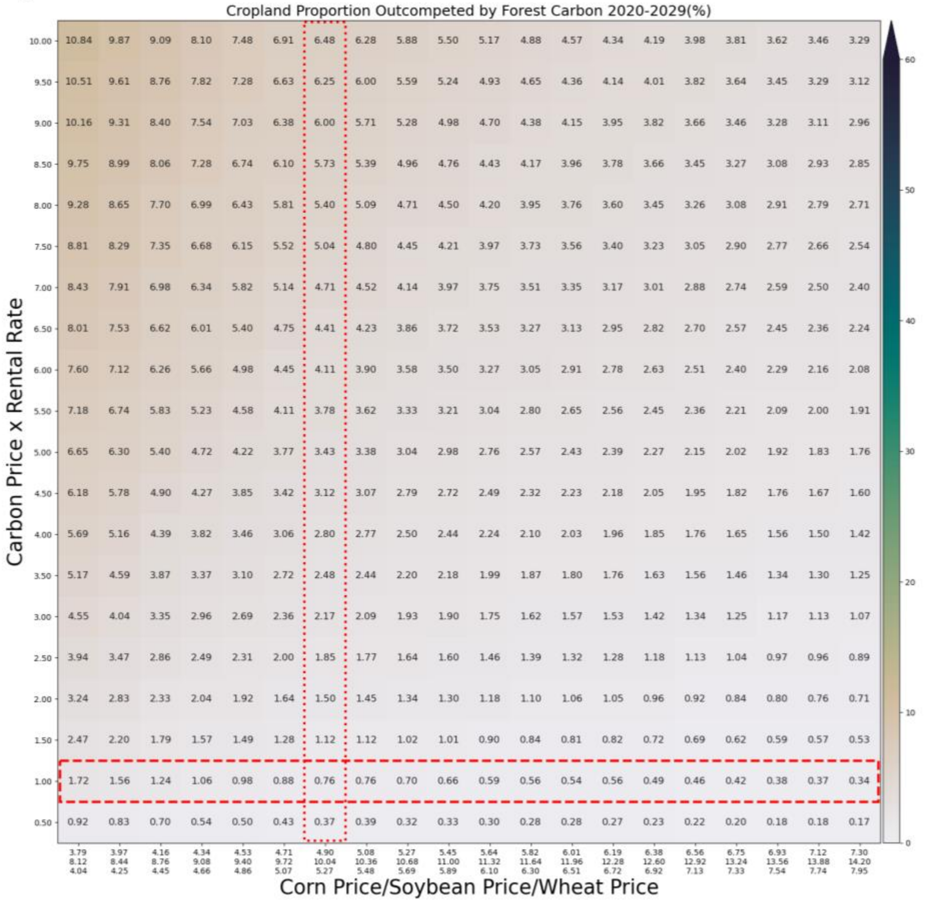
Corn Price/Soybean Price/Wheat Price

continued

Figure B-10: Proportion of Maryland cropland area outcompeted by forest carbon revenue immediately in 2011 (a) and additionally between 2012-2019 (b) and 2020-2029 (c) under twenty economic scenarios with zero subsidies. Where both red boxes intersect is the baseline economic scenario. The vertical dotted box highlights the impact of maintaining the baseline crop pricing scenario but changing the carbon rental scenario. The horizontal dashed box highlights the impact of maintaining the carbon pricing scenario under changing crop pricing scenarios.

Figure B-10 continued

c



Cropland Proportion Outcompeted by Forest Carbon 2020-2029(%)

Carbon Price x Rental Rate	3.79 8.12 4.04	3.97 8.44 4.25	4.16 8.76 4.45	4.34 9.08 4.66	4.53 9.40 4.86	4.71 9.72 5.07	4.90 10.04 5.27	5.08 10.36 5.48	5.27 10.68 5.69	5.45 11.00 5.89	5.64 11.32 6.10	5.82 11.64 6.30	6.01 11.96 6.51	6.19 12.28 6.72	6.38 12.60 6.92	6.56 12.92 7.13	6.75 13.24 7.33	6.93 13.56 7.54	7.12 13.88 7.74	7.30 14.20 7.95
10.00	10.84	9.87	9.09	8.10	7.48	6.91	6.48	6.28	5.88	5.50	5.17	4.88	4.57	4.34	4.19	3.98	3.81	3.62	3.46	3.29
9.50	10.51	9.61	8.76	7.82	7.28	6.63	6.25	6.00	5.59	5.24	4.93	4.65	4.36	4.14	4.01	3.82	3.64	3.45	3.29	3.12
9.00	10.16	9.31	8.40	7.54	7.03	6.38	6.00	5.71	5.28	4.98	4.70	4.38	4.15	3.95	3.82	3.66	3.46	3.28	3.11	2.96
8.50	9.75	8.99	8.06	7.28	6.74	6.10	5.73	5.39	4.96	4.76	4.43	4.17	3.96	3.78	3.66	3.45	3.27	3.08	2.93	2.85
8.00	9.28	8.65	7.70	6.99	6.43	5.81	5.40	5.09	4.71	4.50	4.20	3.95	3.76	3.60	3.45	3.26	3.08	2.91	2.79	2.71
7.50	8.81	8.29	7.35	6.68	6.15	5.52	5.04	4.80	4.45	4.21	3.97	3.73	3.56	3.40	3.23	3.05	2.90	2.77	2.66	2.54
7.00	8.43	7.91	6.98	6.34	5.82	5.14	4.71	4.52	4.14	3.97	3.75	3.51	3.35	3.17	3.01	2.88	2.74	2.59	2.50	2.40
6.50	8.01	7.53	6.62	6.01	5.40	4.75	4.41	4.23	3.86	3.72	3.53	3.27	3.13	2.95	2.82	2.70	2.57	2.45	2.36	2.24
6.00	7.60	7.12	6.26	5.66	4.98	4.45	4.11	3.90	3.58	3.50	3.27	3.05	2.91	2.78	2.63	2.51	2.40	2.29	2.16	2.08
5.50	7.18	6.74	5.83	5.23	4.58	4.11	3.78	3.62	3.33	3.21	3.04	2.80	2.65	2.56	2.45	2.36	2.21	2.09	2.00	1.91
5.00	6.65	6.30	5.40	4.72	4.22	3.77	3.43	3.38	3.04	2.98	2.76	2.57	2.43	2.39	2.27	2.15	2.02	1.92	1.83	1.76
4.50	6.18	5.78	4.90	4.27	3.85	3.42	3.12	3.07	2.79	2.72	2.49	2.32	2.23	2.18	2.05	1.95	1.82	1.76	1.67	1.60
4.00	5.69	5.16	4.39	3.82	3.46	3.06	2.80	2.77	2.50	2.44	2.24	2.10	2.03	1.96	1.85	1.76	1.65	1.56	1.50	1.42
3.50	5.17	4.59	3.87	3.37	3.10	2.72	2.48	2.44	2.20	2.18	1.99	1.87	1.80	1.76	1.63	1.56	1.46	1.34	1.30	1.25
3.00	4.55	4.04	3.35	2.96	2.69	2.36	2.17	2.09	1.93	1.90	1.75	1.62	1.57	1.53	1.42	1.34	1.25	1.17	1.13	1.07
2.50	3.94	3.47	2.86	2.49	2.31	2.00	1.85	1.77	1.64	1.60	1.46	1.39	1.32	1.28	1.18	1.13	1.04	0.97	0.96	0.89
2.00	3.24	2.83	2.33	2.04	1.92	1.64	1.50	1.45	1.34	1.30	1.18	1.10	1.06	1.05	0.96	0.92	0.84	0.80	0.76	0.71
1.50	2.47	2.20	1.79	1.57	1.49	1.28	1.12	1.12	1.02	1.01	0.90	0.84	0.81	0.82	0.72	0.69	0.62	0.59	0.57	0.53
1.00	1.72	1.56	1.24	1.06	0.98	0.88	0.76	0.76	0.70	0.66	0.59	0.56	0.54	0.56	0.49	0.46	0.42	0.38	0.37	0.34
0.50	0.92	0.83	0.70	0.54	0.50	0.43	0.37	0.39	0.32	0.33	0.30	0.28	0.28	0.27	0.23	0.22	0.20	0.18	0.18	0.17

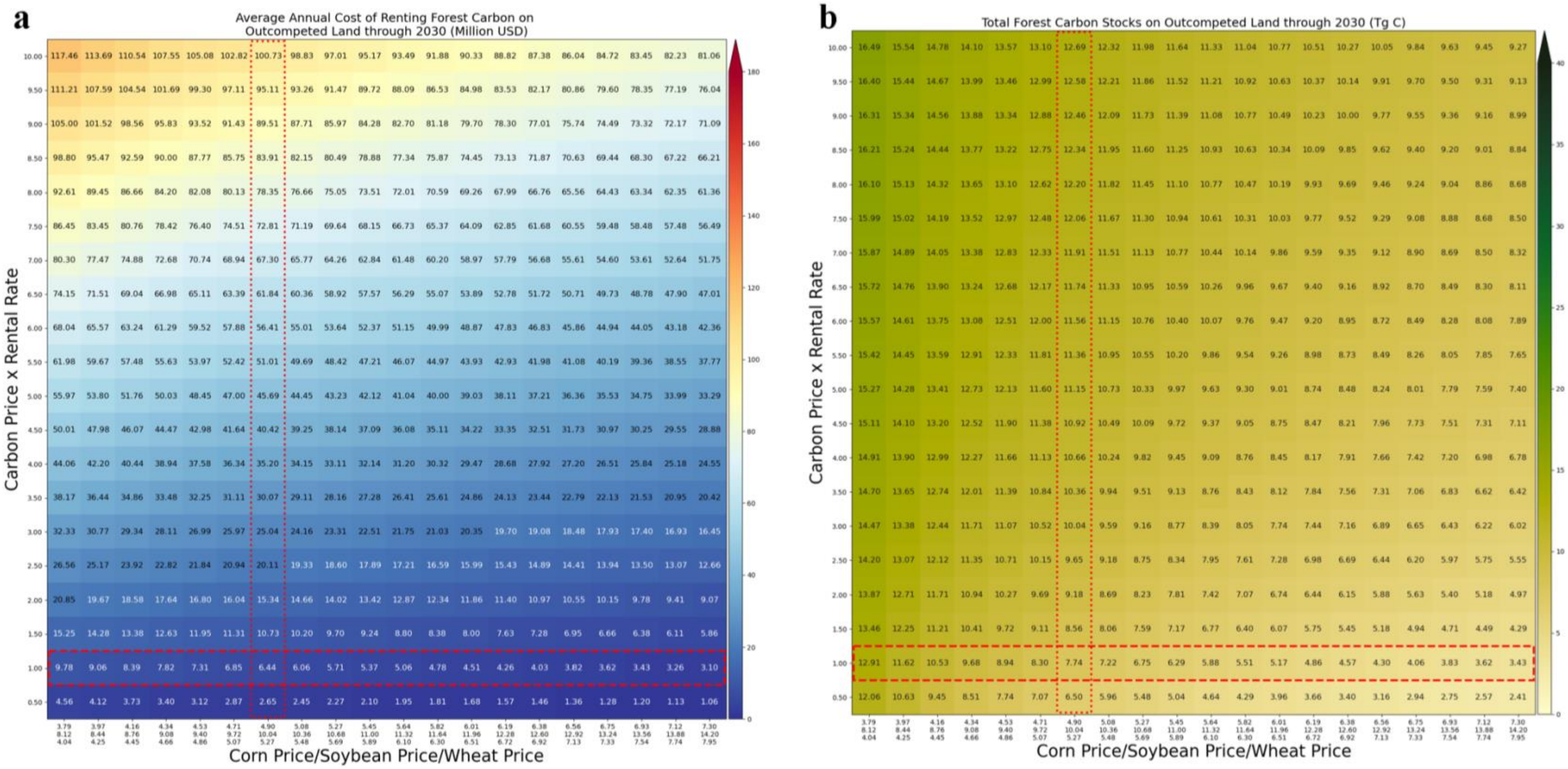
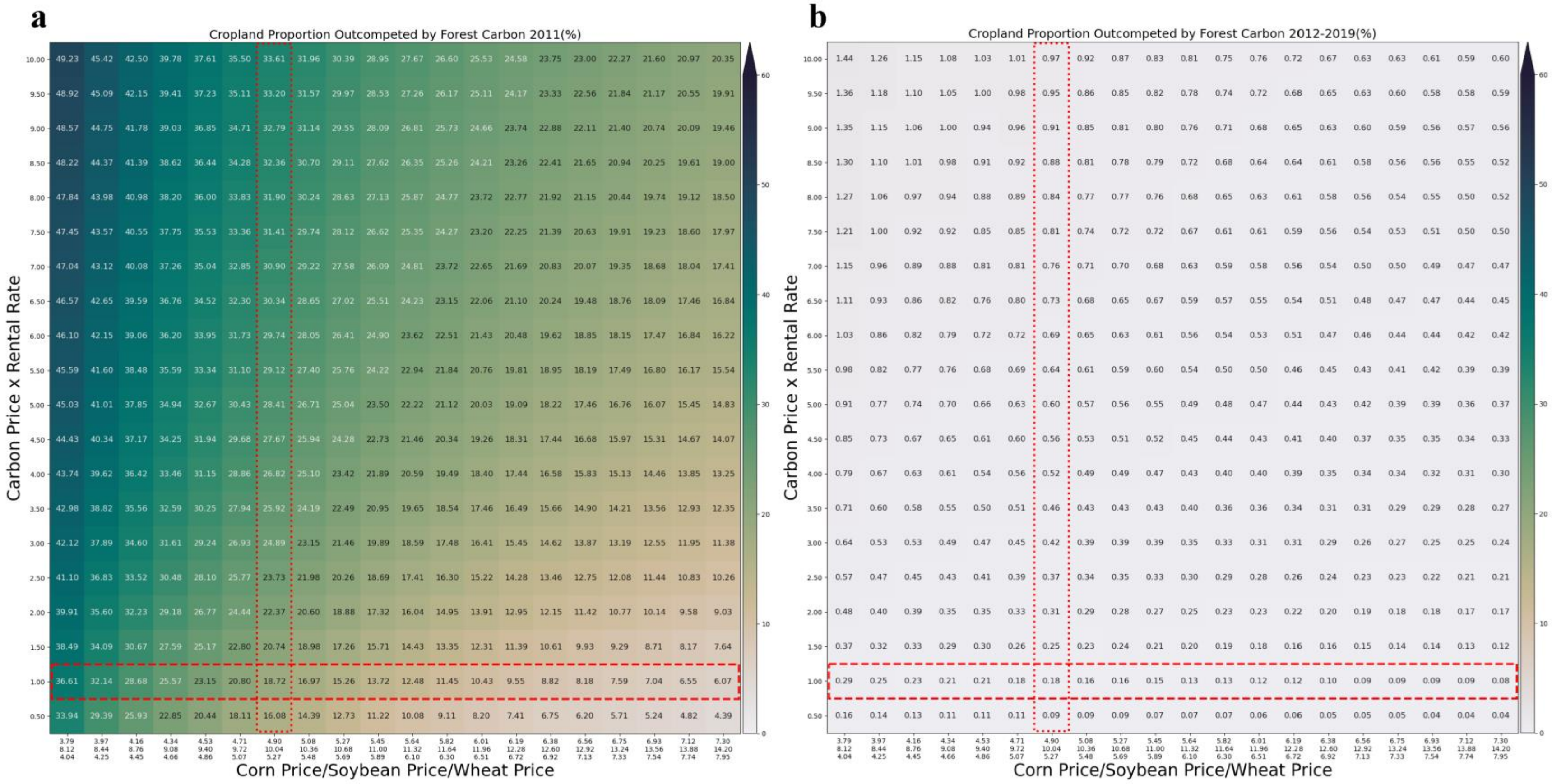


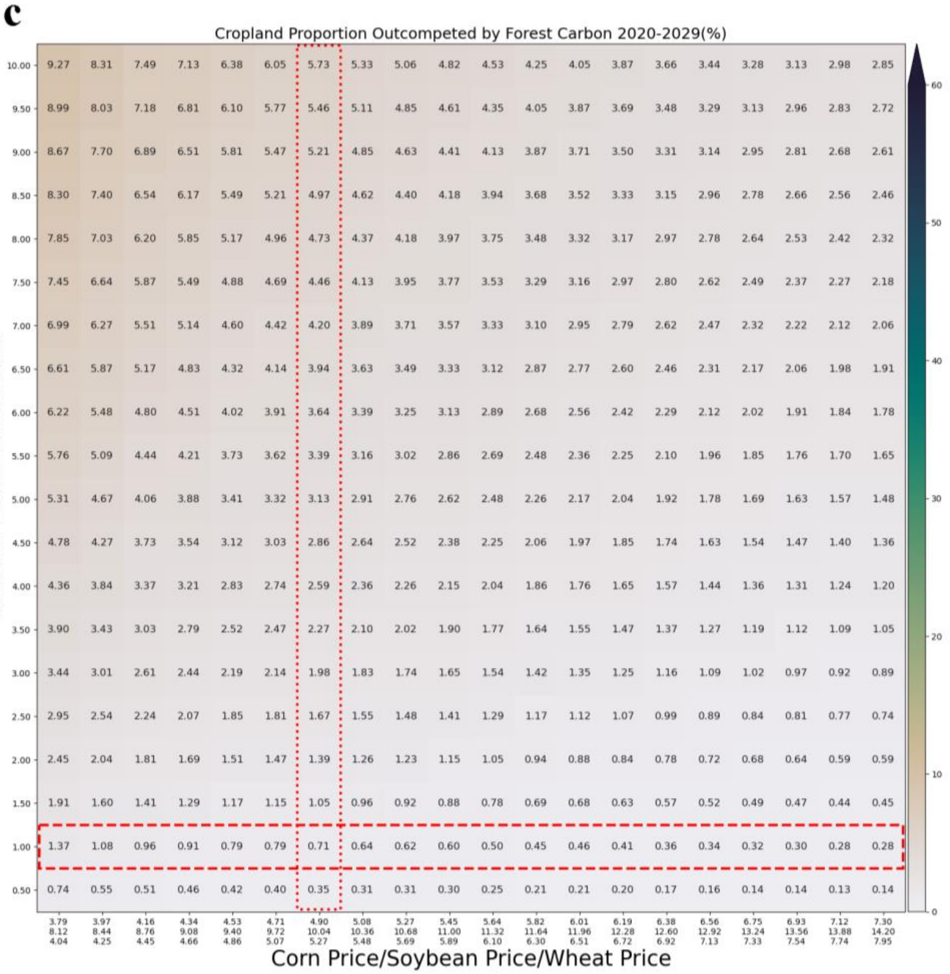
Figure B-11: Average annual rental payments for all lands outcompeted by 2030 assuming zero subsides (a) and the corresponding amount of forest carbon accumulated on such lands in Tg C, including the ongoing growth of existing trees and regrowth from new plantings (b). Where both red boxes intersect is the baseline economic scenario. The vertical dotted box highlights the impact of maintaining the baseline crop pricing scenario but changing the carbon rental scenario. The horizontal dashed box highlights the impact of maintaining the carbon pricing scenario under changing crop pricing scenarios.



continued

Figure B-12: Proportion of Maryland cropland area outcompeted by forest carbon revenue immediately in 2011 (a) and additionally between 2012-2019 (b) and 2020-2029 (c) under a range of economic scenarios with double subsidies. Where both red boxes intersect is the baseline economic scenario. The vertical dotted box highlights the impact of maintaining the baseline crop pricing scenario but changing the carbon rental scenario. The horizontal dashed box highlights the impact of maintaining the carbon pricing scenario under changing crop pricing scenario

Figure B-12 continued



Carbon Price x Rental Rate	3.79 8.12 4.04	3.97 8.44 4.25	4.16 8.76 4.45	4.34 9.08 4.66	4.53 9.40 4.86	4.71 9.72 5.07	4.90 10.04 5.27	5.08 10.36 5.48	5.27 10.68 5.69	5.45 11.00 5.89	5.64 11.32 6.10	5.82 11.64 6.30	6.01 11.96 6.51	6.19 12.28 6.72	6.38 12.60 6.92	6.56 12.92 7.13	6.75 13.24 7.33	6.93 13.56 7.54	7.12 13.88 7.74	7.30 14.20 7.95
10.00	9.27	8.31	7.49	7.13	6.38	6.05	5.73	5.33	5.06	4.82	4.53	4.25	4.05	3.87	3.66	3.44	3.28	3.13	2.98	2.85
9.50	8.99	8.03	7.18	6.81	6.10	5.77	5.46	5.11	4.85	4.61	4.35	4.05	3.87	3.69	3.48	3.29	3.13	2.96	2.83	2.72
9.00	8.67	7.70	6.89	6.51	5.81	5.47	5.21	4.85	4.63	4.41	4.13	3.87	3.71	3.50	3.31	3.14	2.95	2.81	2.68	2.61
8.50	8.30	7.40	6.54	6.17	5.49	5.21	4.97	4.62	4.40	4.18	3.94	3.68	3.52	3.33	3.15	2.96	2.78	2.66	2.56	2.46
8.00	7.85	7.03	6.20	5.85	5.17	4.96	4.73	4.37	4.18	3.97	3.75	3.48	3.32	3.17	2.97	2.78	2.64	2.53	2.42	2.32
7.50	7.45	6.64	5.87	5.49	4.88	4.69	4.46	4.13	3.95	3.77	3.53	3.29	3.16	2.97	2.80	2.62	2.49	2.37	2.27	2.18
7.00	6.99	6.27	5.51	5.14	4.60	4.42	4.20	3.89	3.71	3.57	3.33	3.10	2.95	2.79	2.62	2.47	2.32	2.22	2.12	2.06
6.50	6.61	5.87	5.17	4.83	4.32	4.14	3.94	3.63	3.49	3.33	3.12	2.87	2.77	2.60	2.46	2.31	2.17	2.06	1.98	1.91
6.00	6.22	5.48	4.80	4.51	4.02	3.91	3.64	3.39	3.25	3.13	2.89	2.68	2.56	2.42	2.29	2.12	2.02	1.91	1.84	1.78
5.50	5.76	5.09	4.44	4.21	3.73	3.62	3.39	3.16	3.02	2.86	2.69	2.48	2.36	2.25	2.10	1.96	1.85	1.76	1.70	1.65
5.00	5.31	4.67	4.06	3.88	3.41	3.32	3.13	2.91	2.76	2.62	2.48	2.26	2.17	2.04	1.92	1.78	1.69	1.63	1.57	1.48
4.50	4.78	4.27	3.73	3.54	3.12	3.03	2.86	2.64	2.52	2.38	2.25	2.06	1.97	1.85	1.74	1.63	1.54	1.47	1.40	1.36
4.00	4.36	3.84	3.37	3.21	2.83	2.74	2.59	2.36	2.26	2.15	2.04	1.86	1.76	1.65	1.57	1.44	1.36	1.31	1.24	1.20
3.50	3.90	3.43	3.03	2.79	2.52	2.47	2.27	2.10	2.02	1.90	1.77	1.64	1.55	1.47	1.37	1.27	1.19	1.12	1.09	1.05
3.00	3.44	3.01	2.61	2.44	2.19	2.14	1.98	1.83	1.74	1.65	1.54	1.42	1.35	1.25	1.16	1.09	1.02	0.97	0.92	0.89
2.50	2.95	2.54	2.24	2.07	1.85	1.81	1.67	1.55	1.48	1.41	1.29	1.17	1.12	1.07	0.99	0.89	0.84	0.81	0.77	0.74
2.00	2.45	2.04	1.81	1.69	1.51	1.47	1.39	1.26	1.23	1.15	1.05	0.94	0.88	0.84	0.78	0.72	0.68	0.64	0.59	0.59
1.50	1.91	1.60	1.41	1.29	1.17	1.15	1.05	0.96	0.92	0.88	0.78	0.69	0.68	0.63	0.57	0.52	0.49	0.47	0.44	0.45
1.00	1.37	1.08	0.96	0.91	0.79	0.79	0.71	0.64	0.62	0.60	0.50	0.45	0.46	0.41	0.36	0.34	0.32	0.30	0.28	0.28
0.50	0.74	0.55	0.51	0.46	0.42	0.40	0.35	0.31	0.31	0.30	0.25	0.21	0.21	0.20	0.17	0.16	0.14	0.14	0.13	0.14

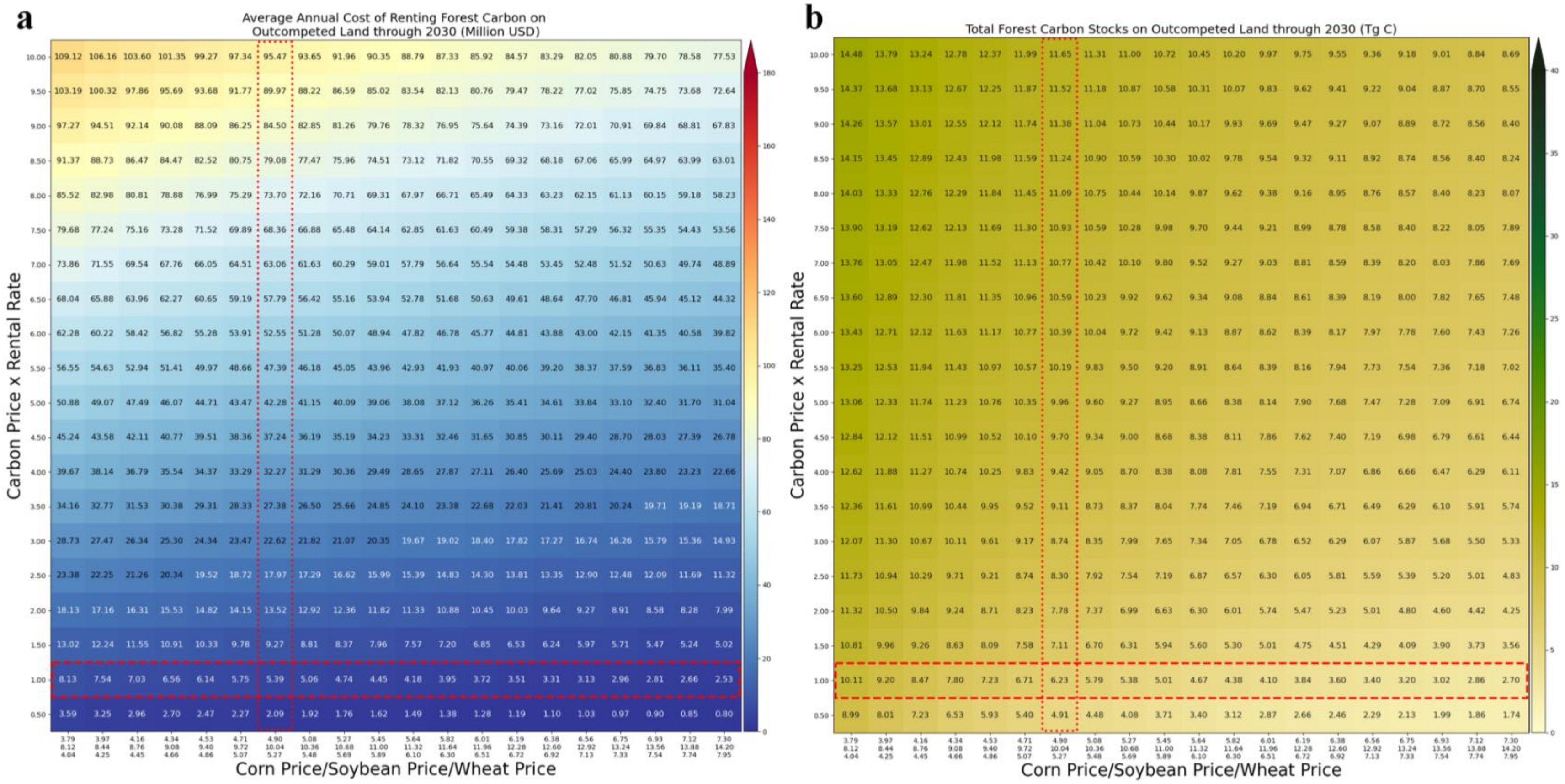


Figure B-13: Average annual rental payments for all lands outcompeted by 2030 assuming double subsides (a) and the corresponding amount of forest carbon accumulated on such lands in Tg C including the ongoing growth of existing trees and regrowth from new plantings (b). Where both red boxes intersect is the baseline economic scenario. The vertical dotted box highlights the impact of maintaining the baseline crop pricing scenario but changing the carbon rental scenario. The horizontal dashed box highlights the impact of maintaining the carbon pricing scenario under changing crop pricing scenarios.

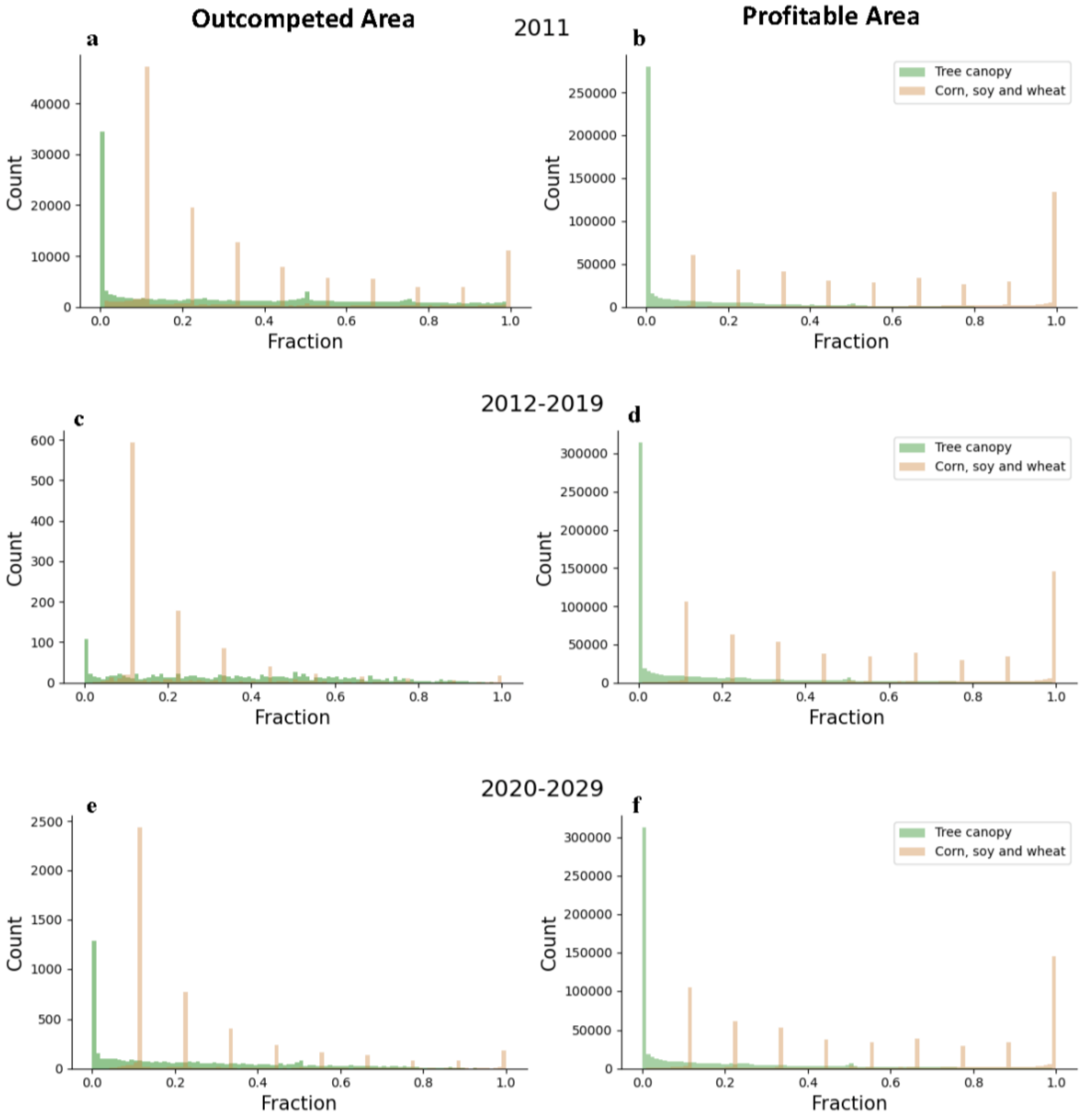


Figure B-14: Tree canopy cover and cropland fraction on both outcompeted areas (a, c, e) and areas where cropland remains profitable (b, d, f) under a twenty-year rental agreement. Panels c and e reflect areas that are newly outcompeted during each subsequent decade. Count reflects number of 90m grid cells.

Appendix C: Supplementary material for Chapter 4

Table C-1. Protected area fraction by management type at the county level

County (Cnty)	**Protected Areas (PA)(km^2)**	**Federal Mang (% of Cnty PA)**	**Local Mang (% of Cnty PA)**	**NGO Mang (% of Cnty PA)**	**State Mang (% of Cnty PA)**	**Unkwn Mang (% of Cnty PA)**
Statewide	5782.55	14.2	15.3	11.0	59.5	<1.0
Allegany	316.74	8.7	1.5	2.5	87.3	--
Anne Arundel	172.10	41.4	22.2	6.8	28.9	0.8
Baltimore	388.15	2.8	27.3	13.9	56.0	--
Baltimore City	23.81	0.8	97.7	0.4	1.1	--
Calvert	75.14	2.5	25.6	9.8	62.1	--
Caroline	214.16	1.6	1.3	10.5	86.7	--
Carroll	277.44	0.2	22.9	1.9	75.0	--
Cecil	154.97	0.5	4.0	16.2	79.2	--
Charles	232.94	11.1	14.0	17.2	57.7	<1.0
Dorchester	476.77	30.2	0.8	14.8	54.1	--
Frederick	278.39	17.0	17.7	14.8	50.5	--
Garrett	457.71	11.1	0.6	4.3	84.0	--
Harford	289.64	53.5	8.8	3.9	33.8	--
Howard	133.16	0.0	57.8	3.8	38.4	<1.0
Kent	177.22	5.5	1.5	41.5	51.6	--
Montgomery	300.47	8.1	59.6	3.8	28.5	--
Prince George’s	204.69	26.4	49.0	6.3	18.3	--
Queen Anne’s	282.74	0.4	32.4	14.9	52.3	--
Somerset	289.11	11.8	1.2	6.2	80.8	--
St. Mary’s	148.47	20.1	10.0	7.9	62.0	--
Talbot	119.32	1.7	3.5	47.2	47.6	<1.0
Washington	242.64	24.6	8.4	6.5	60.5	--
Wicomico	189.93	6.8	2.0	16.5	74.6	--
Worcester	336.83	15.4	3.0	12.2	69.5	--

Table C-2: Protected area fraction by gap status at the county level

County (Cnty)	Protected Areas (PA)(km^2)	Fraction of PA as Gap Status 1 (%)	Fraction of PA as Gap Status 2 (%)	Fraction of PA as Gap Status 3 (%)	Fraction of PA as Gap Status 4 (%)
Statewide	5782.55	0.3	12.5	42.9	44.4
Allegany	316.74	--	15.0	73.9	11.1
Anne Arundel	172.10	--	33.2	15.3	51.5
Baltimore	388.15	--	10.9	48.5	40.6
Baltimore City	23.81	--	17.9	12.0	70.1
Calvert	75.14	--	25.6	30.4	43.9
Caroline	214.16	--	4.9	21.9	73.2
Carroll	277.44	--	4.0	20.0	76.0
Cecil	154.97	<1.0	6.7	45.6	47.6
Charles	232.94	--	18.2	36.2	45.7
Dorchester	476.77	--	15.4	49.1	35.4
Frederick	278.39	--	22.7	26.0	51.3
Garrett	457.71	--	7.7	72.7	19.6
Harford	289.64	--	5.3	14.5	80.2
Howard	133.16	--	18.4	41.9	39.7
Kent	177.22	--	7.1	45.8	47.1
Montgomery	300.47	--	3.7	60.2	36.1
Prince George’s	204.69	--	37.8	28.7	33.5
Queen Anne’s	282.74	--	0.5	20.9	78.6
Somerset	289.11	5.8	14.2	58.2	21.8
St. Mary’s	148.47	--	0.5	36.2	63.3
Talbot	119.32	--	4.6	40.0	55.3
Washington	242.64	--	16.4	32.2	51.5
Wicomico	189.93	--	17.5	52.8	29.7
Worcester	336.83	--	12.1	54.4	33.6

Table C-3: Aboveground biomass (AGB) and carbon sequestration potential gap (CSPG) of protected areas (PA) at the county scale

County (Cnty)	**AGB (Tg C)**	**CSPG (Tg C)**	**PA AGB (Tg C)**	**Fraction of Cnty AGB (%)**	**PA CSPG (Tg C)**	**Fraction of Cnty CSPG (%)**
Allegany	8.07	3.22	2.78	34.5	0.46	14.3
Anne Arundel	5.61	8.71	1.00	17.9	1.21	13.9
Baltimore	8.31	13.14	2.76	33.2	2.91	22.2
Baltimore City	0.38	1.20	0.11	29.3	0.20	16.5
Calvert	4.49	4.11	0.67	14.9	0.44	10.6
Caroline	1.89	9.64	0.44	23.1	2.53	26.2
Carroll	4.57	11.87	1.11	24.4	2.63	22.2
Cecil	4.40	8.07	0.83	18.8	1.45	18.0
Charles	8.65	6.86	1.73	20.0	1.13	16.4
Dorchester	1.68	9.58	0.47	27.9	2.06	21.5
Frederick	7.88	16.18	1.88	23.9	2.13	13.1
Garrett	12.35	6.10	4.01	32.5	0.95	15.5
Harford	5.30	9.67	0.88	16.6	1.24	12.8
Howard	3.63	6.16	1.15	31.7	0.91	14.7
Kent	1.63	9.20	0.46	28.2	2.13	23.2
Montgomery	4.71	13.45	1.75	37.2	2.42	18.0
Prince George’s	6.41	9.82	1.30	20.2	1.22	12.4
Queen Anne’s	2.12	11.43	0.54	25.6	3.44	30.1
Somerset	1.36	5.05	0.47	34.8	0.89	17.6
St. Mary’s	5.27	6.13	0.78	14.9	0.99	16.2
Talbot	1.71	7.99	0.28	16.1	1.38	17.2
Washington	5.60	8.88	1.68	30.0	1.30	14.6
Wicomico	2.41	8.49	0.61	25.5	1.14	13.5
Worcester	2.16	8.79	0.61	28.1	1.22	13.9

Table C-4: Aboveground biomass (AGB) of protected areas by management type at the county scale

County (Cnty)	PA AGB (Tg C)	Fraction of Fed (%)	Fraction of Loc (%)	Fraction of State (%)	Fraction of Ngo (%)	Fraction of Unkn (%)
Allegany	2.78	7.6	1.2	89.2	2.0	--
Anne Arundel	1.00	39.6	20.9	29.0	9.4	1.23
Baltimore	2.76	1.3	36.2	50.3	12.1	--
Baltimore City	0.11	0.1	98.9	0.3	0.7	--
Calvert	0.67	0.9	31.5	56.8	10.8	--
Caroline	0.44	2.0	1.9	85.1	11.0	--
Carroll	1.11	0.1	40.7	56.9	2.3	--
Cecil	0.83	1.1	4.0	84.3	10.6	--
Charles	1.73	9.1	18.0	53.5	19.4	<1.0
Dorchester	0.47	12.6	1.3	69.8	16.3	--
Frederick	1.88	22.0	23.4	40.1	14.6	--
Garrett	4.01	8.9	0.3	87.1	3.7	--
Harford	0.88	1.5	20.4	71.6	6.5	--
Howard	1.15	--	56.4	41.1	2.6	<1.0
Kent	0.46	2.6	1.8	49.0	46.6	--
Montgomery	1.75	10.8	65.9	21.2	2.0	--
Prince George’s	1.30	22.3	48.4	19.6	9.7	--
Queen Anne’s	0.54	0.6	35.1	46.5	17.8	--
Somerset	0.47	5.5	0.8	89.6	4.0	--
St. Mary’s	0.78	13.6	14.4	63.1	8.8	--
Talbot	0.28	0.6	5.6	39.2	54.6	<1.0
Washington	1.68	27.8	7.7	60.9	3.6	--
Wicomico	0.61	3.5	2.4	81.4	12.7	--
Worcester	0.61	4.3	2.7	79.4	13.7	--

Table C-5: Carbon sequestration potential gap (CSPG) of protected areas by management type at the county scale

County (Cnty)	**PA CSPG (Tg C)**	**Fraction of Fed (%)**	**Fraction of Loc (%)**	**Fraction of State (%)**	**Fraction of Ngo (%)**	**Fraction of Unkn (%)**
Allegany	0.46	13.6	3.0	78.0	5.4	--
Anne Arundel	1.21	38.2	22.2	33.6	5.3	0.7
Baltimore	2.91	1.6	18.0	61.2	19.1	--
Baltimore City	0.20	1.0	97.9	0.5	0.5	--
Calvert	0.44	4.3	20.8	65.6	9.3	--
Caroline	2.53	1.4	0.9	89.4	8.3	--
Carroll	2.63	0.2	17.5	80.4	1.9	--
Cecil	1.45	0.2	3.3	76.5	20.1	--
Charles	1.13	10.3	11.6	60.2	17.9	<1.0
Dorchester	2.06	18.8	1.9	57.0	22.3	--
Frederick	2.13	10.6	14.0	60.0	15.4	--
Garrett	0.95	15.7	1.2	75.9	7.2	--
Harford	1.24	1.1	16.9	73.3	8.8	--
Howard	0.91	--	55.6	38.3	6.0	<1.0
Kent	2.13	3.5	1.4	55.2	39.9	--
Montgomery	2.42	4.3	57.8	32.6	5.3	--
Prince George’s	1.22	28.3	48.0	17.4	6.3	--
Queen Anne’s	3.44	0.2	32.1	55.2	12.5	--
Somerset	0.89	5.6	3.4	83.8	7.2	--
St. Mary’s	0.99	26.5	6.8	59.2	7.5	--
Talbot	1.38	2.1	3.5	52.5	41.8	<1.0
Washington	1.30	18.5	8.4	63.8	9.3	--
Wicomico	1.14	5.7	2.4	79.1	12.8	--

Table C-6: Aboveground biomass (AGB) of protected areas by gap status at the county scale

County (Cnty)	PA AGB (Tg C)	Fraction of Gap 1 (%)	Fraction of Gap 2 (%)	Fraction of Gap 3 (%)	Fraction of Gap 4 (%)
Allegany	2.78	--	16.0	75.3	8.6
Anne Arundel	1.00	--	39.4	16.9	43.6
Baltimore	2.76	--	12.4	61.9	25.7
Baltimore City	0.11	--	36.5	12.8	50.7
Calvert	0.67	--	33.7	34.8	31.5
Caroline	0.44	--	5.5	39.8	54.6
Carroll	1.11	--	10.1	42.6	47.3
Cecil	0.83	<1.0	14.2	55.0	30.8
Charles	1.73	--	16.4	43.2	40.4
Dorchester	0.47	--	6.8	60.9	32.3
Frederick	1.88	--	39.0	25.9	35.1
Garrett	4.01	--	7.3	79.2	13.5
Harford	0.88	--	17.7	38.9	43.4
Howard	1.15	--	25.2	47.3	27.5
Kent	0.46	--	5.6	66.1	28.3
Montgomery	1.75	--	5.5	64.4	30.2
Prince George’s	1.30	--	36.7	36.5	26.8
Queen Anne’s	0.54	--	1.0	22.8	76.2
Somerset	0.47	--	6.0	60.7	33.3
St. Mary’s	0.78	--	0.1	46.8	53.1
Talbot	0.28	--	8.3	45.7	46.0
Washington	1.68	--	26.7	33.2	40.1
Wicomico	0.61	--	10.1	64.9	25.0
Worcester	0.61	--	13.7	65.0	21.2

Table C-7: Carbon sequestration potential gap (CSPG) of protected areas by gap status at the county scale

County (Cnty)	PA CSPG (Tg C)	Fraction of Gap 1 (%)	Fraction of Gap 2 (%)	Fraction of Gap 3 (%)	Fraction of Gap 4 (%)
Allegany	0.46	--	18.4	58.5	23.1
Anne Arundel	1.21	--	21.1	13.2	65.7
Baltimore	2.91	--	5.6	40.7	53.7
Baltimore City	0.20	--	14.5	13.7	71.8
Calvert	0.44	--	13.4	26.1	60.5
Caroline	2.53	--	2.2	15.3	82.5
Carroll	2.63	--	2.7	12.3	84.9
Cecil	1.45	<1.0	2.3	39.8	57.8
Charles	1.13	--	10.3	32.6	57.1
Dorchester	2.06	--	4.7	38.5	56.8
Frederick	2.13	--	12.0	25.8	62.2
Garrett	0.95	--	8.6	50.2	41.3
Harford	1.24	--	7.3	23.2	69.5
Howard	0.91	--	11.9	35.8	52.3
Kent	2.13	--	4.7	38.7	56.7
Montgomery	2.42	--	2.5	56.0	41.5
Prince George’s	1.22	--	30.9	24.0	45.2
Queen Anne’s	3.44	--	0.2	17.6	82.2
Somerset	0.89	--	6.7	41.5	51.8
St. Mary’s	0.99	--	0.2	30.5	69.3
Talbot	1.38	--	0.8	37.6	61.5
Washington	1.30	--	6.6	26.5	66.9
Wicomico	1.14	--	10.4	44.2	45.4
Worcester	1.22	--	4.8	42.4	52.8

Table C-8: BioNet area in Maryland, further divided by tier of significance for biodiversity protection

Layer	Size (km2)	Land Area Fraction (%)	AGB (Tg C)	CSPG (Tg C)	Tree Canopy Fraction (%)[a]	Avg AGB Density (Mg C /ha)[a]
Statewide		% of state	(% of state)	(% of state)		
State of Maryland	25255.77	--	110.79	204.11	49.5	51.83
BioNet Area (BN-MD)	14109.60	55.9	91.93 (83.0)	66.91 (32.8)	72.0	85.87
Tier of Significance[b]		% of BN-MD	(% of BN-MD)	(% of BN-MD)		
Tier 1	1280.50	9.1	6.69 (7.3)	4.88 (7.3)	69.6	83.59
Tier 2	1135.85	8.1	5.28 (5.7)	4.71 (7.0)	65.0	79.05
Tier 3	3723.53	26.4	24.42 (26.6)	13.84 (20.7)	76.7	88.38
Tier 4	3934.42	27.9	26.40 (28.7)	21.16 (31.6)	68.4	82.99
Tier 5	4035.31	28.6	29.15 (31.7)	22.33 (33.4)	73.9	88.48

[a] based on contemporary metrics (circa 2011); due to the marshland/impervious surface mask, some of this land area does not have AGB/CSPG estimates

[b] Tier 1 areas are considered critically significant for biodiversity; Tier 2 areas are extremely significant; Tier 3 areas are highly significant; Tier 4 areas are moderately significant; and Tier 5 areas are significant.

Table C-9: Maryland BioNet area and relative tier fraction at the county scale

County (Cnty)	**BioNet area (BN) (km^2)**	**Tier 1 (% of Cnty BN)**	**Tier 2 (% of Cnty BN)**	**Tier 3 (% of Cnty BN)**	**Tier 4 (% of Cnty BN)**	**Tier 5 (% of Cnty BN)**
Statewide	14109.60	9.1	8.1	26.4	27.9	28.6
Allegany	930.67	8.5	3.1	44.3	35.4	8.7
Anne Arundel	546.10	8.1	1.7	9.6	27.0	53.5
Baltimore	704.78	2.1	9.8	12.3	27.1	48.8
Baltimore City	16.44	0.0	0.0	0.1	34.0	65.9
Calvert	403.09	8.0	2.7	3.0	58.5	27.8
Caroline	347.28	18.5	13.1	28.1	23.7	16.7
Carroll	551.11	6.1	8.2	22.9	20.1	42.8
Cecil	474.11	4.6	8.2	19.0	14.7	53.5
Charles	945.44	10.0	4.5	34.8	42.6	8.1
Dorchester	834.76	6.9	30.5	44.1	9.8	8.7
Frederick	787.91	1.6	11.1	46.3	8.9	32.1
Garrett	1399.36	11.5	6.2	34.9	33.8	13.6
Harford	628.62	13.7	9.2	5.5	25.5	46.1
Howard	237.14	1.5	2.4	9.6	20.5	65.9
Kent	207.76	4.1	12.3	14.5	4.7	64.5
Montgomery	508.81	6.1	2.9	26.5	16.1	48.4
Prince George’s	619.43	11.4	4.8	6.6	40.6	36.6
Queen Anne’s	329.83	16.6	12.7	13.1	15.9	41.7
Somerset	502.40	4.9	1.5	25.7	37.4	30.5
St. Mary’s	622.21	6.8	1.9	12.5	51.9	26.9
Talbot	218.51	2.6	6.1	15.9	30.5	44.9
Washington	510.47	9.6	7.9	40.4	16.4	25.8
Wicomico	524.22	4.1	11.6	40.1	16.6	27.6
Worcester	884.34	16.7	5.7	28.0	34.2	15.4

Table C-10: Statewide overlap between designated protected areas and identified BioNet area

Layer	**Size (km2)**	**Land Area Fraction(%)**	**AGB (Tg C)**	**CSPG (Tg C)**
Statewide		% of state	(% of state)	(% of state)
State of Maryland	25255.77	--	110.79	204.11
Protected Areas (PAD-MD)	5782.55	22.3	28.32 (25.6)	36.37 (17.8)
BioNet Area (BN-MD)	14109.60	55.9	91.91 (83.0)	66.91 (32.8)
Intersections		%	(%)	(%)
BN-MD inside PAD-MD (BN-PA-IN)	3980.40	68.8 of PAD-MD	26.18 (92.5 of PAD-MD)	14.65 (40.3 of PAD-MD)
BN-MD outside PAD-MD (BN-PA-OUT)	10129.20	71.8 of BN-MD	65.80 (71.5 of BN-MD)	52.26 (78.1 of BN-MD)
BN-PA-IN by Tier[a]		*% of PAD-MD*	*(% of PAD-MD-IN)*	*(% of PAD-MD-IN)*
Tier 1	556.98	9.6	3.45 (12.2)	1.67 (4.6)
Tier 2	436.19	7.5	2.31 (8.2)	1.39 (3.8)
Tier 3	1502.30	26.0	10.65 (37.6)	4.45 (12.2)
Tier 4	784.54	13.6	4.78 (16.9)	3.63 (10.0)
Tier 5	700.40	12.1	5.00 (17.6)	3.52 (9.7)
BN-PA-OUT by Tier[a]		*% of BN-MD-OUT (% of Tier)*	*(% of BN-MD-OUT)*	*(% BN-MD-OUT)*
Tier 1	723.52	5.1 (56.5)	3.23 (4.9)	3.21 (6.1)
Tier 2	699.65	5.0 (61.6)	2.97 (4.5)	3.33 (6.4)
Tier 3	2221.23	15.7 (59.7)	13.77 (20.9)	9.39 (18.0)
Tier 4	3149.89	22.3 (80.0)	21.62 (32.9)	17.53 (33.5)
Tier 5	3334.92	23.6 (82.6)	24.16 (36.7)	18.81 (36.0)

[a] Tier 1 areas are considered critically significant for biodiversity; Tier 2 areas are extremely significant; Tier 3 areas are highly significant; Tier 4 areas are moderately significant; and Tier 5 areas are significant

Table C-11: Portion of protected areas that include BioNet area, and the relative fraction of county-level BioNet tier included in this area of overlap

County (Cnty)	**Overlap area (km2)**	**Fraction of Cnty Tier 1 in PA (%)**	**Fraction of Cnty Tier 2 in PA (%)**	**Fraction of Cnty Tier 3 in PA (%)**	**Fraction of Cnty Tier 4 in PA (%)**	**Fraction of Cnty Tier 5 in PA (%)**
Statewide	3980.40	43.5	38.4	40.3	20.0	17.4
Allegany	301.65	69.2	43.5	51.2	6.4	2.9
Anne Arundel	119.85	68.8	23.2	34.4	21.1	13.0
Baltimore	260.73	70.1	67.5	62.3	37.8	22.7
Baltimore City	7.89	--	--	0.0	69.0	37.2
Calvert	61.62	46.9	41.4	49.3	11.7	7.7
Caroline	94.77	34.2	31.6	30.2	19.3	22.8
Carroll	150.43	23.0	18.5	48.4	21.7	20.9
Cecil	86.54	33.2	28.4	34.4	3.6	13.7
Charles	200.08	36.1	54.4	20.8	15.9	13.9
Dorchester	366.58	60.9	48.0	51.2	16.4	10.5
Frederick	175.47	85.6	34.1	29.1	13.0	7.7
Garrett	411.91	57.3	42.9	43.0	13.1	5.4
Harford	183.55	25.5	21.2	33.9	45.9	22.1
Howard	85.89	63.9	73.4	74.9	45.5	25.7
Kent	62.49	34.0	57.3	40.2	27.7	22.5
Montgomery	219.51	69.1	55.6	53.8	40.4	34.2
Prince George’s	145.31	47.3	34.6	34.7	18.1	18.5
Queen Anne’s	98.54	31.1	32.1	32.8	32.6	26.8
Somerset	192.66	28.4	43.6	51.9	40.4	25.8
St. Mary’s	95.47	3.2	56.1	22.3	13.7	15.4
Talbot	41.25	63.1	21.5	22.2	20.2	13.9
Washington	157.21	38.3	31.1	45.7	24.2	8.8
Wicomico	147.70	67.8	25.1	41.8	15.2	11.6
Worcester	313.28	63.0	40.4	41.8	25.4	14.2

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Table C-12: The increased connectivity provided by 225m buffers across the state, where the connectivity increase is the fraction of all protected area units in the county that are newly connected due to overlapping buffer areas

County	**Protected Area Units**	**PA Units after Buffer**	**Connectivity Increase (%)**
Statewide	9895[1]	2504	75
Allegany	85	43	49
Anne Arundel	428	183	57
Baltimore	1009	206	80
Baltimore City	452	48	89
Calvert	449	112	75
Caroline	125	53	58
Carroll	708	166	77
Cecil	183	101	45
Charles	784	184	77
Dorchester	240	79	67
Frederick	476	190	60
Garrett	89	47	47
Harford	434	166	62
Howard	1124	60	95
Kent	126	63	50
Montgomery	1263	102	92
Prince George’s	558	188	66
Queen Anne’s	211	85	60
Somerset	199	64	68
St. Mary’s	195	107	45
Talbot	123	76	38
Washington	229	99	57
Wicomico	191	87	54
Worcester	343	136	60

Table C-13: Comparison of BioNet area newly protected by tier of significance for biodiversity protection under both reforestation scenarios

Layer	**Land Area Fraction (%)**	**Fraction of Tier 1 area (%)**[a]	**Fraction of Tier 2 area (%)**[a]	**Fraction of Tier 3 area (%)**[a]	**Fraction of Tier 4 area (%)**[a]	**Fraction of Tier 5 area (%)**[a]
Existing Protected Areas	22.9	43.5	38.4	40.3	19.9	17.4
Reforestation Scenarios	*(total %)*[b]	*(total %)*[b]	*(total %)*[b]	*(total %)*[b]	*(total %)*[b]	*(total %)*[b]
Optimized Corridors	22.3	20.4	16.8	15.7	20.6	21.8
(Corr-MD) – 1km	(45.2)	(63.9)	(55.2)	(56.0)	(40.5)	(39.1)
Protected Area Buffers	22.1	18.4	18.4	19.7	19.9	22.7
(Buff-MD) – 225m	(45.0)	(61.9)	(56.8)	(60.0)	(39.8)	(40.1)

Table C-14: Total area and county area fraction of optimized corridors and protected area buffers. Area overlap between scenario land area is recorded as a fraction of each respective scenario

County (Cnty)	**Area (km^2)**	**Corridor Area (km^2)**	**Frac of Cnty (%)**	**Buffer Area (km^2)**	**Frac of Cnty (%)**	**Scenario overlap (% Corr)**	**Scenario overlap (% Buff)**
Statewide	25255.77	5625.26	22.3	5588.27	22.1	33.4	33.6
Allegany	1098.77	171.24	15.6	120.94	11.0	12.8	18.0
Anne Arundel	1071.40	259.05	24.2	197.65	18.4	26.6	34.8
Baltimore	1552.41	355.80	22.9	486.58	31.3	40.1	29.4
Baltimore City	210.41	65.63	31.2	86.35	41.0	58.9	44.8
Calvert	554.83	183.49	33.1	152.11	27.4	42.6	51.3
Caroline	829.04	186.35	22.5	177.19	21.4	28.4	29.9
Carroll	1164.38	435.20	37.4	385.62	33.1	42.2	47.7
Cecil	902.61	207.66	23.0	124.45	13.8	21.9	36.6
Charles	1191.92	365.75	30.7	315.09	26.4	39.6	45.9
Dorchester	1403.97	142.44	10.1	214.70	15.3	22.6	15.0
Frederick	1716.24	463.03	27.0	301.04	17.5	26.7	41.1
Garrett	1704.20	192.76	11.3	248.82	14.6	19.4	15.0
Harford	1134.18	311.62	27.5	229.31	20.2	33.0	44.8
Howard	652.20	233.06	35.7	324.28	49.7	61.4	44.2
Kent	725.34	161.85	22.3	127.40	17.6	25.6	32.6
Montgomery	1286.86	421.63	32.8	518.08	40.3	54.7	44.6
Prince George’s	1255.67	310.13	24.7	293.53	23.4	35.4	37.4
Queen Anne’s	962.64	154.60	16.1	241.83	25.1	29.1	18.6
Somerset	829.74	81.12	9.8	174.48	21.0	27.0	12.6
St. Mary’s	931.50	167.44	18.0	139.43	15.0	22.6	27.2
Talbot	697.43	159.58	22.9	112.16	16.1	21.3	30.3
Washington	1186.48	292.64	24.7	215.88	18.2	22.9	31.0
Wicomico	972.65	142.65	14.7	174.87	18.0	22.7	18.5
Worcester	1220.91	153.62	12.6	226.49	18.6	25.5	17.3

Table C-15: AGB and tree cover (TC) fraction of optimized corridors and protected area buffers. Overlap between scenario AGB is recorded as a fraction of each respective scenario

County (Cnty)	TC (%)	AGB (Tg C)	Corridor TC (%)	Corridor AGB (Tg C)	Frac of Cnty AGB (%)	Buffer TC (%)	Buffer AGB (Tg C)	Frac of Cnty AGB (%)	Scenario overlap (% Corr)	Scenario overlap (% Buff)
Allegany	79.1	8.07	74.2	1.17	14.5	73.5	0.81	10.1	11.4	16.4
Anne Arundel	58.6	5.61	54.5	1.42	25.3	59.1	1.01	18.0	26.6	37.4
Baltimore	48.8	8.31	46.5	1.89	22.8	48.8	2.55	30.6	40.2	29.9
Baltimore City	27.0	0.38	25.3	0.11	28.2	25.0	0.14	35.6	51.2	40.5
Calvert	63.1	4.49	61.1	1.54	34.3	60.7	1.19	26.5	40.8	52.9
Caroline	34.8	1.89	24.3	0.41	21.5	38.7	0.45	23.8	30.8	27.8
Carroll	35.6	4.57	31.4	1.49	32.7	36.1	1.51	33.1	44.0	43.4
Cecil	44.9	4.40	37.9	0.87	19.8	45.0	0.60	13.6	23.6	34.4
Charles	69.1	8.65	65.0	2.91	33.6	66.6	2.22	25.7	37.7	49.3
Dorchester	38.1	1.68	25.6	0.25	14.8	45.4	0.30	17.8	26.5	22.0
Frederick	42.2	7.88	37.3	1.87	23.7	41.9	1.35	17.1	26.3	36.5
Garrett	72.1	12.35	65.7	1.27	10.3	73.8	1.83	14.8	19.1	13.2
Harford	40.9	5.30	43.3	1.56	29.4	48.9	1.28	24.2	35.2	42.7
Howard	50.4	3.63	46.9	1.22	33.6	48.4	1.64	45.2	56.3	41.8
Kent	29.0	1.63	19.0	0.31	18.7	34.3	0.35	21.2	29.7	26.2
Montgomery	49.2	4.71	46.3	1.44	30.6	45.3	1.66	35.2	49.8	43.4
Prince George’s	51.7	6.41	48.5	1.53	23.9	48.9	1.35	21.0	33.1	37.6
Queen Anne’s	31.6	2.12	25.1	0.36	17.0	36.3	0.65	30.6	33.7	18.7
Somerset	42.0	1.36	33.6	0.20	14.7	49.8	0.35	25.9	27.5	15.6
St. Mary’s	61.5	5.27	60.4	1.25	23.7	62.7	0.79	14.9	22.2	35.2
Talbot	33.7	1.71	25.2	0.40	23.1	38.3	0.33	19.1	26.0	31.5
Washington	48.3	5.60	44.6	1.27	22.7	53.6	1.17	21.0	24.0	26.1
Wicomico	47.8	2.41	32.9	0.37	15.4	53.2	0.45	18.9	24.8	20.3
Worcester	52.3	2.16	29.1	0.36	16.5	53.8	0.41	19.0	24.7	21.5

Table C-16: Carbon sequestration potential gap (CSPG) and impervious surface (IM) fraction of optimized corridors and protected area buffers. Overlap between scenario CSPG is recorded as a fraction of each respective scenario

County (Cnty)	IM (%)	CSPG (Tg C)	Corr IM (%)	Corridor CSPG (Tg C)	Frac of Cnty CSPG (%)	Buffer IM (%)	Buffer CSPG (Tg C)	Frac of Cnty CSPG (%)	Scenario overlap (% Corr)	Scenario overlap (% Buff)
Allegany	2.1	3.22	3.3	0.62	19.3	4.0	0.40	12.3	14.0	21.9
Anne Arundel	12.9	8.71	13.0	2.46	28.2	12.4	1.63	18.7	26.3	39.6
Baltimore	9.1	13.14	5.7	3.53	26.9	9.4	4.26	32.4	39.6	32.9
Baltimore City	46.4	1.20	49.4	0.36	30.0	50.4	0.45	37.1	53.7	43.4
Calvert	2.9	4.11	3.2	1.53	37.2	3.6	1.20	29.3	44.3	56.3
Caroline	1.4	9.64	1.6	2.59	26.8	1.6	1.95	20.2	27.6	36.6
Carroll	2.4	11.87	2.9	4.74	40.0	3.3	3.87	32.6	41.6	51.0
Cecil	3.0	8.07	3.6	2.09	25.9	3.0	1.11	13.8	20.8	39.2
Charles	3.2	6.86	3.1	2.54	37.0	3.9	1.87	27.3	40.3	54.6
Dorchester	2.1	9.58	2.8	1.95	20.3	2.2	1.46	15.3	21.6	28.6
Frederick	3.4	16.18	4.0	4.72	29.1	5.5	2.77	17.1	25.9	44.0
Garrett	0.6	6.10	0.6	0.87	14.3	0.8	0.88	14.4	19.5	19.4
Harford	4.6	9.67	4.9	3.31	34.2	5.1	2.21	22.9	31.9	47.7
Howard	8.8	6.16	8.2	2.37	38.4	11.7	3.14	50.9	62.8	47.4
Kent	0.9	9.20	1.2	2.42	26.2	1.3	1.51	16.4	25.0	40.0
Montgomery	10.1	13.45	10.2	4.73	35.2	11.6	5.76	42.8	56.1	46.0
Prince George’s	14.7	9.82	16.5	2.69	27.4	18.2	2.35	23.9	35.5	40.6
Queen Anne’s	1.8	11.43	1.8	2.07	18.1	2.4	2.71	23.7	27.7	21.2
Somerset	1.8	5.05	2.5	1.04	20.5	1.6	1.23	24.3	26.6	22.5
St. Mary’s	3.3	6.13	2.5	1.40	22.9	3.5	0.88	14.3	22.9	36.6
Talbot	2.4	7.99	2.9	2.20	27.5	2.1	1.24	15.6	20.5	36.2
Washington	4.0	8.88	4.6	2.35	26.4	5.1	1.43	16.1	21.3	34.9
Wicomico	4.4	8.49	5.3	1.78	21.0	2.9	1.42	16.8	22.0	27.5
Worcester	3.9	8.79	3.5	2.06	23.4	4.3	1.66	18.9	25.4	31.5

Table C-17: The carbon sequestration potential time gap (CSPTG) of both corridors and buffers across the state

County	**CSPTG - Corridors (years)**	**CSPTG – Buffers (year)**
Statewide	298	294
Allegany	140	132
Anne Arundel	221	219
Baltimore	233	219
Baltimore City	158	155
Calvert	172	174
Caroline	319	302
Carroll	275	260
Cecil	252	236
Charles	168	165
Dorchester	322	307
Frederick	257	240
Garrett	152	124
Harford	245	227
Howard	235	230
Kent	320	295
Montgomery	278	278
Prince George’s	216	212
Queen Anne’s	310	293
Somerset	311	296
St. Mary’s	191	190
Talbot	306	289
Washington	235	202
Wicomico	301	293
Worcester	308	291

Table C-18: Average aboveground biomass (AGB) density of protected areas (PA) and the time in years to achieve a similar average AGB density across optimized corridors and protected area buffers at the county level. Where the AGB density time gap is zero, contemporary AGB densities are as high or higher than that of the protected areas

County	**Avg PA AGB Density (Mg C / ha)**	**Time to Achieve Avg PA AGB Density - Corridors (years)**	**Time to Achieve Avg PA AGB Density – Buffers (year)**
Statewide	65.73	28	24
Allegany	66.23	0	0
Anne Arundel	64.53	15	12
Baltimore	62.82	16	14
Baltimore City	63.65	100+	100+
Calvert	67.75	0	0
Caroline	61.79	40	33
Carroll	61.32	35	31
Cecil	63.75	30	19
Charles	68.52	0	0
Dorchester	61.12	45	36
Frederick	60.02	27	23
Garrett	66.52	0	0
Harford	63.83	19	13
Howard	63.90	17	19
Kent	61.71	41	32
Montgomery	59.29	33	37
Prince George’s	63.19	22	25
Queen Anne’s	61.33	38	33
Somerset	63.43	39	31
St. Mary’s	67.13	0	0
Talbot	62.20	38	32
Washington	61.53	31	18
Wicomico	61.69	39	30
Worcester	61.53	39	34

Table C-19: Total BioNet area within optimized corridors, the relative fraction of each tier included in the corridor, and fraction of total tier area in the county

County (Cnty)	**BioNet Area in Corr (km^2)**	**T1 Frac. (%)**	**Frac. of Cnty T1 (%)**	**T2 Frac. (%)**	**Frac. of Cnty T2 (%)**	**T3 Frac. (%)**	**Frac. of Cnty T3 (%)**	**T4 Frac. (%)**	**Frac. of Cnty T4 (%)**	**T5 Frac. (%)**	**Frac. of Cnty T5 (%)**
Statewide	2727.35	9.6	--	7.0	--	21.5	--	29.7	--	32.2	--
Allegany	142.11	9.1	19.8	2.9	16.8	28.3	11.8	34.7	18.1	8.0	16.8
Anne Arundel	118.88	1.7	10.0	1.2	31.9	2.1	10.6	14.7	25.8	26.2	23.2
Baltimore	171.16	0.7	18.0	4.0	20.4	4.9	20.1	13.4	24.9	25.2	26.0
Baltimore City	4.21	0.0	--	0.0	--	0.0	0.0	1.7	20.3	4.7	28.4
Calvert	130.68	7.3	41.2	0.6	11.0	0.9	14.0	41.9	32.6	20.5	33.6
Caroline	68.91	10.2	29.8	7.4	30.5	8.6	16.5	7.0	15.9	3.7	11.8
Carroll	213.32	5.3	69.4	6.3	60.2	10.4	35.8	10.5	41.4	16.6	30.6
Cecil	100.86	4.2	39.8	5.5	29.4	9.0	20.7	6.2	18.4	23.7	19.4
Charles	289.65	7.1	27.3	1.4	11.7	27.0	30.1	38.1	34.6	5.7	26.9
Dorchester	43.10	3.7	9.0	4.2	2.4	11.2	4.3	6.3	10.9	4.9	9.7
Frederick	209.49	0.5	16.4	5.6	29.4	22.4	28.4	4.3	28.8	12.5	22.8
Garrett	156.78	13.2	15.8	6.7	14.9	24.7	9.8	21.5	8.7	15.2	15.4
Harford	180.12	13.4	48.6	7.3	39.4	3.5	31.8	11.5	22.3	22.0	23.7
Howard	80.30	0.5	34.3	0.6	24.9	2.3	23.7	5.4	26.0	25.6	38.1
Kent	28.77	1.0	18.2	1.0	6.1	2.3	12.5	0.7	11.3	12.8	15.5
Montgomery	148.45	1.5	19.9	1.1	31.9	7.7	24.1	5.6	28.9	19.3	33.1
Prince George’s	134.20	3.3	14.5	2.1	21.7	2.4	18.5	17.2	21.2	18.2	24.9
Queen Anne’s	50.58	9.7	27.4	3.3	12.3	2.4	8.5	4.3	12.7	13.0	14.6
Somerset	45.75	5.7	18.9	0.7	7.8	10.0	6.3	23.9	10.3	16.1	8.5
St. Mary’s	116.02	4.1	16.2	0.5	7.7	9.5	20.4	41.0	21.3	14.1	14.1
Talbot	38.38	0.7	19.9	1.6	19.2	4.6	21.2	7.7	18.5	9.4	15.3
Washington	116.46	4.7	28.2	3.5	25.3	13.5	19.1	5.7	20.1	12.4	27.6
Wicomico	60.29	1.6	10.9	4.5	10.5	14.5	9.8	11.4	18.7	10.3	10.1
Worcester	75.35	6.3	6.6	1.4	4.3	6.8	4.2	25.5	13.0	9.0	10.1

Table C-20: Total BioNet area within protected area buffers, the relative fraction of each tier included in the buffer, and fraction of total tier area in the county

County (Cnty)	**BioNet Area in Buff (km^2)**	**T1 Frac. (%)**	**Frac. of Cnty T1 (%)**	**T2 Frac. (%)**	**Frac. of Cnty T2 (%)**	**T3 Frac. (%)**	**Frac. of Cnty T3 (%)**	**T4 Frac. (%)**	**Frac. of Cnty T4 (%)**	**T5 Frac. (%)**	**Frac. of Cnty T5 (%)**
Statewide	2880.05	8.2	--	7.2	--	25.5	--	27.1	--	32.9	--
Allegany	96.14	7.3	11.1	3.4	14.2	46.1	13.5	18.2	6.7	4.4	6.6
Anne Arundel	105.24	3.5	15.5	0.9	19.5	3.7	14.1	16.8	22.6	28.3	19.1
Baltimore	206.94	0.6	21.7	2.7	19.3	4.5	25.4	12.5	31.9	22.1	31.3
Baltimore City	5.61	0.0	--	0.0	--	<1.0	100.0	1.8	28.4	4.6	36.9
Calvert	110.01	5.9	27.9	2.1	30.2	1.8	22.8	43.7	28.2	18.8	25.5
Caroline	82.17	9.4	26.1	6.3	24.6	12.2	22.1	10.0	21.5	8.5	25.8
Carroll	180.95	2.8	32.4	4.2	35.5	10.0	30.4	10.6	36.8	19.4	31.8
Cecil	67.61	2.1	12.0	5.7	18.2	13.9	19.2	5.1	9.1	27.5	13.5
Charles	246.75	7.3	24.2	3.0	22.3	27.0	25.9	34.4	26.9	6.6	27.2
Dorchester	139.31	5.7	21.2	21.7	18.3	26.8	15.6	5.6	14.8	5.0	14.8
Frederick	132.55	0.5	10.6	5.1	17.4	21.3	17.6	4.9	21.2	12.3	14.6
Garrett	206.64	11.6	17.9	4.9	14.1	36.5	18.6	21.9	11.5	8.1	10.6
Harford	126.79	9.7	25.7	3.9	15.5	3.1	20.4	11.3	16.1	27.4	21.6
Howard	98.75	0.3	25.2	0.4	22.4	1.7	24.4	5.6	37.3	22.5	46.6
Kent	43.28	2.3	34.1	4.9	24.3	3.1	13.2	1.7	22.6	22.0	20.9
Montgomery	171.87	1.1	19.3	0.9	32.8	6.7	25.8	5.7	36.2	18.7	39.2
Prince George’s	126.58	5.1	21.1	1.3	13.0	3.1	22.1	14.8	17.3	18.9	24.4
Queen Anne’s	95.02	7.0	30.9	4.8	27.6	4.0	22.5	6.9	31.9	16.6	29.2
Somerset	117.83	2.8	20.3	1.0	21.5	18.3	24.8	24.6	22.8	20.9	23.8
St. Mary’s	95.56	2.8	9.2	1.4	16.2	11.5	20.6	38.1	16.4	14.7	12.3
Talbot	40.69	0.7	13.4	2.1	18.0	5.8	18.7	11.5	19.4	16.1	18.5
Washington	104.94	4.6	20.3	2.2	11.8	20.8	21.8	8.7	22.5	12.3	20.1
Wicomico	110.65	2.8	23.2	6.5	18.8	28.4	23.6	12.2	24.5	13.3	16.1
Worcester	168.18	10.7	16.4	4.1	18.2	23.5	21.5	25.3	19.0	10.6	17.6

Table C-21: Portion of immediately outcompeted cropland in 2011 and fraction outcompeted by 2030 under a baseline forest carbon rental model across two reforestation scenarios

County (Cnty)	**Outcompeted cropland by 2011 - Corridor (%)**[a]	**Outcompeted cropland by 2030 – Corridor (%)**	**Outcompeted cropland by 2011 - Buffer (%)**	**Outcompeted cropland by 2030 – Buffer (%)**
Statewide	17.5	18.3	19.7	20.6
Allegany	62.1	63.1	67.2	68.4
Anne Arundel	25.7	28.3	30.6	33.4
Baltimore	17.6	18.4	20.3	21.3
Baltimore City	--	--	--	--
Calvert	52.9	57.1	56.3	60.3
Caroline	6.4	6.7	9.0	9.3
Carroll	18.0	18.6	19.4	20.2
Cecil	11.2	11.7	13.2	13.8
Charles	56.6	58.2	56.1	57.8
Dorchester	8.8	9.2	13.5	14.1
Frederick	19.8	20.5	20.0	20.6
Garrett	26.1	27.2	25.6	26.0
Harford	13.3	14.4	14.8	15.9
Howard	19.2	20.7	20.6	22.5
Kent	4.4	4.8	7.4	8.0
Montgomery	27.1	28.0	28.2	29.2
Prince George’s	65.1	66.8	64.6	66.2
Queen Anne’s	7.6	7.9	8.7	9.3
Somerset	10.1	11.0	15.5	16.9
St. Mary’s	31.2	33.2	28.7	31.0
Talbot	3.8	4.2	6.3	6.8
Washington	15.3	15.8	18.7	19.4
Wicomico	34.5	35.8	40.6	42.0
Worcester	17.1	18.3	23.0	24.2

Table C-22: Portion of each reforestation scenario projected to experience land-use change to development under four IPCC emissions scenarios

County (Cnty)	**A1B - Corr**	**A2 - Corr**	**B1 - Corr**	**B2- Corr**	**A1B - Buff**	**A2 - Buff**	**B1 - Buff**	**B2 - Buff**
Statewide	7.4	6.5	6.4	6.3	6.4	5.8	5.7	5.6
Allegany	3.03	2.64	2.33	2.39	2.22	1.93	1.84	1.79
Anne Arundel	25.91	23.77	21.05	20.85	25.62	24.45	21.80	21.84
Baltimore	10.09	8.55	9.75	9.48	10.33	9.18	9.66	9.42
Baltimore City	7.12	7.15	6.96	6.95	6.68	6.64	6.61	6.60
Calvert	4.78	4.87	4.84	4.88	4.23	4.26	4.28	4.28
Caroline	1.67	1.48	1.23	1.23	1.00	1.06	0.86	0.84
Carroll	2.12	1.11	2.34	2.15	1.70	0.97	1.94	1.76
Cecil	7.68	6.59	6.62	6.51	5.80	4.61	4.45	4.32
Charles	7.49	6.91	5.26	5.23	6.38	5.86	4.43	4.38
Dorchester	2.91	2.27	1.90	1.97	1.17	1.04	0.88	0.76
Frederick	2.24	1.46	2.53	2.32	1.70	1.17	1.81	1.74
Garrett	0.25	0.25	0.24	0.25	0.21	0.21	0.21	0.21
Harford	6.67	5.20	6.11	5.81	6.70	5.20	5.82	5.38
Howard	10.21	8.55	9.70	9.28	10.81	9.37	10.23	10.00
Kent	1.01	0.97	0.90	0.97	1.03	0.96	0.99	0.98
Montgomery	9.92	8.80	9.01	8.81	10.05	8.73	9.29	9.12
Prince George’s	26.90	25.35	23.05	23.10	23.66	22.53	20.65	20.56
Queen Anne’s	1.11	1.10	1.09	1.09	0.91	0.90	0.88	0.89
Somerset	4.60	4.28	3.01	2.72	1.24	1.17	0.71	0.66
St. Mary’s	2.62	2.63	2.63	2.60	2.11	2.13	2.13	2.03
Talbot	10.58	8.74	6.95	6.86	6.97	6.03	4.42	4.26
Washington	4.61	3.42	3.76	3.63	3.19	2.48	2.56	2.57
Wicomico	6.92	5.36	4.68	4.68	1.88	1.64	1.38	1.30
Worcester	2.35	2.09	1.79	1.77	0.78	0.81	0.67	0.70

Table C-23: Portion of projected land-use change on agricultural land across both reforestation scenarios, optimized corridors (Corr) and protected area buffers (Buff)

County (Cnty)	**A1B - Corr**	**A2 - Corr**	**B1 - Corr**	**B2- Corr**	**A1B - Buff**	**A2 - Buff**	**B1 - Buff**	**B2 - Buff**
Statewide	22.05	19.98	21.60	21.19	17.56	14.26	14.93	14.71
Allegany	26.88	21.51	22.11	22.18	22.89	18.75	14.96	16.10
Anne Arundel	15.23	13.17	13.98	13.72	12.72	11.60	11.54	11.86
Baltimore	21.14	17.33	22.79	22.33	13.82	11.30	15.14	14.81
Baltimore City	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Calvert	29.92	30.71	30.47	30.86	21.54	22.25	22.01	22.17
Caroline	45.05	43.53	44.17	41.13	53.21	51.72	52.13	51.09
Carroll	30.24	30.38	33.15	31.81	23.80	23.86	24.78	23.81
Cecil	33.65	32.07	35.36	33.87	29.85	27.97	29.87	28.66
Charles	23.93	24.55	28.70	28.09	20.43	20.69	22.94	22.76
Dorchester	53.52	54.64	48.20	51.73	44.98	46.91	44.40	40.30
Frederick	37.76	38.49	40.26	38.63	22.94	22.86	21.99	25.12
Garrett	25.00	25.00	25.86	25.42	15.38	15.15	15.38	15.38
Harford	33.37	28.45	33.87	33.59	28.84	22.35	27.25	25.54
Howard	8.88	7.32	10.53	9.74	8.60	7.81	9.40	9.02
Kent	58.91	61.34	65.36	61.34	50.62	49.01	51.92	50.00
Montgomery	6.35	5.48	7.00	6.74	7.45	6.32	7.94	7.58
Prince George’s	10.37	9.78	9.76	9.99	9.04	8.78	7.93	8.17
Queen Anne’s	66.04	66.99	67.31	67.31	42.86	43.49	44.49	44.15
Somerset	25.81	29.84	18.94	17.65	36.33	35.06	25.66	27.46
St. Mary’s	45.02	44.85	44.85	45.35	34.07	33.88	33.88	34.67
Talbot	68.92	68.76	64.50	65.14	60.62	60.96	57.35	56.44
Washington	34.80	29.13	31.03	28.73	26.27	24.81	25.04	25.58
Wicomico	44.54	40.47	41.87	41.70	30.86	33.90	32.11	32.74
Worcester	47.64	49.37	46.76	47.92	43.78	47.35	46.81	49.23

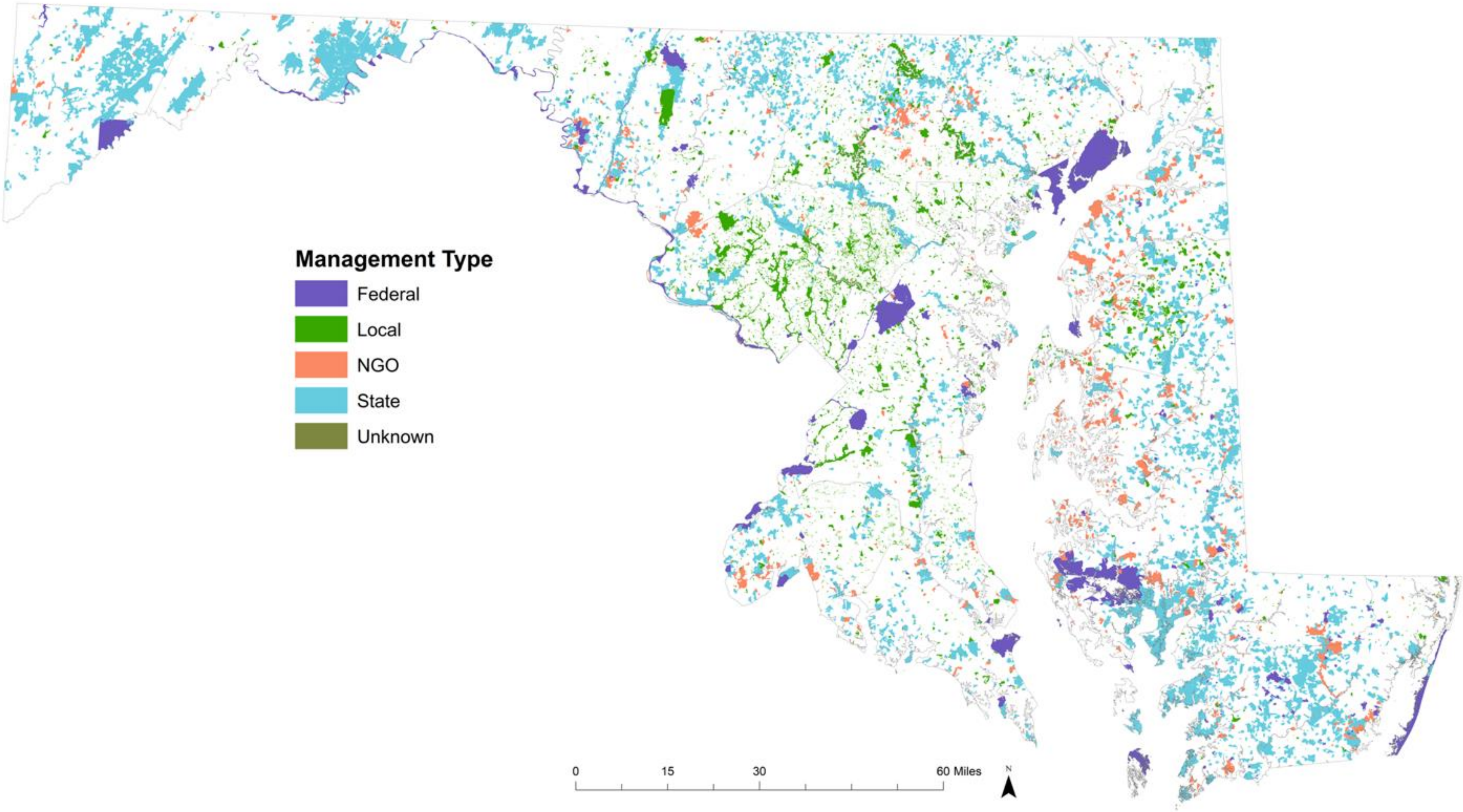


Figure C-1: Protected areas in Maryland classified by land management type.

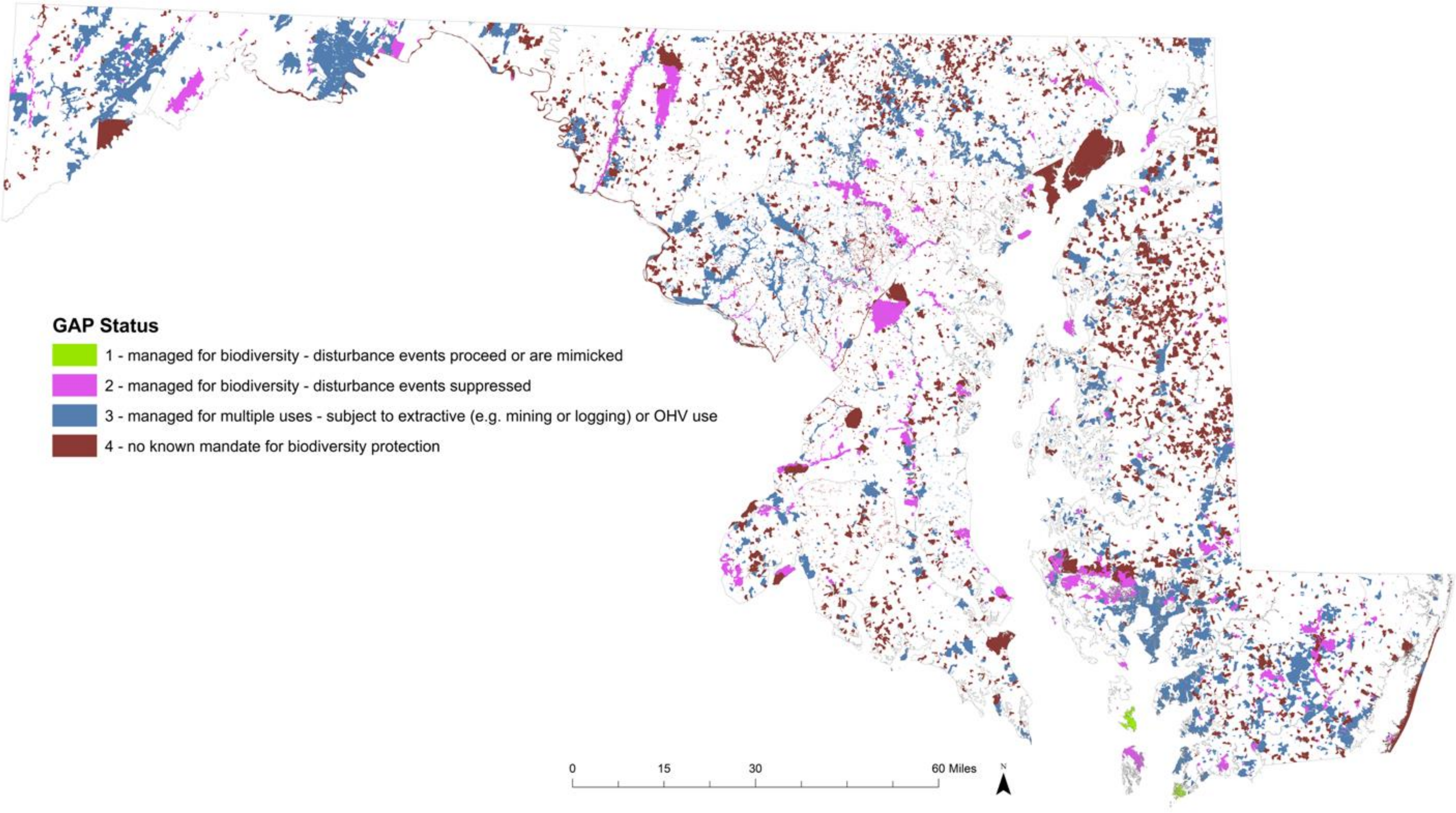


Figure C-2: Protected areas in Maryland classified by GAP status.

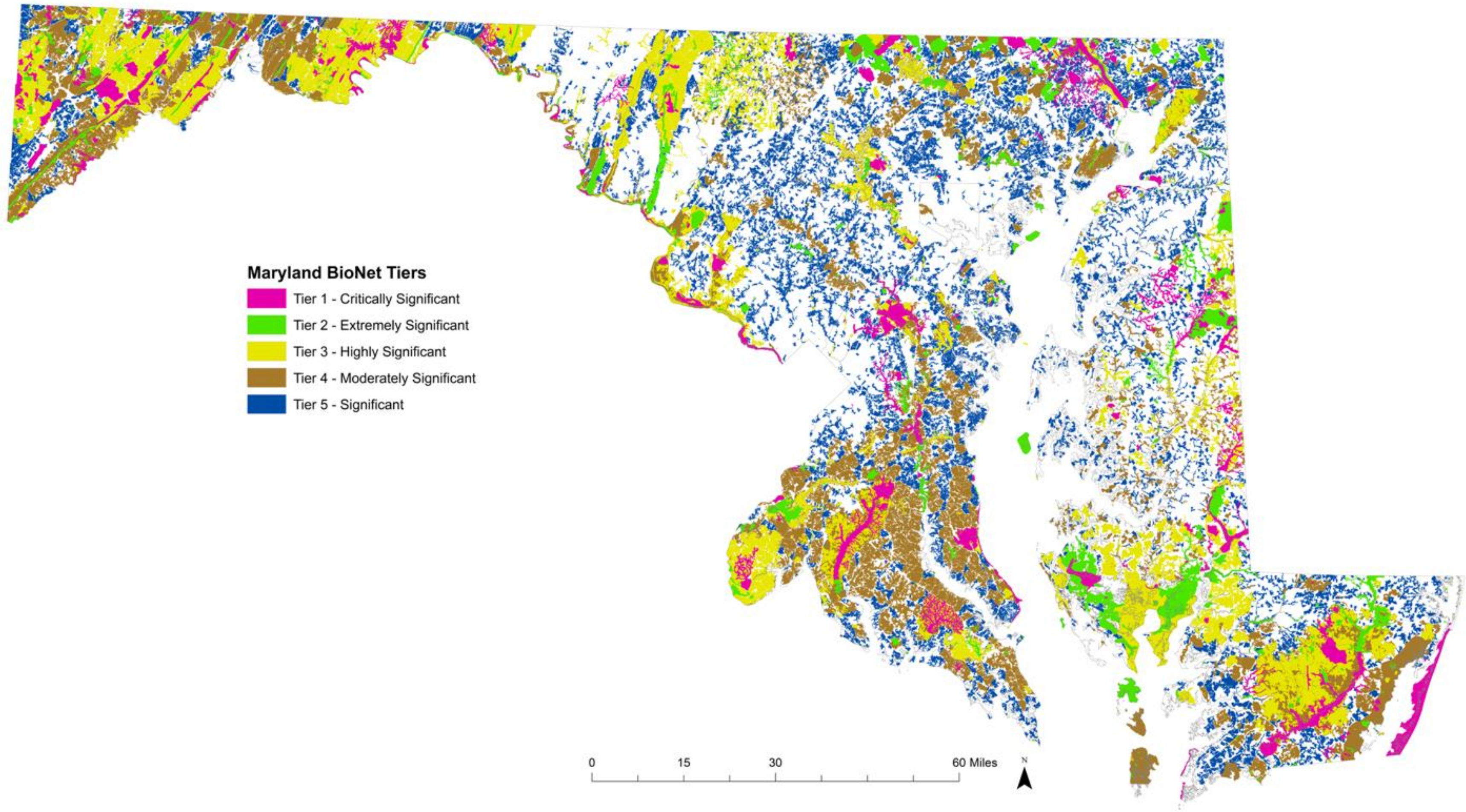
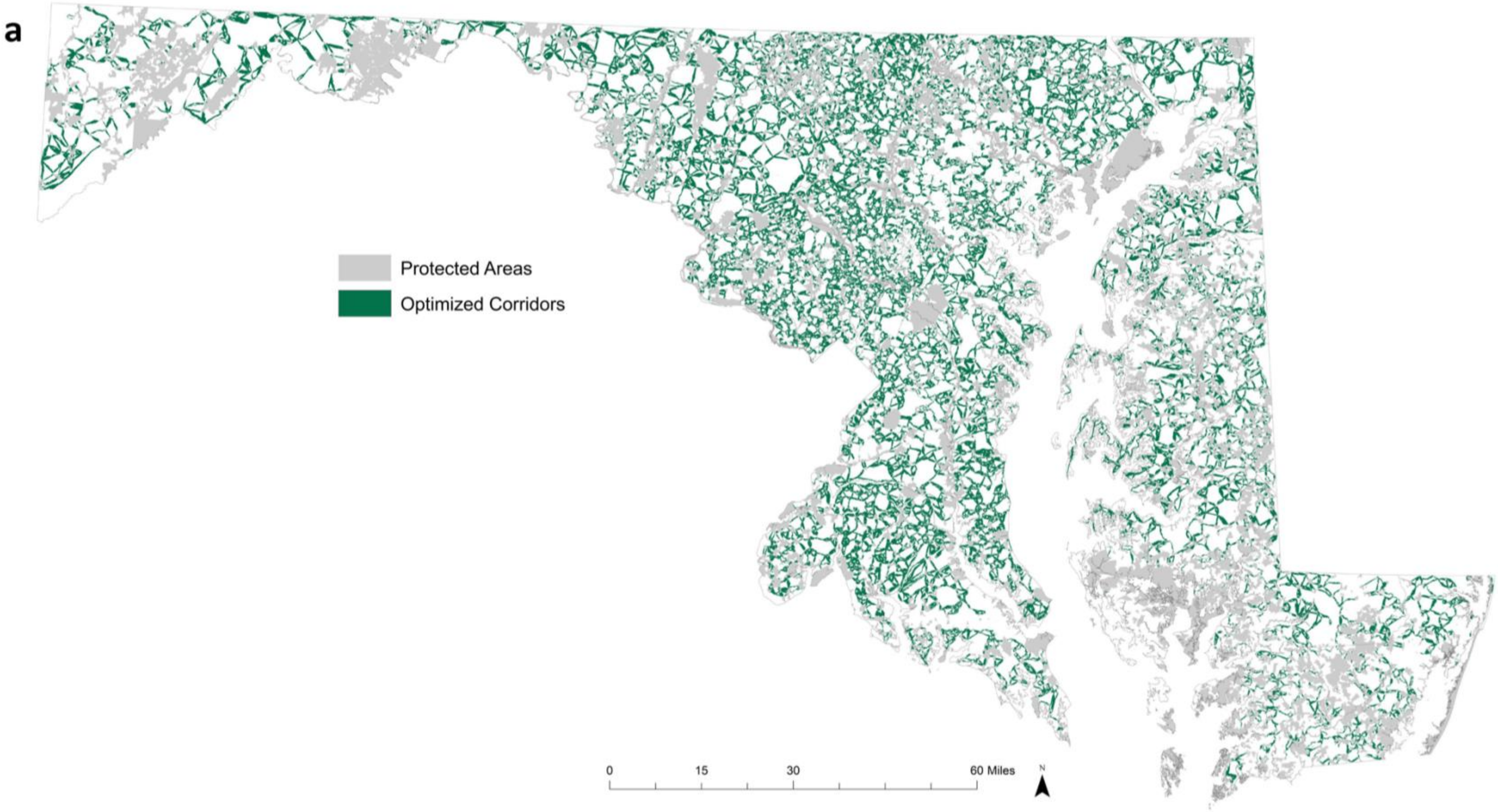


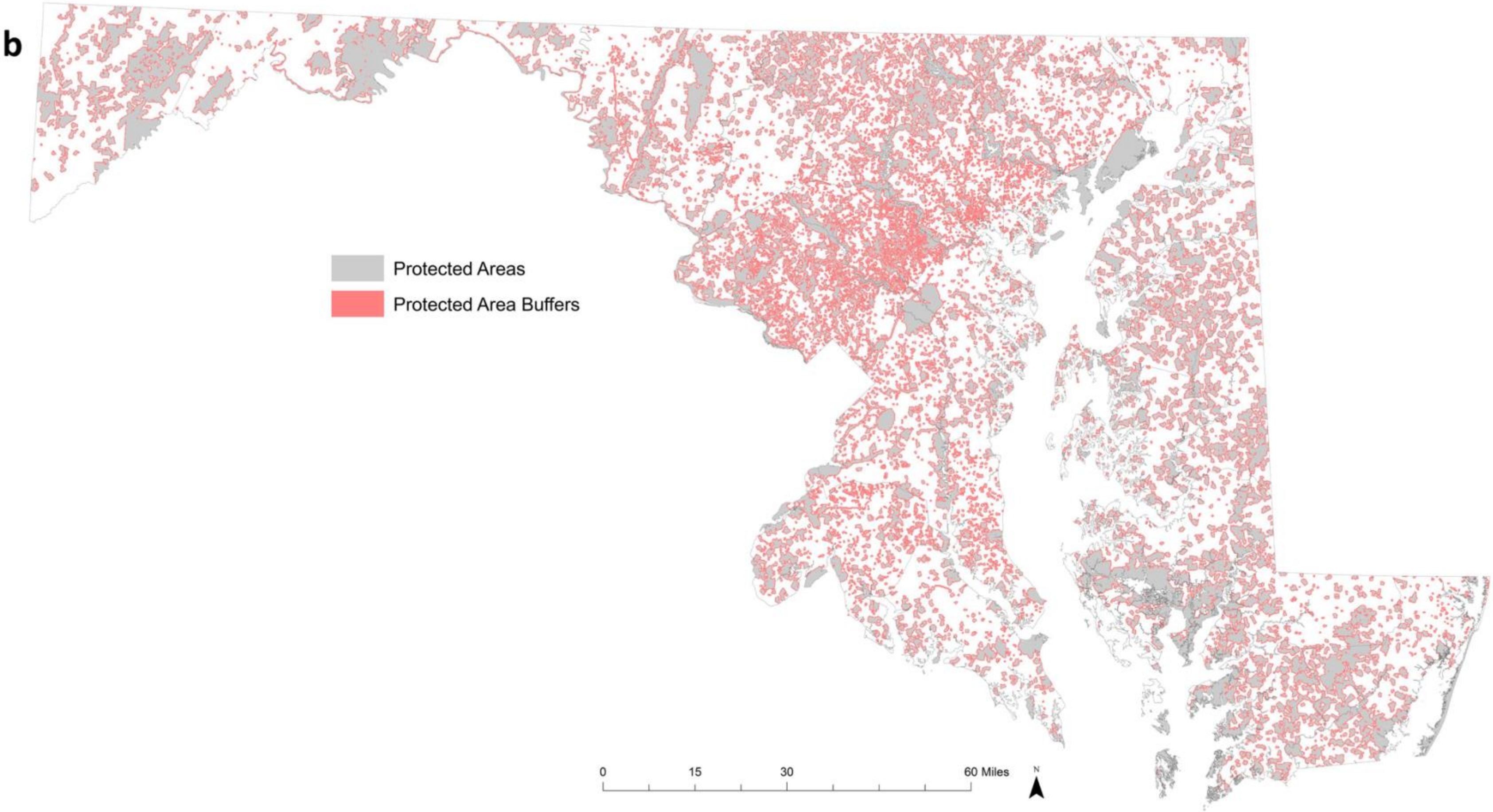
Figure C-3: BioNet areas in Maryland, classified by five tiers of importance for biodiversity conservation.

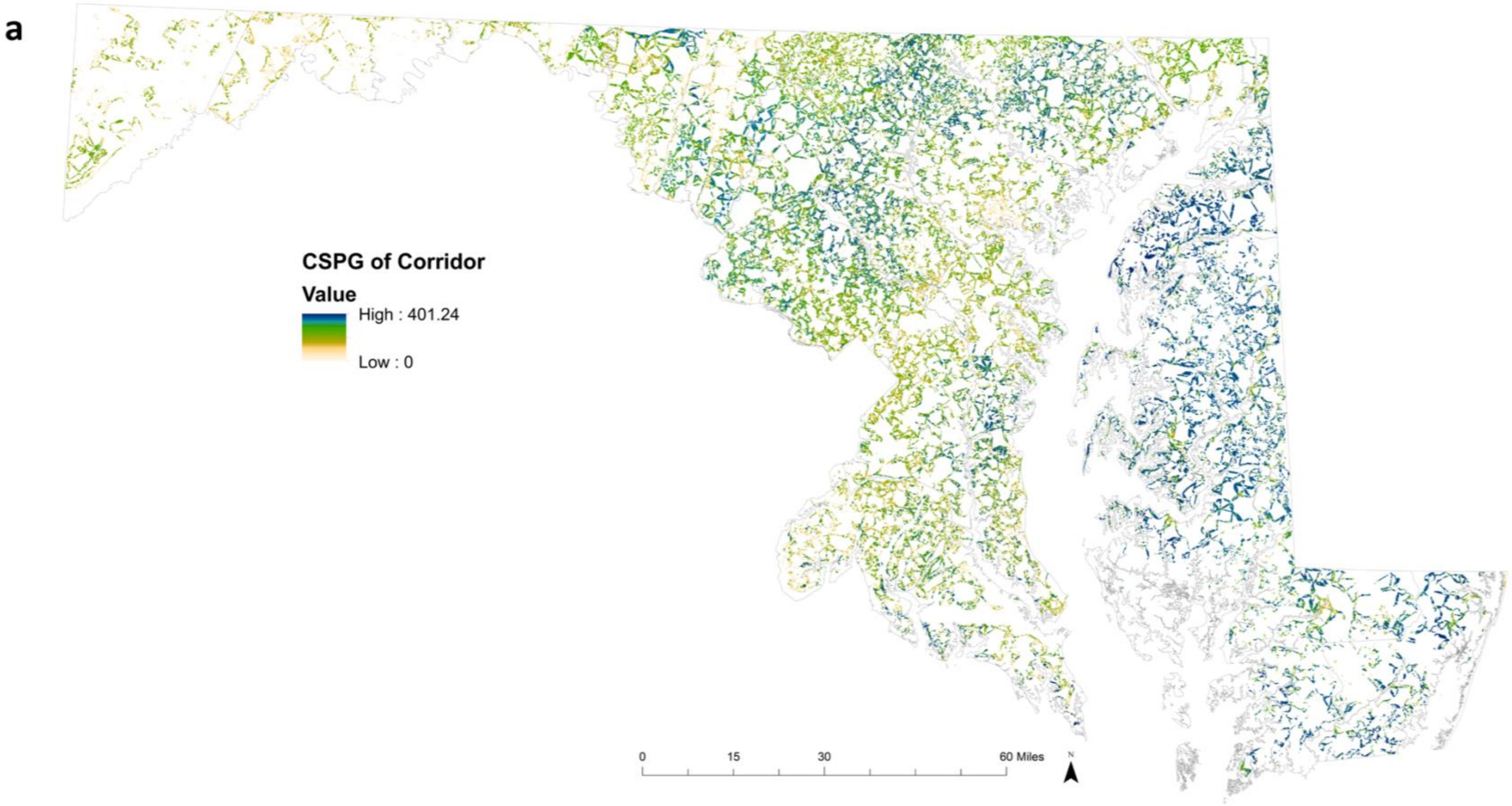


continued

Figure C-4: Mapped statewide corridors (1km) (a) and protected area buffers (225m) (b).

Figure C-4 continued

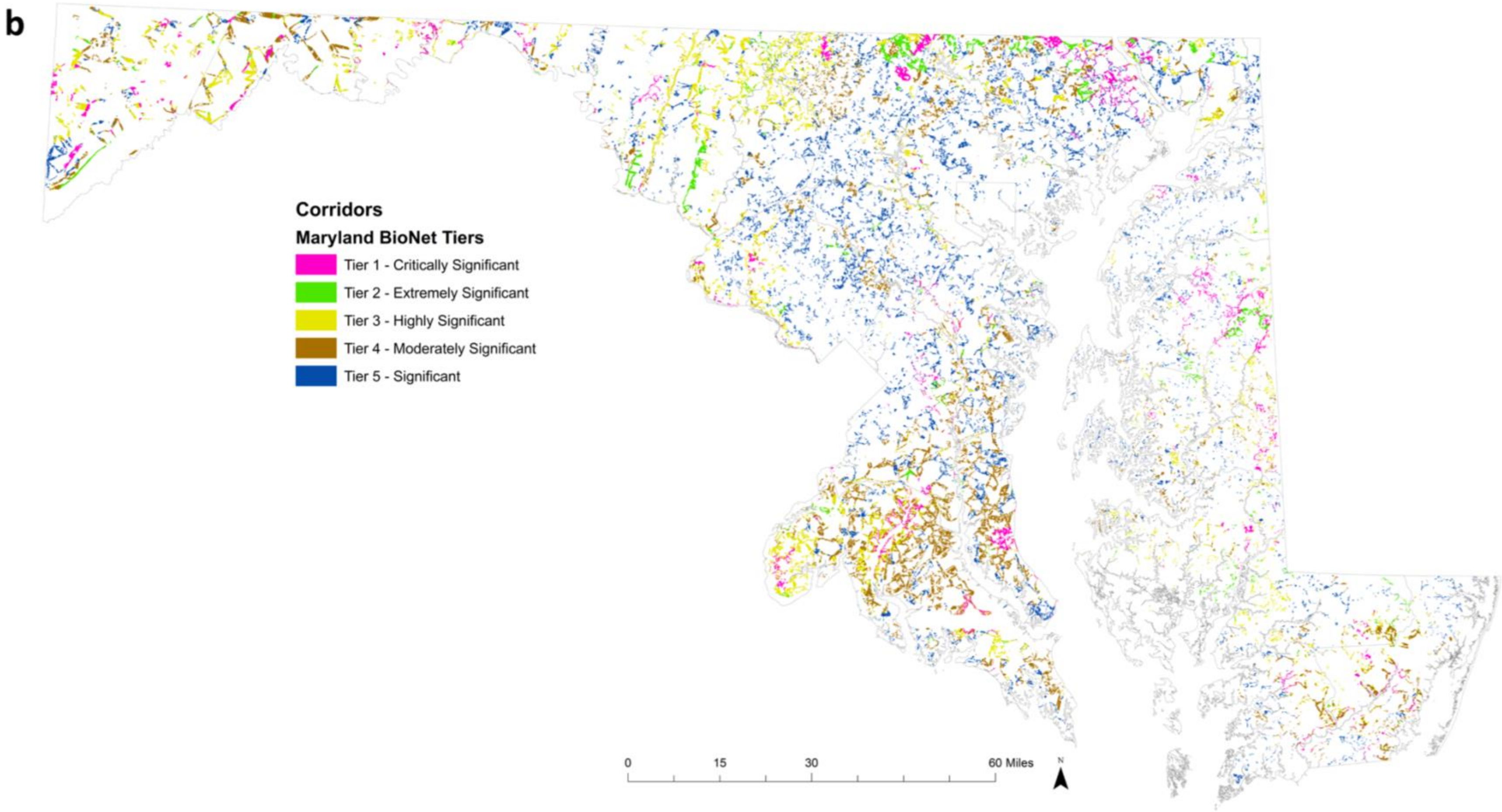




continued

Figure C-5: Mapped statewide corridors (1km) with related 90m CSPG (Mg/ha) estimates (a) and included BioNet area by tier (b).

Figure C-5 continued



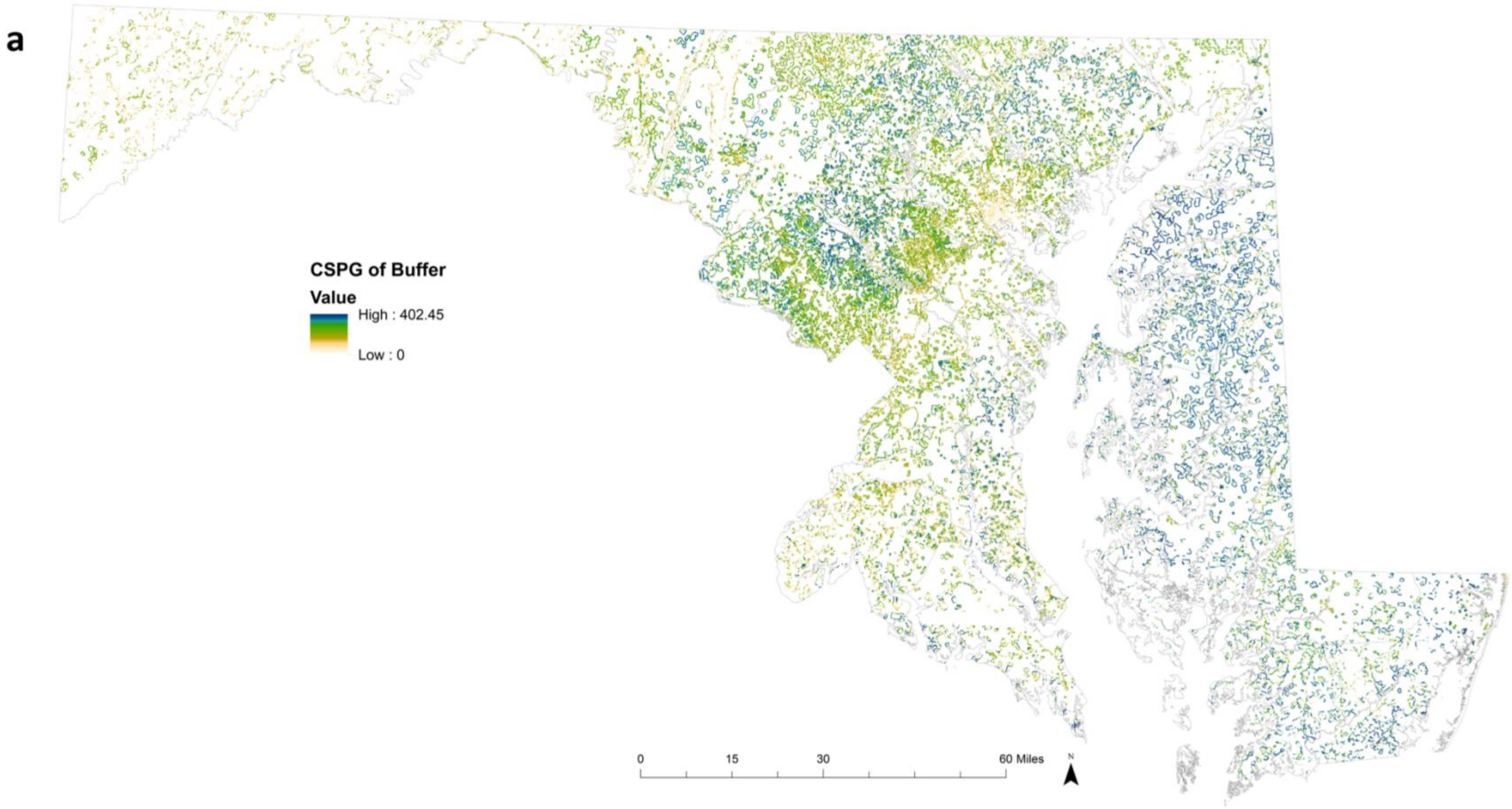
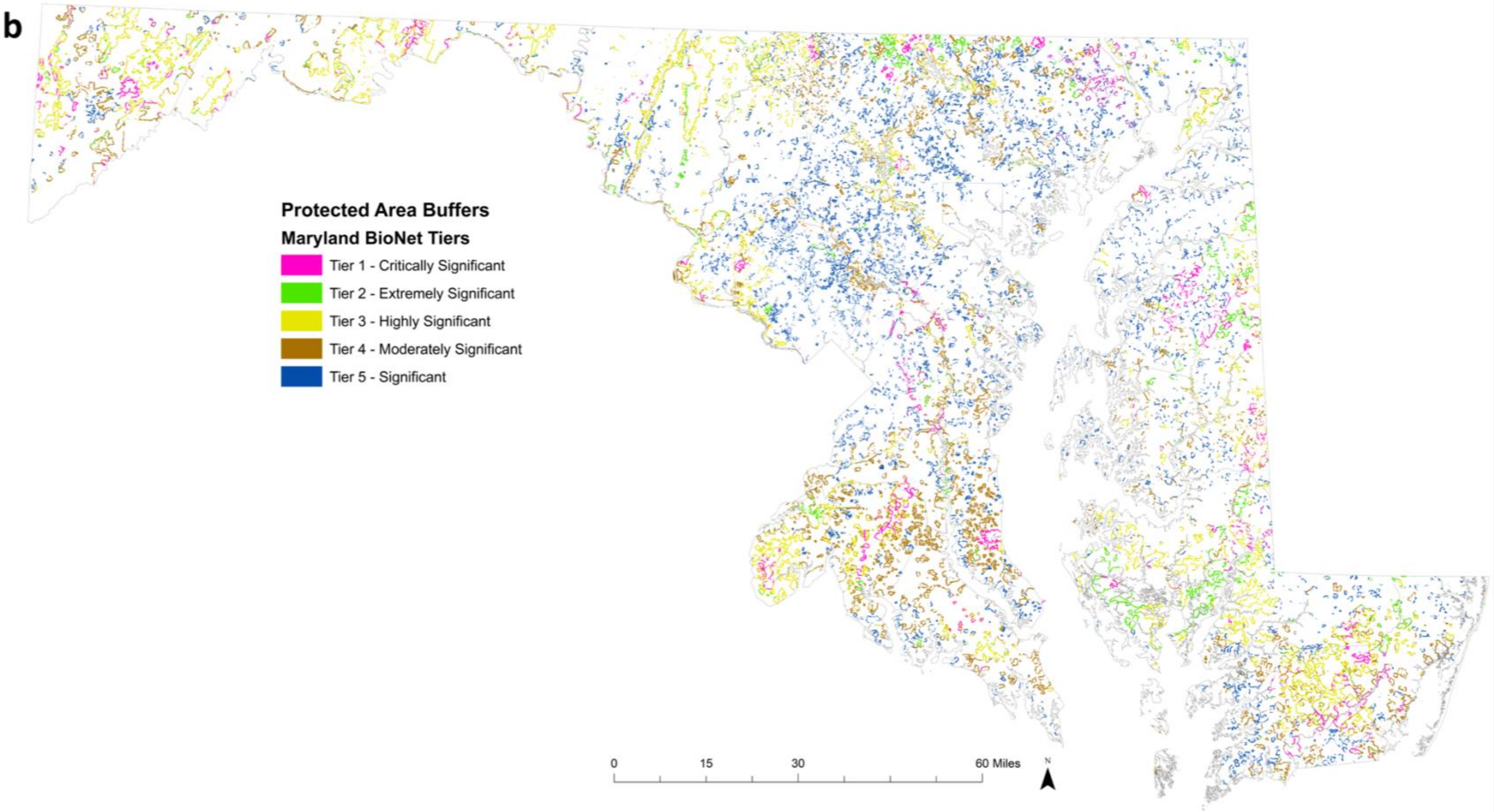


Figure C-6: Mapped statewide buffers (225m) with related 90m CSPG (Mg/ha) estimates (a) and included BioNet area by tier (b).

Figure C-6 continued



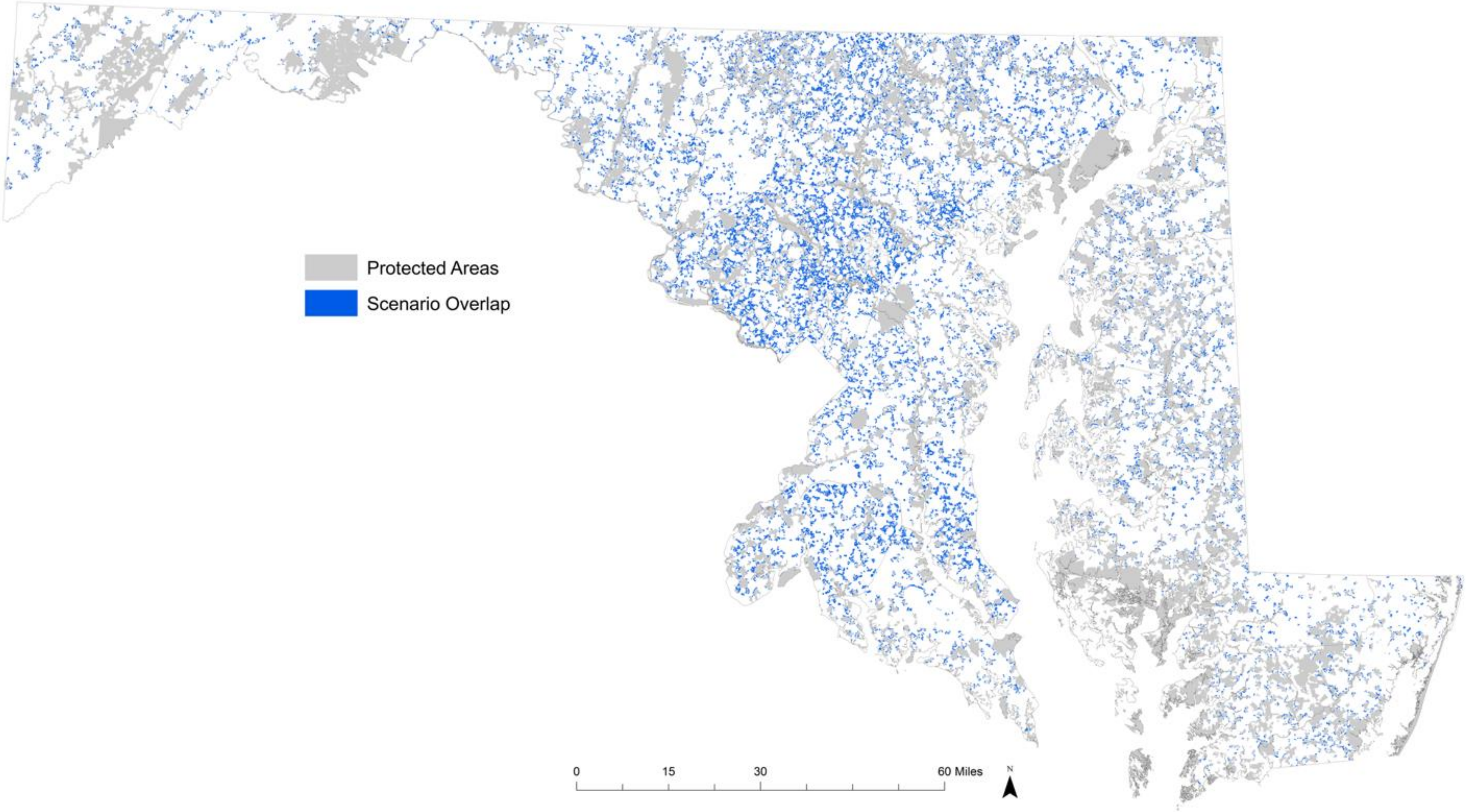


Figure C-7: Areas of spatial overlap between corridors and protected area buffers.

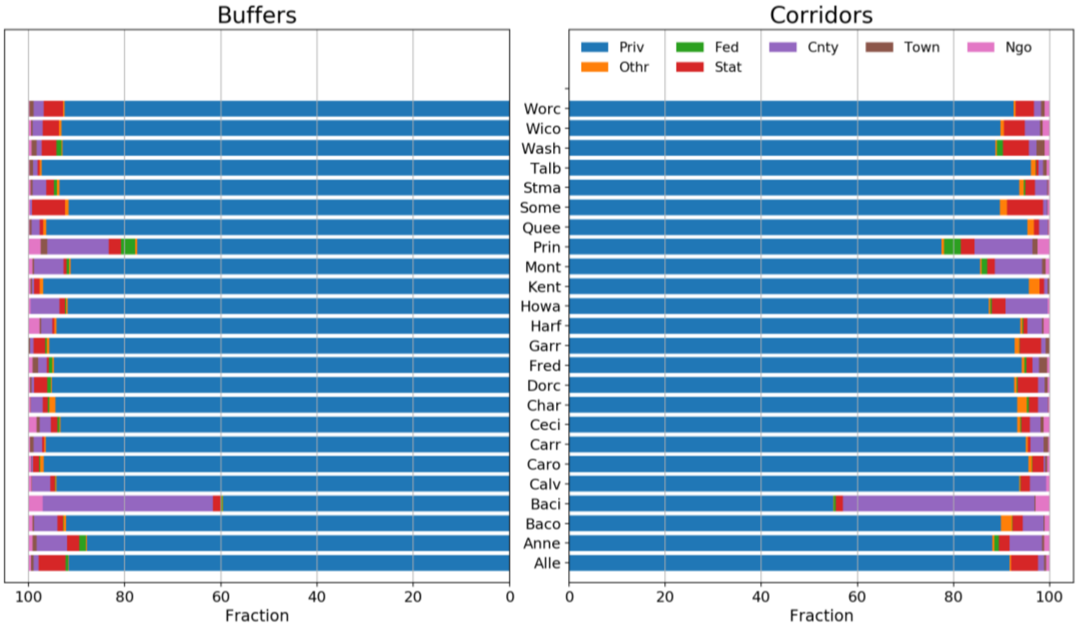


Figure C-8: Land-ownership fraction of corridors and buffers at the county-scale.

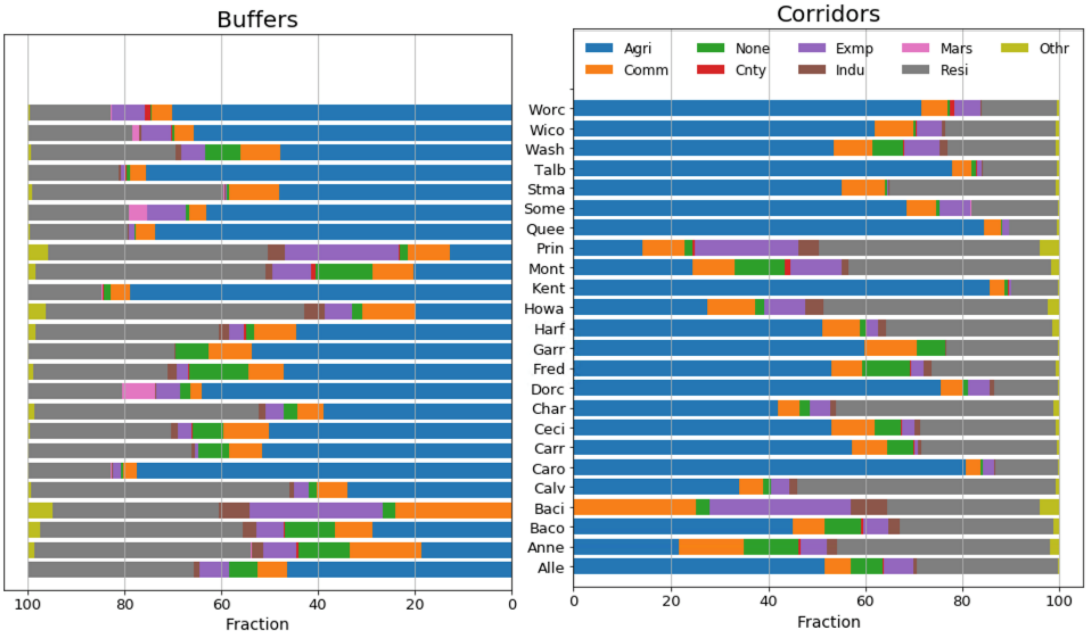


Figure C-9: Land-use fraction of corridors and buffers at the county-scale.

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