

Technical Study on Changes in Forest Cover and Tree Canopy in Maryland

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Harry R. Hughes
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Executive Summary

Forests represent one of Maryland's most important natural resources, critical to its economy, sustainability, health and identity. Forest conservation and tree planting are central strategies to achieve the goals laid out in the 2014 Chesapeake Bay Watershed Agreement (CBWA) and are reinforced in many parts of the Maryland legal code. To monitor forest and tree canopy cover status and progress toward its commitments, the Maryland General Assembly enacted legislation (House Bill 991) in 2021 requiring a ***Technical Study of Changes in Maryland's Forest Cover and Tree Canopy***. This study, with results presented here, improves Maryland's statewide inventory of forest and tree canopy cover, assesses near and long-term change and assesses the effectiveness of forest and tree programs operating in the state. Notably, this study makes use of a newly released, innovative, very high-resolution (1-m) land use and land cover dataset for the Chesapeake Bay Watershed used for the first time to monitor individual trees within and outside forests across Maryland. This is complemented by moderate-resolution satellite imagery, ground observations and other research to generate insights on the status of tree canopy cover in the state.

Maryland's forests cover 2.448 to 2.566 million acres of the state's land area, according to the USDA Forest Service Forest Inventory and Analysis (FIA) program and the Chesapeake Bay Program Office (CBPO). When tree canopy outside forests is included, the state's total tree canopy covers an estimated 3.095 million acres (CBPO). Percent forest cover estimates range from 39-42% of the state's total land area, depending on the dataset and approach used (FIA, CBPO). Findings from three independent data sources (FIA, CBPO, and the National Land Cover Dataset or NLCD) agree on similar trends in Maryland's forests. Forest area has shown a slightly decreasing trend over 5- and 20-year intervals but with a trend toward stabilization in the past 10 years (-0.14% annually from 2013-2018; -0.23% annually from 1999-2019). The decrease in forest cover has been offset somewhat by an increase in tree canopy outside forests, resulting in a more modest decrease in the total tree canopy (-0.077% annually) (Table ES-1) (Task 1). Despite the slightly decreasing, yet now stabilizing, trend, the state's tree canopy has been remarkably stable given considerable increases in human population over the same period (880,738 people or nearly 17% growth from 2000-2020).

This represents an opportunity for the state to achieve a net gain of forests and tree canopy in the near future, given continued investment in forest conservation measures and tree planting.

Table ES-1. *Forest and tree canopy extent estimates from key data sources.*

Source	Initial Year	Extent (thousand acres)	End Year	Extent (thousand acres)	Total % Change (Annual % Change)
Forest[1]					
FIA[2]	1999	2,566 (+/- 770)	2019	2,448 (+/- 108)	-4.6% (-0.23%)
CBPO	2013	2,584	2018	2,566	-0.70% (- 0.14%)
Tree Canopy					
Total Tree Canopy (NLCD)	2001	2,802	2019	2,791	-0.39% (-0.022%)
Within Forest (CBPO)	2013	2,584	2018	2,566	-0.70% (- 0.14%)
Outside Forest (CBPO	2013	523	2018	529	+1.15% (+0.23%)
Total Tree Canopy (CBPO)[3]	2013	3,107	2018	3,095	-0.39% (-0.077%)

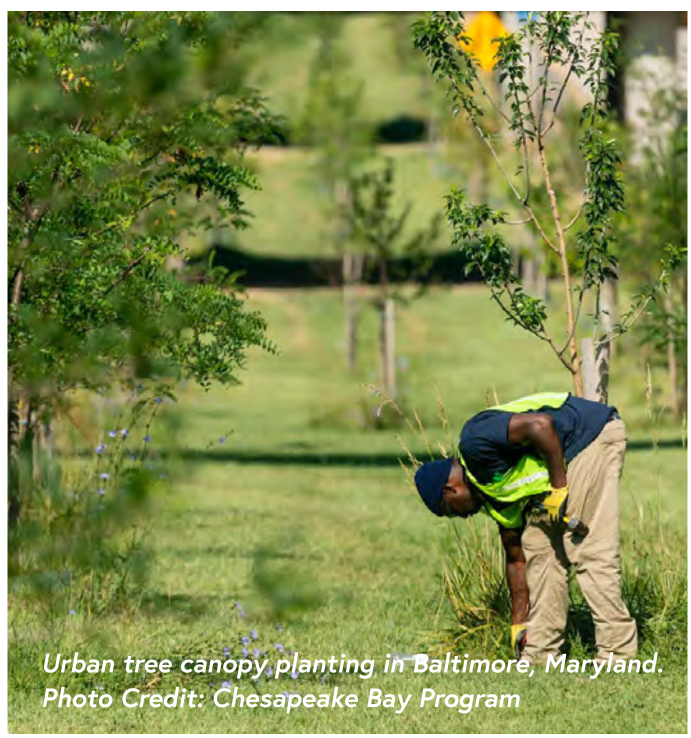
Notes: 1. Definitions of forest differ between datasets. 2. Forest Inventory Assessment (FIA) error estimates presented here represent 95% confidence intervals (Frieswyk 2001). Confidence intervals are not defined for Chesapeake Bay Program Office (CBPO) dataset or National Land Cover Dataset (NLCD), but accuracy is discussed in the Data and Methods section. 3. Total Tree Canopy (CBPO) = Tree Canopy within Forest (e.g., Forest) + Tree Canopy Outside Forest.

While forests exhibit modest recent net change statewide, there are greater amounts of gain and loss and higher local variability than the statewide balance suggests. Some regions demonstrate modest amounts of forest cover gain and others experienced substantial loss. Additionally, forest and tree canopy gain and loss show greater variability than statewide net change. Other observed statewide trends include forest fragmentation and conversion of existing forests for development. While Maryland's forest extent is relatively stable, overall forest health is at risk. An already patchy mosaic of forests has apparently become increasingly fragmented from 2013 to 2018. Some of the increase in tree canopy outside forest originates from fragmentation of forests into patches too small to meet the forest definition. Causes include human and natural causes and changes observed include temporary and permanent forest changes. Further research and longer term monitoring are needed to clarify all important drivers of change. In addition, ground observations indicate that approximately 12% of forests have experienced recent disturbance with invasive species being the largest risk factor (Task 2).

Urban tree canopy is essential for air quality, stormwater mitigation, mental wellbeing, urban heat reduction and environmental justice (Task 3). Within urban areas, this study observed a net loss of 13,164 acres of forest from 2013-2018, which incorporates total tree canopy loss of 17,829 acres and an observed gain of 4,665 acres. While newly planted trees are not represented here due to detection delays for young trees to reach sufficient stature, reports and projections of urban trees planted during the study period have not been sufficient to offset observed losses. Therefore, we conclude there was a trend toward tree canopy loss in urban areas from 2013-2018.

Tree canopy cover has been recognized as essential infrastructure to keep the Bay and surrounding watershed clean. To this end, the CBWA signatories set a collective goal of 70% cumulative tree canopy coverage within riparian areas throughout the watershed by 2025. Maryland's riparian areas had 58% coverage in the year 2018, representing progress toward, though not the achievement of this goal. Best management practice certification reports under Maryland's Phase III Watershed Implementation Plan indicate continued progress toward county-specific riparian and urban canopy goals, but with substantial variation (Task 3).

From 2001-2019, forest loss has been most associated with development. New forest mainly emerged from wetlands, shrublands and herbaceous vegetation, followed by agricultural lands (Task 4). More recently, from 2013-2018, forest was converted most frequently to development, natural low-lying land cover and productive uses (Figure ES-1).



Urban tree canopy planting in Baltimore, Maryland. Photo Credit: Chesapeake Bay Program

CBPO Land Use/Land Cover Transitions from 2013-2018

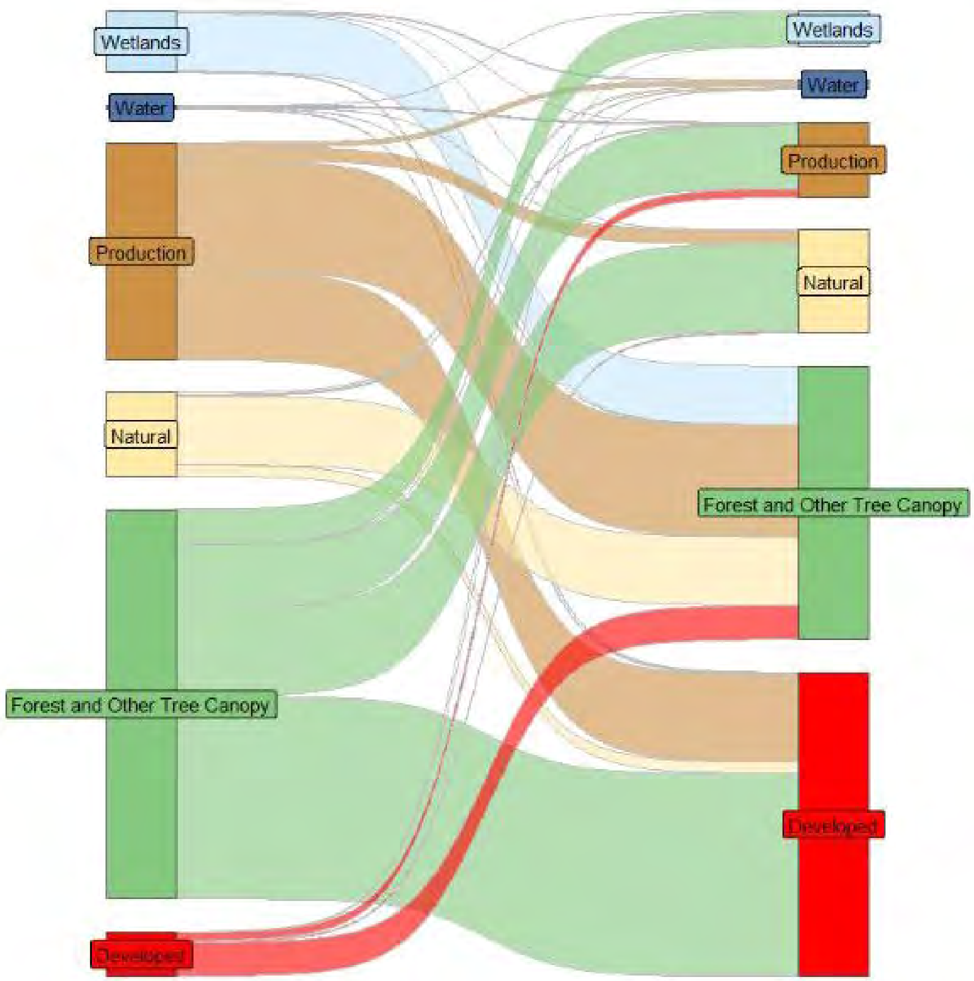


Figure ES-1. *Land Cover Transitions from 2013-2018. "Forest and other tree canopy" (Total Tree Canopy) shows the greatest loss of extent (12,792 acres) while impervious classes showed the greatest gain (10,509 acres).*

We note that patterns and drivers of tree canopy change (including tree canopy within and outside of forests) vary regionally. All but one region lost forest cover, and the region that gained was the Lower Eastern Shore region where the timber industry is active, signaling regrowth after extraction. All regions but Central Maryland experienced a net gain in tree canopy outside forests, indicative of forest fragmentation and tree planting. Central Maryland, representing the rapidly urbanizing Washington, D.C. suburbs, was the only region that experienced a loss of tree canopy cover from outside and within forest (Figure ES-2). The distribution of tree canopy loss is highly skewed — two counties, Montgomery and Prince George's, accounted for more than 50% of the state's total tree canopy loss and five counties accounted for 73% of its tree canopy loss. Though there was a statewide trend toward forest fragmentation and development (Figure ES-3), we also observed transitions of developed land to tree canopy, indicating an effort toward urban greening. The transition of forests to wetlands in coastal counties may be indicative of sea level rise. A parallel analysis found that Priority Funding Areas for development were more vulnerable to tree canopy loss, further indicating development as an important driver of change in the state.

Change in Area (Acres)

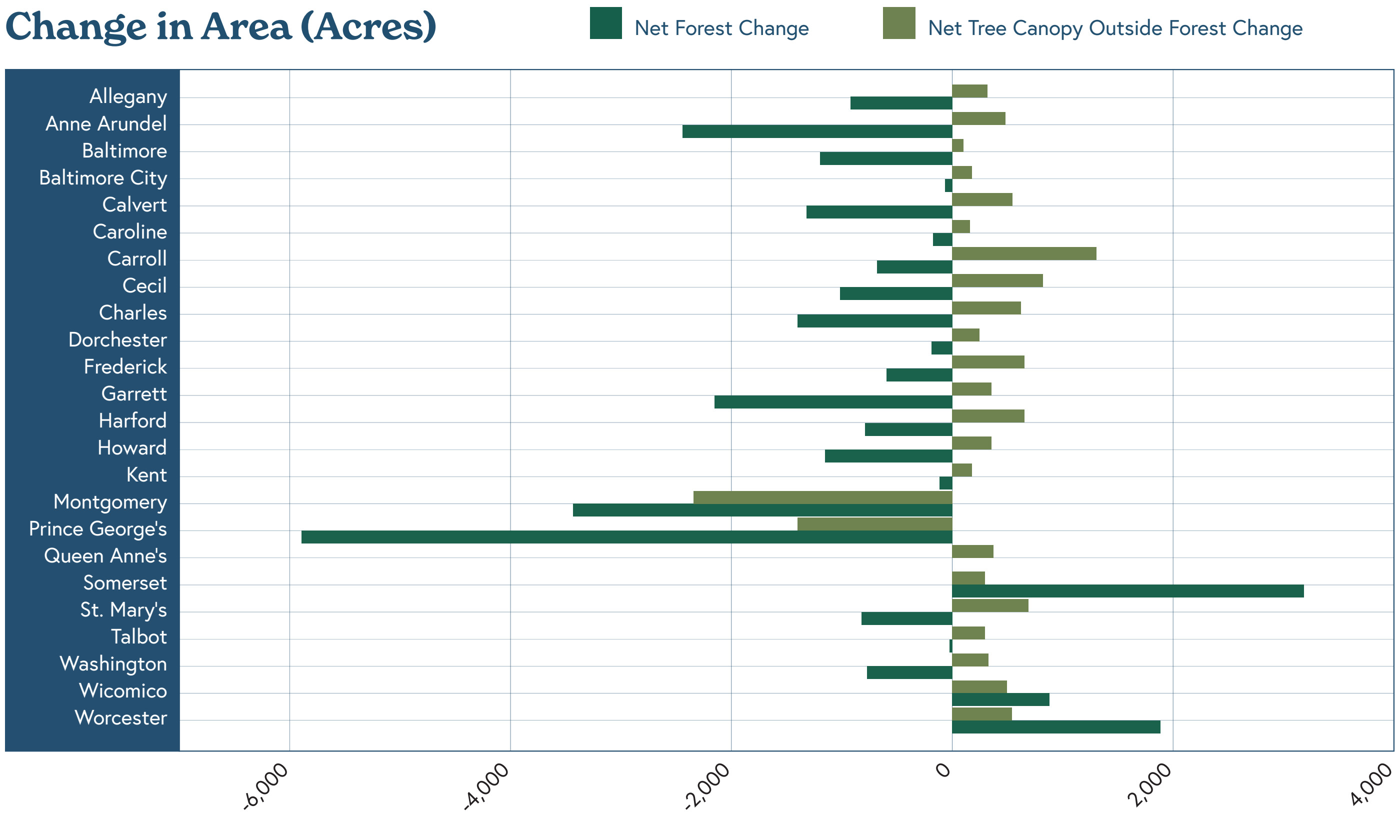


Figure ES-2. *Net change in the extent of forest and tree canopy outside forest, by jurisdiction (acres).*

Transition Area (Acres)

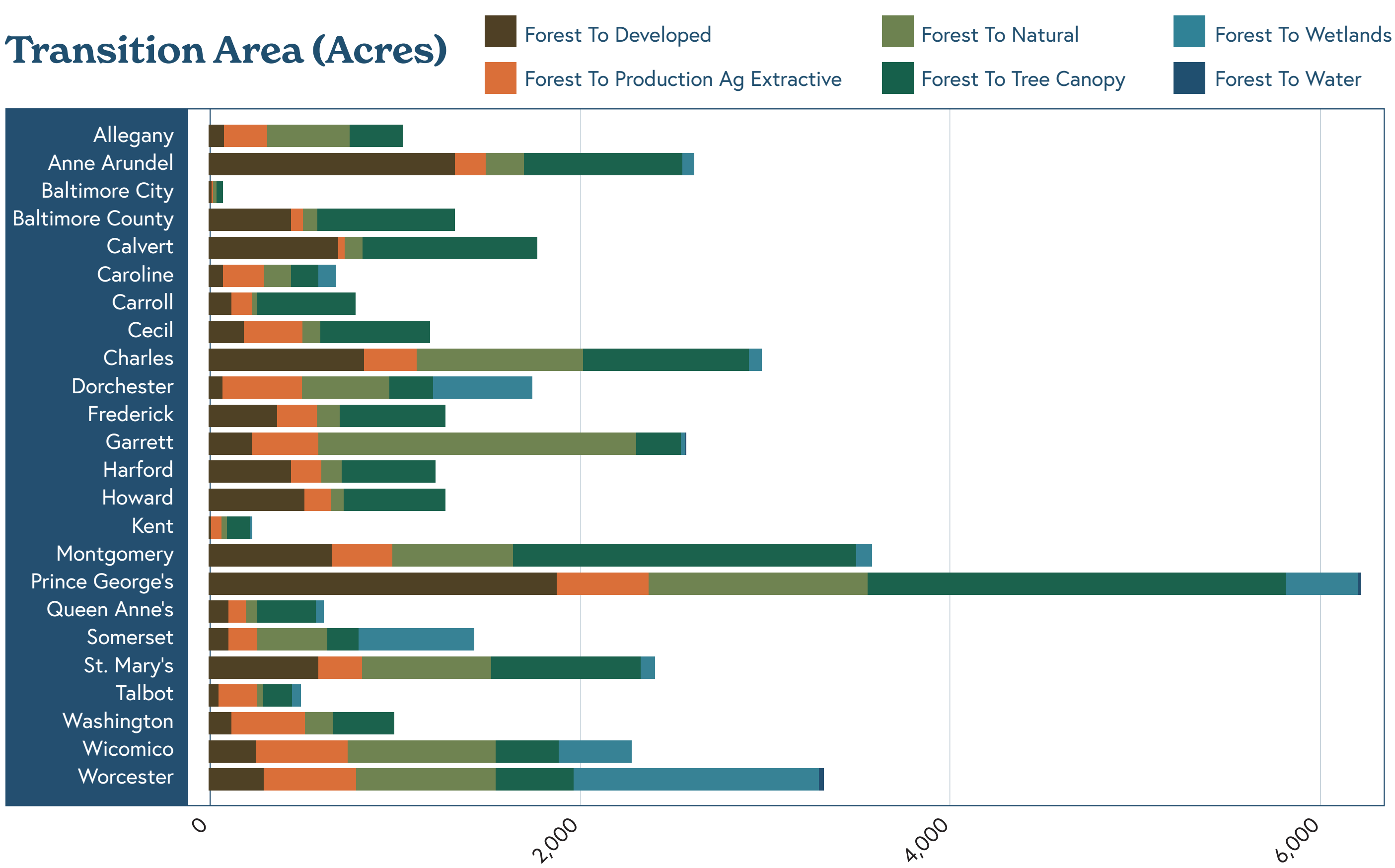


Figure ES-3. *Forest transitions to other land covers and uses (acres).*

In 2018, 33% of Maryland's forests and 9% of tree canopy outside forests were protected by government parks or private easements. Protected lands experienced a significantly lower rate of forest loss and a much higher rate of total tree canopy increase compared with statewide rates. We conclude that protection benefits forest conservation in Maryland and leads to forest expansion. This finding has implications for the management of Priority Protection Areas, which are important ecological areas that may or may not have protective measures in place. These areas were at greater risk of forest and total tree canopy cover loss than protected areas.

Future forest cover projections completed with the Chesapeake Bay Land Change Model (CBLCM) based on a business-as-usual scenario predict statewide loss in forest cover from 2025 to 2055, accompanied by an increase in impervious surfaces and canopy over impervious surfaces (Task 5). This trend may be offset in part by tree planting, reforestation and afforestation programs operating in the state. These programs — which include Healthy Forests Healthy Waters, Backyard Buffers, the Conservation Reserve Enhancement Program (CREP), the Environmental Quality Incentives Program (EQIP) and others — assist Maryland in achieving its Total Maximum Daily Load (TMDL) commitments under the CBWA while addressing associated environmental and human health goals.

In 2018 and 2019, government and private tree planting programs were responsible for the planting of an estimated 1,853 cumulative acres, more than half of which was in response to the Forest Conservation Act (Task 7). This trend toward increasing tree planting should continue and accelerate with implementation of the Tree Solutions Now Act of 2021 that sets the goal of planting an additional 5 million trees (~12,500 acres) over the eight-year period from 2023 to 2031. There is ample land area providing opportunity for planting trees; this study identified over 373,500 acres of potential afforestation and reforestation sites in Maryland on non-agricultural lands. Planting only 3.3% of the identified area would enable Maryland to reach its TSNA goal.

Forest mitigation banks are a mechanism under the Forest Conservation Act that enables developers to fulfill their afforestation or reforestation requirements by purchasing credits for trees preserved or planted off-site. Banks have been established in 15 of the 18 Maryland counties that have provisions for forest mitigation banking in their regulations. All counties with banking programs have geographic requirements or priorities for the location of banks to incentivize tree planting in areas that provide the greatest ecosystem services. Across the state, 81.1% of reported mitigation bank acres protect existing forest, with newly planted forest only making up 18.9% of forest bank acres. This suggests that steps may need to be taken to encourage the creation of planted forest banks, since forest banks can no longer be created from existing forest (at least until June 30, 2024 per the provisions of the Tree Solutions Now Act of 2021). The market for banking varies by county and depends on factors such as the number of development projects and the feasibility of on-site mitigation. The percentage of development projects within a county that rely on banking credits for mitigation shows great variation (0 to 80%). There is little evidence of a relationship between current fee-in-lieu rates and the market for banking, but higher fee-in-lieu rates could encourage the creation of newly planted forest banks in the future. There is ample evidence of the benefits of afforestation on water quality and the effectiveness of wetland mitigation banks to support forest mitigation banks as a water quality protection mechanism. The majority of banks in the state, however, represent preservation of existing forest rather than afforestation.

In conclusion, the rate of forest loss in Maryland has moved from rates of significant decline toward stabilization since the Forest Conservation Act of 1991. However, forest loss for development and forest fragmentation continue to be significant trends, especially

Development in Prince George's County, Maryland. Photo Credit: Chesapeake Bay Program

in Central Maryland, though with regional variation. In order to reverse this trend, the state should prioritize forest protection as a mechanism for not only maintaining, but also increasing, forest area. Protecting existing tree canopy may provide greater near-term growth in the area covered by trees compared to tree planting, which may require five to 10 or more years to establish a sizable canopy area. A variety of policies and programs already underway may accelerate the protection of existing forest and tree canopy, complemented by expanding efforts to plant trees and promote reforestation or afforestation, such as the Tree Solutions Now Act. High-resolution monitoring of forest and tree canopy, complemented by long-term moderate resolution satellite monitoring and the Forest Service FIA field sampling program, provide the means to assess long-term trends as well as regional patterns, drivers of forest and tree canopy change and the first opportunity to systematically measure tree canopy outside forest statewide. Continued support for forest and tree canopy monitoring as well as consistent and standardized data collection on tree planting and mitigation programs will help assure progress toward various environmental, economic and social justice goals.

Restored wetlands on a farm in Caroline County, Maryland Photo Credit: Chesapeake Bay Program

Introduction

The State of Maryland has an evolving history of forest stewardship, marked particularly by the Forest Conservation Act of 1991 and subsequent legislation. In recent years the state government identified a need to improve its inventory of forest and tree canopy cover, assess near- and long-term change and assess the effectiveness of forest and tree planting programs operating in the state. To address this need, the Maryland General Assembly enacted legislation in 2019 and 2021 requiring a ***Technical Study of Changes in Maryland's Forest Cover and Tree Canopy*** to be conducted by the Harry R. Hughes Center for Agro-Ecology, in consultation with the Department of Natural Resources, the Department of the Environment, the Department of Planning, the Department of Agriculture and the Chesapeake Bay Program (SB 729/HB 735 in 2019; HB 991, Tree Solutions Now Act of 2021). Individuals from those organizations directly contributed to this work and report and are collectively known as the Advisory Committee. Specifically, the bill authorized the following deliverables:

i) a statewide mapping of the current status of forest cover and tree canopy in the state, in addition to a mapping of potential reforestation and afforestation locations;

ii) an analysis of the health and quality of forests in the state;

iii) an assessment of the state's progress toward expanding urban tree canopy acres and riparian forest buffers as part of its commitment to the Chesapeake Bay Watershed Agreement;

iv) an analysis of existing and projected changes due to development, management and other causes by applying the Chesapeake Bay Phase 6 Model, Chesapeake Assessment Scenario Tool (CAST);

v) an analysis of observed and projected changes in forest and tree cover due to state and local tree planting, afforestation and reforestation programs and forest identified for preservation through federal, state and local government-led programs;

vi) a review of forest mitigation banking in the state; and

vii) a programmatic and funding review of federal, state and local tree and forest planting programs in the state.

This report, prepared in partnership with the Chesapeake Conservancy and the University of Vermont Spatial Analysis Lab presents these deliverables. An associated online StoryMap with a map viewer provides the opportunity to view and interact with data and findings produced in support of this study.

Forests represent one of Maryland's most important natural resources, critical to its economy, sustainability, health and identity. They are vitally important for water filtration, stormwater mitigation, air pollution removal, climate resilience and carbon sequestration. Forest conservation and tree planting have been identified as a central strategy to achieve the goals laid out in the 2014 Chesapeake Bay Agreement. Forests have been recognized as an important climate adaptation strategy, offering protection against storm surges, floods, sea level rise and extreme temperatures. Trees outside forests, including urban trees, serve important functions, mitigating the urban heat island effect, improving air quality, providing natural heating and cooling factors and benefiting human mental and physical health. Tree cover is an important component of "green infrastructure," and serves a critical environmental justice role in low income and other disadvantaged communities.

Maryland's legal code references forest and tree conservation, restoration and afforestation in multiple places. In addition to the pivotal ***Forest Conservation Act of 1991*** (Title 08 Subtitle 19, Natural Resources

(NR) Article § 5-1601 to 5-1613), Maryland passed the Forest Preservation Act of 2013 (MD NR Code § 5-101 (2021)/HB 706 2013), the ***Maryland Reforestation Law of 1989*** (MD NR Code § 5-103), the ***Greenhouse Gas Emissions Reduction Act (GGRA) - Reauthorization of 2016*** (SB 323), the ***Climate Solutions Now Act of 2022*** (SB0528/CH0038) and the ***Conservation Finance Act of 2022*** (HB653/SB348). Maryland is also a signatory to the Chesapeake Bay Watershed Agreement (CBWA) of 2014 and Directive 06 - ***Protecting the Forests of the Chesapeake Bay Watershed.*** The ***Tree Solutions Now Act of 2021*** (HB991), requires this technical study in addition to the planting of 5 million trees in Maryland by 2031. The results of this technical study have relevance to all of these commitments.

Characteristics of Maryland Forests

The State of Maryland is at the intersection of three ecological provinces. The Mid-Atlantic Coastal Plains and Flatwoods, primarily composed of mixed forests, span the eastern part of the state surrounding the Chesapeake Bay and lining the eastern shore. The Northern Appalachian Piedmont, composed of primarily Eastern Broadleaf Forests, occupies the central region of the state, and Central Appalachian Broadleaf-Coniferous Forests and meadows dominate the mountains of the west (Cleland et al. 2007).

The United States Department of Agriculture (USDA) Forest Inventory Assessment (FIA) estimated in 2020 that forests make up an estimated 39.7% of the state's land area, or 2.4 million acres (USDA Forest Service 2020). Maryland forests are particularly unique and biodiverse due to the state's varied topography, climate and soil, in addition to its geographic position at the northern and southernmost ranges of certain tree species (MDNR Forest Service n.d.). Oak/hickory dominant forests represent about 60% of the state's forest, particularly in the northeast and central regions. Loblolly and shortleaf pine are most prevalent in the southernmost counties. In fact, Maryland represents the northernmost part of these species ranges. In western Maryland, maple and birch are the dominant tree species (Lister 2017).

Forests offer a range of ecosystem services that benefit the state's people and economy. They are critically important for water filtration to remove pollutants and toxins from surface water, stormwater mitigation to prevent flooding and erosion, air pollution removal to improve air quality and human health and carbon sequestration to draw heat trapping gasses from the atmosphere (Hurtt et al. 2019; MDE 2021; State of Maryland 2019). Forest conservation and tree planting have been identified as a central strategy to achieving the goals laid out in the Chesapeake Bay Agreement, particularly for their water filtration and storage benefits. This natural resource has been identified as critical to achieving Total Maximum Daily Load (TMDL) pollutant goals (State of Maryland 2019; Center for Watershed Protection 2005; CBWA 2014). Forests, as buffers and natural filters, have been recognized as an important climate adaptation strategy which should enable the state to better adapt to storm surges, floods, sea level rise and extreme temperatures (State of Maryland 2019). Trees outside forests also offer important services. Urban trees help mitigate the heat island effect, improve air quality, provide natural heating and cooling factors and benefit human mental and physical health (State of Maryland 2019).

Forests also offer important wildlife habitat. The state has over 20,000 documented species of flora and fauna, including 21 federally listed endangered and threatened species. Many of these species rely on habitats or services provided by forests for all or part of their life cycles (Maryland Biodiversity Project, n.d.; USFWS 2015).

Forests and trees offer tangible benefits to the state's economy. Forests and wetlands contribute an estimated $3.1 billion/yr in flood prevention and stormwater mitigation, an estimated $140 million/yr in reducing air pollution and $246 million/yr in surface water protection (Campbell et al. 2019). These are expenses the state would need to pay if it were to develop and apply technologies to serve these functions. The outdoor recreation industry is significant, contributing $14.0 billion per year in spending to the state's economy (Outdoor Industry Association 2017). Natural resource-based economies, including forestry, fishing and hunting and agriculture, contribute $26.5 billion to the state's economy every year (Guy et al. 2017). Currently, the 1.5 million acres of protected land in Maryland (much of which is forested) generates 4 billion dollars annually (Campbell et al. 2019). At the micro level at home, one large tree can eliminate up to 5,000 gallons of stormwater runoff per year and reduce building energy costs by 15-35% for individual home and business owners (State of Maryland 2019).

Historical Context

When the first European settlers arrived in what was to become Maryland in the 1600s, the state was primarily under old growth forest. The region was inhabited by several Native American tribes who relied on hunting and fishing for subsistence, including the Assateague, Accohannock, Delaware, Matapeake, Nanticoke, Nause-Waiwash, Piscataway Conoy, Piscataway, Pocomoke and Shawnee (State of Maryland 2021; NPS n.d.). As European settlements were established and human population expanded, 90% of the state's forests were cleared for agriculture and timber until about the mid-1800s. Between that time and the latter half of the twentieth century, forest extent followed a generally increasing trend. From 1964 until 2008, forest extent decreased by 16%, with the most rapid loss between 1964 and 1976 (Figure 1). The primary cause of modern-day forest loss is population growth and development (Widmann 2002; Lister 2017; MDP n.d.a.). While the rate of forest loss appears to have slowed in the last couple of decades, the state's forests showed an approximately 1% decline in extent compared with the previous decade, largely attributed to aging trees, development and disease (Maryland DE 2021; Domke et al. 2020).

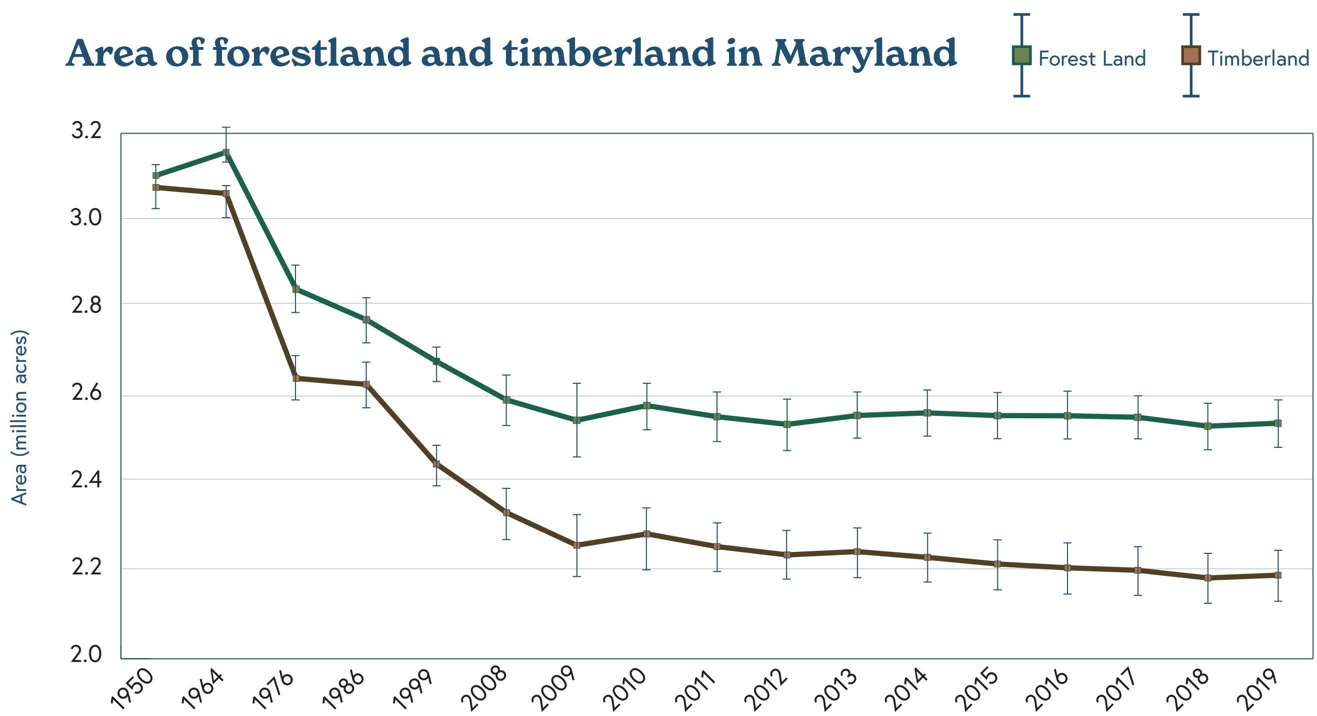


Figure 1. *Area of forestland and timberland in Maryland (1950-2019) (USDA Forest Service 2022).*

Despite overall decreases over the past 50 years, the state's forest cover has been remarkably stable given the considerable increase in human population. According to the 2020 U.S. Census, Maryland has a population of nearly 6.2 million, having experienced nearly 17% growth since 2000 and more than tripled since 1940 (State of Maryland 2020, Figure 2). Human population and population growth has been unevenly distributed throughout the state, with the highest population density in and around the cities of Baltimore and Annapolis and north of Washington, D.C. Maryland has concurrently experienced large-scale land use change (MDP n.d.b.). From 1973 to 2010, a land use/land cover assessment indicates that developed land more than doubled and is estimated to cover about 27% of Maryland's land area, or nearly 1.7 million acres (MDP 2010). Since 1950, nearly 50% of agricultural land has gone out of production and most of this has been converted to development or regenerated forests on private land. The fact that a large proportion of agricultural land has been converted to forests, coupled with the fact that population increases have been centered in and around urban areas, has counteracted the potentially negative impacts of large-scale population growth on forest extent (Widmann 2002).

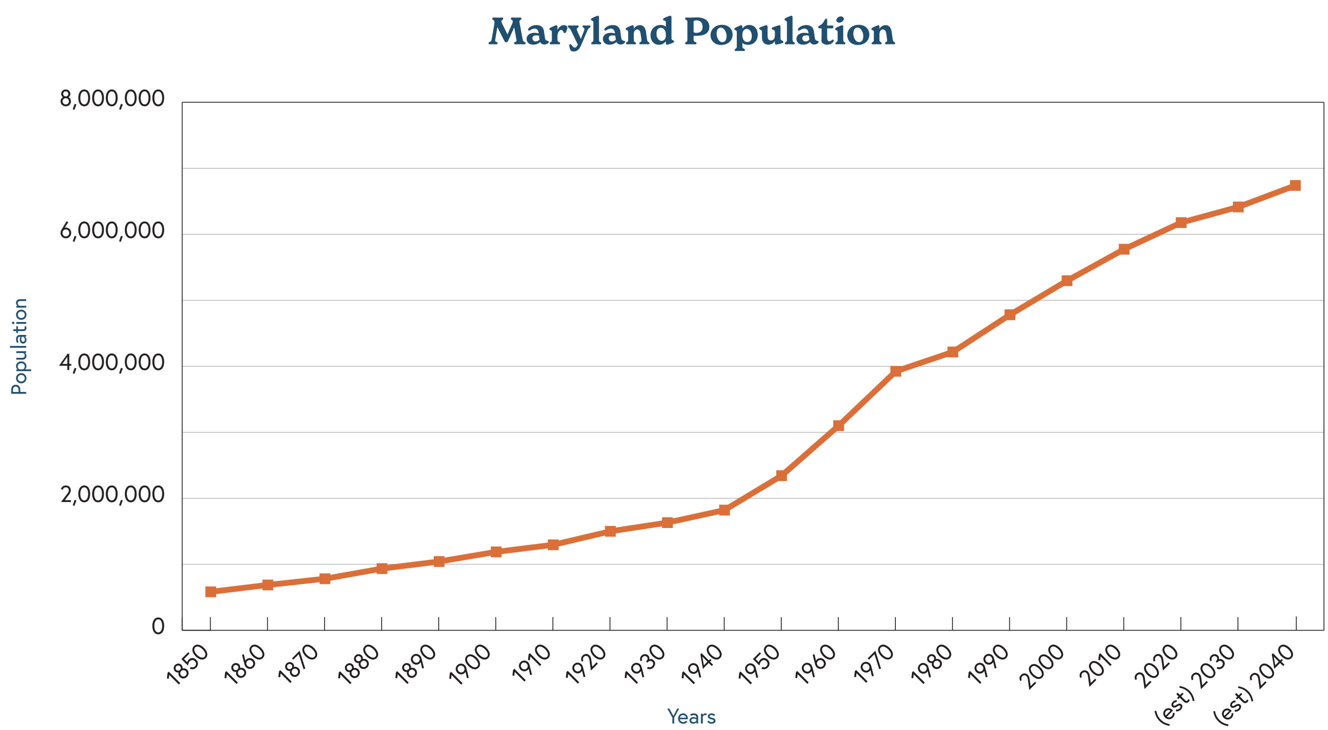


Figure 2. *Observed and projected changes in population, 1850-2040 (__State of Maryland 2020__).*

Today, the Coastal Plains surrounding the Chesapeake Bay continue to host the most densely populated areas of the state, including Baltimore and the Washington, D.C. suburbs. Beyond urban areas, the coastal plains and piedmont regions have a mosaic of agricultural land, forest and low density development. The Appalachian Mountains of the west remain primarily under forest cover (MDP 2010).

It is worth noting that a large proportion of Maryland's forests are fragmented. Forest fragmentation analysis from the early 2000s found that 60% of Maryland's forest is within 300 feet of agriculture or development and that about 30% of forest is within 330 feet of road (Lister et al. 2011). Forest patches vary considerably in size by county (Lister et al. 2011, Figure 3). A large proportion of small patches in a landscape can indicate fragmentation and poor habitat quality (Riedler and Lang 2018).

Distribution of Forest Land

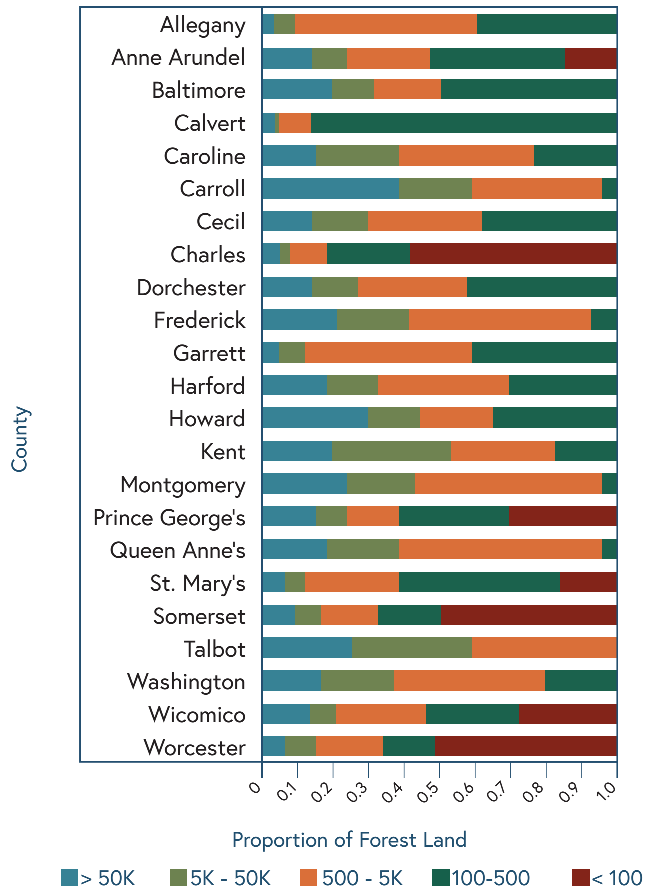


Figure 3. *Distribution of forest land by patch size and county, Maryland, 2000 (**Lister et al. 2011**).*

Maryland's forests are predominantly mature, with implications for their overall resilience, as well as for wildlife and carbon sequestration rates. Seventy-eight percent of forests are dominated by trees with large diameter trunks, while only 7% of forests have predominantly small diameter trees (Lister 2017). Forests that lack diverse age classes are vulnerable to loss all at once as older trees reach the natural end of their lives or succumb to disease (Spencer, n.d.). Some wildlife species, such as the golden-winged warbler (Vermivora chrysoptera), American woodcock (Scolopax minor) and cottontail rabbit (Sylvilagus floridanus) require younger stands to survive (Lister 2017; Spencer, n.d.). The overall rate of carbon sequestration slows among mature trees. Due to aging, Maryland trees experienced an approximately 17% decrease in the rate of carbon sequestration between the first and second decades of the 21st century, though the amount of carbon stored in forests still continues to increase (**Domke et al. 2020**; MDE 2021). A more recent UMD/NASA study agrees that Maryland's carbon sink is expanding, though at a higher rate than Domke et al. (2020) suggests (R. Lamb, MDE, personal communication, May 20, 2022).

While forest fragmentation and the predominantly mature State of Maryland's forests are two forest health concerns, the third is invasive species. Prior to 2008, FIA data indicated that the multiflora rose (Rosa multiflora) and Japanese honeysuckle (Lonicera japonica) are the most common invasive species affecting forests in Maryland. The multiflora rose is of concern due to its tendency to form dense, homogenous mats on the forest floor and prevent growth of new trees, while the Japanese honeysuckle emerges as vines that can girdle young trees or form dense canopies that block out light. Other concerning identifications included the common buckthorn (Rhamnus cathartica), which changes soil chemistry and suitability for native species and the emerald ash borer (Agrilus planipennis), which attacks ash trees. Ash represents 4% of tree species in Maryland. The hemlock woolly adelgid (Adelges tsugae) attacks hemlock trees, which were particularly common in Garrett County in the western part of the state (Lister et al. 2011).

Other indicators of forest health include well-leafed out crowns, soil health, standing dead trees (as habitats), understory vegetation and down woody materials. Assessment prior to 2008 indicated that Maryland's intact forests scored relatively well with respect to these indicators. Air pollution remains an additional, moderate threat to the health of Maryland forests (Lister et al. 2011).

Forests in Maryland are under a mosaic of management types. Seventy-three percent of forests are under private ownership, while the largest public owner of forest land in Maryland is the state (USDA Forest Service 2020). The variety of ownership produces conservation and management challenges.

Policy Context

Maryland has a tradition of emerging forest stewardship through its legal code.

Recognizing the challenges posed by diverse ownership of forests in Maryland, the **Forest Conservation Act (FCA) of 1991** (Natural Resources Article, § 5-1601--5-1612, Annotated Code of Maryland, State of Maryland 1991) provides a consistent set of management criteria applied across ownership types and jurisdictions. Under this law, landowners are required to identify forest stands and priority areas for conservation prior to implementing development projects. Priority areas are those adjacent to streams or wetlands, those on steep or erodible soils or those within or adjacent to large contiguous blocks of forest or wildlife corridors. The Maryland Department of Natural Resources (MDNR) Forest Service administers the FCA, and it is implemented on a local level. Gaining approval of the required Forest Conservation Plan may require long-term protection of identified priority areas for planting or replanting (afforestation or reforestation) or protection of a sensitive area off-site (MDNR n.d.a; State of Maryland 1991). A 15-year review of the FCA indicated that between 1993 and 2007, nearly 200,000 acres of land were reviewed for development. Of this, 60% of forest area was retained, particularly in priority areas, and 35% was cleared. In addition, about 21,000 acres were planted with new forest (MDNR Forest Service 2010). This is arguably a better outcome for forests and associated ecosystem services than would have occurred in the absence of the act.

The **Forest Preservation Act of 2013** (Maryland General Assembly HB 706) builds on the FCA by setting a target of No Net Forest Loss, seeking to maintain the state's estimated 40% tree canopy cover (HB 706, 2013). The Act uses new and modified incentives for private landowners to conserve and preserve forestland, including tax credits, certifications and financing mechanisms (Georgetown Climate Center 2013).

The **Maryland Reforestation Law of 1989** applies to highway projects financed by state funds that are exempt from the FCA. In cases where forest is cleared for a new highway, forest acreage must be replaced on a 1:1 basis on public lands in other parts of the watershed or county. When this is not possible, funds must be deposited into a Reforestation Fund administered by MDNR to plant trees. Since being enacted in 1989, 2,173 acres of forested land have been cleared by highway construction and 2,487 acres have been replanted, for a net gain of 314 acres (State of Maryland 1989; MDNR n.d.b.).

A few other agreements emphasize forest stewardship as an important strategic component. The **Chesapeake Bay Watershed Agreement (CBWA) of 2014** commits its signatories from seven relevant jurisdictions (Maryland, Delaware, Virginia, District of Columbia, West Virginia, Pennsylvania and New York) to restore the Bay watershed (CBWA 2014). This agreement recognizes the vital services of forests and trees outside forests for maintaining the integrity of the bay, including water quality, ecosystem and human health. It recommends a series of strategies for maintaining and expanding tree cover and forest health, elaborated in Maryland's most current Chesapeake Bay watershed restoration plan (State of Maryland 2019). The CBWA of 2014 was preceded by **Directive 06-1 - Protecting the Forests of the Chesapeake Bay Watershed**, which articulated goals related to forest protection, riparian habitats and protective policies in the watershed (Chesapeake Executive Council 2006, 2007). Prior to this, the Maryland Critical Area Act of 1984 established a Commission to set minimum requirements for the protection of water quality and the conservation of plants and wildlife in defined Critical Areas of the Chesapeake Bay tidal zone. These included the requirement that jurisdictions maintain intact, interior forest habitats for wildlife in these Critical Areas (Jones et al. 2000; Chesapeake Bay Foundation 2004).

Maryland's Climate Solutions Now Act of 2022 (CSNA) commits the state to achieve a 60% reduction in statewide greenhouse gas (GHG) emissions by 2031 compared with a 2006 baseline and reach net zero emissions by 2045 (Maryland SB 0528/CH0038; Fischer 2022). This legislation updates the **Greenhouse Gas Emissions Reduction Act (GGRA)- Reauthorization of 2016**, which previously established a 40% emissions reduction goal by 2030. The 2030 GGRA Plan recognizes natural and working lands, including forests, as vital carbon sinks. Recent estimates suggest that more than 110 teragrams of carbon (Tg C) are presently stored in Maryland forests in the form of aboveground forest carbon, with the potential for further sequestration equal to twice that amount (Hurtt et al. 2019). For this reason, forest preservation, reforestation and afforestation, as well as planting and maintaining trees outside forests, are emphasized as a vital component of the state's emissions reduction strategy (MDE 2021). The Maryland Commission on Climate Change (MCCC) recognized a need to improve baseline estimates and conduct ongoing monitoring of forest carbon stocks; it thus has supported updates to the state's 2020 GHG Inventory based in part on the high-resolution tree canopy data as used in this study (R. Lamb, personal communication, December 2021).

The **Conservation Finance Act of 2022** expands the way private financing can benefit state climate, water quality and conservation goals while making green infrastructure, other natural infrastructure and social equity a greater part of Maryland environmental programs (SB 348/HB 653; CC 2022).

Recognizing the need to inventory the state's existing forest resources and assess recent trends, the Maryland General Assembly enacted SB 729 in 2019 (**Technical Study on Changes in Forest Cover and Tree Canopy in Maryland**). The Act required a technical study of changes in Maryland's forest cover and tree canopy. This report, prepared as a partnership between the Harry Hughes Center for Agroecology, the Chesapeake Conservancy and the University of Vermont Spatial Analysis Lab presents the findings of this technical study.

To accelerate tree planting, the General Assembly passed the **Tree Solutions Now Act of 2021** (HB 991). The Act sets the goal of growing 5 million new native trees in Maryland from 2022-2031, 10% of which are required to be planted in underserved urban areas (Butler 2021). The Act also reiterated the request to perform a technical study of changes in Maryland's forest cover and tree canopy (again, this report).

Our Approach

Our methods for inventorying forest and tree canopy cover rely on statewide land use and land cover data at two scales. To report on large-scale forest cover trends over the past 20 years, we used data from USDA's National Forest Inventory and Analysis (FIA) Program and the USGS National Land Cover Database (NLCD) from 2001-2019 (USDA Forest Service 2020; MRLCC 2021). The FIA is a multi-decadal field sample inventory of forest plots across the state, while the NLCD is a land cover classification based on remote sensing utilizing 30-meter resolution imagery from the Landsat satellite program. At the time of this study, an accuracy assessment had not been conducted for the 2019 NLCD Data, which is considered provisional, but accuracy assessment of the 2016 land cover data (produced using a comparable automated methodology) was 91% (Wickham et al. 2021).

We complemented these with analyses based on a newly released, innovative, very high-resolution (1-m) land use/land cover dataset available statewide for Maryland, representing the years 2013 and 2018. These datasets were created by the Chesapeake Bay Program in partnership with Chesapeake Conservancy, U.S. Geological Survey and the University of Vermont Spatial Analysis Lab, using aerial imagery available from the National Aerial Imagery Program (USDA-FSA-APFO n.d.) and LiDAR (a laser based remote sensing technology) (CBPO, 2022a, 2022b, 2022c, 2022d, Clagget et al. 2022). Accuracy assessment revealed 94% in Maryland for the purpose of this study (see Data and Methods section).

The 1-m tree canopy data is powerful in that it can detect changes in individual trees, whereas the coarse data can only detect large patches of tree canopy. Within large areas of forest, the high-resolution technology is useful for detecting tree or canopy loss (i.e., from invasive species, aging, pests, selective logging) or gain (i.e., from natural succession, growth). Outside of core forest areas, the tree canopy data detects changes at forest edges, changes in the shape or spatial structure of fragmented tree patches and in urban settings. In contrast with the 30-m resolution Landsat imagery, the aerial imagery and LiDAR used to produce the 1-meter resolution tree canopy data became available recently and is only flown every few years, limiting the interval for which high-resolution change detection analyses can be completed (in this case, from 2013-2018). Coupled with LiDAR and ground-based data sources, high-resolution tree canopy data is powerful for estimating carbon stored in existing forest areas.

These moderate and high-resolution datasets were used as inputs into various analyses conducted throughout the report. More details on the methods are available in the Data and Methods section, and results are presented in this report by task (Table 1).

Tasks

Table 1 includes the associated bill task, description and section heading for the results of each analysis.

Task	Description	Section Heading
Task 1	Survey and Mapping	Extent
Task 1a	Existing forest cover and tree canopy in the state	Forest and tree canopy extent
Task 1b	Potential afforestation and reforestation locations in the state	Afforestation and reforestation opportunities
Task 2	An analysis of the health and quality of forests in the state	Health
Task 3	An analysis of the progress toward the state's commitments to expand urban tree canopy acres and plant riparian forest buffers under the 2014 Chesapeake Bay Agreement	Progress Urban tree canopy Riparian forest buffers
Task 4	An analysis of observed and projected changes in land cover and the amount of forest cover in the state due to development or other causes, using the Chesapeake Bay Phase 6 Model, Chesapeake Assessment Scenario Tool (CAST) and county and municipal forest conservation annual reports and land use plans, including the extent and nature of: 1. Mitigation activities involving existing forest conserved, tree planting, reforestation or afforestation under the Forest Conservation Act (Note: Covered in Tasks 6 and 7) 2. Forest clearing, planting and mitigation activity inside and outside priority funding areas and locally designated growth areas 3. The clearing and mitigation of forest considered to be a priority for retention and protection under §5-1607(c) of the Natural Resources Article and in state-identified targeted ecological areas and greenways, hubs and corridors; and the zoned density and sewer status of those areas	Change • Observed forest cover loss and gain ◊ Priority funding areas ◊ Locally designated growth areas ◊ Targeted ecological areas ◊ Zoning ◊ Sewer Service Areas
Task 5	An analysis of observed and projected changes in the amount of forest cover in the state based on: 1. Relevant state or local programs involving tree planting, reforestation or afforestation and 2. The amount of forest preserved through federal, state and local programs, including agricultural preservation, open space, conservation easement and other land preservation programs.	Forest & tree canopy commitments Projected forest change Amount of forest protected

Task	Description	Section Heading
Task 6	A review of forest mitigation banking in the state, including: 1. Capacity and location of active banks 2. Regulation of siting and creation of new banks 3. Geographic limitations on the use of mitigation banks 4. The relationship between fee-in lieu rates under the Forest Conservation Act and the market for forest mitigation banks 5. Whether expanding the use of forest mitigation banks could provide water quality improvements and other beneficial results 6. The extent to which existing forest mitigation banks are composed of forests that have been created or restored versus forests that are under qualified conservation (HB 991) and 7. The effect of using qualified conservation completed in a forest mitigation bank to meet afforestation or reforestation requirements under state or local programs on the state's policy of achieving no net loss of forest (HB 991)	Mitigation
Task 7	A programmatic and funding review of federal, state and local tree and forest planting programs such as: 1. Marylanders Plant Trees 2. Lawn to Woodland 3. Backyard Buffers 4. Conservation Reserve Enhancement Program 5. Other programs used to further TMDL Watershed Implementation Plans and MS4 permit compliance	Forest and Tree Planting Programs

Forest and tree canopy extent (Task 1a)

Forests cover approximately 2.448 to 2.566 million acres of Maryland's land area (FIA, CBPO). Estimates of percent of Maryland's land covered by forest range from 39% to 42%, depending on the approach used (USDA Forest Service 2020; Claggett et al. 2022). When tree canopy outside forest is also considered, total tree canopy covers 50% (3.095 million acres) of the state's land. Maryland's forest extent has shown a slight decreasing trend over the past two decades, but with a turn toward stabilization in the past 10 years. Tree canopy cover varies greatly by jurisdiction, from 28.6% cover at the low end, to 81.9% at the highest. The state has ample opportunities for tree planting, and this study identified over 373,500 potentially suitable acres.

Statewide Patterns

Forest and tree canopy extent estimates were provided from three main data sources (Table 2). The USDA Forest Service's Forest Inventory and Analysis (FIA) Program is based on statistical analysis of field-sampled plots and provides the longest record of forest extent and change available. Approximately 14% of the state's permanent field sample plots are measured each year by the U.S. Forest Service. Estimates from the National Land Cover Dataset (NLCD) are based on time series analysis of moderate (30m) resolution satellite imagery from Landsat, the longest satellite data record available (MRLCC 2021; Potapov et al. 2021). Though this dataset is periodic and provides wall-to-wall coverage, its resolution limits information about conditions on the ground. High-resolution (1-m) tree canopy change detection was completed using data recently published by the Chesapeake Bay Program Office (CBPO) representing the five-year interval from 2013-2018 (CBPO 2022a, 2022c; O'Neil-Dunne 2019). Only the CBPO data provide updated estimates for tree canopy outside forests, and this study represents the first-ever near statewide analysis of tree canopy cover change outside forests (excluding only Aberdeen Proving Ground). While the CBPO dataset is powerful for the combination of its comprehensive coverage and spatial granularity, this dataset is limited in terms of temporal availability as the image collection began more recently.

The FIA estimates forest cover in Maryland in 2019 to be 2,448,000 (+/- 108,000) acres, while the CBPO estimates 2,566,000 acres of forest in 2018 (e.g., tree canopy within forest). The CBPO estimates an additional 529,000 acres of tree canopy outside forest (TCOF), to total 3,095,000 acres of total tree canopy (Total TC) in 2018. The NLCD estimate of tree canopy cover is 2,791,000 acres for 2019, but the capability of this dataset to detect small patches of forest and individual trees is compromised by its resolution (30-m) (Table 2). The 2018 CBPO dataset showed an accuracy of 94% for detecting tree canopy cover, and the NLCD accuracy for 2019 is estimated at approximately 91% (also see Data and Methods).

Table 2. *Forest extent estimates from key data sources.*

Source	Initial Year	Extent (thousand acres)	End Year	Extent (thousand acres)	Total % Change (Annual % Change)
Forest					
FIA[1,2]	1999	2,566 (+/- 770)	2019	2,448 (+/- 108)	-4.6% (-0.23%)
CBPO	2013	2,584	2018	2,566	-0.70% (- 0.14%)
Tree Canopy					
Total Tree Canopy (NLCD)	2001	2,802	2019	2,791	-0.39% (-0.022%)
Within Forest (CBPO)	2013	2,584	2018	2,566	-0.70% (- 0.14%)
Outside Forest (CBPO	2013	523	2018	529	+1.15% (+0.23%)
Total Tree Canopy (CBPO)[3]	2013	3,107	2018	3,095	-0.39% (-0.077%)

Notes: 1. FIA error estimates presented here represent 95% confidence intervals (Frieswyk 2001), Confidence intervals are not available for the CBPO and NLCD datasets, but accuracy is estimated at 94% and 91% in the latter year of each dataset, respectively (see Data and Methods). 2. The FIA defines Forest Land as land that is at least 10% stocked by trees of any size or formerly having been stocked and not currently developed for non-forest use. The area with trees must be at least 1 acre in size and 120 feet wide, measured stem-to-stem from the outermost edge. Forested strips must be 120.0 feet wide for a continuous length of at least 363.0 feet in order to meet the acre threshold (USDA Forest Service 2021), 3. CBPO defines Forest as contiguous patches of trees at least one acre in extent with a patch width of at least 240 feet (CBP 2022d, Clagget et al. 2022). 4. Study extents differ for each dataset. In particular, the CBPO dataset excludes the Aberdeen Proving Ground. More on extent is provided in Data and Methods.

Variations in forest extent estimates are due to differences in forest definitions, study extents and detection methods applied. For example, the NLCD defines forest as >20% tree cover in a given 30 m pixel (900 m2 or 0.2 acres). The CBPO and FIA, by contrast, apply a stricter definition of forest, setting the minimum extent of forest land to at least 1 acre of tree cover and with minimum girth (see Definitions section for details). The NLCD forest estimates include moderately sized tree patches that would otherwise be classified as tree canopy outside forest by the CBPO dataset, so we consider the NLCD forest class to be a representation of tree canopy by this study. Unlike the high-resolution CBPO dataset, however, the NLCD isn't capable of detecting single trees or small patches of trees (<30m). For this reason, the overall estimates of tree canopy cover estimated by the NLCD are lower than those provided by the CBPO dataset. Notably, the CBPO study excludes Aberdeen Proving Ground (38,954 acres) from its extent, so estimates from this dataset do not represent all statewide forest cover. Since preparation methods vary considerably between data sources, we dissuade direct comparison of extent estimates between datasets without a holistic understanding of their differences. It is, however, useful to look at trends over time for each individual product and feasible to compare and contrast trends among products.

CBPO estimates that forest covers 42% of the state's land area (2018), though FIA estimates forests to cover 39.4% (USDA Forest Service 2020). Total tree canopy, including tree canopy within and outside forest, represents 50% of Maryland's total land area, based on CBPO data. Variations in the percent forest area estimates offered by different datasets are not only due to the different approaches used to estimate forest extent (as cited above, for the numerator), but the different approaches to estimate study extent or land area (for the denominator). In this case, land area estimates that form the denominator of the percent tree canopy and forest estimates vary from 6,154,413 acres in the case of CBPO to 6,212,714 land area for FIA. More on these methods and sources are provided in the Data and Methods section (Claggett 2022, US Census Bureau 2010). We note that despite differences in technology and methods, a decreasing trend in forest extent was detected by all three datasets over their respective study periods. FIA detected an annual net loss of 0.23% forest extent annually from 1999-2019, while NLCD detected an annual net loss of 0.022% over a similar time frame (2001-2019). The CBPO study also detected a decreasing trend in forest cover statewide, with an estimated loss of 18,000 acres from 2013 to 2018, representing 0.70% forest cover loss over five years or -0.14% annually. Taken together, these datasets provide compelling evidence that forest cover in Maryland is declining over this period.

At the same time, CBPO data indicated that Maryland gained approximately 6,000 acres of tree canopy outside forests (1.15% increase overall, or +0.23% annual change), indicating a potential trend toward increased forest fragmentation but also greening of urban, suburban and agricultural areas. Maryland thus experienced a resultant net decrease of about 12,000 acres of tree canopy cover overall during the five-year study interval, representing about -0.39% tree canopy change overall (-0.077% annual, see Table 2). We note that somewhat small net changes in statewide forest and tree canopy are exceeded by far more spatially dynamic gain and loss change patterns that vary widely across the state (Table 12).

Since methodological differences can lead to variations in absolute estimates of forest cover and percent land coverage, the tracking of temporal trends, particularly using more than one dataset, can provide a more reliable indicator of forest cover status and change. When using forest extent and percent land area extent as indicators, detailed attention needs to be provided to the datasets and methods used to produce it.

Patterns by jurisdiction

Tree cover in Maryland varies greatly by region. Western and Southern Maryland have the greatest tree cover overall (>60% of land area), and this is predominantly within forest. Upper Eastern and North Central Maryland have lower tree cover due to greater agricultural and urban land use. While tree canopy within forest blocks tends to occupy a larger percent land area than tree canopy outside forest across all regions, Central Maryland has the largest area of tree canopy outside forest, indicative of fragmentation associated with development (Figure 4).

When individual counties are observed, we note that the counties with the largest extents of tree cover are located in western Maryland. Allegany County in the west is primarily forest (78.0%), with a small proportion of tree canopy outside forest (3.9%). Garrett County, in the westernmost corner of the state, is largely covered by trees (73.7%), with 70.7% tree canopy within forest and 3.0% tree canopy outside forest (Table 3). Southern Maryland and Worcester county on the Eastern Shore also have more than 50% of land area as forest.

Baltimore City, a small jurisdiction with high population density, has the least amount of tree canopy cover extent and percent coverage of any jurisdiction, with 14,881 acres of tree canopy covering 28.7% of the city's boundary. In other jurisdictions with high populations, we see a fairly even balance between forest and tree canopy outside forest. Montgomery County, for example, is 28.1% forest and 18.5% tree canopy outside forest; Prince George's County is 37.2% forested and 15.0% tree canopy outside forest.

Jurisdictions with under 40% tree canopy cover include several on the Upper Eastern Shore and adjacent to the Chesapeake Bay where more wetlands and low vegetation are naturally present. These include Kent and Queen Anne's counties (Table 3, Figure 4). The percent tree canopy cover calculations presented here are based on land use data within the study area of each jurisdiction and largely excludes areas of open water in the Chesapeake Bay.

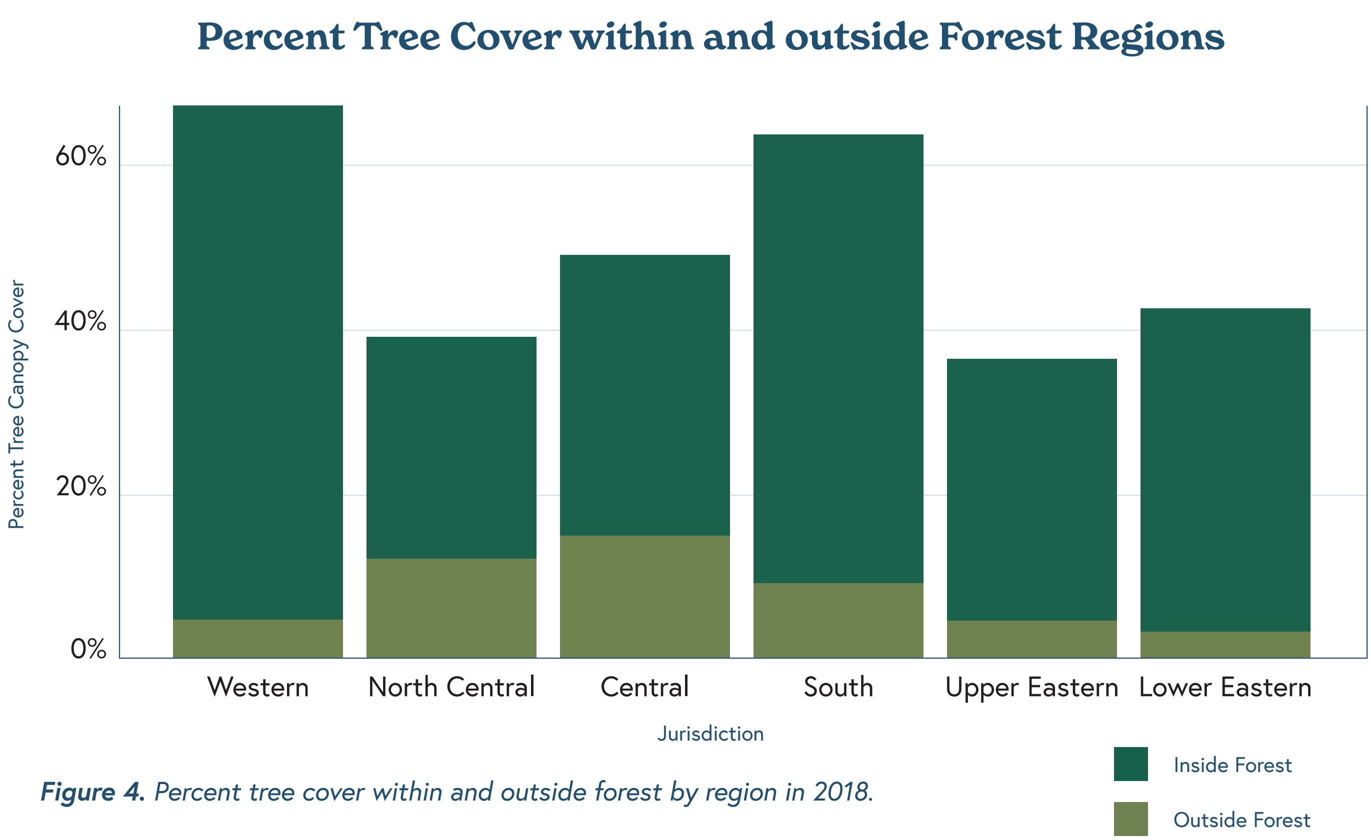


Figure 4. *Percent tree cover within and outside forest by region in 2018.*

Table 3. Percent tree cover within and outside forest by jurisdiction in 2018.

County/Group	Forest (Ac.)	% Forest	Tree Canopy Outside Forest (Ac.)	% Tree Canopy Outside Forest	Total Land Area (Ac.)
Western	**628,171**	**64.3%**	**41,640**	**4.3%**	**976,672**
Allegany	211,462	78.0%	10,684	3.9%	271,203
Garrett	292,797	70.7%	12,446	3.0%	414,364
Washington	123,913	42.6%	18,510	6.4%	291,105
North Central	**271,736**	**28.2%**	**120,979**	**12.5%**	**964,130**
Baltimore	114,092	29.8%	55,283	14.4%	383,212
Baltimore City	3,404	6.6%	11,477	22.1%	51,935
Carroll	68,282	23.8%	28,870	10.1%	286,934
Harford	85,959	35.5%	25,349	10.5%	242,049
Central	**506,581**	**34.4%**	**220,073**	**15.0%**	**1,471,947**
Anne Arundel	105,510	40.0%	51,572	19.5%	263,914
Frederick	147,005	34.7%	34,704	8.2%	423,219
Howard	50,590	31.5%	28,985	18.1%	160,479
Montgomery	88,965	28.1%	58,514	18.5%	316,411
Prince George's	114,511	37.2%	46,297	15.0%	307,923
Southern	**362,795**	**55.1%**	**61,089**	**9.3%**	**657,852**
Calvert	71,938	52.7%	19,014	13.9%	136,623
Charles	177,449	60.6%	20,670	7.1%	292,616
St. Mary's	113,408	49.6%	21,405	9.4%	228,613
Upper Eastern	**446,047**	**33.1%**	**58,741**	**4.4%**	**1,348,164**
Cecil	81,183	36.6%	16,961	7.6%	221,921
Caroline	68,887	33.8%	6,011	2.9%	203,844
Dorchester	128,876	38.0%	8,325	2.5%	339,220
Kent	46,138	26.1%	6,509	3.7%	176,491
Queen Anne's	71,337	30.2%	9,450	4.0%	235,989
Talbot	49,627	29.1%	11,486	6.7%	170,701
Lower Eastern	**351,440**	**47.8%**	**28,315**	**3.8%**	**735,649**
Somerset	87,270	43.4%	6,044	3.0%	200,981
Wicomico	107,639	45.2%	12,837	5.4%	238,124
Worcester	156,532	52.8%	9,435	3.2%	296,545
Maryland (total)	**2,566,770**	**41.7%**	**530,837**	**8.6%**	**6,154,413**

Note: The study extent for this table is Maryland land area, calculated with CBPO dataset.

The land area for Aberdeen Proving Ground (38,954 acres) is not included in Harford County metrics as the area was omitted in the imagery used to develop the CBPO data.

Land cover distribution

When we assessed land cover distribution statewide and by county, we note that tree canopy (49.8%) is the most common class, followed by low vegetation (38.4%) (Figure 5). Areas of water make up 4.2% of the state and are notably high in the coastal and bay-adjacent counties. Developed land cover classes such as buildings (1.8%), roads (2.1%) and other impervious surfaces (3.1%) account for 7% of the state's land area, collectively. Barren areas make up only 0.5% of the state. At the county level, land cover composition varies according to the location of urban population centers and general patterns of land use. Baltimore City, a small, urban jurisdiction, had the

[1] See Data and Methods section for further information about our study area (notably, Aberdeen Proving Ground is not included, as are some open water areas of the Chesapeake Bay).

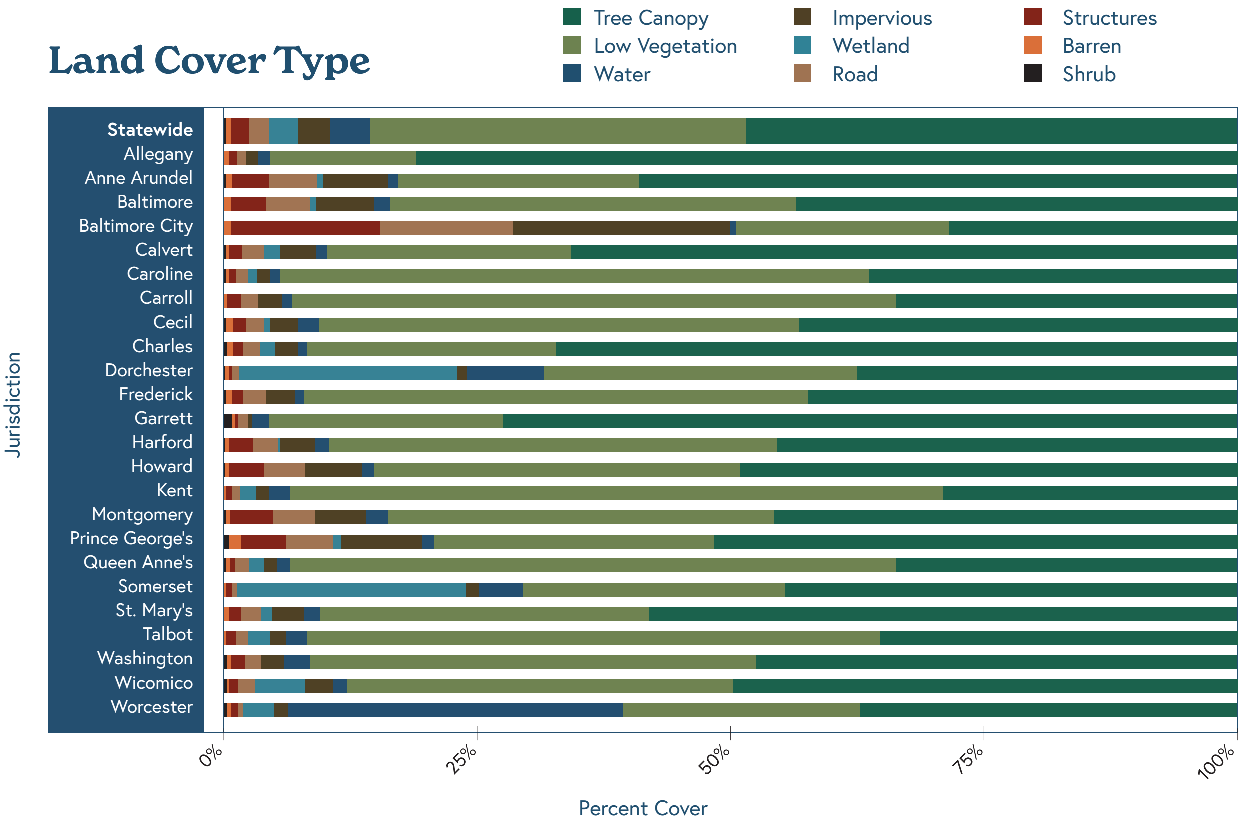


Figure 5. *2018 1-meter resolution land cover distribution by jurisdiction.*

highest percentage of buildings, roads and impervious surfaces. Anne Arundel, Montgomery and Prince George's counties also have high proportions of impervious surfaces. The state's wetlands are concentrated in the coastal and tidal counties on the Eastern Shore of Maryland, evident by Dorchester, Somerset and Worcester counties' high quantity of both water and wetland classes (Figure 5).

Afforestation and reforestation opportunities (Task 1b)

In order to meet tree canopy, forest cover and water quality goals in the State of Maryland, the state will need to plant new trees in addition to protecting existing forests and trees outside forests. An analysis of potential afforestation and reforestation opportunities was conducted to inform where those plantings could be implemented. This analysis focused on the identification of suitable areas for tree planting outside agricultural areas. Tree planting goals and opportunities in agricultural areas are summarized in Task 3.

Plantable Areas are defined as existing low vegetation and barren land cover and exclude areas generally unsuitable areas for planting trees such as roads, buildings, other impervious areas, wetlands and open water and certain features (e.g., airports, prime agricultural soils, powerline right of ways, important bird area grasslands and areas within a 15-foot buffer of buildings). Small plantable areas were defined as plantable areas =< 100 m2 and width =<10 m. Large plantable areas were defined as those areas > 100 m2 and width =<10 m. The Data and Methods section contains a detailed Plantable Areas definition as well as a list of exclusion areas and datasets.

We identified a total of 373,507 acres of potential afforestation and reforestation locations in Maryland (Table 4). Baltimore County led the state with the most potential plantable acres (46,607), followed by Montgomery (37,145 acres) and Prince George's (36,482 acres) counties. Kent and Somerset counties have the least amount of plantable area, with 3,157 and 2,159 acres respectively. Dorchester and Wicomico counties have the lowest percent of potential plantable areas at 1% of total land area (Figure 6).

Table 4. Area (acres) of potential sites for enhancing tree canopy or forest by jurisdiction.

County/Group	Plantable Area (Acres)	Total Land Area (Acres)	% Plantable Area
Western	**45,438**	**976,672**	**4.7%**
Allegany	13,476	271,203	5%
Garrett	15,818	414,364	3.8%
Washington	16,144	291,105	5.5%
North Central	**93,702**	**964,130**	**9.7%**
Baltimore	46,607	383,212	12.2%
Baltimore City	5,757	51,935	11.1%
Carroll	19,193	286,934	6.7%
Harford	22,146	242,049	9.1%
Central	**128,290**	**1,471,947**	**8.7%**
Anne Arundel	21,547	263,914	8.2%
Frederick	16,726	423,219	4%
Howard	16,391	160,479	10.2%
Montgomery	37,145	316,411	11.7%
Prince George's	36,482	307,923	11.8%
Southern	**47,883**	**657,852**	**7.3%**
Calvert	11,546	136,623	8.5%
Charles	21,533	292,616	7.4%
St. Mary's	14,804	228,613	6.5%
Upper Eastern	**38,667**	**1,348,164**	**2.9%**
Cecil	15,362	221,921	6.9%
Caroline	4,810	203,844	2.4%
Dorchester	3,514	339,220	1%
Kent	3,157	176,491	1.8%
Queen Anne's	6,365	235,989	3.2%
Talbot	5,459	170,701	3.2%
Lower Eastern	**19,526**	**735,649**	**2.7%**
Somerset	2,159	200,981	1.1%
Wicomico	11,822	238,124	5%
Worcester	5,545	296,545	1.9%
Maryland (total)	**373,507**	**6,154,413**	**6.1%**

Note: Study extent for this table is Maryland land area, calculated with CBPO dataset. The land area for Aberdeen Proving Ground (38,954 acres) is not included in Harford County metrics as the area was omitted in the imagery used to develop the CBPO data.

Among Plantable Areas, we identified 20,655 acres of "small" plantable areas and 352,851 acres of "large" plantable areas in Maryland (Figure 6). Thus, nearly 95% of plantable acres are within large areas and potentially desirable for large-scale planting projects.

Due to limitations including cost, landowner interest and other factors, only a fraction of plantable areas will realistically be feasible for planting. However, the large amount of total area identified indicates the opportunity to meet and exceed tree planting goals across the state in a variety of geographies. Results of this analysis and the geospatial dataset of planting locations may be used by the state and local jurisdictions for planning and prioritization purposes, as well as for quantifying the projected benefits of tree canopy enhancement.

Figure 6. *Classification of plantable areas in Baltimore City by size.*

It is important to highlight a few areas excluded from this Plantable Areas definition. This analysis focused on areas suitable for planting outside agricultural lands; however, agricultural areas in Maryland do often provide opportunities for tree planting as recognized by Maryland's Watershed Implementation Plan (WIP) (State of Maryland 2019). The WIP details a set of best management practices (BMPs) and county-specific goals for enhancing tree canopy and forest cover in agricultural lands. Examples of planting opportunities in agricultural areas include silvopasture, alley cropping, planting for pollinator habitat and other forest buffers. Progress toward agricultural tree planting goals, in addition to urban and riparian area planting goals, is detailed in Task 3 results.

Other areas not represented here as plantable, such as golf courses, may be targeted as mitigation sites by local jurisdictions. Moreover, we note that some urban areas are removing impervious surfaces for conversion to plantable areas for street trees and other plantings. This reduction in impervious surface may be part of a jurisdiction's plan to comply with their MS4 permit. These areas would complement plantable barren or low vegetation areas that may have been identified as plantable by this analysis.

Health (Task 2)

The health of Maryland forests is at risk. Maryland's forests exhibit increasing fragmentation. In addition, approximately 12% of Maryland's forests were disturbed in recent years, with invasive species a key source of disturbance.

The spatial configuration and composition of forests are important indicators of their overall health. Healthy forests tend to be large and connected, enabling species to move or disperse throughout. They interface with other natural ecosystem types, such as wetlands and grasslands as opposed to developed areas and roads. Healthy forests tend to have a diversity of native flora and fauna at different life stages. Healthy forests are resilient to moderate levels of natural disturbances and may be able to adapt better to the long-term pressures caused by climate change (Thompson et al. 2009).

We assessed the overall health and quality of Maryland forests first by analyzing spatial configuration through a forest fragmentation analysis. Secondly, we analyzed disturbance and invasive species observations in survey plot data available from the USDA Forest Service.

Forest Fragmentation

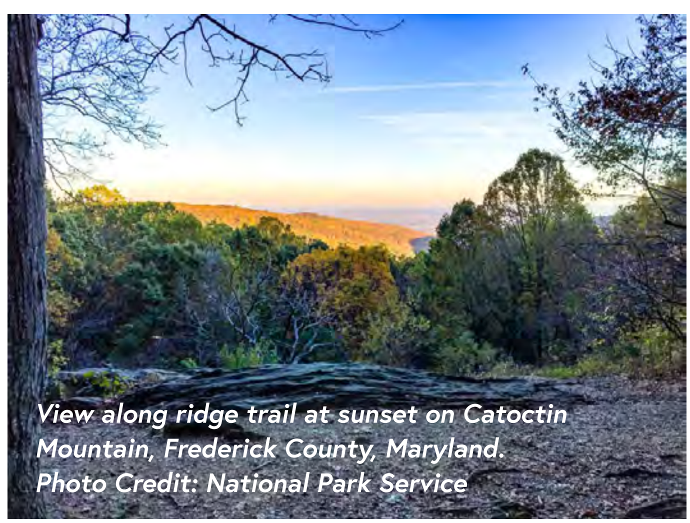
A fragmentation analysis was used to assess the configuration and overall connectivity of Maryland's forest landscape. To conduct the analysis, we categorized forest areas into three sizes of core forest, as well as patch, edge and perforated blocks. Core areas represent large blocks of interior forest that, based on their configuration and size, offer higher-quality habitats and are relatively resilient compared with other configurations. Core areas were defined as forest areas greater than 100 meters (across forest edges) from the nearest alternate land cover type (Jones et al. 2000). Core areas were further categorized into three different size categories: small core forests are less than 250 acres, medium core forests are 250-500 acres and large core forests are greater than 500 acres.

Edges are defined as the forest habitat located in the 100m zone between non-forest at the perimeter and core interior patches. Edge habitats are defined in their own class because they usually have a different composition than interior forest due to increased light penetration, exposure to disturbance (both human and natural) and exposure to predators and invasive species risk (Strelke and Dickson 1980; Wilcove 1985; Maier et al. 2005). These areas may also have a different composition of fauna from interior habitats that prefer ecotones and forest edges (Plante et al. 2004; Jackson et al. 2005). For example, at least 25 bird species in Maryland require forest interior habitat for their survival (Jones et al. 2000).

Patches are defined as small, isolated areas of forest less than 200 meters across, surrounded by non-forest (see Figure 7). Forest patches provide ecosystem services such as carbon sequestration, stormwater mitigation, air and water filtration, shade and aesthetic value — but often with lower biodiversity, habitat value and resilience than large, core forest patches. Perforated areas are small forest gaps within core forest areas (Figure 7). These small gaps within core forests can be created through anthropogenic activities like small buildings but do not necessarily indicate degraded habitat associated with edge effects as gaps can also be naturally occurring such as in old growth forests or because of downed trees. A healthy natural landscape would have a diversity of forest habitat types, but with the vast majority of forest found in large, core areas. Human-dominated landscapes tend to have a higher percentage of small patches, small core areas and forest edges.

Figure 7. *Classification and distribution of forest types from 2018 conditions in one area of Frederick County, Maryland.*

The results of this fragmentation analysis (Table 5, Table 6, Figure 8) provide an indicator of forest health and contextualize change over time. Edges are the most common forest type throughout the state (62% of forested area) — indicating that forests are heavily fragmented. Core forest areas occupy the next largest area (727,087 acres). While large core areas (>500 acres) occupy the greatest total area, small core areas (100-250 acres) follow shortly behind, and there are a far greater number of small core forest areas. Eighty percent of forest loss from 2013-2018 occurred as a result of loss of small core forest patches and edge habitats. Core habitats experienced the greatest loss of any habitat type (-0.94%), primarily driven by the loss of these small core forests (-3.1% area). While both medium and large core forests experienced an increase in number of features and overall area size, their gains did not counterbalance the loss within small core forests. Small forest patches (<100m across) increased in total area, suggesting that core forest area and edges may have been converted to patches. Other core areas were converted to forest units sized between small cores and patches.



View along ridge trail at sunset on Catoctin Mountain, Frederick County, Maryland. Photo Credit: National Park Service

Table 5. *Total number, area and change of forest fragment areas from 2013 to 2018 (acres).*

Forest Fragmentation Type	Number 2013	Number 2018	Difference	Acres 2013	Acres 2018	Difference (area % change)
Small Core	13,403	13,207	-196	306,864	297,443	-9,422 (-3.1%)
Medium Core	271	276	+5	95,105	95,950	+845 (+0.9%)
Large Core	252	254	+2	332,048	333,694	+1,646 (+0.5%)
Total Core Area	**13,926**	**13,737**	**-189**	**734,017**	**727,087**	**-6,930 (-0.94%)**
Patch	272,555	236,052	-36,503	252,180	255,432	+3,252 (+1.3%)
Edge	6,719	6,685	-34	1,597,053	1,582,611	-14,442 (-0.9%)

From 2013 to 2018, all core forest categories saw a decrease in mean size of the area types. Isolated forest patches experienced an increase in mean and median patch size (Table 6). Though small forest patches may be increasing slightly in size and overall area statewide, the overall trend is toward a loss of core forest both in terms of total area and number of patches. This indicates a trend toward forest fragmentation in the state. Thus, while overall forest and tree canopy extent statewide is decreasing minimally (See Task 1a), encroachment and fragmentation in those areas of forest change is a threat to forest health.

Table 6. *Mean and median areas (acres) of each forest fragmentation type in 2013 and 2018.*

Forest Fragmentation Type	2013 Area (Acres)		2018 Area (Acres)		Percent Change	
	Mean	*Median*	*Mean*	*Median*	*Mean*	*Median*
Patch	0.925	0.025	1.082	0.049	16.97%	96%
Small Core	22.895	6.795	22.521	6.696	-1.63%	-1.45%
Medium Core	350.941	337.990	347.643	329.688	-0.93%	-2.45%
Large Core	1317.652	935.207	1313.756	939.186	-0.29%	0.42%

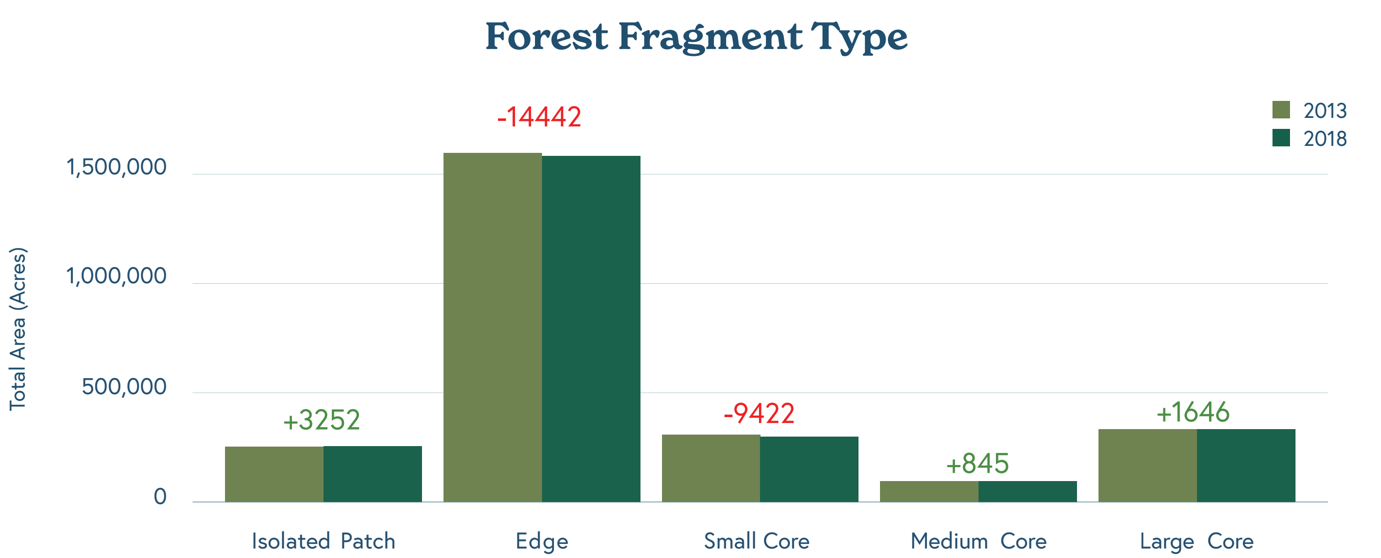


Figure 8. *The total area change for each forest fragment type from 2013 to 2018. Bar labels provide the total change in acres.*

We observed that nearly all regions experienced a decrease in edge forest acres, with Central Maryland experiencing the largest loss. The large increase of isolated patches in this same region probably occurs as a result of fragmentation and loss of edge forest, as well as decreases in small and medium core forest areas. This likely indicates the transition of core forest to more isolated patches as these highly populated counties face pressure from development. Lower Eastern Maryland experienced the most significant increase in large core forest, reducing concern for its loss of small cores — some of which may have been connected into large core areas. This may also be indicative of regrowth after timber harvest. Western Maryland experienced the greatest decrease in large core forest area (Figure 9). This region had significant timber operations during this period, suggesting that these areas may not have been permanently lost, but cut back temporarily (Figure 20). Indeed, fragmentation dynamics should be considered in light of forestry operations in each region.

Change of Each Forest Type by Region

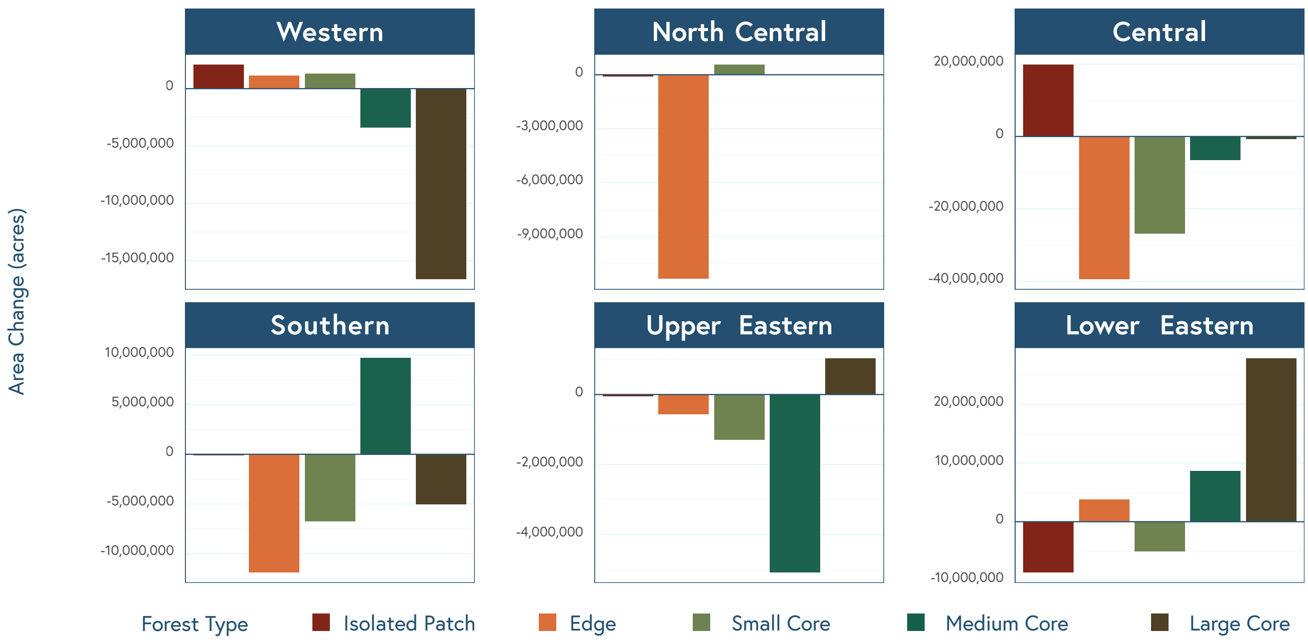


Figure 9. *The total area change of each forest type by region, 2013-2018 (acres).*[2]

While these spatial configuration results present cause for concern, we note that the analysis of forest fragmentation between 2013 and 2018 is sensitive to small changes in forest contiguity and perforations in the forest cover as small as 100 square meters. These include perforations associated with natural succession or other temporary forest dynamics. Fragmentation should thus be monitored over a longer timeframe to gain a better understanding of fragmentation trends and drivers.

Disturbance

FIA forest plot data indicate that 12% of forest land showed indications of recent large-scale disturbance over the 2013-2019 time period (USDA Forest Service FIA n.d.). Of these, suppression of trees by vegetation, including

[2] Certain counties with better LiDAR collections may have demonstrated more accuracy in fragmentation change detection given higher detection capability (Anne Arundel, Calvert, Montgomery, Prince George's and St. Mary's counties).

vines and competition, was the greatest cause, affecting 3.8% of forests. This category may include suppression by invasive vines and plants found in Maryland, such as Oriental bittersweet (Celastrus orbiculata), Japanese honeysuckle (Lonicera japonica) and multiflora rose (Rosa multiflora). Other indications of potential invasive species are insect damage, which affected nearly 2% of the forest landscape. All of the categories that are potential indicators of invasive species (insect damage, disease and vegetation suppression) comprised over half of the major disturbances recorded and affected 6.6% of Maryland forests (Figure 10).

Deer and other ungulates, species that do well in human-dominated landscapes and prefer forest ecotones, have a major effect on the Maryland forest landscape, affecting an estimated 1.8% of Maryland's forest area. High wind and flooding, both natural disturbances, have resulted in disturbance to more than 2% of the area. These types of disturbance are part of the natural forest life cycle when they follow historical trends and usually contribute to habitat heterogeneity and a variety of successional habitats as forests regrow. If these trends become more frequent and/or severe with changing climate as predictions suggest, Maryland could see larger areas disturbed, including those in early successional or wetland states. New human-caused disturbance affected only about 0.4% of total forest area (USDA Forest Service FIA n.d.).

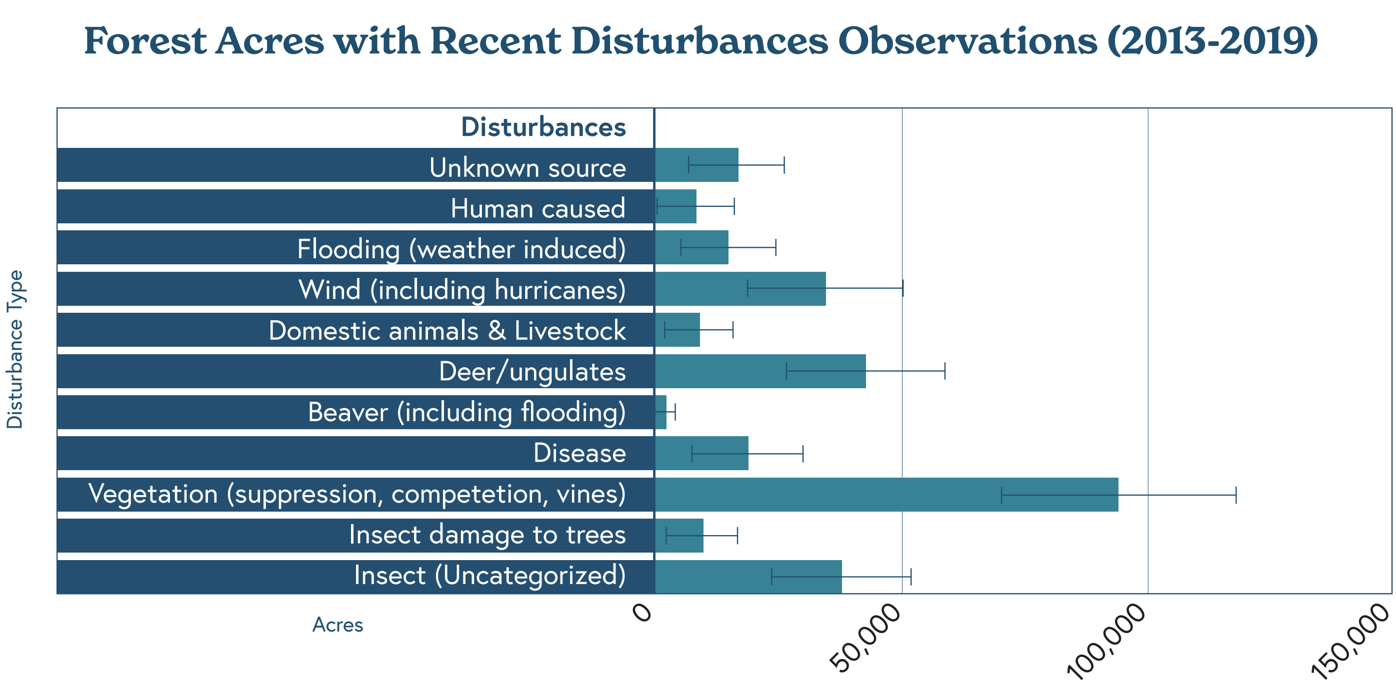


***Figure 10.** Forest acres with recent disturbance observations (2019). Error bars display 1 standard error around the estimate or a 68% confidence interval (USDA Forest Service FIA n.d.).*

FIA monitors for the presence of invasive plant species (IPS) on a small subset of inventory plots in Maryland. An analysis of 49 surveyed plots from 2014-2019 found IPS on two-thirds of the plots (29). In this survey period, a total of 16 IPS were identified across all plots, out of a list of 20 potential IPS species. Multiflora rose was observed most frequently (on 18 plots or 37%), followed by Japanese honeysuckle (17 plots, 35%). Nepalese browntop (Microstegium vimineum, also known as Japanese stiltgrass) and garlic mustard (Alliaria petiolata), were each observed in 15 plots, each covering about 31% of all plots (Figure 11). When these results were compared with earlier survey results of 75 plots that occurred from 2010-2014, we found a consistent percentage of total

IPS affected plots. The six most frequently observed IPS were also consistent across both survey periods. However, we note that observations of Nepalese browntop, tree of heaven and autumn olive increased in frequency from survey period 1 to survey period 2, suggesting that these species are maintaining their hold and may be expanding their reach. This conclusion, however, is uncertain given the decrease in plot count between the two time periods and emphasizes the necessity of continued monitoring for changes in IPS presence in the region (USDA Forest Service 2019a; USDA Forest Service FIA n.d.).

Percent of Invasive Species Plots with Species (2019)

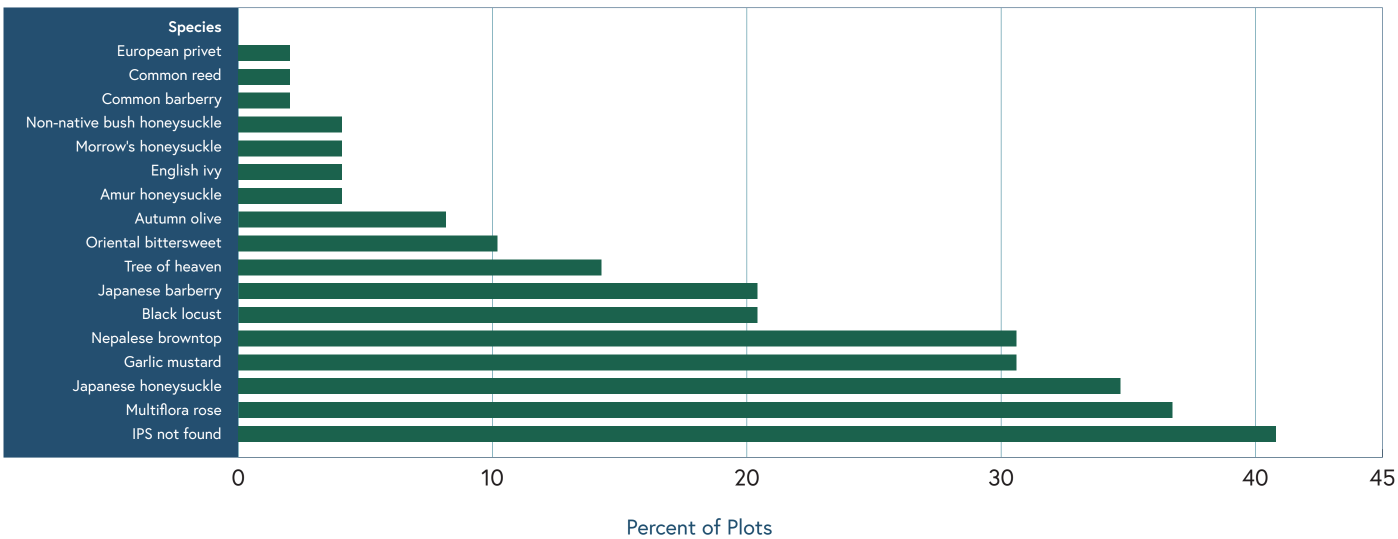


Figure 11. *Percent of surveyed plots with IPS observed from 2014-2019 (USDA Forest Service 2019a; USDA Forest Service FIA n.d.).*

Average plot coverage by IPS was evaluated as an indicator of severity. Of the set of IPS surveyed from 2014-2019, Nepalese browntop covered the largest extent of all surveyed forest land, nearly 7% in 2019. This forest land included plots where Nepalase browntop was not observed. Japanese honeysuckle covered about 2.6% of all forest land, followed by multiflora rose and black locust (each covering about 1.25% total forest plot area total). When percent coverage was calculated as a proportion of the forest land where a given IPS was observed, common reed (Phragmites australis australis) was highest at 60%. However, with low sample sizes, this data should be cautiously interpreted. Common reed was only observed on one plot. The next greatest coverage was Nepalese browntop at 22% (15 plots) and Morrow's honeysuckle at 20% (2 plots). Invasive species, once introduced, often have pervasive and fast-moving effects (USDA Forest Service n.d.).

The emerald ash borer (Agrilus planipennis) is an invasive insect that affects ash (Fraxinus spp.) trees. It was first detected in Prince George's County in Maryland in 2002-2003 and quickly branched out from there to cover most of the state by 2019. At the time of this study, the ash borer had affected an estimated 83% of ash volume in the state and had been detected in all counties but Worcester and Wicomico counties in eastern Maryland. In 2019 (the year of available data), Washington, Anne Arundel, Montgomery, Frederick, Howard and Allegany counties experienced the most severe ash mortality by volume. Anne Arundel is losing the largest volume of ash per acre (USDA Forest Service FIA 2019b).

The hemlock woolly adelgid (Adelges tsugae) is a similarly invasive insect that affects hemlock and spruce trees (Tsuga spp.; Picea spp.). The hemlock woolly adelgid was first identified in Prince George's, Anne Arundel and Baltimore counties in 1986 and spread out from there, affecting hemlocks in all counties in Maryland by 2012. Beech bark disease, which is caused by the beech scale insect (Cryptococcus fagisuga), had been identified in the two western counties of Maryland by the year 2016. It was first identified in Garrett County between 1990 and 2005 and subsequently in Allegany County after 2005 (USDA Forest Service FIA 2019).

The National Insect and Disease Risk Map is an effort of the U.S. Forest Service to spatially identify watersheds at highest risk of impacts from invasive insects and disease from 2013-2027. This study identified the westernmost watersheds of Maryland to be at highest risk, with more than 25% of treed areas at risk in some areas. Central Maryland and the Eastern Shore generally have areas at moderate risk of tree loss (1-15% of treed areas at risk). Watersheds around Maryland's urban centers, including the Washington, D.C. and Baltimore suburbs and Annapolis, tend to have less risk, perhaps because these trees have already been heavily affected by invasive pests and disease (Figure 12, U.S. Forest Service 2018; Krist et al. 2014). The result is a composite of predicted risk from a variety of insects and diseases that include exotic insects, root diseases, bark beetles and oak death and gypsy moth.

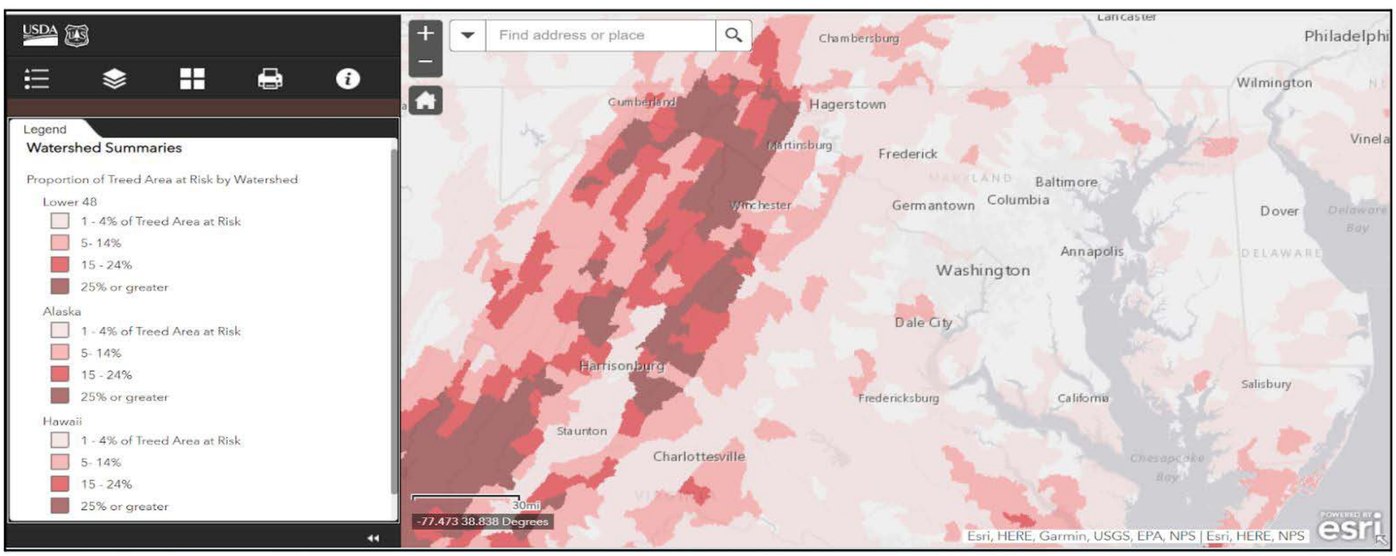


Figure 12. *Percent Treed Area at Risk, according to the National Insect and Disease Composite Risk Map, 2013-2027 (U.S. Forest Service 2018).*

Progress (Task 3)

Statewide from 2013 to 2018, this study detected a loss of 17,829 acres of tree canopy in urban areas and a gain of 4,665 acres, resulting in an overall net decrease of 13,164 acres of urban tree canopy. Tree canopy covers an estimated 58% of riparian zones throughout Maryland, which is shy of the 70% Chesapeake Bay watershed-wide goal. Riparian forest coverage varies substantially by county, and counties are making varying rates of progress toward meeting their own riparian buffer goals under Maryland's Watershed Implementation Plan.

Observed and Reported Urban Tree Canopy Trends

In 2014, the signatories of the CBWA agreed to expand tree canopy in urban areas by 2,400 acres watershed-wide by 2025 (CBWA 2014). Since that time, counties set individual urban tree planting goals for the year 2025 in support of the watershed-wide goal (see Appendix C, "State of area" and "urban cluster"). This trend, however, had spatial variation, with some areas achieving a net gain (Figure 13).

The urban areas that experienced the largest amount of net loss are those near Washington, D.C. and Baltimore. The Waldorf area, just south of D.C., experienced the third highest net loss. These three regions experienced a net loss of 12,674 acres.

While further attention should be paid to areas of net loss, there are some census urbanized areas that experienced net gains in tree cover: Salisbury, Westminster-Eldersburg, Chestertown, Easton, Mountain Lake Park, Glenwood and Philadelphia's Maryland suburbs (Figure 13). Salisbury and Westminster-Eldersburg in particular showed substantial net gains in urban tree canopy of 221 and 158 acres, respectively. These successes can be replicated in other regions with careful planning and if further loss is mitigated.

It can take years for newly planted trees to reach sufficient height (3m) to be detected by our satellite imagery. Tree canopy gain reported here (in the 2013-2018 time frame) is reflective of trees planted in the 2003-2015 time frame due to these detection delays from tree planting to satellite observation. A tree planted from seed may take 7-15 years

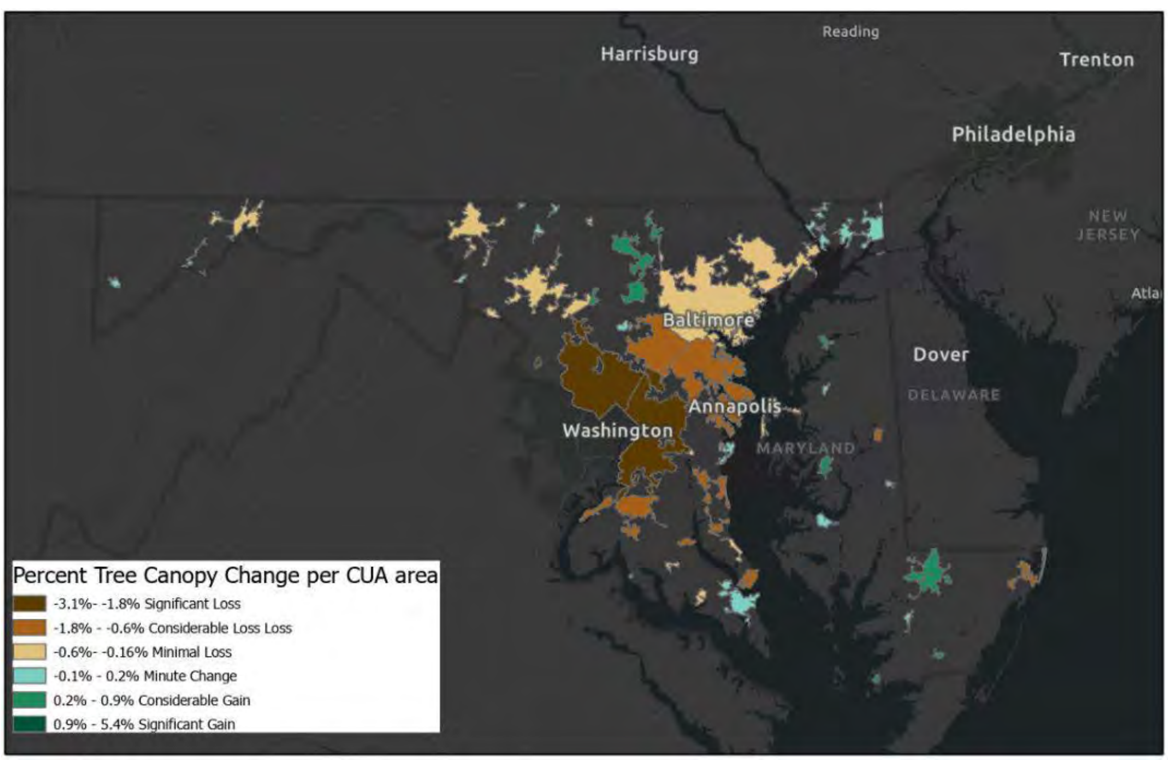


Figure 13. *Relative change in tree canopy area in census urban areas (CUA), 2013-2018.*

to gain sufficient stature to be detected, but new urban trees are often already a few years old when planted, reducing that detection delay. Regardless, results based solely on satellite image reports should be understood to map mature tree canopy and not number of trees. To get a better sense of how recent tree planting efforts may affect reforestation progress and future tree canopy coverage, we augmented the satellite observation results with recent ground reports on trees planted in urban areas.

The Harry Hughes Center reviewed trees planted through federal, state and local programs in 2018 and 2019 (Table 19). Approximately 33,488 trees (74 acres at 450 trees per acre) were identified as having been planted in urban areas through municipal and county-level programs. However, the ground data collected was not exhaustive, as not all municipalities and programs responded to our request for information, and we did not conduct a systematic review of private planting efforts. Additionally, there were several planting efforts that could not be separated into urban and non-urban, such as those implemented under the FCA (~414,585 trees), by the Maryland Department of Transportation, and through county-level programs such as Creek ReLeaf (159 acres) and Tree Montgomery (1,345 trees). Even considering that not all planted trees will survive, the actual number of urban trees established in 2018 and 2019 is almost certainly higher than our estimate.

The 2018-2019 plantings add to ongoing urban tree planting efforts which, though significant in terms of numbers of trees planted (and intended to be planted), primarily seek to mitigate trees lost to development (MDE 2021). When we consider tree canopy loss observations alongside reports of urban trees planted during the same period, we conclude that Maryland experienced a significant net loss of about 13,000 acres of urban tree canopy from 2013-2018.[4]

Observed Progress on Riparian Planting Goals

Signatories of the 2014 CBWA agreed to the goal of replanting and restoring riparian areas until 70% of riparian areas are forested watershed-wide (CBWA 2014). Supporting the watershed-wide goals for riparian forest cover and TMDL mitigation, Maryland's counties have set unique targets for riparian buffer planting to the year 2025 (State of Maryland 2019).

In the year 2018, we observed that 58% of Maryland's riparian habitats were covered by tree canopy. Riparian forests are unevenly distributed throughout the state, and we found that only one-third (33%) of counties (8) have 70% riparian forest coverage (Figure 14). The largely wooded Allegany County has the highest percentage of tree canopy cover in riparian areas (79%), while Somerset County, with riparian zones naturally characterized by low vegetation and wetlands, has the lowest riparian tree canopy cover (26%). For Eastern Shore counties with plentiful tidal wetlands such as Somerset, Dorchester and Wicimoco, 70% riparian forest coverage may not be an appropriate goal. Caroline, Cecil, Frederick, Prince George's and St. Mary's counties all have at least 60% tree canopy cover.

[3] The 2030 GGRA Plan notes a projection of 2.65 million urban trees planted (or 5,888 acres at 450 urban trees/acre) from 2006-2030, with the majority of these trees counting towards tree loss mitigation. If the projections are being achieved and trees are planted at a constant rate, we would see 245 acres of urban trees mitigated per year, or up to 1,227 acres over the period from 2013-2018.
[4] Net urban tree canopy loss is ~13,089 acres when we subtract the sum of observed and reported tree canopy gain (4,739 acres) from observed tree canopy loss (17,829 acres). Due to reasons mentioned about, this may modestly overestimate net loss if tree canopy gain is underestimated.
[5] We defined riparian areas as areas within 100 feet of a modeled flowpath (EFP). A minimum 60-acre drainage area threshold is used for the delineation of the EFP. Water areas found in these regions were removed from the percent calculations. For more information, please see the Data and Methods section.

Riparian Buffer Zones

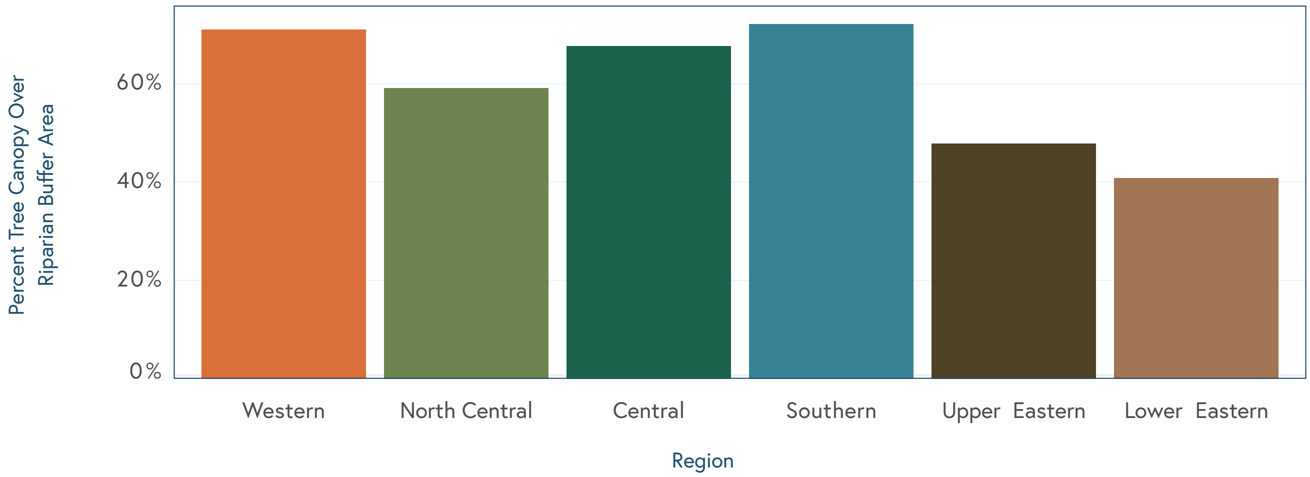


Figure 14. *Percent of riparian buffer zones that are covered by tree canopy, by county.*

Hundreds of thousands of trees were reportedly planted in Maryland by tree planting programs from 2018-2021. Many sites were in riparian areas. These additional acres would not have been detected by this study as they were planted after the time frame of our imagery. As noted earlier, satellite observations underestimated new trees planted during the study time frame (2013-2018) and are more reflective of trees planted from 2003-2015 (depending on whether they were planted from seed or sapling)), since trees need to be at least 3 meters to be observed. Undetected saplings will add acreage to riparian zones over time or at least mitigate loss (See Task 7). This assumes that considerable tree loss has not also occurred since 2018. Despite the acknowledged undercounting of "new trees," the methodology uses a consistent technology to accurately and reliably detect existing tree canopy.

Future research questions emerge from this analysis. One question is where are the gaps in riparian tree canopy? Do they tend to be upstream or downstream? What percent of gaps are in agriculture versus turf grass? How much of the riparian zone is impervious? Answering these questions can help inform policies targeted towards reforestation on farmland vs developed areas.

Reported Progress Toward Maryland's Watershed Implementation Plan Goals

Maryland's Phase III Watershed Implementation Plan (WIP) required counties to set tree planting goals in urban, riparian and undeveloped upland areas to restore the watershed and reduce TMDL pollutant load to the Bay and waterways. These goals are operationalized through Best Management Practice (BMP) modeled credits and monitored via ground-based audits. Table 7 presents a sum of BMP implementation reported by MDE to the EPA through 2020 compared with the 2025 goal. County goals for 2025 were set during WIP Phase III planning by applying the Chesapeake Assessment Scenario Tool (CAST) to determine the optimal distribution of pollution mitigation strategies (CBP 2020a). BMP certifications are not comparable to observed satellite data, but may be used independently from satellite data sources to assess trends, particularly trends beyond the final date of our satellite image time series.

According to reported BMP implementation records, the state is on its way to achieve its urban (developed) WIP-prescribed planting goals for 2025, at 83.7% complete. Urban Forest Planting is least complete, with only 58.5%

of the goal accomplished. Planting of distributed trees for urban tree canopy actually exceeds the 2025 goal. Statewide planting goals in the Agricultural Sector are 89.8% achieved, including Riparian Forest Buffer planting goals in the Agricultural Sector are 87.6% complete. Riparian Forest Buffers in the developed sector are slightly behind that, with 75.9% of the goal complete. There is significant variance in how far along counties are in their individual planting goals, summarized in Appendix C.

Table 7. *Statewide progress toward WIP Phase III tree planting goals for 2025 compared with the 2009 baseline, according to BMP certification reports (acres and % change).*

Sector and BMP Name	Statewide Tree Planting BMP Targets (MD Phase III WIP, 2025 Goals)	Total BMP Amount Credited (CAST 2020 Progress Scenario)	Percent of Phase III WIP Goal Implemented by 2020
Agriculture Sector	**23,771.39**	**21,351.45**	**89.8**
Forest Buffer	19,098.05	16,722.63	87.6
Tree Planting	4,673.34	4,628.82	99.0
Developed (Urban) Sector	**10,627.78**	**8,893.85**	**83.7**
Forest Buffer	722.13	548.27	75.9
Forest Planting	6,614.27	3,867.67	58.5
Tree Planting - Canopy	3,291.37	4,477.92	136.1
MD Total	**34,399.16**	**30,245.31**	**87.9**

Sum units are in acres. In the Agricultural Sector, "Forest Buffer" refers to riparian buffer areas, and "Tree Planting" refers to other non-riparian tree planting. "Developed Sector" is used to describe urban areas. "Developed Forest Planting" refers to tree planting on mixed land uses: acres of forest in non-riparian areas (beyond 300m from streams) in a contiguous area, usually to mitigate for forest cleared during urban development. "Tree Planting - Canopy" refers to tree planting in urban areas that do not qualify as forest buffers or forest planting and do not need to be planted in a contiguous area (MDE, MDA, MDNR 2016; CBP 2018). according to BMP certification reports (acres and % change).

Land Cover and Forest Change (Tasks 4 and 5)

Development was observed to be the biggest driver of tree canopy loss in Maryland over both short- and long-term time frames, representing 41% of forest changes in the NLCD data (2001 to 2019) and 52% in the CBPO change data (2013 to 2018). Forest was also converted to natural land cover and productive uses, such as agriculture and natural land covers. New forest emerged from a number of classes, including wetlands, shrub and herbaceous vegetation, indicative of natural succession. Some new tree canopy was also found in formerly agricultural areas, suggestive of the introduction of best management practices, tree planting and afforestation in these productive areas. Maryland has an active timber industry, and observations of tree canopy loss and gain in some counties may actually be observations of the resulting dynamics.

Patterns and drivers of tree canopy change vary by county. All but three counties lost forest cover, and those that gained were Eastern Shore counties in which the timber industry is active and perhaps a signal of regrowth after extraction. All but two counties experienced a net gain in tree canopy cover outside forest, possibly due to a combination of forest

fragmentation, forest recovery and tree planting. The counties that lost tree canopy cover from outside forest and within forest were both located in the Washington, D.C. suburbs, a rapidly urbanizing area. These counties accounted for over 50% of the state's total tree canopy loss, and five counties accounted for 73% of its loss, indicating skewed spatial distribution of tree canopy loss. Though there was a statewide trend toward forest fragmentation and development, we also observed transitions of developed land to tree canopy, indicating an effort toward urban greening.

A parallel analysis found that Priority Funding Areas for development were selectively more vulnerable to tree canopy loss. Priority Protection Areas showed a 37% lower rate of forest cover loss than statewide rates and much higher rates of tree canopy gain, indicating operational mitigation measures in at least some of these areas. Future forest cover projections completed with the Chesapeake Bay Land Change Model (CBLCM) based on business-as-usual population, employment, zoning and other factors predict statewide loss in forest cover from 2025 to 2055, accompanied by an increase in impervious surfaces and tree canopy over impervious surfaces. This trend may be offset in part by tree planting, reforestation and afforestation programs operating in the state.

Observed Forest and Land Cover Loss and Gain

Historical Forest Change from 2001 to 2019

We analyzed land cover transitions over the 18-year period from 2001-2019 using the National Land Cover Database's (NLCD) 30-meter resolution data. Using Sankey diagrams, we offer a visual tool that demonstrates relative quantities of transitions of forest to multiple non-forest classes and the reverse. Through this approach, we can better understand the drivers of forest loss and gain over time. Factors influencing these transitions include trends and policies in agriculture, mitigation activities, climate change, saltwater intrusion, timber harvesting and development.

NLCD Change between 2001-2019

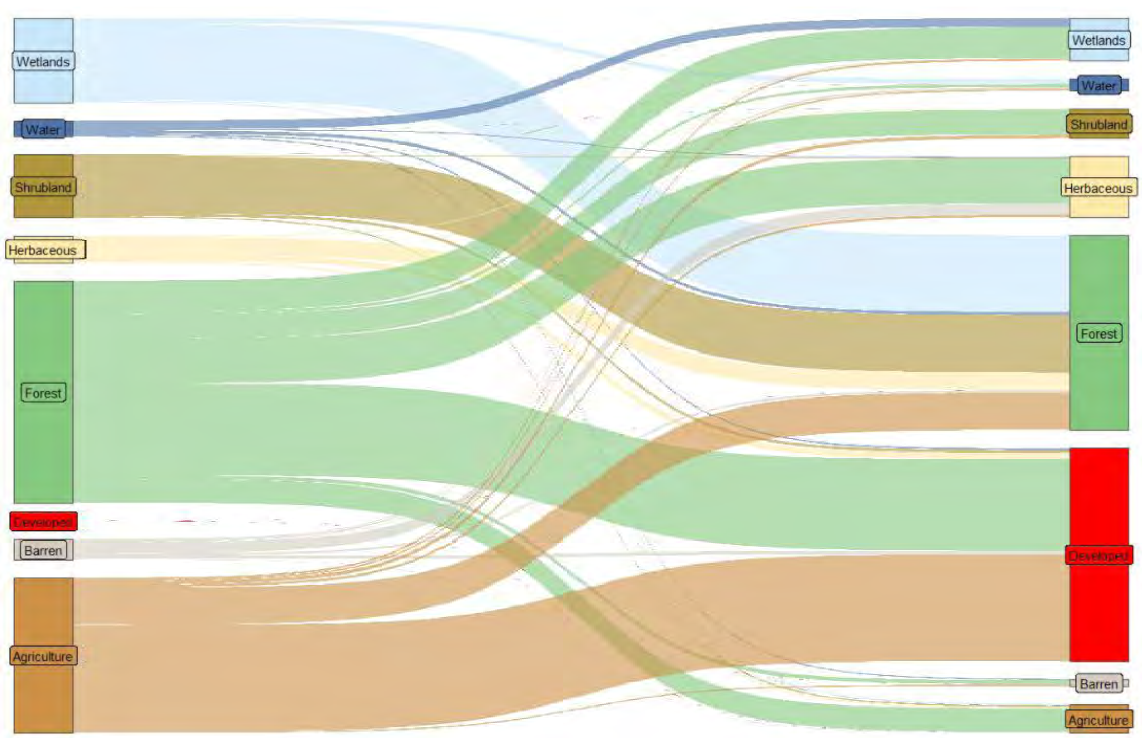


Figure 15. *NLCD land cover class transitions, 2001-2019.*

__Table 8.__ Total change (acres, % of total change area) of NLCD source and destination classes, 2001-2019.

2001 Class (Source)	Acres	% of Total Change Area
Forest	95,766	37.8
Agriculture	66,841	26.4
Wetlands	36,327	14.3
Shrubland	27,148	10.7
Herbaceous	11,497	4.5
Barren	8,795	3.5
Water	6,746	2.7
Developed	84	0.0
Grand Total	**253,202**	**100.0**
2019 Class (Final)	**Acres**	**% of Total Change Area**
Developed	91,974	36.3
Forest	84,015	33.2
Herbaceous	26,073	10.3
Wetlands	18,211	7.2
Shrubland	12,782	5.0
Agriculture	12,295	4.9
Water	4,945	2.0
Barren	2,908	1.1
Grand Total	**253,202**	**100.0**

From 2001 to 2019, the forest class represents the largest source of changes to other land uses. Meanwhile, developed is the largest destination class with respect to changed land use (Table 8). Forest transitioned mainly to development, followed by herbaceous vegetation, wetlands and shrubland. The latter transitions may be a result of either natural or human disturbances (Figure 15). The predominance of the forest to developed transition, in particular, indicates the importance of replacing trees removed for development if Maryland wants to retain and increase its levels of forest/tree canopy cover. Another major transition was from agriculture to developed land, documenting the overall trend of urbanization.

The largest contributors to new forest from 2001-2019 were wetlands, shrublands and agricultural lands (Figure 15). This is indicative of processes that include natural succession, forest harvesting and regrowth and perhaps implementation of best management practices in agricultural lands.

High-Resolution Land Use/Land Cover Change

We also analyzed land cover transitions using high-resolution land cover data over a shorter period, from 2013 to 2018 (Table 9, Figure 16). These classes were not identical to the NLCD classes, negating direct comparison. From 2013 to 2018, the largest contributors to new tree canopy were the low vegetation and scrub/shrub classes (Figure 16), indicative of natural succession. Tree canopy transitioned mainly to low vegetation, impervious surfaces (including structures) and barren classes. Tree canopy and low vegetation were the primary sources of new impervious land cover in 2018.

Challenges for decision makers to balance needs across the state are reflected in this data. For example, the extent of tree canopy transitions to impervious and barren classes demonstrates the importance of requiring the replacement of cleared trees to retain overall tree canopy cover. The significant transition of low vegetation to impervious cover may indicate additional pressure on trees, since tree canopy to low vegetation is also a common transition. (This hints at conversion of tree canopy to impervious cover through a two-step process, from tree canopy to low vegetation and then to impervious cover.) Low vegetation to tree canopy may indicate the growth of small trees into larger ones, indicative of natural succession.

Low vegetation and tree canopy represented the predominant changed classes in both 2013 and 2018, but their percent representation decreased in 2018 as a destination class compared with the percent change area represented as a source class in 2013. Meanwhile, impervious surfaces increased from 2.7% of change area as a source class in 2013 to 18.0% of destination class area in 2018, representing its growth as a land cover class (Table 9).

High-resolution Land Cover Change between 2013-2018

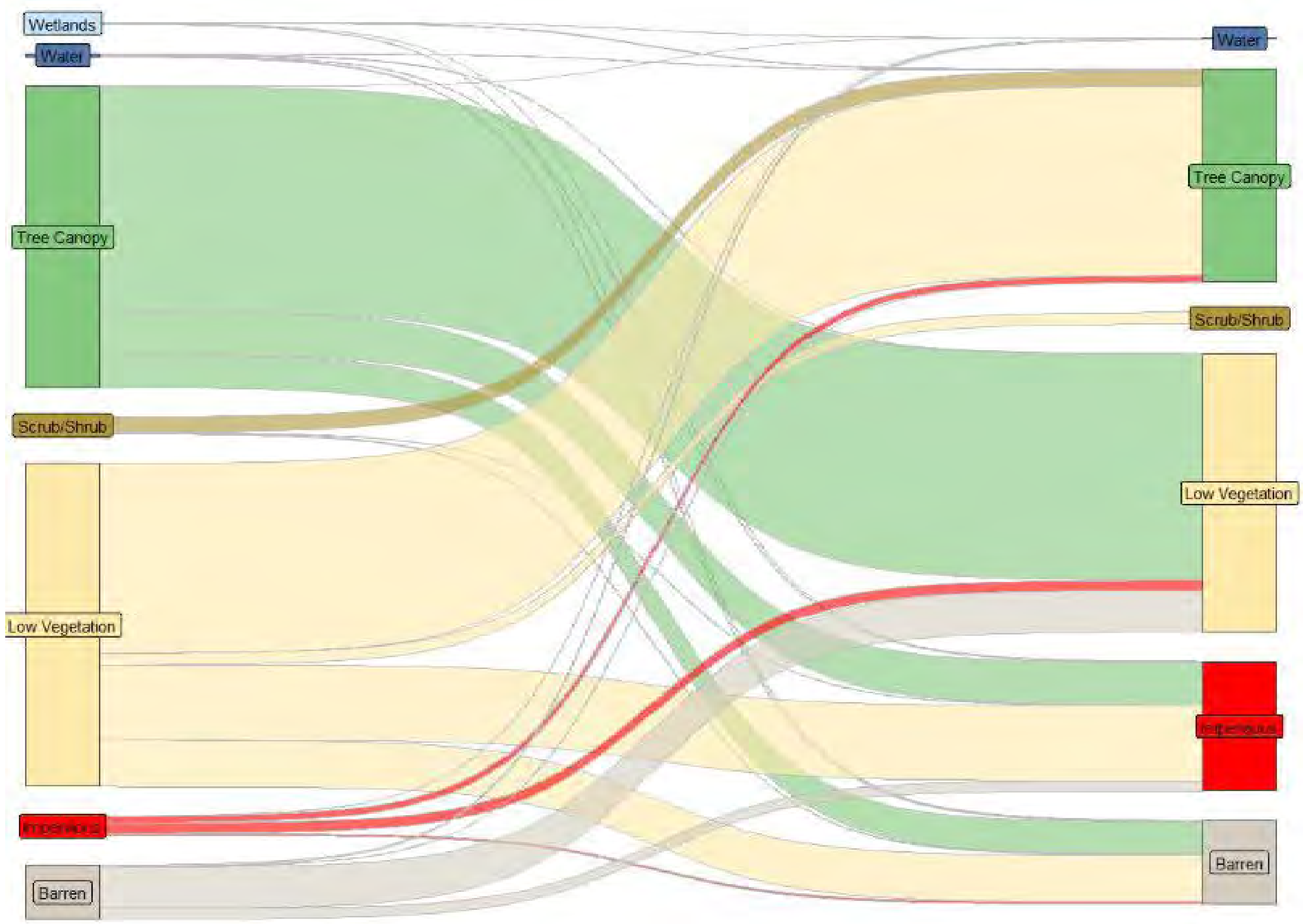


Figure 16. *High-resolution land cover transitions, 2013 to 2018.*

__Table 9.__ Total change (acres, % of total change area) for high-resolution source and destination land cover classes, 2013-2018.

2013 Class (Source)	Acres	% of Total Change Area
Low Vegetation	47,054	45.0
Tree Canopy	43,785	41.9
Barren	7,815	7.5
Impervious	2,774	2.7
Scrub/Shrub	2,463	2.4
Water	410	0.4
Wetlands	227	0.2
Grand Total	**104,529**	**100.0**
2018 Class (Final)	**Acres**	**% of Total Change Area**
Low Vegetation	40,514	38.8
Tree Canopy	31,060	29.7
Impervious	18,851	18.0
Barren	12,130	11.6
Scrub/Shrub	1,705	1.6
Water	268	0.3
Grand Total	**104,529**	**100.0**

Figure 17 shows transitions among consolidated land use/land cover classes from 2013-2018. Total tree canopy (within and outside forest) is most frequently converted to developed land, followed by production, natural and wetland classes. Some of these transitions are permanent, whereas others may be a result of disturbance. Likewise, new tree canopy most often emerges from agricultural or extractive production areas, followed by formerly natural areas and r wetlands. Some of this may be a result of tree planting or protection; in other cases this may be indicative of natural succession. It is worth noting that transitions between tree canopy and wetlands in this figure do not reflect gain or loss of wetland area, but vegetation change within the overall wetland. Table 10 indicates that Tree Canopy and Production are the most common source areas, while Developed and Tree Canopy represent the largest destination classes.

High-resolution Land Use Change between 2013-2018

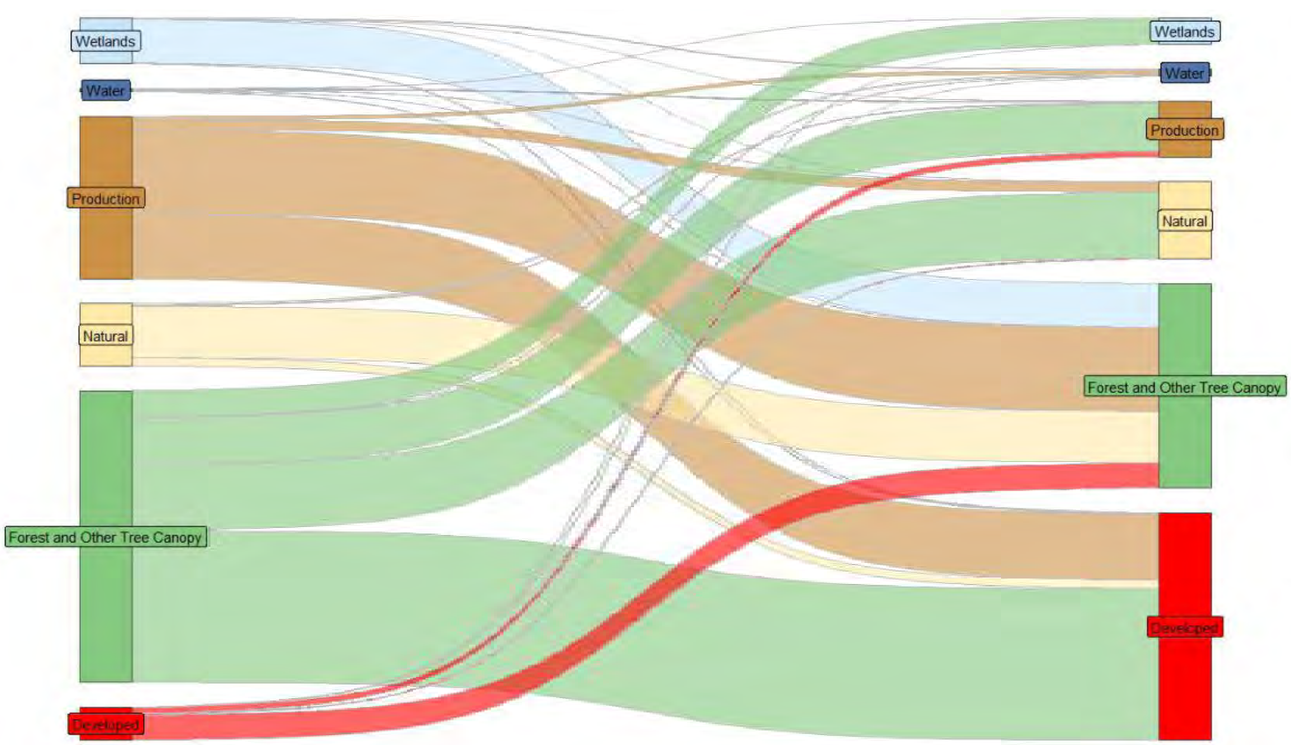


__Figure 17.__ High-resolution land use/land cover class transitions, 2013 to 2018.

Table 10. Total change (acres, % of total change area) for high-resolution source and destination land use/land cover classes, 2013-2018.

2001 Class (Source)	Acres	% of Total Change Area
Forest and Other Tree Canopy	43,870	48.8
Production	24,423	27.2
Natural	9,387	10.4
Wetlands	6,892	7.7
Developed	4,964	5.5
Water	410	0.5
Grand Total	**89,947**	**100.0**
2018 Class (Final)	**Acres**	**% of Total Change Area**
Developed	34,209	38.0
Forest and Other Tree Canopy	30,735	34.2
Natural	11,576	12.9
Production	8,405	9.3
Wetlands	3,965	4.4
Water	1,057	1.2
Grand Total	**89,947**	**100.0**

These results provide an additional argument for continued monitoring of high-resolution land use data to assess long-term trends, particularly land in an interim state. Some areas harvested for timber are in natural succession (and therefore, not tallied as forest) while other areas that were developed with structures over the five-year period may have been in an interim "cleared, but not yet built" state in 2013. Longer-term monitoring would be needed to know if these areas were previously agriculture or forest.

Change Across Land Cover and Land Use Datasets

In reviewing land use/land cover change at moderate resolution, over longer temporal history, there are two clear drivers for forest and tree canopy change: natural successional trends between tree canopy, wetlands, herbaceous and shrubland areas and loss of tree canopy to developed features (Figure 15). Areas of tree canopy growth in agricultural lands could be an indicator of state-led programs to increase forested buffers in agricultural lands. High-resolution imagery from 2013-2018 confirms that gains in forest and other tree canopy are the result of natural succession, followed by tree planting or regrowth in production areas. We did see some tree canopy emerge in developed areas, perhaps due to tree replanting, not easily captured by the coarser data. Observing losses in forest and other tree canopy, it is clear that most change is driven by development; ; of the 43,869 acres of change to forest and tree canopy, over half of these (52% or 22,844 acres) were to developed classes including structures, impervious surfaces or turf grass. About 10% of tree canopy loss resulted from conversion to agriculture or extractive production (Table 10, Figure 17).

Timber Harvests from 2013 to 2021

We conducted an analysis of the effects of timber harvest on Maryland forests based on best available datasets. These included tabular data from Maryland DNR on total area permitted for timber harvest by year, complemented by FIA data on dominant tree species. Timber harvest permit area overestimates the actual area harvested for a few reasons: 1) timber companies may not choose to log a permitted area, 2) they will practice selective logging of hardwood species in particular and/or 3) they are required to avoid high-risk areas such as steep slopes and riparian zones (personal communication, A. Hairston-Strang, MDNR, December 2022). As spatial data were not available, we were unable to assess observed tree canopy changes within areas permitted for harvest. Initial assessments of actual timber harvest using satellite imagery confirmed that actual harvest areas represent a fraction of total permitted areas (personal communication, P. Claggett, USGS, December 2022). It is important to note that timber-managed areas in Maryland often have tree regrowth beginning after harvest — and these forest areas are typically not permanently lost unless the harvest was followed by development. Timber-managed areas have forest in a variety of successional stages.

Between 2013 and 2021, timber harvest permits were issued for over 149,156 acres of land. The vast majority of harvest permits (covering 131,767 acres) were issued for privately owned land. Annually, total area permitted for harvest ranged from 11,590 acres in 2014 to 21,752 acres in 2018 (Table 11).

Table 11. *Permitted area (acres) for timber harvest on private and state lands, 2013-2021 (MDNR).*

Year	Private (Acres)	State (Acres)	Total (Acres)
2013	13,253	1,750	15,002
2014	10,310	1,280	11,590
2015	14,863	2,153	17,016
2016	15,421	1,960	17,381
2017	19,673	1,629	21,302
2018	19,151	2,601	21,752
2019	12,112	2,704	14,816
2020	13,156	1,858	15,014
2021	13,830	1,435	15,283
Grand Total	**131,767**	**17,371**	**149,156**

We also reviewed the total area permitted for harvest by region. For interpretation, note that hardwoods are selectively logged, while softwoods tend to be clear-cut. It follows that the western counties (where hardwoods are dominant) have much lower "actual harvest area" than the permitted area would indicate. In the Eastern Shore region of Maryland, there is a mix of hardwoods and softwoods (each representing about 50% of harvest), so actual harvest area may more closely resemble permitted area. In all parts of the state, however, total harvest permit area likely overestimates total actual harvest area (personal communication, A. Hairston-Strang, MDNR, December 2022). Figure 18 and Figure 19 show the total estimated harvest removals by FIA region.

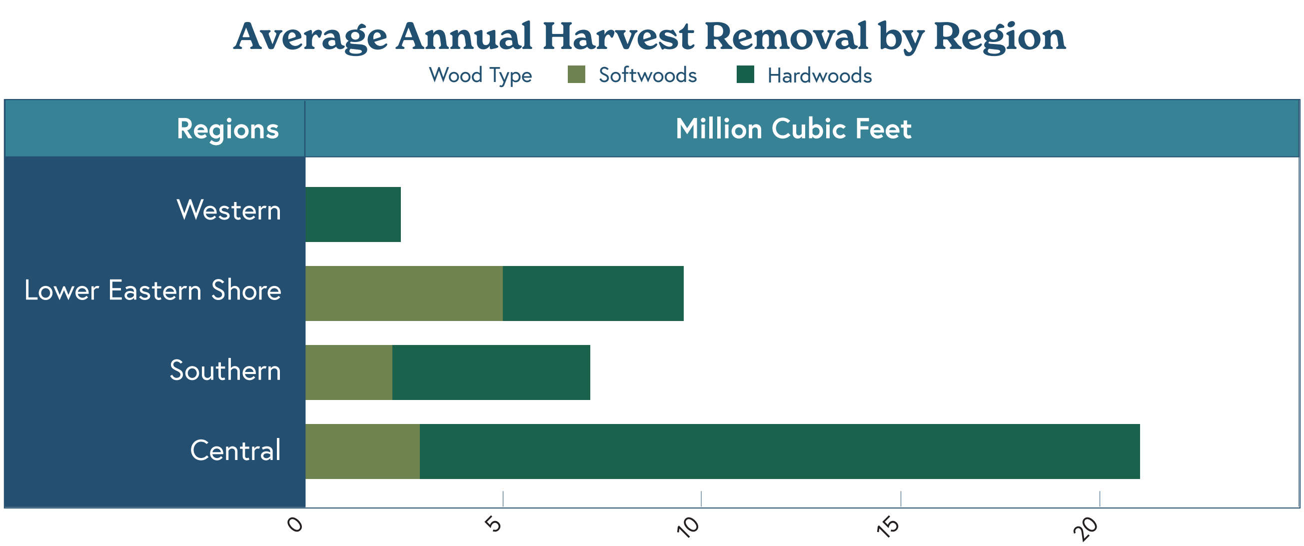


Figure 18. *Average annual harvest removals of merchantable bole volume of growing-stock trees (at least 5 inches d.b.h.), in cubic feet, on forest land by region.*

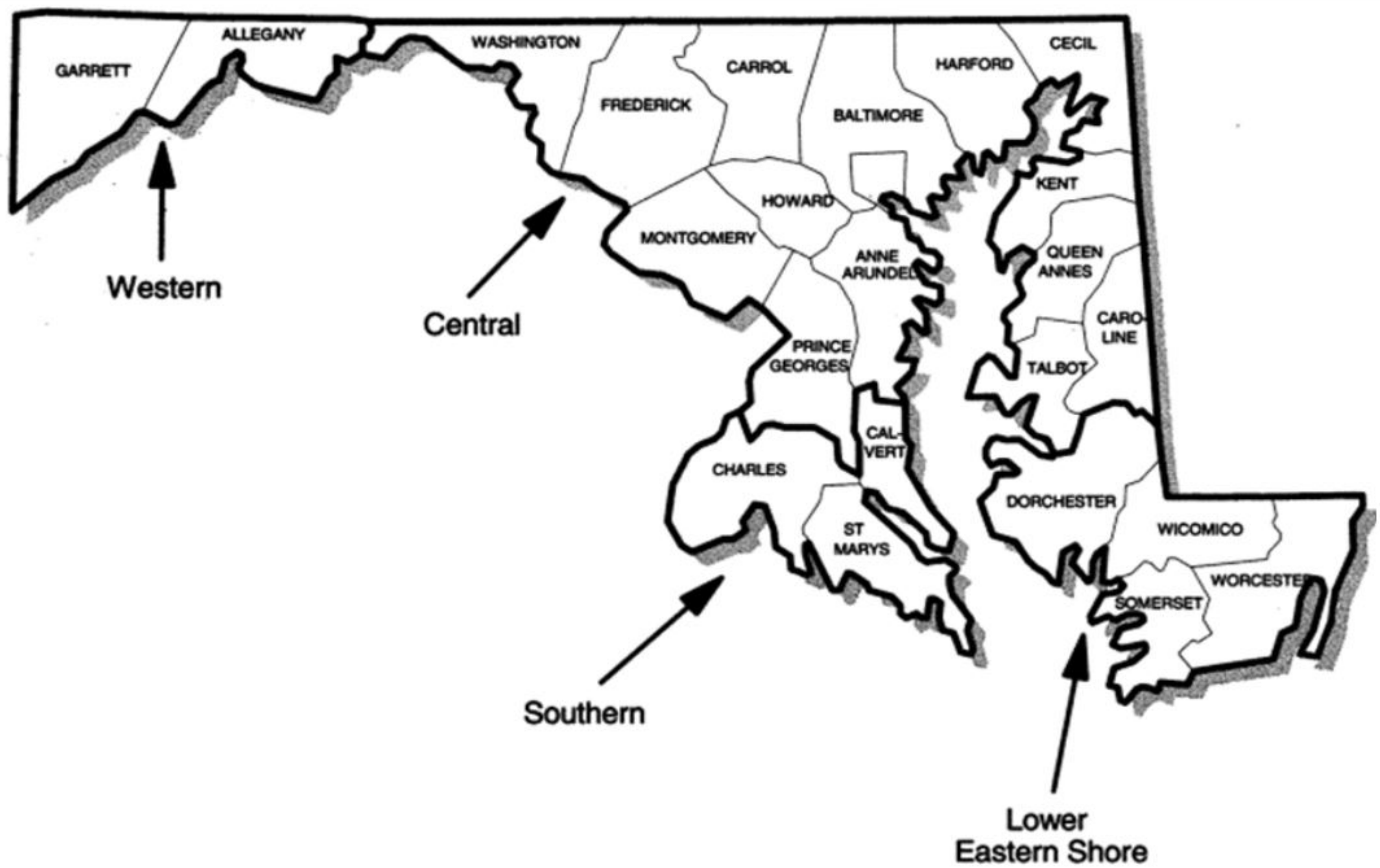


Figure 19. *Map of major regions of Maryland (USDA Forest Service FIA n.d.).*

At the county level, total area of timber harvest permits ranged from 26,595 acres in Garrett County in Western Maryland (2013-2021) to 0 acres in Howard County (Figure 20). Garrett County in fact issued permits for the most acres of timber for each year except 2021, where Somerset slightly exceeded that. This tally overestimates actual harvest area, given that trees in the western and central regions are hardwoods subject to selective logging, in addition to the fact that not all harvest permits are implemented each year. Worcester, Somerset, Wicomico and Dorchester counties, located in Maryland's Eastern Shore region, all issued permits for significant areas of timber harvest, as did Charles County in southern Maryland. Closer to Maryland's urban core, Montgomery County, north of Washington, D.C., only permitted 10 acres of timber harvest in 2021. Baltimore County issued timber harvest permits for 3,101 acres of timber between 2013 and 2021. Prince George's County issued permits for up to 2,469 acres of timber between 2013 and 2021. Given Maryland's active timber industry, it is worth noting that observations of tree canopy loss and gain in some counties may be observations of timber harvest and regrowth, a dynamic process.

The Timber Industry should be closely monitered.
Photo Credit: Daniel Soderman

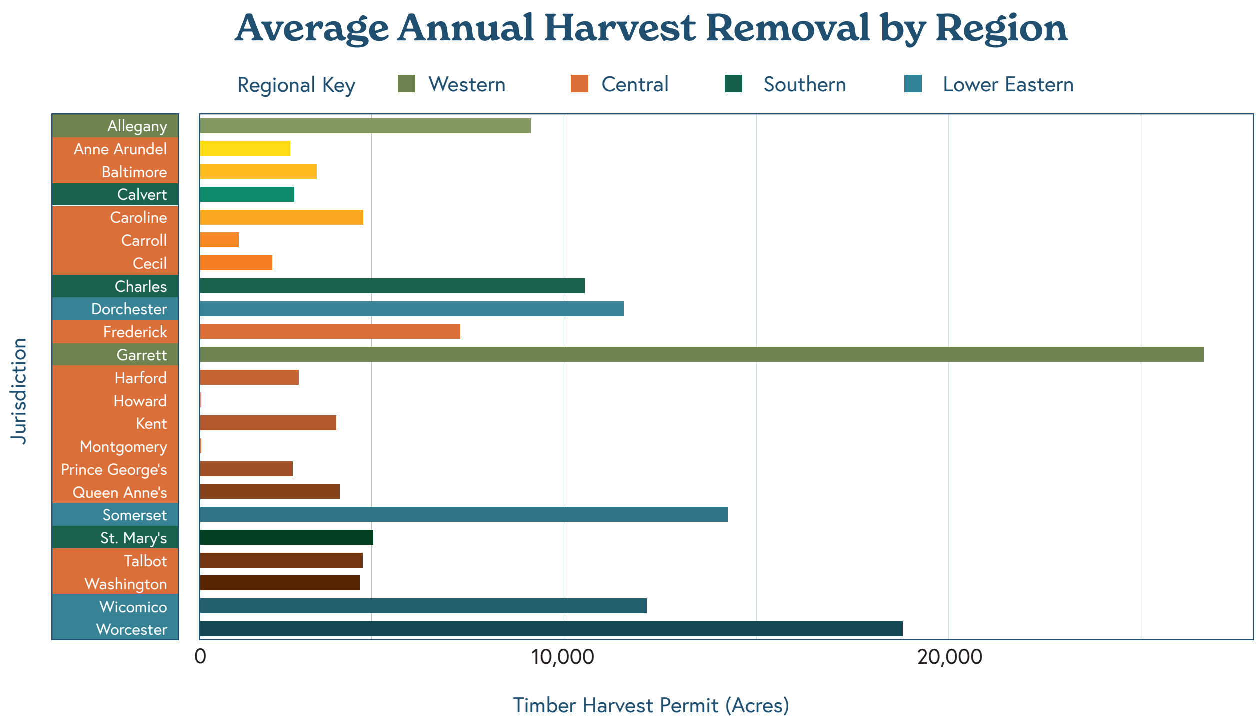


Figure 20. *Total cumulative area (acres) of timber harvest permits issued for private and state lands by jurisdiction, 2013 and 2021.*

High-resolution land cover and land use change by jurisdictions.

Remaining analyses in this section are based on high-resolution land use data for the Chesapeake Bay area (CBPO 2022c; CBPO 2022d) that parses tree canopy into two classes, forest and tree canopy outside forest based on minimum size criteria (see Definitions and Abbreviations). Figure 21 shows net change in forest cover and tree canopy cover by region. All regions except Lower Eastern Maryland experienced net loss in forest cover. Forest loss was most severe in Central Maryland, and this county also experienced a net loss in tree canopy outside forest. This is a result of rapid development outside Washington, D.C. in Prince George's and Montgomery counties in particular (Table 12). The observed net forest gain in Lower Eastern Maryland is likely explained by forest regrowth after harvest. Harvested areas were excluded from forest loss estimates in this analysis, so the regrowth process after harvest is represented as net gain. By contrast, all regions except Central Maryland experienced observable tree canopy cover gain outside forests. When accompanied by observations of net forest loss, this pattern might be explained by the fragmentation of intact forest to tree canopy patches that are too small to be considered forest. Understanding the causes of forest and tree canopy loss at the regional level can help determine management and mitigation measures.

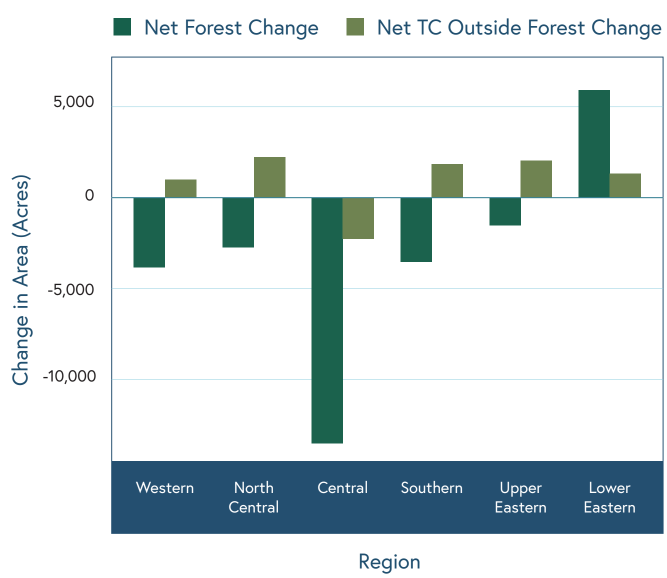


Figure 21. *T Net change in the extent of forest and tree canopy outside forest by region (acres), 2013-2018.*

Table 12. *Net change in the extent of forest and tree canopy outside forest (TCOF) by region and jurisdiction (acres, %), 2013-2018.*

LAND		NET CHANGE					
County or Jurisdiction	**Land Area (Acres)**	**Net forest change**	**Net forest change %**	**Net TCOF change**	**Net TCOF change %**	**Net Total TC change**	**Net Total TC change %**
Western	**976,672**	**-3,836.9**	**-0.4%**	**982.7**	**0.1%**	**-2,854.2**	**-0.3%**
Allegany	271,203	-912.1	-0.3%	311.8	0.1%	-600.3	-0.2%
Garrett	414,364	-2,154.9	-0.5%	347.8	0.1%	-1,807.1	-0.4%
Washington	291,105	-769.8	-0.3%	323.1	0.1%	-446.8	-0.2%
North Central	**964,130**	**-2,745.6**	**-0.3%**	**2,220.6**	**0.2%**	**-525.0**	**-0.1%**
Baltimore	383,212	-69.5	0.0%	176.6	0.0%	107.1	0.0%
Baltimore City	51,935	-1,196.5	-2.3%	101.5	0.2%	-1,095.0	-2.1%
Carroll	286,934	-684.8	-0.2%	1,300.9	0.5%	616.1	0.2%
Harford	242,049	-794.8	-0.3%	641.6	0.3%	-153.2	-0.1%
Central	**1,471,946**	**-13,525.6**	**-0.9%**	**-2,269.7**	**-0.2%**	**-15,795.4**	**-1.1%**
Anne Arundel	263,914	-2,443.6	-0.9%	469.9	0.2%	-1,973.7	-0.7%
Frederick	423,219	-591.9	-0.1%	652.8	0.2%	60.9	0.0%
Howard	160,479	-1,158.7	-0.7%	351.3	0.2%	-807.4	-0.5%
Montgomery	316,411	-3,444.3	-1.1%	-2,340.1	-0.7%	-5,784.4	-1.8%
Prince George's	307,923	-5,887.1	-1.9%	-1,403.7	-0.5%	-7,290.7	-2.4%
Southern	**657,852**	**-3,548.3**	**-0.5%**	**1,841.6**	**0.3%**	**-1,706.8**	**-0.3%**
Calvert	136,623	-1,319.0	-1.0%	539.3	0.4%	-779.6	-0.6%
Charles	292,616	-1,407.1	-0.5%	618.2	0.2%	-788.9	-0.3%
St. Mary's	228,613	-822.3	-0.4%	684.1	0.3%	-138.3	-0.1%
Upper Eastern	**1,348,164**	**-1,524.0**	**-0.1%**	**2,030.7**	**0.2%**	**506.6**	**0.0%**
Cecil	221,921	-1,020.5	-0.5%	821.9	0.4%	-198.6	-0.1%
Caroline	203,844	-173.2	-0.1%	147.7	0.1%	-25.5	0.0%
Dorchester	339,220	-182.2	-0.1%	240.9	0.1%	58.7	0.0%
Kent	176,491	-119.1	-0.1%	169.7	0.1%	50.6	0.0%
Queen Anne's	235,989	2.4	0.0%	365.8	0.2%	368.2	0.2%
Talbot	170,701	-31.4	0.0%	284.7	0.2%	253.3	0.1%
Lower Eastern	**735,649**	**5,921.8**	**0.8%**	**1,318.6**	**0.2%**	**7,240.3**	**1.0%**
Somerset	200,981	3,173.7	1.6%	288.7	0.1%	3,462.4	1.7%
Wicomico	238,124	869.6	0.4%	491.4	0.2%	1,360.9	0.6%
Worcester	296,545	1,878.5	0.6%	538.5	0.2%	2,416.9	0.8%
Maryland (total)	**6,154,413**	**-19,258.7**	**-0.3%**	**6,124.3**	**0.1%**	**-13,134.4**	**-0.2%**

Notes: Total TC = Total Tree Canopy = Forest + Tree Canopy Outside Forest. TCOF = Tree Canopy Outside Forest.

The study extent for this table is Maryland land area, calculated with CBPO dataset. The land area for Aberdeen Proving Ground (38,954 acres) is not included in Harford County metrics as the area was omitted in the imagery used to develop the CBPO data.

In addition to net change, it is helpful to look at total amounts of tree canopy loss and gain to understand the dynamics occurring in a landscape. Here, we see that across Maryland, total rates of tree canopy loss and gain exceed amounts of net change, indicating a far more dynamic landscape than net change numbers suggest. As expected, a quantity of forest and tree canopy outside forest that is lost is balanced out by growth or regrowth of tree canopy in other parts of the state. This pattern is reflective of natural change dynamics (e.g., loss and regrowth driven by wind, floods, natural fire), timber harvest and tree planting, reforestation and afforestation efforts, including mitigation efforts occurring as a result of FCA implementation (Table 13).

Table 13. *Forest, tree canopy outside forest (TCOF), and Net total tree canopy (Total TC) loss and gain by region, 2013-2018 (acres).*

LAND		FOREST AND TCOF LOSS (ACRES)			FOREST AND TCOF GAIN (ACRES)		
County or Jurisdiction	Land Area (Acres)	Forest loss	TCOF loss	Total TC loss	Forest gain	TCIFt gain	Total TC gain
Western	**976,672**	**4,583**	**413**	**4,996**	**746**	**1,396**	**2,142**
Allegany	271,203	1,046	79	1,125	134	391	525
Garrett	414,364	2,547	64	2,611	392	412	804
Washington	291,105	990	270	1,260	220	593	813
North Central	**964,130**	**3,398**	**1,747**	**5,145**	**652**	**3,968**	**4,620**
Baltimore	383,212	78	115	193	8	292	300
Baltimore City	51,935	1,323	909	2,232	127	1,010	1,137
Carroll	286,934	786	266	1,052	101	1,567	1,668
Harford	242,049	1,211	457	1,668	416	1,098	1,514
Central	**1,471,946**	**14,823**	**10,310**	**25,133**	**1,298**	**8,040**	**9,337**
Anne Arundel	263,914	2,595	731	3,326	151	1,201	1,353
Frederick	423,219	1,270	555	1,824	678	1,208	1,885
Howard	160,479	1,264	513	1,777	105	865	970
Montgomery	316,411	3,552	4,649	8,201	108	2,309	2,416
Prince George's	307,923	6,143	3,861	10,004	256	2,458	2,713
Southern	**657,852**	**7,087**	**1,600**	**8,686**	**3,538**	**3,441**	**6,979**
Calvert	136,623	1,755	631	2,386	436	1,170	1,607
Charles	292,616	2,951	523	3,474	1,544	1,142	2,685
St. Mary's	228,613	2,380	445	2,826	1,558	1,129	2,687
Upper Eastern	**1,348,164**	**4,954**	**938**	**5,892**	**3,429**	**2,969**	**6,398**
Cecil	221,921	1,187	305	1,492	167	1,127	1,293
Caroline	203,844	688	124	812	515	271	786
Dorchester	339,220	1,727	183	1,910	1,545	424	1,969
Kent	176,491	241	67	309	122	237	359
Queen Anne's	235,989	622	170	792	624	536	1,160
Talbot	170,701	488	90	577	456	375	831
Lower Eastern	**735,649**	**6,940**	**691**	**7,631**	**12,861**	**2,010**	**14,871**
Somerset	200,981	1,410	118	1,529	4,584	407	4,991
Wicomico	238,124	2,254	310	2,564	3,124	801	3,925
Worcester	296,545	3,275	263	3,538	5,154	802	5,955
Maryland (total)	**6,154,413**	**41,784**	**15,698**	**57,482**	**22,525**	**21,823**	**44,348**

Note: The study extent for this table is Maryland land area, calculated with CBPO dataset. The land area for Aberdeen Proving Ground (38,954 acres) is not included in Harford County metrics as the area was omitted in the imagery used to develop the CBPO data.

Figure 22 and Table 14 illustrate the amount of tree canopy cover change both within and outside forest that is associated with development, a key request of this study. Results show great variation by county. Prince George's and Montgomery counties experienced the most significant conversion of tree canopy to developed land, representing more than 50% of the state's tree canopy loss to development. Five counties, Prince George's, Montgomery, Anne Arundel, Charles and Baltimore, represent 73% of the state's tree canopy cover lost to development. Prince George's, Anne Arundel and Charles counties had the largest extent of intact forest converted to developed land. A few counties exhibited an opposing trend, though more modest: Carroll County and Baltimore City experienced a greater transition from developed land to tree canopy than loss of tree canopy to development. Harford and Frederick counties also had significant observable transitions from developed land to tree canopy, though a net loss of tree canopy to development. While the transition from developed to tree canopy may represent trees planted in urban areas, this pattern is still significant. It indicates that tree planting and protection programs can be effective at mitigating or even reversing tree canopy loss and can have significant economic and quality of life benefits in human-dominated areas.

Forest and Tree Canopy Change Associated with Development

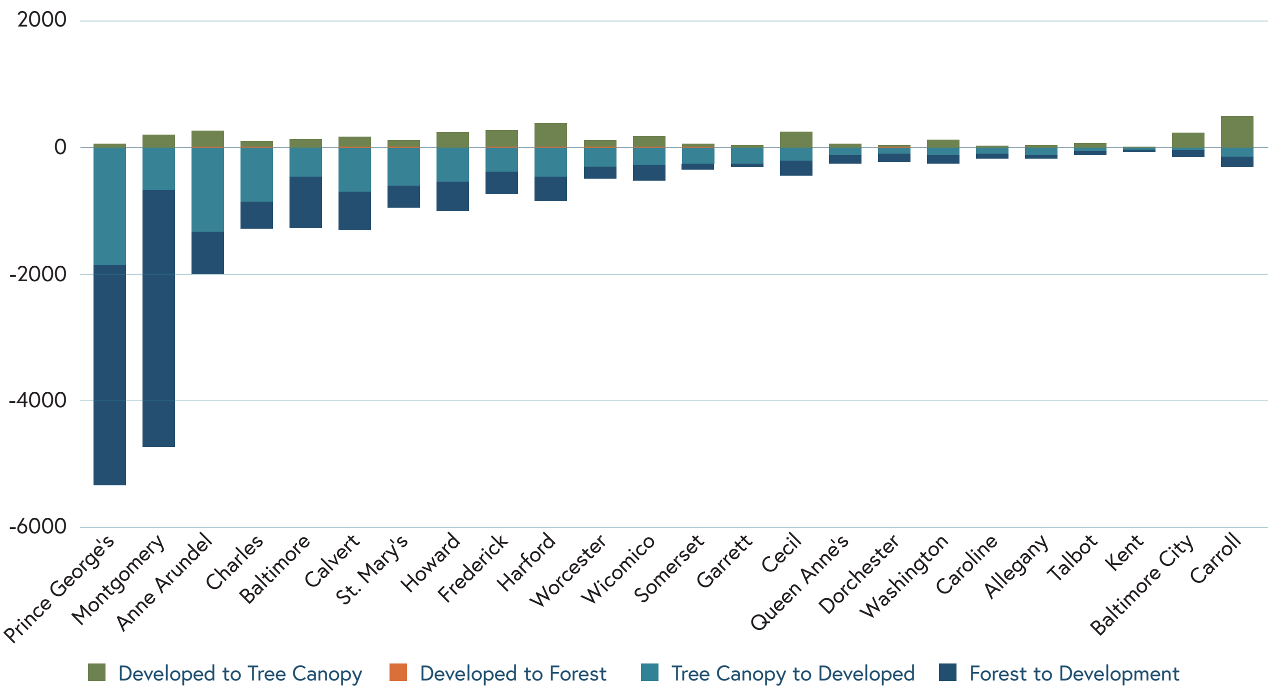


Figure 22. *Forest cover change due to development, by jurisdiction.*

When evaluated by region, we see that all regions of Maryland lost more tree canopy to development than they gained from it. Central Maryland experienced the largest conversion (area, % change) of tree canopy to development, including both forest and tree canopy outside forest (Table 14, Figure 23). This is consistent with the results by jurisdiction, primarily driven by tree canopy change in two counties. Southern Maryland and North Central Maryland also experienced a large loss of tree canopy to development. North Central and Central Maryland experienced the greatest increase of tree canopy from/in developed land, perhaps indicative of tree planting in developed areas or redevelopment. Indeed, nearly all this gain was tree canopy outside forest, as opposed to forest growth.

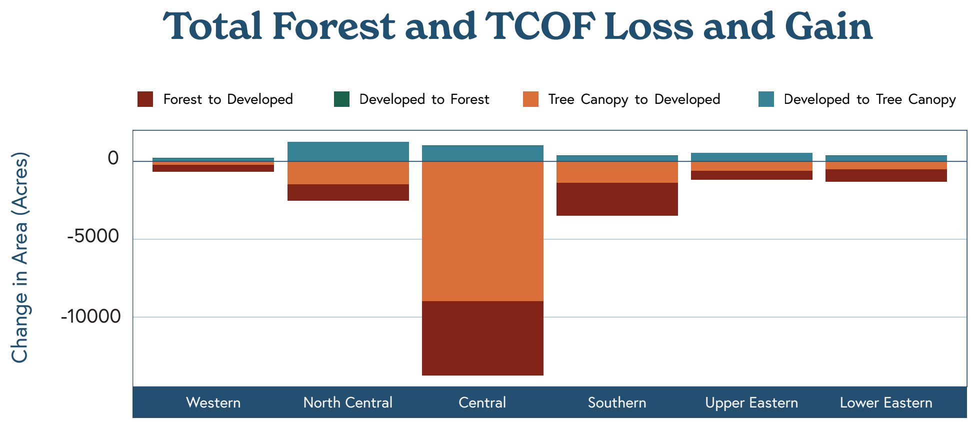


Figure 23. *Forest cover change due to development, by jurisdiction.*

Table 14. *Forest, TCOF, and Total TC change associated with development by region, 2013-2018 (acres).*

LAND		FOREST AND TCOF TO DEVELOPED (ACRES)			
County or Jurisdiction	**Land Area (Acres)**	**Forest to Developed**	**TCOF Change to Developed**	**Total TC to Developed**	**% Total TC Change to Developed**
Western	**976,672**	**466**	**200**	**666**	**13.3%**
Allegany	271,203	103	42	145	12.9%
Garrett	414,364	243	38	280	10.7%
Washington	291,105	120	120	241	19.1%
North Central	**964,130**	**1,049**	**1,465**	**2,514**	**48.9%**
Baltimore	383,212	27	112	139	71.8%
Baltimore City	51,935	447	822	1,269	56.8%
Carroll	286,934	127	160	287	27.3%
Harford	242,049	449	371	820	49.2%
Central	**1,471,946**	**4,751**	**8,977**	**13,728**	**54.6%**
Anne Arundel	263,914	1,321	657	1,978	59.5%
Frederick	423,219	378	331	709	38.8%
Howard	160,479	519	437	956	53.8%
Montgomery	316,411	663	4,077	4,741	57.8%
Prince George's	307,923	1,870	3,474	5,344	53.4%
Southern	**657,852**	**2,125**	**1,355**	**3,480**	**40.1%**
Calvert	136,623	698	578	1,277	53.5%
Charles	292,616	836	438	1,274	36.7%
St. Mary's	228,613	590	338	929	32.9%
Upper Eastern	**1,348,164**	**548**	**604**	**1,152**	**19.6%**
Cecil	221,921	200	221	421	28.2%
Caroline	203,844	78	67	145	17.9%
Dorchester	339,220	86	119	205	10.7%
Kent	176,491	18	27	45	14.6%
Queen Anne's	235,989	118	115	233	29.4%
Talbot	170,701	48	54	103	17.8%
Lower Eastern	**735,649**	**796**	**507**	**1,303**	**17.1%**
Somerset	200,981	248	77	325	21.3%
Wicomico	238,124	253	248	501	19.5%
Worcester	296,545	295	183	477	13.5%
Maryland (total)	**6,154,413**	**9,736**	**13,108**	**22,844**	**39.7%**

Note: TCOF = Tree Canopy Outside Forest; Total TC = Total Tree Canopy. The study extent for this table is Maryland land area, calculated with CBPO dataset. The land area for Aberdeen Proving Ground (38,954 acres) is not included in Harford County metrics as the area was omitted in the imagery used to develop the CBPO data.

Figure 24 shows forest transitions to other land uses by jurisdiction, while Table 15 shows the predominant forest transition for each county. Prince George's County experienced the largest loss of forest of all counties, with transitions to tree canopy (representative of forest fragmentation), developed land and "natural" cover types such as grassland or shrub. Montgomery and Charles counties followed a similar trend. Garrett County lost the majority of its forest cover to natural cover types, while Anne Arundel lost the majority of its forest to development. Worcester, Wicomoco, Dorchester, Somerset and Prince George's counties lost a significant amount of forest to wetland, which may indicate flooding or sea level rise in coastal counties. Nearly all counties lost some forest to agriculture or extractive industries, most notably the Eastern Shore counties and Washington County. Results indicate that forest clearing results from a variety of drivers, ranging from development, to agriculture, to private land clearing to natural causes. Some transitions, such as forest to development, are considered permanent, while other transitions, such as forest to natural habitats or wetlands, are more temporary and indicative of disturbance (including natural and human caused) or succession.

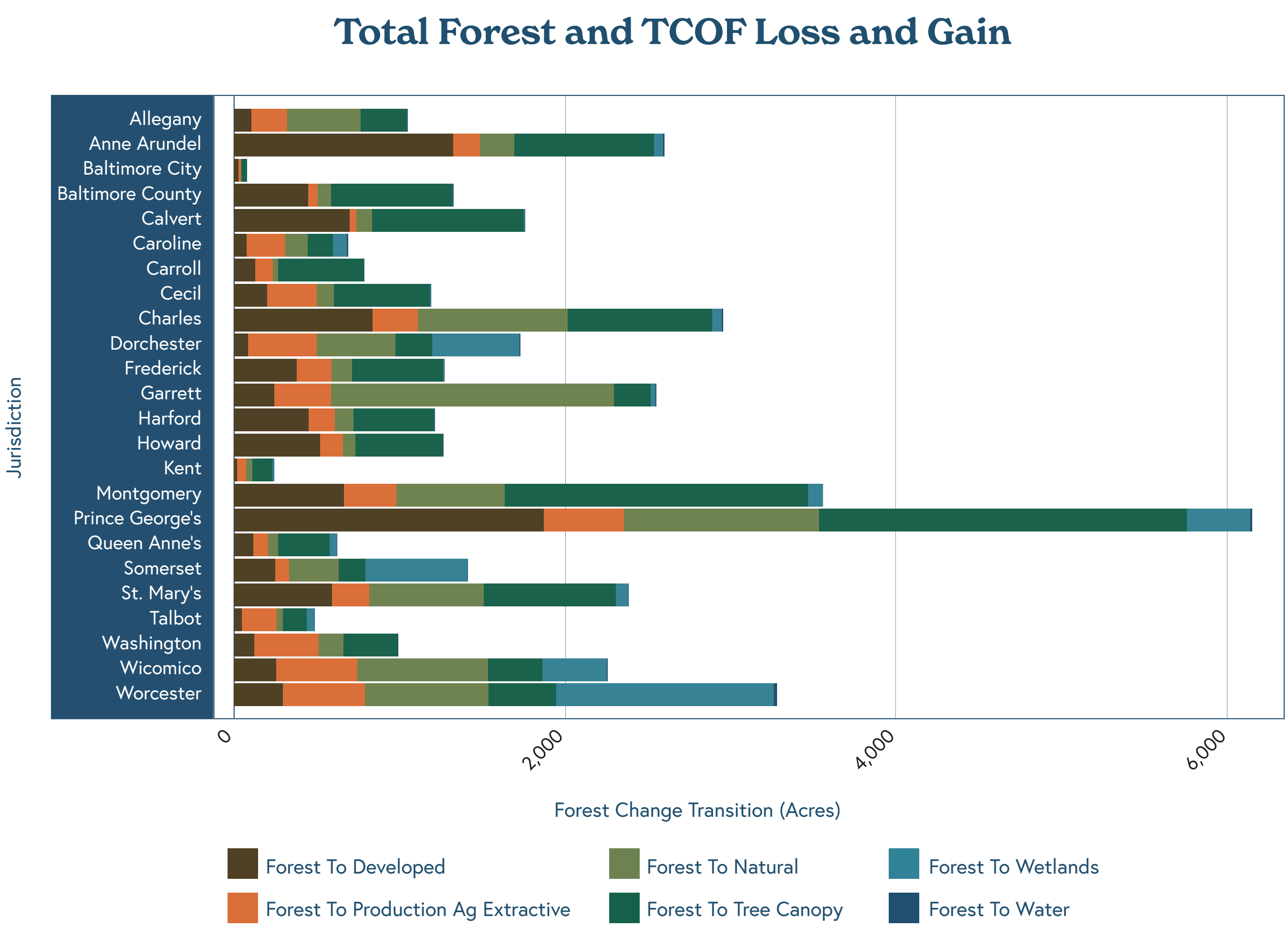


Figure 24. *Forest transitions to other land covers and uses, 2013-2018 (acres).*

Table 15. Predominant land use change for each Maryland jurisdiction, with percent of total acres of forest loss.

Forest Transition to Other Land Use	Jurisdictions Where This Forest Transition Is Predominant	% of Total Forest Change
Forest to Tree Canopy Outside Forest	Baltimore County	55.5%
	Calvert County	52.2%
	Montgomery County	51.5%
	Kent County	50.3%
	Queen Anne's County	50.2%
	Cecil County	48.9%
	Baltimore City	43.9%
	Frederick County	43.3%
	Howard County	42.0%
	Washington County	39.2%
	Prince George's County	36.1%
	St. Mary's County	33.5%
Forest to Developed	Anne Arundel County	50.9%
Forest to Natural	Garrett County	66.9%
	Allegany County	42.5%
	Wicomico County	35.0%
	Charles County	30.6%
Forest to Production (Ag/Extractive)	Talbot County	42.8%
	Washington County	39.2%
	Caroline County	33.5%
Forest to Wetlands	Somerset County	43.8%
	Worcester County	40.1%
	Dorchester County	30.6%

Figure 25 shows the amount of tree canopy in each county converted to other land use classes. The primary driver of tree canopy cover loss was to development in almost all counties. While the primary driver of tree canopy loss in Frederick and Washington counties was development, these counties lost a slightly higher proportion than other counties to agriculture. Montgomery and Prince George's counties also lost a significant amount of tree canopy cover to agriculture as well as to natural, non-forest vegetation types. To combat this trend, local governments need to account for the potential for tree loss that would occur as a result of construction and agricultural development.

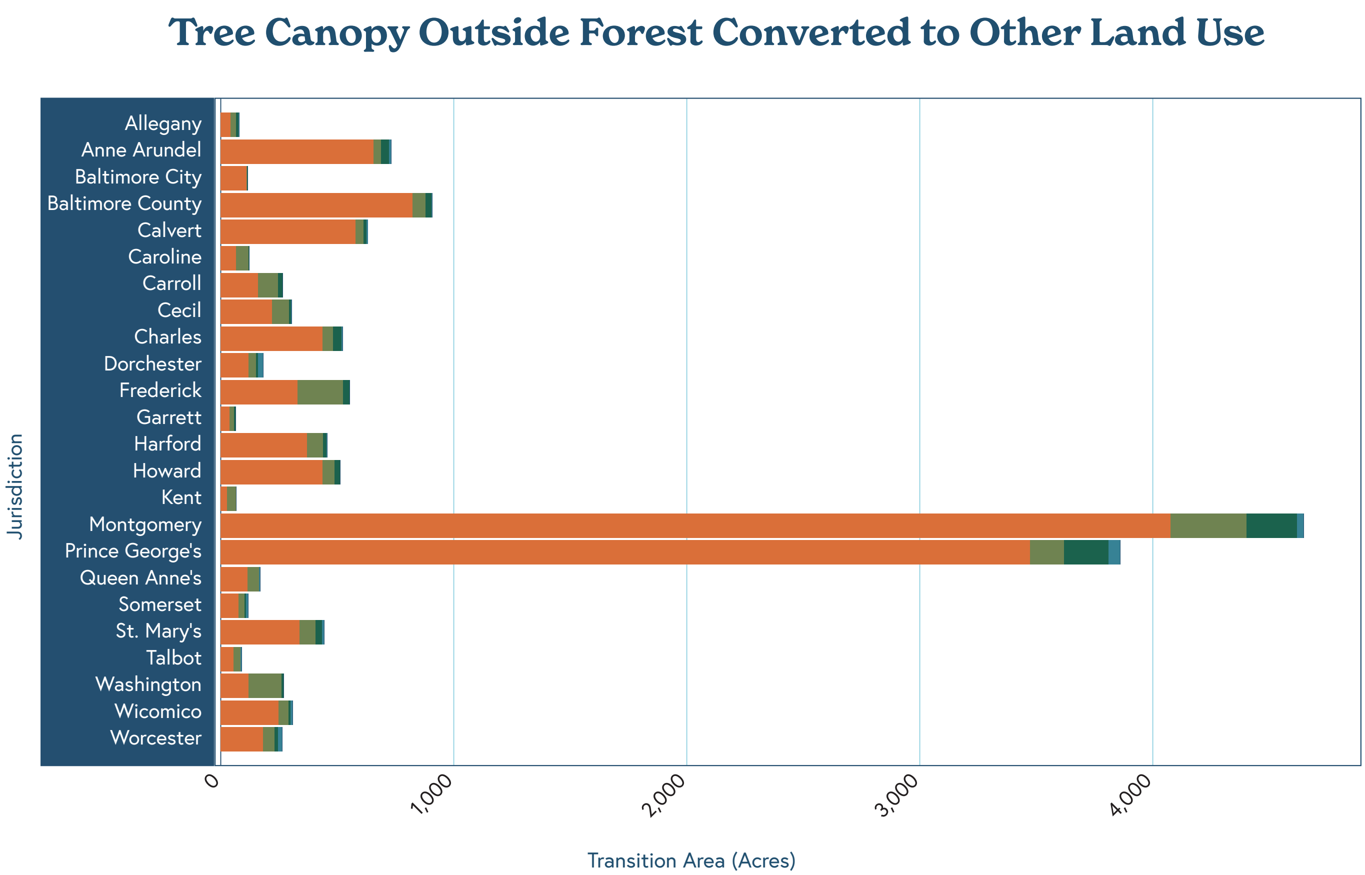


Figure 25. Area of Tree Canopy Outside Forest Converted to Other Land Use Classes (acres).

Figure 26 shows how tree canopy cover change varies according to county population growth rate. Generally, counties that experienced net population loss also experienced a net increase in tree canopy cover. These counties included Talbot, Kent, Somerset, Baltimore City and Dorchester. At the same time, counties that experienced net population increase tended to experience a net decrease in tree canopy cover. These counties included Montgomery, Anne Arundel, Prince George's and Wicomico. There are other counties, however, that did not adhere to this pattern. Frederick and Queen Anne's counties, for example, experienced net population growth and a net increase in tree canopy cover, indicating potentially good land use planning. Garrett and Allegany counties, alternately, experienced net losses in both population and tree canopy cover, perhaps indicative of timber harvest, zoning or conversion pressures. The pattern is nonlinear, indicating that while population may influence tree canopy cover loss, it is not the only factor affecting land cover change. Management, zoning, and change to wetland or other natural land covers can have critical roles as well.

Change in Forest and Tree Canopy by Jurisdiction

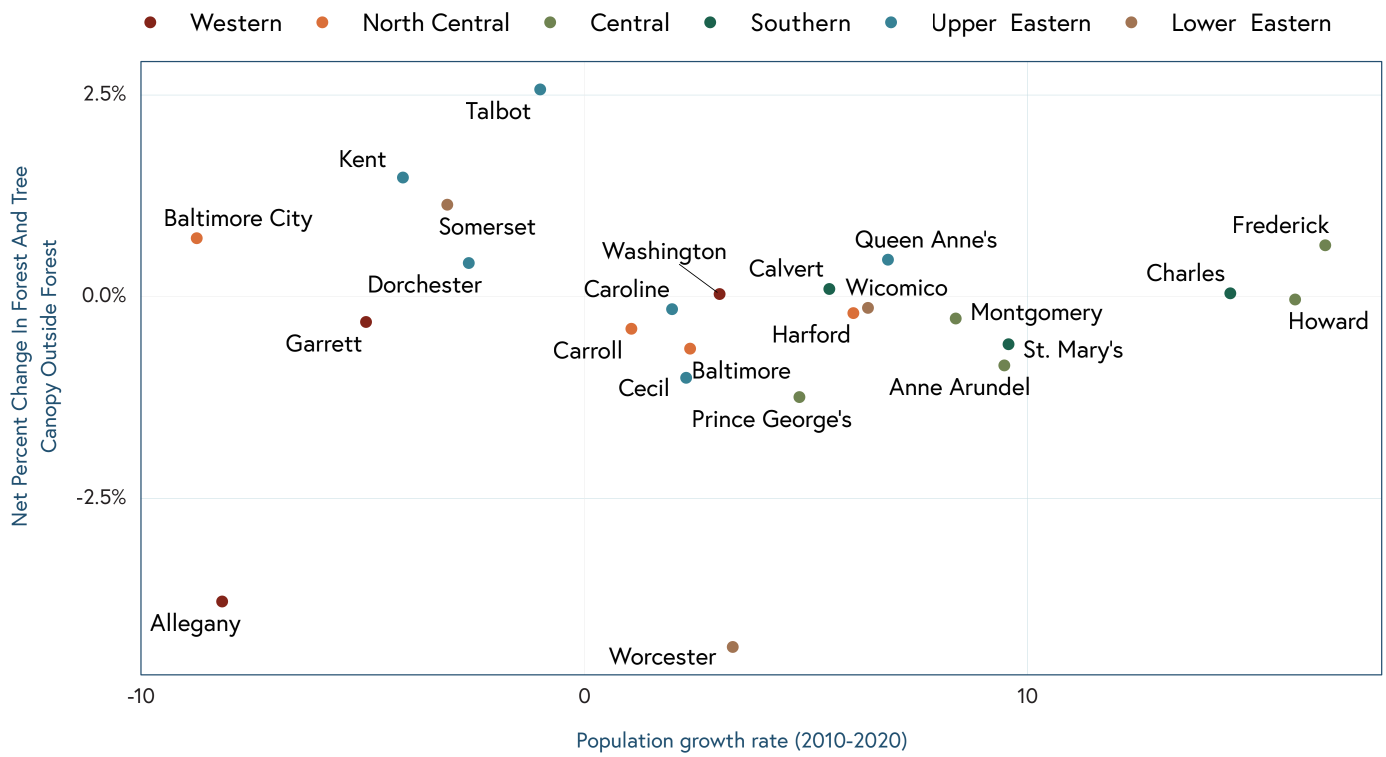


Figure 26. *Net percent change in forest and tree canopy by jurisdiction population growth rate, 2010-2020.*

Priority Funding Areas

Priority funding areas (PFAs) are existing communities and places designated by local governments for state investment to support future growth. Figure 27 shows their distribution throughout the state, notably in urban and suburban areas including the suburbs of Washington, D.C. and Baltimore City, as well as Salisbury on the Eastern Shore. Priority funding areas experienced a net loss of 1,240,014 acres, representing a greater percentage loss of forest (3.7%) than non-PFA areas (0.37%). Growth-related projects include development such as highways, sewer and water construction, economic development assistance and construction of new offices. PFAs coordinate state and local governments' needs to support development (MDP 2019).

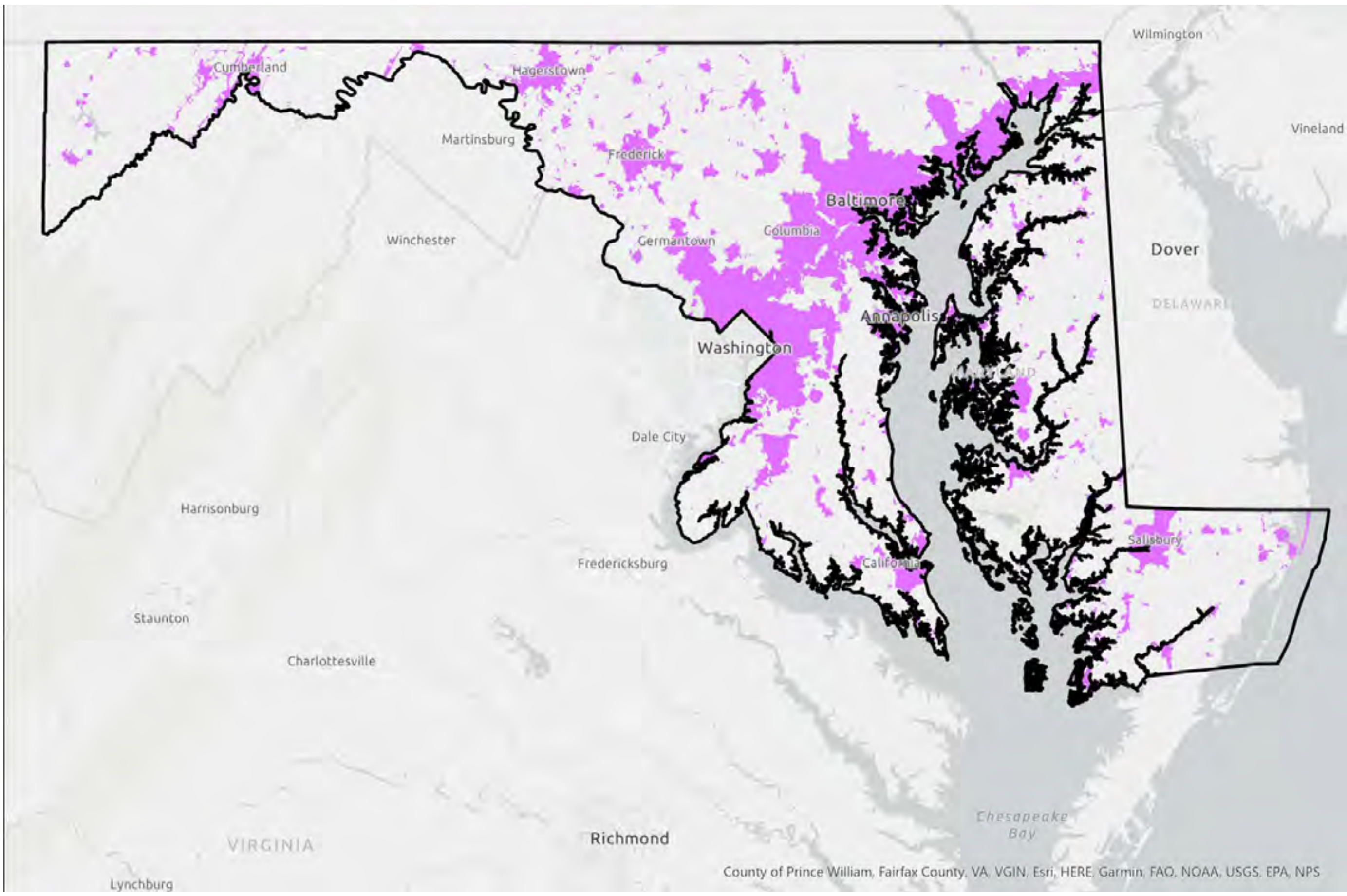


Figure 27. *Priority Funding Areas, shown in light purple.*

Table 16 presents change in forest and tree canopy outside forest area inside and outside PFAs. Between 2013 and 2018 there was a 9,583-acre decrease in forests within current PFAs (MDP 2019), representing 3.7% forest cover loss over the five-year period. Forests outside PFAs experienced one-tenth that rate of loss, or 0.37%. Within PFAs, tree canopy cover outside forests also decreased significantly (by 2,536 acres, or -1.07%). Outside PFAs, tree canopy outside forests increased although some of that increase is due to fragmentation of forests into blocks smaller than the minimum forest size definition. Results show, as expected, that tree canopy is at greater risk of loss within PFA development zones than outside these zones. Nearly half the tree canopy in PFAs is outside forests, so ongoing monitoring with high-resolution data would be required to track trends in these areas.

Table 16. Forest and tree canopy area and change within and outside Priority Funding Areas, 2013-2018.

AREA	FORESTS*				TREE CANOPY OUTSIDE FORESTS			
	2013	2018	Net Change	% Change (% Annual change)	2013	2018	Net Change	% Change (% Annual change)
Inside PFA (Acres)	259,218	249,635	-9,583	-3.7 (-0.74)	236,411	233,875	-2,536	-1.07 (-0.21)
Outside PFAs (Acres)	2,327,011	2,318,438	-8,573	-0.37 (-0.07)	288,461	296,746	8,285	+2.87(0.57)

*Tree canopy within forest land use

Forest Change in Retention and Protection Priority Areas

For this analysis, we quantified forest loss within several areas that are prioritized for retention and protection: Green Infrastructure hubs and corridors, Targeted Ecological Areas (TEAs) and 100-year floodplains (MDNR [2005] 2021; FEMA [2017] 2017; MDNR [2011] 2019). These datasets were merged into one region called "Protection Priority Areas." Forest and tree canopy outside forest was summarized within this area (Table 17). Priority Protection Areas are identified as having important ecological value, but may or may or may not have protective measures operating at this time.

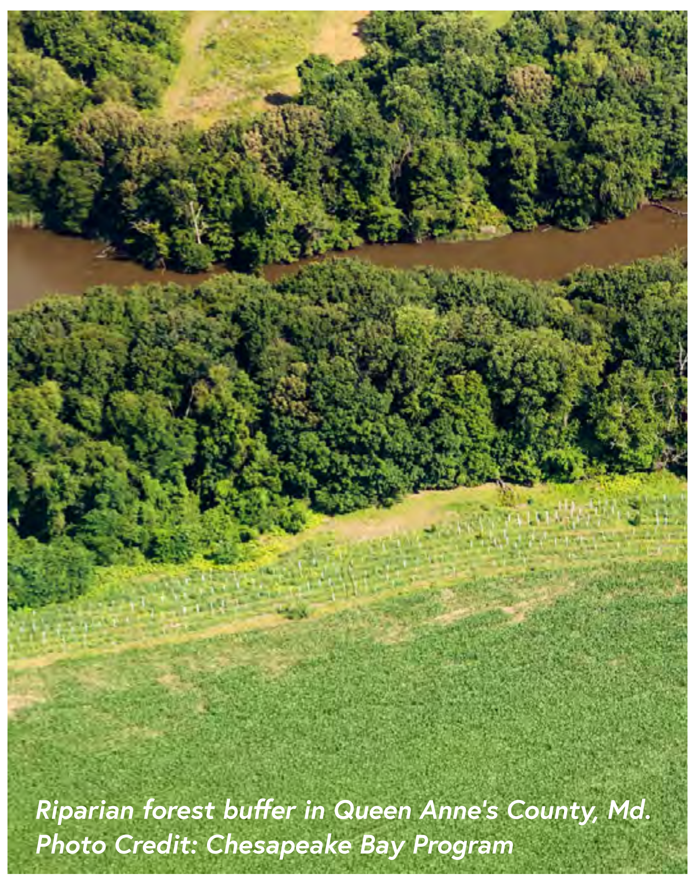
Table 17. Forest and tree canopy area and change within Priority Protection Areas, 2013-2018.

Dataset	2013	2018	% Change (% Annual Change)
Forest	2,017,778	2,008,948	-0.44% (-0.088)
Tree Canopy Outside Forest	163,731	169,606	+3.52% (+0.70)

Based on our analysis, a total of 8,830 acres (-0.44%) of forest was lost within these areas between 2013 and 2018. However, there was an increase of 5,875 (+3.52%) acres of tree canopy outside forest in the same time period, indicating a forest fragmentation as well as some tree planting. The rate of forest loss within Priority Protection Areas is 37% lower than the statewide rate of forest cover loss, which suggests management of portions of these environmentally sensitive areas discourages forest loss.

Core Forest Expansion

For this task, we examined potentially plantable areas (from Task 1b) that were located near forest edges, as determined by the CLEAR forest fragmentation analysis for 2018 (Task 3). To identify these areas, we buffered the 2018 forest edge class by 100m and overlapped with potentially plantable areas (Figure 28). There are relatively small amounts of plantable area within 100m of forest edge, but these areas could provide opportunities to restore and enhance existing core forest.



Riparian forest buffer in Queen Anne's County, Md. Photo Credit: Chesapeake Bay Program

__Figure 28.__ Plantable areas near forest edges (orange with black outline).

Table 18 displays the amount of plantable acreage that could be prioritized to expand core forest regions, by jurisdiction. Noting that while edge areas are not inherently bad and many species inhabit forest edge regions, the results of this analysis can be complemented with other information to identify areas for potential restoration of core forest across the state.

Table 18. Plantable area within 100m of forest edge, by jurisdiction and statewide.

Jurisdiction	Buffer (acres) in Jurisdiction	Plantable Acres within Buffer	% of Buffer that is Plantable
Allegany	197,371.18	10,372.80	5.26
Anne Arundel	147,044.83	8,456.83	5.75
Baltimore	168,481.93	12,813.00	7.60
Calvert	106,585.09	8,098.84	7.60
Caroline	112,636.86	2,553.80	2.27
Carroll	108,435.64	5,447.67	5.02
Cecil	125,649.21	7,089.09	5.64
Charles	231,473.19	1,4899.48	6.44
Dorchester	166,262.75	1,473.89	0.89
Frederick	204,075.98	6,157.41	3.02
Garrett	297,487.73	12,826.71	4.31
Harford	140,886.33	8,925.92	6.34
Howard	77,103.74	5,289.24	6.86
Kent	71,479.45	1,098.88	1.54
Montgomery	130,387.37	8,358.26	6.41
Prince George's	154,403.54	12,177.14	7.89
Queen Anne's	121,344.07	2,439.09	2.01
St. Mary's	165,599.70	9,658.10	5.83
Somerset	109,514.46	1,389.27	1.27
Talbot	83,558.02	2,148.62	2.57
Washington	148,361.25	5,997.66	4.04
Wicomico	144,679.61	4,798.72	3.32
Worcester	185,923.87	3,188.29	1.71
Baltimore City	2,970.47	265.53	8.94
Statewide	**3.401,716.27**	**155,924.24**	**4.58**

Statewide, approximately 155,924 acres within 100m of forest edge are identified as plantable, representing about 4.58% of the total buffered area. Charles County, followed by Garrett, has the most plantable area in acres in their buffered edge areas, while Baltimore City has the least amount. However, Baltimore City has the highest percent of its buffered area that is plantable, at nearly 9% (Table 18). Based on trends observed in the assessment of fragmentation by jurisdiction in Task 2, these findings align with other results from this study.

Projected Change (Tasks 4 and 5)

We projected changes in forest cover by applying the Chesapeake Bay Land Change Model (CBLCM), which forecasts future, county-specific development trends resulting from population and employment projections, while considering land use conditions, zoning, protected lands, slope and other factors affecting growth. For each county, the model estimates the portion of future population and jobs accommodated by infill and redevelopment and allocates the remaining portion to new development resulting in the conversion of forests and farmland. Additional scenarios are certainly feasible using this tool and may have included best management practice implementation and/or GGRA and TSNA related tree planting scenarios, but we were unable to pursue these for this study.

All counties are projected to lose forests to development between 2025 and 2055, with Anne Arundel County projected to experience the most loss (7,436 acres) and Kent County expected to lose the least (79 acres) (Figure 29). Although forest is projected to be lost between 2025 and 2055, tree canopy over impervious surfaces and tree canopy over turf grass are projected to increase in all counties due to increased commitments to urban tree planting (CCP 2021). Anne Arundel County is projected to gain the greatest extent of tree canopy over impervious surfaces, with 770 acres gain projected, while Worcester County is projected to gain the smallest extent of this class (6 acres). Charles County is projected to gain the greatest extent of tree canopy over turf, with 2,240 acres of projected gain, and Kent County is expected to experience the least increase in this cover class with 30 acres of expected gain (Figure 28).

Impervious roads and other impervious surfaces are projected to increase in area for all counties. Anne Arundel County is projected to gain the largest area of impervious roads (587 acres), and Worcester County is projected to gain the least area of new road (18 acres). Harford County is projected to gain the greatest extent of "other impervious surfaces" (2,265 acres), and Worcester County is projected to gain the least (62 acres) (Figure 29).

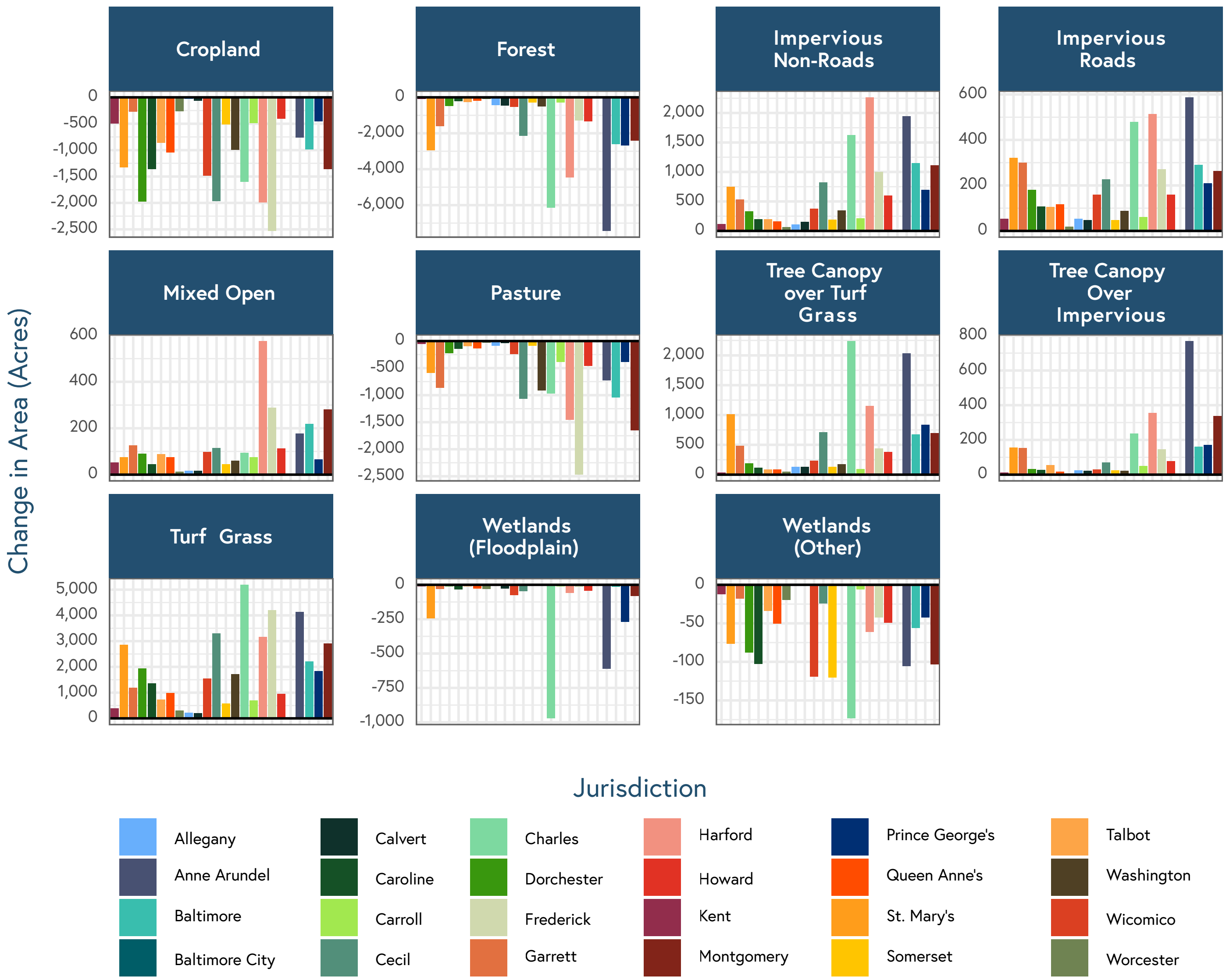


Figure 29. *Projected change in forest cover by jurisdiction, 2025 to 2055 (acres).*

There is some uncertainty in the predictions of forest cover change to 2055 given that only one scenario was run. The study does not incorporate the Maryland-specific Land Policy BMP scenario that will reduce the rate of forest loss compared with the baseline. The model also does not account for specific past, ongoing and planned reforestation and afforestation activities being done by state agencies. The model does not account for the potential role of the Tree Solutions Now Act of 2021 (HB991), an initiative to plant 5 million trees in Maryland (CCP 2021). If properly implemented, this legislation could contribute an estimated 12,500 acres of new tree canopy coverage statewide by the year 2031 (est. 400 trees/acre), partially mitigating statewide trends in tree cover loss. The 2030 Greenhouse Gas Emissions Reduction Act (GGRA) Plan projects 68,530 acres of afforestation and reforestation by 2030 compared with a 2006 baseline and the planting of 7.65 million trees, 2.15 million of which are urban trees primarily intended for tree loss mitigation (MDE 2021). These should also help to mitigate some of the expected forest and urban tree loss from population growth and development (MDE 2021).

Forest and Tree Canopy Commitments (Task 5)

There are a variety of government and privately funded tree planting, reforestation and afforestation programs operating in the state. In 2018 and 2019, these programs were responsible for the planting of an estimated 1854 cumulative acres, more than half of which was in response to the Forest Conservation Act. This trend should continue and accelerate with implementation of the Tree Solutions Now Act that sets the goal of planting an additional 5 million trees (~12,500 acres) from 2021-2031.

In 2018, 33% of Maryland's forests and 9% of tree canopy outside forests were protected by government parks or private easements. Protected lands experienced a significantly lower rate of forest loss and a much higher rate of tree canopy increase compared with statewide rates. While a few factors may be responsible for this trend, it is reasonable to conclude that protection is an effective management strategy for forests in Maryland.

Tree Planting, Reforestation and Afforestation Programs

Survey results indicate that approximately 550,741 trees and an additional 477 acres were planted in 2018 and 2019 by tree planting programs operating in Maryland. Assuming 400 trees planted on average per acre and no duplicate reports, we estimate 1854 cumulative acres of trees planted through government programs in 2019 and 2020. The Forest Conservation Act was responsible for planting more than half of these as part of mitigation efforts: 414,000 trees or 1,035 acres. (See Task 7 for detail.) As mentioned above, the Tree Solutions Now Act sets substantial afforestation, reforestation and tree planting goals that, if actualized, could substantially add to new tree canopy cover over the next eight years if existing trees are also protected. The TSNA aims to plant 5 million trees (500,000 in urban areas) from 2021-2031 (~12,360 acres). This adds to the efforts of currently operating tree planting programs in the state that aim to add or restore over 68,530 acres of forest and 9,000 cumulative urban tree canopy acres by 2030, compared with the year 2006 (MDE 2021; Gilchrest 2021).

Protected Lands

Land protection has been identified as an effective means of reducing forest loss (Andam et al. 2008); it has therefore been adopted as a key strategy implemented under the Forest Conservation Act and within the Chesapeake Bay Program to retain forest. Utilizing a subset of datasets sourced from MD iMAP, and shown collectively on the Maryland Protected Lands Dashboard, we examined change in forest and tree canopy outside forest in Maryland's protected lands between the two LULC time periods, 2013 and 2018 (MDNR, MDA, MDP 2022) (see Data and Methods for more information).

We based our analysis on the Maryland Protected Lands layer for the year 2018 and used this layer to assess forest cover in the years 2013 and 2018. Protected lands represent a substantial portion of the state's tree canopy: 33.2% of Maryland's forests and 9.3% of tree canopy outside forests are currently protected. This compares to 26.9% of land in Maryland protected in 2018 (1,667,185 acres). As of 2021, protected acreage in the state increased to 29% (1,797,294 acres) (MDP 2022).

In 2018, there were 851,710 acres of forest and 49,030 acres of tree canopy outside forest within protected area boundaries (Table 19). Since 2013, forest extent in these areas decreased by 267 acres (-0.031%) and the extent of tree canopy outside forest increased by 2,493 acres (+5.36%). Overall, the total extent of tree canopy cover (within and outside forests) had increased by 2,226 acres (+0.25%) in protected areas over the five-year period. This is in contrast to forest cover statewide, which had decreased by nearly five times (-0.14%) the rate of decrease within protected area boundaries alone. Tree canopy cover overall also experienced a net decrease statewide (-0.39%) from 2013-2018, compared with the net increase in canopy cover within protected area boundaries.

Table 19. *Tree canopy changes within protected lands (acres, % change), 2013-2018.*

	2013 (Acres)	2018 (Acres)	Net Change (Acres)	% Change	(Annual % Change)
Forest	851,977	851,710	-267	-0.031	(-0.006)
Tree Canopy Outside Forest	46,537	49,030	+2,493	+5.36	(+1.07)
Total	898,514	900,740	+2,226	+0.25	(+0.050)

Mitigation (Tasks 6 and 7)

Forest Mitigation Banking

Forest mitigation banking is implemented at the county level. Of the 21 counties governed by the FCA, 18 have provisions for forest mitigation banking within their regulations. Each county's regulations include geographic limitations on potential sites for afforestation and reforestation to incentivize the planting of trees in areas that provide the greatest ecosystem services.

The market for forest mitigation banking varies greatly between counties, with the approximate proportion of development projects that rely on mitigation banking credits to fulfill some or all of their forest conservation requirements ranging from 0% in Calvert, Kent and Queen Anne's counties to 80% in Wicomico County. Across all counties, existing forest banks comprise 81.1% of reported forest bank acreage with a total area of 13,997 acres, while planted forests only make up 18.9% of reported forest bank acreage, with an area of 3,261 acres. This suggests that steps may need to be taken at the county or state level to encourage the creation of planted forest banks, now that existing forest banks can no longer be created.

The evidence does not suggest a meaningful relationship between fee-in-lieu rates and the market for mitigation banks. However, higher fee-in-lieu rates could stimulate the creation of newly planted forested mitigation banks in the future.

While water quality improvement is not a stated goal of the FCA, several studies (e.g., State of Maryland 2019; Campbell et al. 2019; Outdoor Industry Association 2017) have found that afforestation is linked to improved water quality. This is especially true for trees planted in riparian zones, which are one of the priority areas for mitigation banks listed in the FCA. However, we must also keep in mind that 81.1% of reported forest bank acreage in the state consists of existing forest rather than planted forest and thus does not represent afforestation.

Background

One of the goals of the FCA was to minimize the loss of Maryland's forests from development by identifying priority areas to conserve or replant as part of building site planning. One way to do this is to require that any trees cut down must be replanted on the same property. If this is not feasible, developers are required to replant (or fund) planting offsite, such as through a forest mitigation bank Reforestation requirements for developers subject to the FCA are dependent on the amount of forest cleared. Afforestation is required if less than 15% or 20% of the net tract area is in forest cover, depending on land use category (Natural Resources Article 5-1606). All counties have a priority sequence for methods of afforestation and reforestation, with strategies for on-site mitigation prioritized over those for off-site mitigation, which may include the purchase of credits from a forest mitigation bank. Several counties further prioritize afforestation within the same watershed as the planned development project when possible. If a developer can demonstrate that none of the on- or off-site mitigation strategies can be reasonably accomplished, developers can instead pay a fee-in-lieu into the county's Forest Conservation Fund. This is with the exception of Carroll, Dorchester and Harford counties, which do not have fee-in-lieu programs. Fee-in-lieu rates are set at the county level, and all counties have a second, lower rate for development within Priority Funding Areas, which are existing communities and places designated by local governments indicating where they want state investment to support future growth. Some counties have exceptions for small-scale projects, where fee-in-lieu can be used instead of on- or off-site mitigation, such as projects with a mitigation requirement of less than one-quarter acre in Frederick County.

As mentioned previously, one potential option for off-site reforestation or afforestation is through forest mitigation banking, defined in the FCA as "the intentional restoration or creation of forests undertaken expressly for the purpose of providing credits for afforestation or reforestation requirements with enhanced environmental benefits from future activities" (Natural Resources Article 5-1601). As per HB 991, existing forest banks that were established on or before December 31, 2020, can continue to sell credits until June 30, 2024, but new banks that protect existing forest can no longer be established and all new banks must consist of newly planted forest.

Summary of Forest Mitigation Banking in Maryland

The FCA applies to 22 Maryland jurisdictions: 21 of the 23 counties, as well as to Baltimore City. Garrett and Allegany counties are exempt from the FCA due to their high forest cover, as counties that have and maintain more than 200,000 acres of their land area in forest cover are not required to implement the FCA (Natural Resources Article 5-1602). A survey at the beginning of 2022 found that 18 of the 22 jurisdictions subject to the FCA have provisions for forest mitigation banking programs within their regulations, with the exceptions being St. Mary's, Talbot and Harford counties and Baltimore City. The agency charged with implementing the FCA varies by county, though the responsibility most commonly falls on the Department of Planning and Zoning. The information about forest mitigation banking presented in this section was gathered by surveying the 18 counties' governments' agency staff responsible for forest mitigation banking programs and by reviewing their forest conservation regulations. Appendix D contains links to the regulations for each county. Forest mitigation banking programs are administered differently in each county and have varying levels of resources. While the level of information we gathered varied by county, all but Anne Arundel, Cecil and Dorchester counties were able to provide the data requested. The collected data represents each county's most recent records as of winter/spring 2022 (Table 20).

In comparing newly planted and previously existing forest banks, existing forest banks are far more widespread. Carroll County has never allowed existing forest banks, and Baltimore County stopped allowing them in 2019. Of the remaining counties from which this information was collected, six only have previously existing forest banks, while the other 4 also have a higher proportion of existing forest compared to planted forest (Table 20). Across all counties, existing forest banks comprise 81.1% of reported forest bank acreage with a total area of 13,997 acres, while planted forests only make up 18.9% of reported forest bank acreage, with an area of 3,261 acres. County representatives largely felt unprepared to comment on how the use of existing forest for forest mitigation banks to meet afforestation or reforestation requirements impacts the state's goal of achieving no net forest loss. In Prince George's County, off-site preservation has to be provided at a 2:1 ratio, so the amount of existing woodland that is put into permanent protection is twice the woodland conservation requirement when it is accepted as planting, allowing the protection of more acres in existing forest ecosystems in priority preservation areas. It was also suggested by a different county representative that well-intentioned tree planting efforts can fail because of the significant time and long-term investment and maintenance required to develop newly planted trees into healthy, mature forests that provide the full suite of desired ecosystem services; in order to fulfill the goals of the FCA, we should use every tool at our disposal, including preserving existing trees to maintain a stable baseline forest canopy. Finally, there is some concern that without the option of creating mitigation banks on forested land, landowners may turn to land clearing or development to realize the economic potential of their land, resulting in overall forest loss. Regardless, the prevalence of existing forest banks indicates that county banking programs will need to change substantially in order to continue thriving now that new existing forest banks are no longer permitted.

Regulations for the Creation of Forest Mitigation Banks

Each county's regulations include geographic limitations on potential sites for afforestation and reforestation to incentivize the planting of trees in areas that provide the greatest ecosystem services. In some cases, these simply serve as guidelines to identify priority areas, while in others they are a mandatory requirement and sites must meet at least one of the criteria. Some counties also have additional geographic and minimum size requirements relating to the creation of mitigation banks. The geographic limitations for afforestation and reforestation identified within county regulations largely reflect the priority areas delineated in the FCA, which are listed below. Additional geographical limitations and specific requirements for banks for individual counties can be found in Table 21, while the minimum acreages for establishing banks are listed in Table 20.

Priority areas for afforestation and reforestation listed in the FCA (Natural Resources Article 5-1607):

1. Establish or enhance forest buffers adjacent to intermittent and perennial streams and coastal bays to widths of at least 50 feet;
2. Establish or increase existing forested corridors to connect existing forests within or adjacent to the site and, where practical, forested corridors should be a minimum of 300 feet in width to facilitate wildlife movement;
3. Establish or enhance forest buffers adjacent to critical habitats where appropriate;
4. Establish or enhance forested areas in 100-year floodplains;
5. Establish plantings to stabilize slopes of 25% or greater and slopes of 15% or greater with a soil K value greater than 0.35 including the slopes of ravines or other natural depressions;
6. Establish buffers adjacent to areas of differing land use where appropriate or adjacent to highways or utility rights-of-way;
7. Establish forest areas adjacent to existing forests so as to increase the overall area of contiguous forest cover, when appropriate; and
8. Use native plant materials for afforestation or reforestation, when appropriate.

Thirteen of the 18 surveyed counties include specific details regarding the siting and creation of forest mitigation banks within their forest conservation regulations (Appendix D). Some of the broad outlines that are common to most counties are summarized below

- The property owner must submit an application and a forest mitigation bank plan containing the required site maps (examples include vicinity maps, forest stand delineations and survey maps) and a forest conservation plan or an afforestation and reforestation plan prepared by an approved qualified professional such as a licensed forester or landscape architect. The application will be reviewed by the appropriate county department.
- The location of the bank must meet the criteria established by the geographic limitations and requirements discussed in the previous paragraph.

- The bank must be protected by an easement, deed restrictions or other covenant which requires the land in the bank to remain forested in perpetuity.
- The property owner must sign a short-term maintenance agreement (usually two years) that sets forth how areas will be maintained to ensure protection and satisfactory establishment and provisions if survival falls below required standards.
- Credits cannot be sold until the end of the maintenance period unless the bank owner has posted a bond or alternate form of security.
- Before any credits are sold, the county will conduct a final inspection and certify the bank.

The Market for Forest Mitigation Banking

The market for forest mitigation banking varies considerably between counties, with the approximate proportion of development projects that rely on mitigation banking credits to fulfill some or all of their forest conservation requirements ranging from 0% in Calvert, Kent and Queen Anne's counties, to 5-10% in Caroline County, 50% in Carroll County and 80% in Wicomico County. In Kent and Queen Anne's counties, most development projects are able to meet their mitigation requirements on-site. Kent County also has relatively few development projects overall (five to 10 subdivided lots and three to four commercial plans each year); therefore, there is no demand for mitigation banks. In addition to the demand for banks, landowner interest in creating new banks is also key. In Calvert County, no forest mitigation banks exist because mitigation banks must be created out of newly planted forest, which does not appeal to landowners. Instead, they utilize the county's Forest Conservation Transferable Development Rights program, which allows landowners to sell forest rights for previously existing forests to developers to fulfill their forest conservation obligations. In other counties that previously allowed retention banks, landowner interest has been negatively impacted by new retention banks no longer being permitted. Multiple county representatives stated that creating newly planted forest banks is not appealing to landowners. Although bank owners can set their own rates for selling credits, establishing a newly planted forest bank involves high upfront costs that are not recouped for multiple years, until after the forest is established and credits are sold. In such cases, there is higher incentive for landowners to enroll their land in other conservation programs such as the Creek ReLeaf reforestation program in Frederick County or to directly allow developers to use their land for off-site mitigation, in the case of Washington County. Some counties have also seen an increase in fee-in-lieu payments due to a lack of new available banking credits. County representatives expressed concern about the added responsibilities that they face as a result. While this is less of an immediate problem, there is also a concern that over time, counties will simply run out of available private lands for establishing newly planted forest banks that are not already under conflicting conservation easements.

The evidence does not suggest a meaningful relationship between fee-in-lieu rates and the market for mitigation banks. It is important to keep in mind that mitigation banks are only one of several options for afforestation and reforestation and prioritized below on-site mitigation, as well as other types of off-site mitigation in certain counties. In many counties, they are only used by a small proportion of development projects. Therefore, we would not expect to single out mitigation banks in particular to be correlated with fee-in-lieu rates.

This is further supported by the counties' current fee-in-lieu rates, which can be found in Table 20. Of the 18 counties surveyed, three do not have a fee-in-lieu option, and three others do not have any forest mitigation banks. Seven of the remaining 12 counties use the fee-in-lieu rates that are outlined in the FCA; four still use the original rates of $0.30 and $0.36 per sq. ft. for projects inside and outside priority funding areas respectively, while three have raised the rates to $0.305 and $0.366 per sq. ft. due to inflation adjustments (COMAR Natural Resources Article 5-1610). Given that the FCA called for inflation adjustments starting in 2014, this suggests that many counties do not adjust fee-in-lieu rates on a regular basis. As a further example, Frederick County has had its current rates of $0.43 and $0.54 per sq. ft. for projects inside and outside priority funding areas since 2007. Some counties do adjust fee-in-lieu rates more regularly, such as Montgomery County. However, in that case, the fee-in-lieu rate is updated every other year, per County Council resolution, based on the consumer price index, without any relation to forest mitigation bank availability.

Calculating a statistical relationship between fee-in-lieu rates and the market for banking would also be challenging, as there is no good metric to represent the market for banking. The acreage available within active banks can vary greatly over time and may not reflect the interest in banking. For example, Montgomery and Baltimore counties have large and active markets for banking credits and high overall acreages in banks. However, high turnover of credits leads to certain periods with zero active banks. In Montgomery County, this is further exacerbated by the recent legislative changes no longer allowing new retention banks (Baltimore County stopped allowing retention banks some years ago). The total acreage of mitigation banks in a county may also not be representative of the current market, as the recent legislative changes have significantly impacted banking in many counties. Finally, we could consider the acreage of forest banks debited within a given time period, but it would be difficult to ascertain whether developers who were interested in purchasing credits from a mitigation bank chose other off-site mitigation options or paid fee-in-lieu due to a lack of available credits.

While there is no clear relationship between the market for mitigation banking and fee-in-lieu rates at present, higher fee-in-lieu rates could stimulate the creation of newly planted forested mitigation banks. As discussed previously, many landowners are not interested in establishing banks, as they require a large investment of time and money that may not be recouped for several years. The representative for Washington County indicated that fee-in-lieu rates would have to be substantially higher to spur that interest. Similarly, the representative for Anne Arundel County stated that while forest banks were not economically practical under the county's previous fee-in-lieu rate of $0.50 per sq. ft., the new rate established in 2019 of $1.25 and $1.50 inside and outside priority funding areas may be sufficiently high to encourage the creation of new banks. It is too early to know if this will be the case.

Forest restoration in Anne Arundel County, Maryland. Photo Credit: Chesapeake Bay Program

Harford County, Maryland Photo Credit: Chesapeake Bay Program

Table 20. Summary of forest mitigation banking information for the Maryland counties that have banks or the option for banks.

COUNTY	BANKS TOTAL			BANKS ACTIVE		MIN. SIZE (ACRES)	FEE-IN-LIEU RATE ($ PER SQ. FT.)	
	No.	Acres Existing	Acres Planted	No.	Acres		Priority	Other
Anne Arundel	20	*	*	1	*	1	1.25	1.50
Baltimore	28	578.4	383	0	0	10	0.55	
Calvert	N.A.	N.A.	N.A.	N.A.	N.A.	1	1.00	1.20
Caroline	1	114	0	1	70	N.A.	0.30	0.36
Carroll	77	N.A.	858	18	59	N.A.	N.A.	
Cecil	7	263	0	7	*	0.92	N.A.	
Charles	71	3232	0	35	1976	N.A.	0.30	0.36
Dorchester	*	*	*	*	*	10	N.A.	
Frederick	182	2599	742	40	370	N.A.	0.43	0.54
Howard	31	182.3	111.6	20	94	1	1.25	1.50
Kent	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	0.305	0.366
Montgomery	31	1334	277	0	0	1	1.30	
Prince George's	218	4525	889	67	1906	10	0.305	0.366
Queen Anne's	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	0.30	0.36
Somerset	1	138.8	0	1	15	10	0.33	
Washington	2	28.3	0	0	0	10	0.30	0.36
Wicomico	27	650	0	4	70	1	N.A.	
Worcester	12	352.1	0	12	188	1	0.305	0.366

Notes: Banks Total refers to the overall number of banks in the county and their total acreage, including acres that have been debited and those that are still available for the purchase of credits. Banks Active refers to the number of active banks and the acreage that is currently available for the purchase of credits, as per the most recent records for each county as of winter/spring 2022. Min. size is the minimum acreage required for the establishment of a new bank. In the Fee-in-Lieu Rate column, Priority and Other refers to the rates for development projects located inside and outside Priority Funding Areas.
**Indicates that the data was not provided.*

Table 21. *Geographic limitations for afforestation, reforestation or retention that add to or alter the priorities delineated in the FCA.*

County	Geographic limitations for afforestation, reforestation or retention that add to to alter those delineated in the FCA / *Limitations on the location of forest mitigation banks*
Baltimore	Minimum stream buffer of 75 ft for surface water designated use I streams and 100 ft for III and IV streams; riverine not 100-year floodplains; slope stabilization of 10% or greater slopes with a soil erodibility K value > 0.24 rather than 15% and >0.35 in FCA.
Carroll	No width specified for stream and wetland buffers or forest corridors; floodplains not included.
Cecil	Minimum stream buffer width of 110 ft for perennial streams.
Charles	Establish or enhance forest plantings on marginal agricultural areas.
Dorchester	Establish forest areas on lands not considered to be prime agricultural lands, as per the County Soil Conservation District / *Requirements for banks: Existing forestland of 10 acres or more; Establishment of riparian forest buffer planting along agricultural stream systems; Enhancement of riparian forested areas by planting adjacent to existing riparian areas; Establishment of planting on less productive agricultural soils.*
Frederick	Areas identified as green infrastructure network and/or sensitive species areas / *Requirements for banks: New or existing forests that provide buffers for streams, creeks, floodplains, wetlands or other hydrologically-sensitive areas on lands that are zoned Agriculture or are primarily in bona fide agricultural use; Existing forest that is critical habitat for threatened or endangered plant or sedentary animal species; Other areas that are i) Water recharge zones for municipal or county public water supplies ii) Not owned by a municipality or other governmental entity iii) Not otherwise substantially protected by Forest Resources chapter of Code or County Zoning Ordinance requirements and iv) Of such significance that loss of forest or the lack of creation of forests on such areas would cause a deleterious effect on the health, safety and welfare of the citizens.*
Howard	Rare, threatened or endangered species; Trees that are part of an historic site or associated with an historic structure; Specimen trees; Green infrastructure network; 75' or 100' undisturbed buffer for perennial streams in residential zoning districts; In or near wetland areas; Slopes of 25% or greater which are at least 20,000 sq. ft. or adjacent to streams or wetlands; Infill between isolated forest stands and groves of specimen trees; Property line or right-of-way buffers that are at least 50 ft wide / *For properties protected by a County Agricultural Land Preservation Easement, banks may only be established in the following areas: Stream buffers - a maximum of 100 feet on either side of the stream bank; Wetlands and wetland buffers - a maximum of 50 feet from the edge of the wetland; Slopes - 25% or greater; Howard County Green Infrastructure Network.*
Kent	Minimum stream buffer width of 100 ft for perennial and intermittent streams.
Montgomery	**Floodplains, stream buffers, steep slopes and critical habitats; Contiguous forests; Rare, threatened and endangered species; Trees connected to an historic site; Champion and other exceptionally large trees; Areas designated as priority save areas in a master plan or functional plan.
Prince George's	**Green infrastructure network elements; Critical habitat areas; Contiguous wooded areas with: high structural and species diversity, few nonnative and invasive species present, very good overall stand health and high potential to provide a significant amount of habitat for forest interior dwelling plant, animal and bird species; Champion trees designated by the federal, state, county or municipal governments; Specimen and historic trees; Forest Legacy Areas; Trees associated with a historic site or resource; Areas adjacent to Primary Management Areas; 100-year floodplains; Wetlands and their buffers; Regulated streams and their buffers; Extensive areas of steep and severe slopes; Hydric soils associated with wetlands and highly erodible soils on slopes 15 percent and greater; Forest Interior Dwelling Species (FIDS) habitat.
Queen Anne's	Minimum stream buffer width of 100 ft for perennial streams.
Somerset	**Nontidal wetlands and associated buffers; Stream buffers (50 feet from stream bank); Critical habitats of rare, threatened, or endangered species; Slopes greater than 15%; Highly erodible soils; Areas immediately adjacent to existing forests; Areas which may serve as buffers between differing land uses / *Requirements for banks: Existing forestland of 10 acres or more; Establishment of riparian forest buffer planting along agricultural stream systems; Enhancement of riparian forested areas by planting adjacent to existing riparian areas; Establishment of planting on less productive agricultural soils.*
Washington	No width specified for stream buffers / *Requirements for banks: Existing forestland of 10 acres or more; Establishment of riparian forest buffer planting along agricultural stream systems; Enhancement of riparian forested areas by planting adjacent to existing riparian areas; Establishment of planting on less productive agricultural soils.*
Worcester	**Located along a coastal bay or a perennial or intermittent stream; Adjacent to and joined with an existing forested area of at least fifty acres in size; Designated as being within a state or County greenway node or corridor; Located within a one-hundred-year floodplain; Located within the C-1 Conservation District as defined by § ZS 1-108 of the Worcester County Zoning Ordinance and as shown on the official Zoning Maps; Wetlands comprise no more than twenty-five percent of the site.

*** Indicates that geographic limitations for that county differ significantly from those in the FCA and the limitations are listed in entirety. The italicized text refers to additional limitations on the location of forest mitigation banks within a county. Information was compiled from each county's forest conservation regulations, linked in Appendix D.*

Forest Mitigation Banking and Water Quality

The Forest Conservation Act was not designed to improve water quality, although water quality improvement can be an additional benefit. Forest mitigation's goal is to maintain net forest cover and mitigation banking is one of the tools used to preserve trees that would otherwise be lost. Only one of the geographic priorities for the creation of banks listed in the FCA is directly linked to water quality, specifically, "establish or enhance forest buffers adjacent to intermittent and perennial streams and coastal bays to widths of at least 50 feet" (COMAR Natural Resources Article 5-1607). If tree planting occurs in a different watershed than the development project being mitigated, those trees will not impact water quality at the initial site, although they could lead to water quality improvement elsewhere.

Forest mitigation banking programs like those in Maryland are relatively uncommon, and we were unable to identify research directly focusing on their effect on water quality. However, the effect of afforestation on water quality and the impact of mitigation banking on wetland preservation have both been well-studied. We can draw inferences from these studies, while keeping in mind that 81.1% of reported forest bank acreage in the state consists of existing forest rather than planted forest and thus does not represent afforestation.

Forests often have positive impacts on water quality, and several studies have found benefits from afforestation. Riparian forest buffers (forests along the banks of streams) are especially adept at improving water quality, including in the Chesapeake Bay watershed. In areas of the watershed with thin soils, such as the inner coastal plain, riparian forest buffer systems can retain 50 to 90% of "sediment in surface runoff and total [nitrogen] in both surface runoff and groundwater" (Lowrance et al. 1997). These forest buffers have a smaller impact on phosphorus. However, their ability to filter sediment and nitrogen, two of Maryland's leading water pollutants, is notable. Another study in the Piedmont region of southern Pennsylvania found similar results, with a smaller but significant reduction in nitrogen and sediments, but no impact on phosphorus (Newbold et al. 2010). Even when used in urban areas, afforestation can benefit the entire watershed. According to watershed simulation modeling, increasing urban forest cover can reduce sediment and nutrient loading, similar to creating riparian buffers. In addition to water quality improvements, afforestation can also decrease stormwater runoff, increase groundwater recharge and make the watershed more resilient to adverse conditions (Matteo et al. 2006). However, according to a 2014 review paper, the optimum width for riparian buffers to improve water quality, habitat and biota in small streams is 30 meters or more, roughly double the 50-foot buffer recommended in the FCA (Sweeney and Newbold 2014).

Lessons may also be learned from wetland mitigation banking. Wetland mitigation banking is "the most mature effort yet to create commodity markets in ecosystem services," so there are numerous studies on its effects (Robertson 2004). Wetland mitigation banking is a politically popular tool but has some implementation issues. One is haphazard and mismatched regulatory regimes (Robertson 2004). In addition, while wetland mitigation banking is conceptually sound, in practice, its implementation has led to an overall net loss in wetlands due to a variety of factors. One relevant to forest mitigation banking is the use of preservation easements in mitigation banks. When deforestation is mitigated with only the protection of an existing forest — especially if that protection is 1:1 — this will inevitably result in an overall forest loss (Brown & Lant, 1999).

Forest and Tree Planting Programs (Task 7)

We conducted a review of federal, state and local tree and forest planting programs in 2018 and 2019, estimating roughly 1,854 acres planted across the two years at a rate of 400 trees per acre. These programs can vary widely in scope, implementation, locale and objectives and as such cannot be directly compared to each other. It is also important to note that this is not a comprehensive estimate, as not all municipalities responded to our request and privately funded efforts were not represented systematically. We must also keep in mind that these numbers represent trees planted, not all of which will survive to maturity.

We support the effort to have the MDE track various tree planting programs operating in support of the Tree Solutions Now Act. We encourage the agency to make this data easily accessible to the public.

The results of a programmatic and funding review of federal, state and local tree and forest planting programs in 2018 and 2019 can be found in Table 22. 2020 was not included in our survey due to the disruption caused by the COVID-19 pandemic. Some programs did provide 2020 data, which is included in the table but was not used while calculating overall tree planting. Results include the number and acres of trees planted by programs, as well as funds spent toward these efforts. Programs reviewed include Marylanders Plant Trees, Lawn to Woodland, Backyard Buffers, Conservation Reserve Enhancement Program (CREP), the Environmental Quality Incentives Program (EQIP) and other programs used to further TMDL Watershed Implementation Plan and MS4 permit compliance. Additionally, we reviewed the Alliance for the Chesapeake Bay's Healthy Forests, Healthy Water program and the Western Maryland Resource and Development Council's Allegany County Reforestation Project. All federal and state contacts responded through email, and the data provided by them is included in Table 22. The response rate for the municipalities contacted through the Maryland Municipal League was 28 out of 144. The counties and municipalities that did not respond through email or the survey are not included in the table.

Table 22. *Trees planted (acres, # trees) and expenditures per entity and program.*

Entity	Program name[8]	Acres/Number of trees	Expenditures	Funding sources[9]
Federal and State-Funded Programs				
Federal	CREP[10]	232 ac (2018) 36 ac (2019)	11,590	Federal and non-federal
	EQIP	25 ac (2018) 23.3 ac (2019) 64.1 ac (2020)	17,016	Farm Bill 2014 and 2018
State	Backyard Buffers	29,855 trees (2018) 40,835 trees (2019)	$30,000 (2018) $36,000 (2019)	State

[8] When funding for a program was received from multiple sources, data were categorized by the program (and level of government) that administers it.
[9] (a) Expenditures reported may be different for each program. One program may have reported just the cost of acquiring the trees, whereas another may have reported the tree, installation and maintenance costs. (b) The funding sources for programs at the state and local level sometimes come from multiple levels of government. Therefore, some trees may be double-counted. (c) Different programs plant different sizes of trees, which cost different amounts of money. Street tree planting programs tend to plant more mature, larger trees, which cost significantly more than tree seedlings planted by other programs.
[10] CREP reports indicate a subset of actual acres planted.
[11] These values only represent the federal cost share for CREP projects, which includes all costs of establishing buffers such as purchasing and planting trees, purchasing and applying pesticides and setting up tree shelters. Installation of tree plantings were co-cost shared between federal and state funding sources, in addition to a $100 per acre signing bonus provided by the state. Additional federal incentives also apply. In 2018, 10 projects totaling 32.11 acres enrolled in CREP without using the federal cost share.

Entity	Program name[8]	Acres/Number of trees	Expenditures	Funding sources[9]
State	FCA[12]	256,050 trees (2018) 158,535 trees (2019)	Not known	Private
	Healthy Forests Healthy Waters (non-profit)	227 ac (2020) (300-400 trees per acre	~1 million (2020)	Chesapeake and Atlantic Coastal Bay Trust Fund
	Marylanders Plant Trees	8,915 trees (2018 and 2019)	$178,300 (both 2018 and 2019)	Power generator settlement for Clean Air Act Violations
	Tree-Mendous	5,072 trees (2018 and 2019)	$202,880 (both 2018 and 2019)	Public land managers purchasing volume-discounted trees
	Allegany County Reforestation Project	47,145 trees (2020)	$624,260 (2020; includes planting, site prep. and maintenance costs)	Chesapeake and Atlantic Coastal Bay Trust Fund
	5-103	5,913 trees (2018) 10,697 trees (2019)[13]	Not reported	Restoration Fund
	Conservation Buffer Initiative (Maryland DoA)	21.6 ac (2021)	Not reported	State
Counties[14]				
Anne Arundel	Replant Anne Arundel	Not reported	Not reported	Bureau of Watershed Protection and Restoration
	Reforestation Program	Not reported	Not reported	Not reported
	Street Tree Program	Not reported	Not reported	Not reported
Baltimore City	Tree Baltimore: Giveaway Program	1,000 trees (2018) 1,000 trees (2019)	$40,000 (2018 and 2019 combined)	Local and Fee-in-lieu
	Tree Baltimore: Community Forestry	2,677 trees (2018) 3,375 trees (2019)	~ 2 million	Local and Fee-in-lieu
Baltimore County	Baltimore County EPS WIP Planting Program	6,215 trees (2018) 7,950 trees (2019) 6,440 trees (2020)	$425,313.22 (2018) $1,320,680.60 (2019) $576,507.99 (2020)	Local
Carroll	The Bureau of Resource Management	2,822 trees (2018)	$92,045.80 (2018)	Chesapeake and Atlantic Coastal Bay Trust Fund (state) and local funds
Charles	Watershed Protection and Restoration Program	1.6 ac (2019)[15]	Not reported	Stormwater Remediation Fee
Federick	Creek ReLeaf	159 ac (2018 and 2019) (300-350 trees per acre)	$650,000 (2018 and 2019; includes planting and initial site maintenance)	Local and Fee-in-lieu
Harford	Chesapeake Bay Critical Area requirements	130 trees and 287 shrubs (2018) 180 trees and 264 shrubs (2019) 208 trees and 402 shrubs (2020)	Not reported	Not reported
Montgomery	Reforest Montgomery*	1,768 trees (fiscal years 2018 and 2019)	$381,700 (fiscal years 2018 and 2019 combined)	Local and Fee-in-lieu
	Tree Montgomery	1,345 trees (2018 and 2019)	$598,000 (2018 and 2019 combined)	Local
	Street Tree Planting	3,600 trees (2018 and 2019)	Not reported	Local

[12] Trees counted here include those planted to fulfill county and municipal-level Forest Conservation Ordinances under the FCA. These may not be reported by the relevant county or municipal entity due to funding source.
[13] Mitigation plantings
[14] No voluntary programs were identified in the following counties: Allegany, Caroline, Cecil, Kent, Talbot, Washington and Worcester; and the following municipalities: Emmitsburg, Middletown, Myersville, New Market, New Windsor, Preston, Queenstown and Taneytown. (In Cecil County: Voluntary plantings are not required by law. Required plantings satisfy FCA, MS4, roadside tree laws and WIP requirements. Required plantings are reported under state or federal programmatic numbers.)
[15] Planted as part of the County's Bensville Park Stormwater Retrofit Project.

Entity	Program name[8]	Acres/Number of trees	Expenditures	Funding sources[9]
Municipalities				
Annapolis	Street Tree Planting	230 trees (2018 and 2019)	$26,450 (2018 and 2019 combined)	Local and Fee-in-lieu
Bel Air	Street Trees	6 trees (2018 and 2019)	$1,800 (both 2018 and 2019 combined)	Local and Fee-in-lieu
Brookeville	Native Tree Planting Rebate	Not reported	$120 (2018 and 2019 combined)	Local
Cheverly	Town plantings[16]	76 trees (2018) 94 trees (2019)	$7,097 (2018), $4,484 (2019)	Local
Chevy Chase Village	Urban Forest Guidelines (Chap. 17 of Village Code) & Reforestation Incentive Program	74 trees (2018 and 2019)	$14,000 (2018 and 2019 combined)	Local
College Park	Tree Canopy Enhancement Program	6 trees (2018) 13 trees (2019)	$552 (2018), $1,263 (2019)	Local
	Street tree replacements	60 trees (2018) 70 trees (2019)	$12,300 (2018), $11,297 (2019)	Local
Denton	Town plantings	765 trees (2018 and 2019)	$40,261.21 (2018 and 2019 combined)	Local
Easton	Town of Easton Street Trees	284 trees (2018 and 2019)	$30,000 (2018 and 2019 combined)	Local and Fee-in-lieu
Edmonston	Town plantings	24 trees (2018) 12 trees (2019)	$2,500 per year	Local
Frostburg	Frostburg Street Trees	69 trees (2018 and	$3,137.57 (2018 and 2019 combined)	Local
Gaithersburg	Community planting event	144 trees (2018 and 2019)	$23,214 (2018 and 2019 combined), average $11,000 per year	City's Forest Conservation Fund
Greensboro	Town plantings	25 trees (2018 and 2019)	Not reported	Local and private
Hagerstown	Street Tree Planting Program	64 trees (2018 and 2019)	$29,305 (2018 and 2019 combined)	Local and Fee-in-lieu
Havre de Grace	Street Tree Planting Program	Not reported	Not reported	Local
Landover Hills	Town plantings	12 trees (2018 and 2019)	$800 (Fiscal years 2018 and 2019 combined	State and Local
Laurel	P&R Tree City USA, Tree management	141 trees (2018) 101 trees (2019)	P&R and DPW combined Tree Maintenance budget: $42,810 (2018), $33,845 (2019)	Local
	Street tree maintenance and replacement	Not reported	Not reported	Not reported
Mount Airy	DWP, Beautification Commission	120 trees (2018 and 2019)	$4,500 (2018 and 2019)	Town Budget
Salisbury	Town plantings	80 trees (2018 and 2019)	Not reported	Local
University Park	Town plantings	129 trees (2018 and 2019)	$20,125 (2018 and 2019 combined)	Local
Williamsburg	Urban Tree Canopy Program	Not reported	Not reported	Not reported

[16] Town and county plantings: Tree plantings undertaken as a result of local government action as opposed to from federal and state funding

Approximately 550,741 trees and an additional 477 acres were planted in 2018 and 2019, according to reports received, for a total of roughly 1854 acres (at 400 trees per acre). The FCA was responsible for planting more than half of these as part of mitigation efforts: 414,000 trees across the two years. It is clear from Table 22 that Maryland has a wide range of tree planting programs and initiatives led by both government entities and nonprofit organizations. Most of them specifically focus on tree planting, but there are exceptions, such as the federally funded EQIP program, in which tree planting is just one of many conservation practices that can be implemented to improve air and water quality, soil health, wildlife habitat and agricultural operations. Trees are planted both for afforestation and mitigation purposes (to replace trees that were cut down) and these purposes vary according to the tree planting program.

As one would expect, programs vary in scope, with state-level programs investing up to $2 million to plant thousands of trees, while individual municipalities may plant less than a hundred. Comparing two initiatives that focus on tree planting on private land, the Healthy Forests, Healthy Waters program provides landowners with a free planting project on land parcels of an acre or more, while College Park's Tree Canopy Enhancement Program reimburses landowners up to $150 per year for individual trees planted on their residential lots.

Tree planting programs may also have different objectives. The Healthy Forests, Healthy Waters program is specifically designed to reduce the runoff of nutrients and sediments into waterways, while the Backyard Buffers program, which assists homeowners in planting streamside buffers on their property, cites several benefits such as creating wildlife habitat, reducing peak winter temperatures, reducing runoff pollution and preventing erosion. Programs like Tree-Mendous Maryland also do not have a specific goal, but broadly target the various environmental, economic and social benefits of planting trees in towns and cities, such as cleaner air, lower energy costs and beautification (Pataki et al. 2021).

It is important to note that with the variation in scope, implementation, locale and objectives, these programs may not be directly comparable to each other and should be assessed individually.

We must also consider that tree planting is likely underreported due to municipalities that plant trees that failed to respond, as well as privately funded plantings that were not systematically represented. We were also unable to arrive at a number for trees planted by the Maryland Department of Transportation, which undertakes reforestation and planting throughout the state. Some double-counting may also have occurred, if the planting of a given set of trees was funded by multiple sources. However, we would expect that to be a relatively low number, and on the whole, the number of trees planted during 2018 and 2019 is almost certainly higher than our figure. It is also important to keep in mind that the number of trees planted was recorded at the time of planting and does not account for survival rate. Site preparation and maintenance is key until trees become established, and not all programs may invest in those additional expenses.

It is worth noting that many counties and municipalities do not have their own tree planting programs. Instead, these counties and municipalities use state and federal programs like CREP or Backyard Buffers. At times, local nonprofits and private organizations administer tree planting programs through the use of grant funds. However, their progress is difficult to track statewide. As part of the Tree Solutions Now Act and in an effort to improve and centralize data collection, MDE will serve as the lead tracking agency for various tree planting programs operating in support of the Act (State of Maryland 2022).

Conclusion and Recommendations

Observations and Goal Progress

As the Forest Conservation Act (FCA) reaches 30 years in practice in 2021, it is important to mark areas where Maryland's forest protection legislation has been successful in slowing the rate of forest and tree canopy loss, while identifying opportunities to further leverage forests and tree canopy to enhance benefits for habitat, water quality protection, climate resilience and mitigation, human health and environmental justice.

The findings of this study indicate a mix of positive and concerning trends in Maryland's forest and tree canopy. Maryland's forest cover has shown a trend toward stabilization since the establishment of the FCA of 1991 with a progressively declining rate of forest loss. Forests in the state exhibit declining forest health, particularly as a result of increasing fragmentation, invasive species introductions and the predominance of overmature, even-aged tree stands vulnerable to disease and decline. The state has made progress on planting and reforestation goals in some riparian and urban areas, but in the face of larger net losses of tree cover. Statewide, Maryland has made progress toward the Chesapeake Bay wide target of 70% riparian buffer coverage by 2025, though progress by individual counties toward their unique riparian buffer goals are mixed.

The Maryland Forest Preservation Act of 2013 set the goal of "No Net Loss of Forest," which the legislation defines as maintaining the state's existing "40 percent tree canopy cover" (Georgetown Climate Center 2013; House Environmental Matters Committee 2013; MD Code, Natural Resources, § 5-101). At the time this law was written, forest cover was estimated to cover just under 40% of the state's land area (Lister & Pugh 2014, USDA Forest Service FIA Program, n.d., USDA Forest Service 2020). Our study, with the advent of new technology, found that forest covers approximately 42% of the state's land area and that total tree canopy covers 50% (CBPOd 2022). Despite a favorable estimate in forest cover as a percent of total land area, all three datasets that we used — USDA Forest Service FIA, NLCD and CBPO — provided agreement on modest decreases in established forest and total tree canopy cover over the study period, indicating that the state had not yet reversed the trend in forest cover loss at the time of the study. This study, however,would not detect new saplings planted in the latter part or beyond the study period - so, with forest conservation measures and active tree planting (perhaps even those efforts occurring now), the state may already be reversing the trend. Given technological advances presented here in the ability to parse tree canopy from forest, it is not possible to assess land use and land cover according to definitions established at the time of the Forest Preservation Act.

Forests and trees outside forests are an essential carbon sink and represent a critical component of Maryland's GGRA 2030 strategy. For this reason, the GGRA Plan describes ambitious goals for afforestation, reforestation and tree planting across the state. The planting of these trees is supported by a variety of programs for riparian and urban tree restoration. The Tree Solutions Now Act (TSNA) adds to existing efforts by funding the planting of 5 million additional trees by 2031, with at least a 10% of these trees targeted for planting in urban underserved areas. This effort could spur substantial progress if existing tree canopy is also protected. The TSNA goals, and the resulting draft 5 million trees plan, reinforce the importance of forests as part of the state's multi-pronged strategy to address the climate crisis while supporting other state values ranging from economic, to environmental, to human health and quality of life (State of Maryland 2022). In addition, forests have an essential role in helping the state adapt to climate change, mitigating somewhat the anticipated effects of more frequent storm surges, sea level rise and extreme temperatures.

Development was identified as the prevailing cause of forest and tree canopy loss in the state. The distribution of this driver varied by region, but it was particularly prevalent in the rapidly urbanizing areas of Central Maryland. The widespread nature of this driver is a concern since development is considered a permanent forest loss. Timber harvest was another important driver of forest cover change in certain regions, but this is associated with cycles of forest harvest and regrowth while retaining forest land use. Other causes of temporary forest dynamics include natural disturbances (e.g., wind, flooding, fire), and we expect that a proportion of tree cover gain and loss observed in this study is linked to the background rates of these natural dynamics. Representative of these dynamics, we note that total area of tree canopy loss (57,482 acres) and gain (44,348 acres) exceed the total area of net change (-13,134 acres), indicating greater amounts of forest change dynamics than net change rates alone suggest. In fact, gross tree canopy change represents nearly eight times the amount of net change in the state.

Important Assumptions and Considerations

This study made use of three key datasets, based on field sampling (USDA Forest Service FIA), long-term satellite imaging at moderate resolution (30m) (NLCD) and a new, highly innovative technology to monitor tree cover at very high resolution (1m) (CBPO). The high-resolution technology was an advance over previous approaches by making the detection of individual trees possible, enabling a first ever statewide assessment of change in tree canopy outside forests, including all urban areas. It also enabled better assessment and monitoring of trees within forests, producing a more accurate estimate of forest cover than previous datasets allowed. The time series was a five-year increment (2013-2018), a higher temporal resolution and more recent snapshot than other studies provided. Despite these improvements, certain assumptions and considerations are relevant to interpretation.

We note that this high-resolution study captures, with a high degree of accuracy, the actual tree canopy cover, gain and loss that occurred during the 2013-2018 study period. Additionally, while the observed trend in net forest loss is corroborated across three different datasets, methodologies and time periods, we note that our analysis may not reflect trends since 2019.

This high-resolution change mapping technology more readily detects tree cover loss than gain within a study period. Given that this study defines trees as vegetation taller than 3m in height, there is a delay from when a tree is planted to when it is detected from satellite. So, while this technology provides a replicable and accurate approach to detect tree *canopy* (at or above 3m), it does not detect all recent tree planting *efforts*.

Recent planting *efforts (indicative of number of trees and future tree canopy)* must be accounted for by ground-based, tree planting records. We found that tracking and collecting data from the different tree planting programs operating in Maryland was difficult. These programs operate at the federal, state, county and municipal levels, as well as by nonprofit organizations. They vary widely in scale, investment, implementation, locale and objectives. As a result, we note that the number and acreage of trees planted is underreported here, as not all municipalities responded to our requests for information and some privately funded efforts may not have been captured.

Definitions of forest are also important for this study. All three datasets had different definitions of forest, involving variations in resolution, tree height, spatial configuration and area. This complicates direct comparison between datasets in forest area estimates. When the same definition is applied over time for a given dataset, trends in forest change can be detected, and similar trends were corroborated across all three datasets studied. We note that while all datasets used in this study had discrete definitions of both trees and forest, ecosystem services function on a continuum, with young trees and trees outside forest providing important ecosystem benefits.

We note that while our study was powerful for detecting tree canopy change, we were not always able to recognize the causes or drivers of change beyond that caused by development. Some of these drivers lead to temporary change dynamics — such as timber harvest and natural causes — and we were able to make inferences on a county scale as to where the effects of timber harvest were being observed. More work would need to be done to more closely link change with its driver.

Forest mitigation banking

Forest mitigation banking has been a key strategy of the FCA for mitigating impacts of development on forests. Forest mitigation banking programs throughout Maryland are in flux following the decision to no longer permit the establishment of retention banks, which currently make up the majority (81%) of all reported bank acreage in the state. Given the prevalence of retention banks across most counties, it is likely that substantial alterations will need to be made at the county or state level to encourage the creation of newly planted forest mitigation banks. One potential approach could be creating programs to assist landowners with the initial costs for establishing newly planted forest banks. Setting higher fee-in-lieu rates could also encourage the establishment of new banks. Further insights may be gleaned from the programs in Carroll County, which has only allowed newly planted forest banks and Baltimore County, which transitioned away from retention banks some years prior.

If one of the goals of expanding forest mitigation banking is to prevent further degradation of or improve water quality, the available evidence shows the need for a more centralized tracking system and better data collection on forest mitigation's impact on water quality. We note, however, that there is strong scientific support for the benefits of trees and forests on water quality (State of Maryland 2019; Campbell et al. 2019; Outdoor Industry Association 2017; CBWA 2014). Investigation is needed on the use of riparian buffers for mitigation and additional priority areas for the establishment of banks where afforestation might maximize improvement in water quality and the generation of other co-benefits.

As with tree planting, banking would benefit from more uniform data collection by counties and from the state making that data easily accessible to the public. Locating information and even identifying the correct county agency was challenging, as most counties did not have banking information readily available on their websites. Recognizing that county employees have limited time to devote to forest mitigation banking, we recommend making the relevant information and resources more easily accessible. We recommend Montgomery County's Forest Mitigation Banking webpage as a model.

Opportunities to Enhance Forest and Tree Canopy

This study identified forest and tree canopy gains in several categories that point towards key opportunities for expanding coverage. First, there is a clear benefit to protecting existing trees in addition to planting new trees. Newly planted trees may take a decade or more to register in monitoring data, representing slow canopy growth in the early years (O'Neil-Dunne 2019). Existing trees, particularly those in middle age, have growth and carbon uptake potential that exceeds that of young trees (MDE 2021). Additionally, protecting existing trees maintains established stormwater management, water quality and wildlife and habitat value. This study identified forest and tree canopy gains in protected areas as well as in agricultural areas reflecting gains generated both by forest protection as well as planting, in riparian forest buffers.

We document increases in forest fragmentation as well as spread of invasive species. Fragmentation creates small patches and edge habitats that have decreased quality and resilience compared with large blocks of natural habitats. It also increases the possibility of invasive species introductions, which can be very detrimental. Longer term monitoring is necessary to determine the course of fragmentation trends detected. Ground-based surveys can help to determine whether trends are natural or human in origin, and whether they are primarily temporary or permanent in nature.

Tree canopy outside forest is critical to meeting statewide tree planting goals and to effectively reap green infrastructure benefits like water quality, stormwater management, climate adaptation and climate change mitigation. Our land use data enabled us to accurately monitor tree canopy outside forests, which is essential to its management, planning, zoning and recovery.

Improving Monitoring Through Technological Innovation

This study offered the first statewide assessment of tree canopy cover change at 1-m resolution that includes trees both within and outside forests, advancing our understanding tremendously on the patterns and processes of tree canopy cover change in the State of Maryland. This technology can detect urban trees and small or narrow patches of trees in agricultural areas and along stream corridors, which was not possible in previous land cover assessments in the state. We present a replicable methodology that can be implemented every few years to generate more frequent updates on tree canopy cover and change than was available in the past. This should improve the state's capacity for adaptive management. Tree canopy monitoring will only continue to improve as computing power, data and technology evolve, generating more frequent and increasingly accurate insights on forest canopy extent and trends. This technology has benefited from the increased availability of high-quality LiDAR data, which has improved the ability to monitor tree cover extent, height and biomass.

More frequent high-resolution monitoring into the future will also help to elucidate the extent of some trends inferred from our study, such as timber harvest areas that may be in a successional stage or areas under construction that may be at an interim stage between forest clearing and construction. And while high-resolution monitoring is revolutionary in the field of tree cover and carbon monitoring, moderate resolution forest cover monitoring continues to add value for assessing long term trends. Satellite imagery from the Landsat and Sentinel programs used in products such as the NLCD and the emerging Global Forest Canopy Height dataset go back decades (Hansen et al. 2013; Potapov et al. 2021; MRLCC 2021). High-resolution data to support this replicable methodology only stretch back one decade. Monitoring and analysis would be further improved and standardized with more broadly available high quality LIDAR data.

Tree canopy cover monitoring efforts presented here directly align with and support the land-based carbon monitoring work that is being led by MDE and UMD in support of the state's GHG Inventory and GGRA Plan (Hurtt et al. 2021a and Hurtt et al. 2021b, MDE 2022a, MDE 2022b). Coordinating tree canopy monitoring with existing carbon monitoring efforts will add value to both studies while improving efficiency. Our tree canopy change monitoring is supplemented by a novel, high-resolution statewide land-use dataset, which helps us more accurately determine and address the causes of tree canopy cover and carbon change — and thus more decisively identify solutions.

While satellite imagery is versatile, it does not provide the full picture. For this reason, we emphasize the need for improved collection and databasing of ground-based, ancillary datasets. This includes data on protected areas and easements, forest mitigation banking locations, opportunity areas for increasing tree cover, tree planting areas and actual timber harvest areas. Satellite analyses would also benefit greatly from further ground based surveys on the causes of tree canopy cover change in order to identify appropriate management interventions. We note that while MDE will serve as the central accountant of tree plantings under the Tree Solutions Now Act, which should improve the tracking process — this Act does not address all data tracking needs. Data currently available in tabular format would provide added value if also available in GIS format (State of Maryland 2022). A similar centralized data repository for other datasets mentioned would be highly valuable.

In conclusion, we note that insights gained from this study are game-changing in the field of forest stewardship. However, Maryland would benefit from continued investment in monitoring to track progress toward reaching its environmental, social and economic goals related to tree canopy cover in the state. At the same time, the state will be able to adapt its management strategies more quickly in response to observed trends.

Definitions & Abbreviations

Definitions

Advisory Committee: This refers to a select group of organizations identified in the original bill that contributed to and were integral to this analysis and study: the Department of Natural Resources, the Department of the Environment, the Department of Planning, the Department of Agriculture and the Chesapeake Bay Program.

Census Urbanized Areas and Census Urban Clusters: We use the US Census Bureau's urban-rural classification to detect urbanized areas. These are densely developed territories and encompass residential, commercial and other non-residential urban land uses. In the 2010 Census, urban areas show a densely settled core of census tracts and/or census blocks that meet minimum population density requirements, along with adjacent territory containing non-residential urban land uses. It also includes adjacent territory with low population density included to link outlying densely settled territory with the densely settled core. To qualify as an urban area, the territory must encompass at least 2,500 people,of which at least 1,500 reside outside institutional group quarters. The Census Bureau identifies two types of urban areas:

-Urbanized Areas (UAs): 50,000 or more people;

-Urban Clusters (UCs): at least 2,500 and less than 50,000 people.

-"Rural": encompasses all population, housing and territory not included within an urban area. (U.S. Census Bureau 2012)

Forest (CBPO): The CBPO defines forest as all contiguous patches of trees ≥1 acre in extent with a patch width ≥240-ft. somewhere in the patch. The 240-ft. girth references potential altered microclimate conditions extending inwards up to 120-ft. from the patch edge. The forest understory is assumed to be undisturbed/unmanaged. Forests that are also wetlands are included in this class (CBPO 2022d, Clagget et al. 2022). Forest classes from the land use that were specifically used for this study include forest, harvested forest barren, harvested forest herbaceous, tidal wetlands forest, riverine wetlands forest and terrene wetlands forest. Also referred to as Tree Canopy within Forest in this study.

Forest (FIA): The USDA Forest Inventory and Analysis Program (FIA) defines forest land as land that is at least 10% stocked by trees of any size or formerly having been stocked and not currently developed for non-forest use. The area with trees must be at least 1 acre in size and 120 feet wide. measured stem-to-stem from the outermost edge. Forested strips must be 120 feet wide for a continuous length of at least 363 feet in order to meet the acre threshold. Forested strips that do not meet these requirements are classified as part of the adjacent non-forest land (USDA Forest Service 2021). Forest land can exist in urban and agricultural areas as long as it meets the above criteria and doesn't have maintained or mowed understory. Examples of land with tree cover that are not considered forest land by FIA definitions include pasture land under tree cover that has been grazed, urban parks with a maintained understory and treed residential areas where underlying grass is maintained (Lister et al. 2011). The FIA detects changes to the overall extent and status of forest through an annualized sampling design of 982 plots throughout the state, of which 433 were forested in the year 2019. Each year, 10-20% of the plots are visited and measured by field crews (USDA Forest Service 2020).

Forest (NLCD): The NLCD defines forest as areas dominated by trees generally greater than 5 meters tall and greater than 20% of total vegetation cover (MRLCC n.d.).

Forest Conservation Act (FCA): The Forest Conservation Act, enacted in 1991 (Natural Resources Article, § 5-1601--5-1612, Annotated Code of Maryland), provides a consistent set of management criteria applied across ownership types and jurisdictions. Under this law, landowners are required to identify forest stands and priority areas for conservation prior to implementing development projects. The Forest Conservation Act provides definitions of forests and other relevant entities. We provide these here for comparison with our forest and tree canopy data definitions.

- "Forest" means a biological community dominated by trees and other woody plants covering a land area of 10,000 square feet or greater. "Forest" includes:

    (1) Areas that have at least 100 live trees per acre with at least 50% of those trees having a 2-inch or greater diameter at 4.5 feet above the ground and larger; and

    (2) Areas that have been cut but not cleared.

    (3) "Forest" does not include orchards.

- "Forest cover" means the area of a site meeting the definition of forest.
- "Tree" means a large, branched woody plant having one or several self-supporting stems or trunks that reach a height of at least 20 feet (6.7 m) at maturity.

For additional definitions provided by the FCA, including reforestation, afforestation, timber harvesting, stream buffer, forest stand, etc., please refer to the Forest Conservation Act code (State of Maryland 1991).

Forest Fragmentation Statistics (this study):

- **Forest Core:** The interior of a patch, beyond 100 meters from the patch boundary that is considered free from edge effects and represents quality natural habitat.
- **Forest Patch:** Area of forest distinct from the land cover surrounding it and isolated from other forested areas.
- **Patch Edge:** A 100-meter buffer area between the boundary of a patch and its interior that is considered vulnerable to edge effects, degraded quality due to influence from neighboring patches of other land use classes.

LiDAR: A laser-based remote sensing technology used in particular to detect vertical structure and elevation. LiDAR data, along with aerial imagery and other spatial data, were used to produce the 1-meter resolution land cover datasets for the years 2013 and 2018 used in this study (CBP, 2022). It is particularly powerful at detecting trees (woody vegetation of a given height) from other vegetation types.

National Aerial Imagery Program (NAIP): The NAIP is operated by the Farm Service Administration of the U.S. Department of Agriculture. Aerial imagery available from the NAIP was used to produce the high-resolution land cover data for Maryland for the years 2013 and 2018 that was the source of the Tree Canopy Cover data that we used for this study (CBP, 2022).

National Land Cover Database (NLCD): The NLCD is a nationally consistent land cover and change dataset available for the years 2001, 2003, 2006, 2008, 2011, 2013, 2016 and 2019. This dataset was derived from 30-m resolution Landsat imagery and produced by the Multi-Resolution Land Characteristics Consortium, a group of federal agencies (MRLCC 2021).

Riparian areas (this study): For this report, we refer to riparian areas as those that are adjacent to streams, and more specifically as noted, for Task 3, areas that are within a 100ft. buffer of streams based on EFPs.

Tree (FIA): The USDA FIA defines tree as any perennial woody plant species that can attain a height of 15 feet (4.6 m) at maturity.

Tree Canopy (CBPO): The CBPO defines tree canopy as deciduous and evergreen woody vegetation of either natural succession or human planting that is over approximately >3 meters in height. Stand-alone individuals, discrete clumps and interlocking individuals are included. MMU = 9 square meters (CBPO 2022b). Tree canopy classes from land use were specifically tree canopy over roads, tree canopy over structures, tree canopy over other impervious, tree canopy over turf grass, other tree canopy, tidal wetlands tree canopy, riverine wetlands tree canopy and terrene wetlands tree canopy. Tree canopy classes from land cover were specifically considered to be: tree canopy, tree canopy over impervious surfaces, tree canopy over other impervious and tree canopy over impervious roads. Tree Canopy is broken into two subclasses for the purposes of this study: Tree Canopy outside Forest and Tree Canopy within Forest (or simply, Forest). The collection of these two classes is often referred to as Total Tree Canopy.

Tree Canopy outside Forest (this study): Tree Canopy that is located outside defined forest areas.

Tree Canopy over Structures (this study): Forest or Tree Cover that overlaps with impervious surfaces rendering the structures partially or completely not visible to plain sight (CBP 2022b, Claggett 2022).

Tree Canopy over Impervious Surfaces (this study): Forest or Tree Cover that overlaps with impervious surfaces rendering the impervious surface partially or completely not visible to plain sight (CBPO 2022b, Claggett et al. 2022).

Tree Canopy over Impervious Roads (this study): Forest or Tree Cover that overlaps with impervious surfaces rendering the roads partially or completely not visible to plain sight (CBP, 2022b, Clagget et al. 2022).

Abbreviations

CAMA - Computer Assisted Mass Appraisal

CAST - Chesapeake Assessment Scenario Tool

CBLCM - Chesapeake Bay Land Change Model

CBP - Chesapeake Bay Program

CBPO - Chesapeake Bay Program Office

CC - Chesapeake Conservancy

CRAB - Climate Ready Action Boundary

CREP - Conservation Reserve Enhancement Program

EQIP - Environmental Quality Incentive Program

FCA - Forest Conservation Act

FIA - Forest Inventory Assessment

GFW - Global Forest Watch

GGRA - Greenhouse Gas Reduction Act (Plan)

GHG - Greenhouse Gas

GLAD - Global Land Analysis and Discovery lab

LiDAR - Light Detection and Ranging

MDDNR/DNR - Maryland Department of Natural Resources

MDP - Maryland Department of Planning

MS4 - Municipal Separate Storm Sewer System

NAIP - National Agriculture Imagery Program

NLCD - National Land Cover Data

NRCS - Natural Resources Conservation Service

PFA - Priority Funding Areas

TC - Tree Canopy

TCOF - Tree Canopy Outside Forest (CBPO dataset)

TDR/PDR - Transfer Development Rights and Purchase Development Rights

TEA - Targeted Ecological Area

TMDL - Total Maximum Daily Load

Total TC - Total Tree Canopy, which is the sum of Forest and TCOF (CBPO dataset)

TSNA - Tree Solutions Now Act

UMD - University of Maryland

USGS - United States Geological Survey

UVM - University of Vermont

US EPA - United States Environmental Protection Agency

USDA - United States Department of Agriculture

USFS - United States Forest Service

Supplemental Materials

Data and Methods

Forest and Tree Canopy Extent (Task 1a)

We mapped forest and tree canopy coverage and change at two different scales, moderate and high resolution.

To identify statewide trends in forest cover, we relied on FIA forest land estimates for the years 1999-2019. The FIA uses site-based inventory techniques to detect changes over time in a set of forest land plots and extrapolates from these. FIA plots are visited every seven years, so that 14% of plots are surveyed in a given year. The FIA defines forest land as land that is at least 10% stocked by trees of any size or formerly having been stocked and not currently developed for non-forest use. The area with trees must be at least 1 acre in size and 120 feet wide, measured stem-to-stem from the outermost edge. Forested strips must be 120 feet wide for a continuous length of at least 363 feet in order to meet the acre threshold (USDA Forest Service 2021). The FIA uses the U.S. Census Bureau estimate of total land area in Maryland (6,212,714 acres) in their calculations of percent forest coverage (States101.com 2022; U.S. Census Bureau 2010).

We complemented the FIA forest land data with an analysis of the National Land Cover Dataset (NLCD), which is based on 30-m resolution Landsat data for 2001-2019. NLCD defines forest as pixels with greater than 20% total vegetation cover that are dominated by trees at least 5 meters in height (MRLCC n.d.). NLCD estimates of forest cover used Maryland county boundaries as the extent.

Moderate resolution datasets such as the NLCD are useful for mapping patterns and trends in larger forest patches, but does not distinguish between tree canopy within and outside forests and cannot detect individual trees. To map tree canopy status and change at high resolution, we began with statewide land use/land cover datasets developed from 1-m imagery for the years 2013 and 2018. These datasets were developed by Chesapeake Conservancy, the U.S. Geological Survey and the University of Vermont Spatial Analysis Lab, using aerial imagery available from the National Aerial Imagery Program (USDA-FSA-APFO n.d.) and LiDAR (a laser-based remote sensing technology) (CBPO, 2022a-d). The tree canopy class of this land cover dataset had a calculated accuracy in Maryland of 94%, and similarly high accuracy is expected in other classes (Table S1).

The study area for this analysis are representative of all jurisdictions within the state, with areas of the open-water Chesapeake Bay excluded (CBP 2020b). Inland perennial and intermittent open waters are included in the broader study area. The study area were derived from the detailed jurisdictional boundaries for Maryland (iMap), with removal of Chesapeake Bay open water areas using the Chesapeake Bay 92 Segments dataset developed by US EPA for the Chesapeake Bay TMDL. This provided a study area for Maryland of 6,441,771 acres. This study area was used for a limited number of analyses in the report where statewide analysis results were normalized by study area; for example, the analysis of forest and tree canopy area change inside and outside priority funding areas (Figure 27). The study area can be viewed on the web viewer.

For analysis of forest and tree canopy extent and using the CBPO high-resolution data, a more refined assessment of land area derived from the CBPO land cover classification was used. This assessment totaled only the land identified in the CBPO data, removing all inland areas classified as water. The total land area derived from the CBPO data for 2018 is 6,154,413 acres. This land area was used as the basis for % forest, % tree canopy outside forest (TCOF), and % total tree canopy (Total TC) metrics at the state and county level. The CBPO data did not map Aberdeen Proving Ground, an area totaling 38,954 acres in Harford County that was not included in the USDA NAIP imagery used to generate the data. The land area calculations derived from CBPO data omit this area in statewide land area totals and within the totals for Harford County; forest and tree canopy were also not mapped for Aberdeen and are omitted from the Maryland and Harford County metrics. All tables including detailed county, regional and statewide metrics have the omission of Aberdeen Proving Ground noted beneath the table; this includes Tables 3, 4, 12, 13 and 14.

The CBPO land use/land cover data have 12 land-cover classes categorized as Water, Emergent Wetlands, Tree Canopy, Scrub/Shrub, Low Vegetation, Barren, Buildings, Roads, Other Impervious Surfaces, Tree Canopy Over Buildings, Tree Canopy Over Roads and Tree Canopy Over Other Impervious Surfaces. Tree canopy status and change used the Tree Canopy, Tree Canopy Over Buildings, Tree Canopy Over Other Impervious Surfaces and Tree Canopy Over Roads classes in the definition of Tree Canopy.

Tree canopy within forest was defined from the 2018 CBPO dataset by selecting the following land cover and land use classes: Forest, Riverine Wetlands Forest, Terrene Wetlands Forest and Tidal Wetlands Forest and Harvested Forest. Harvested Forest is land with a forest land use that does not currently have tree canopy cover. The CBPO defines forest as contiguous patches of trees at least one acre in extent with a patch width of at least 240 feet (CBP 2022d, Claggett et al. 2022).

Tree canopy outside forest included the following: Other Tree Canopy within urban, suburban or agricultural areas not meeting the forest definition; Tree Canopy over Turf Grass; Tree Canopy over Roads; Tree Canopy over Structures; Tree Canopy over Impervious; Riverine Wetlands Tree Canopy; Terrene Wetlands Tree Canopy and Tidal Wetlands Tree Canopy.

Accuracy Assessment for High-Resolution CBPO Land Use/Land Cover Data

A focused accuracy assessment was carried out on the high-resolution tree canopy using a random sampling design following Congalton and Green (2008). 1,200 points were randomly generated for the State of Maryland. Each point was independently assigned a reference class by using the 2018 leaf-on NAIP data. 58 points were dropped as the class was ambiguous in the imagery and could not reliably be determined. The point data were then automatically assigned a mapped class from the 2018 tree canopy dataset through a GIS overlay analysis. An error matrix was computed using these data, which provides the overall, producer's and user's accuracy (Table 16). The overall accuracy of the tree canopy is 94%. The user's accuracy of the tree and not tree classes are 93% and 94%, respectively. The overall accuracy reflects the composite accuracy of the dataset. The user's accuracy indicates the chance that at any given location the identification of tree canopy is accurate (e.g., where the dataset indicates that there is tree canopy, there is a 93% that it is actually tree canopy).

Table S1. *Error matrix for the focused accuracy assessment of the CBPO land use dataset.*

		Reference Class			
		Tree	Not Tree	Total	User's Accuracy
Mapped Class	Tree	**453**	32	485	93%
	Not Tree	38	**619**	657	94%
	Total	491	651	**1142**	
	Producer's Accuracy	92%	95%		94% Overall Accuracy

Afforestation and Reforestation Opportunities (Task 1b)

This task is based on a modified methodology performed by the Maryland DNR for locating tree planting opportunities in the state. Plantable areas are defined as areas of existing low vegetation and barren areas, including turf grass and herbaceous cover. The analysis first identified classes from the 2018 land cover layer suitable for tree planting, including Low Vegetation and Barren classes. Next, suitable plantable classes were identified in the 2018 land use layer, including Turf Grass, Natural Succession (Barren) and Natural Succession (Herbaceous). Areas had to be included in both land cover and land use target layers to be considered plantable. Unsuitable land cover and land use classes for increasing tree cover such as impervious areas, roads, buildings, wetlands and water land cover classes were omitted. The plantable target areas were then converted to vector polygons.

A collection of publicly available datasets from MD iMap, DNR and others were incorporated into a vector exclusion layer, representing areas less suitable for long-term tree planting and growth (Table 24). These features included airports, prime agricultural soils, powerline rights of way, important bird area grasslands and areas within a 15-foot buffer of buildings. A full list of exclusion layers are included in Table 21.

The intent of this analysis was to capture the most easily planted areas, so while there may be some exclusion areas that could be planted, we chose not to include less feasible options. This exclusion layer was erased from the plantable target layer. Geometry attributes were calculated to determine plantable area width and length. Plantable areas less than or equal to 100 square meters and width less than or equal to 10 meters were identified as Small Plantable Areas. Areas larger than that were identified as Large Plantable Areas. Statistics on the total amount of plantable area were calculated for each region. Figure 29 shows Plantable Area by region as a function of the overlap of suitable classes in the land cover and land use/land cover datasets.

__Table S2.__ Exclusion layers for plantable area analysis.

Entity	Program name[8]	Acres/Number of trees	Expenditures
Land Cover	Target	2018 High-Resolution Land Cover	Isolated low vegetation and barren
Land Use	Target	2018 High-Resolution Land Use	Isolated turf grass, natural succession-barren and natural succession-herbaceous
Airports	Exclusion	"Maryland Transit - Airports"- IMap (2019); Property Parcel Data (2020)	Identified airport locations with IMap point data, parcels that those points landed in were identified as airports.
Beaches	Exclusion	MDP Internal Data	Identified areas classified as "Beach" in land cover dataset
Ecologically Sensitive Area	Exclusion	DNR Internal Data	NA
Agriculture	Exclusion	PropertyView Land Use; "Maryland SSURGO Soils - SSURGO Soils"; National Hydrology Dataset	Identified agricultural parcels and "Prime Farmland"/ "Farmland of Statewide Importance" with the SSURGO dataset. Calculated where they overlap and removed 100ft stream buffers based on NHD data.
Important Bird Areas	Exclusion	DNR Internal Data	NA
Powerlines	Exclusion	"Electric Power Transmission Lines"- Homeland Infrastructure Foundation-Level Data; PropertyView	Created 20m buffer around power lines and identified and parcels owned by power companies in parcel data, merged the two layers
Railroads	Exclusion	"TIGER/Line Shapefile, nation, U.S., Rails National Shapefile"- Data.gov	Created 10m buffer around railroads
Wetlands	Exclusion	2018 1-meter Resolution	Isolated wetlands and created 100ft buffer
Buildings	Exclusion	2018 1-meter Resolution	Isolated buildings and created 15ft buffer
Sea level rise	Exclusion	CRAB	Created a mask of the raster
Cemetery	Exclusion	MDP Internal Data	NA
Golf Course	Exclusion	MDP Internal Data	NA

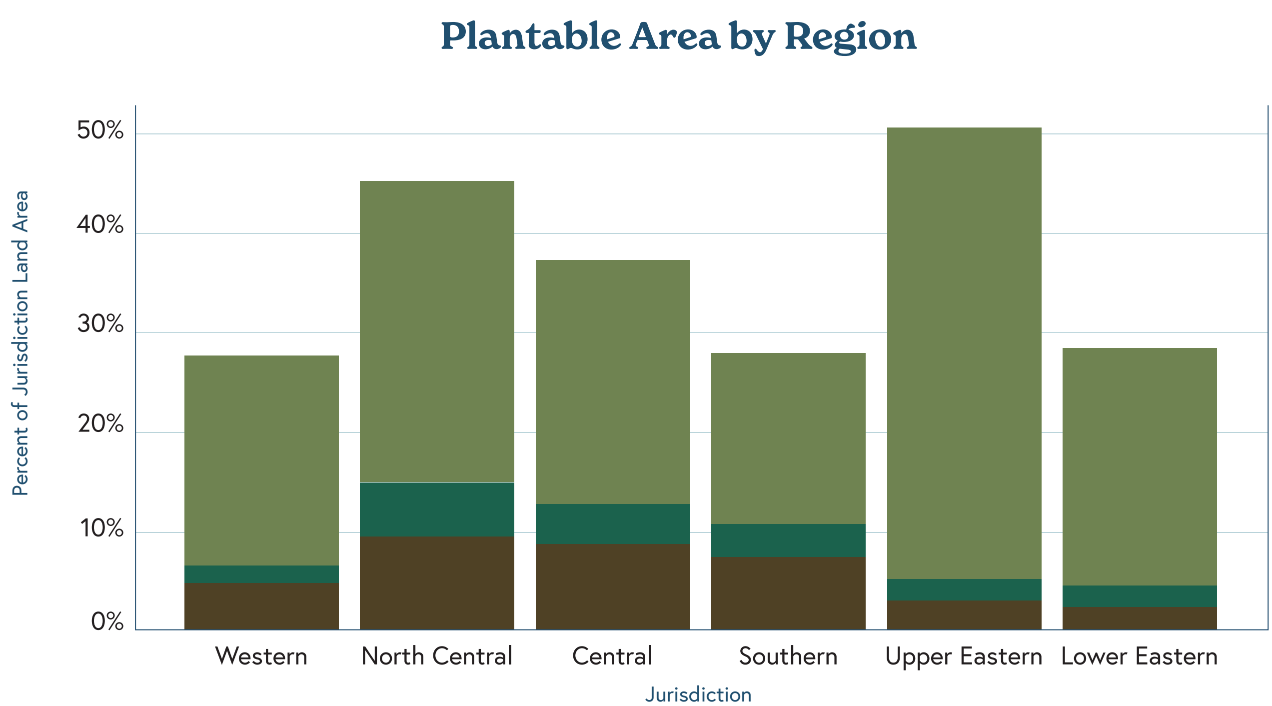


__Figure S1.__ Percent of plantable land area by region.[17]

[17] 1) LC: meets target land cover classes, 2) LU/LC: meets target land use classes and 3) Plantable Area: meets target classes and not in other excluded areas

Health (Task 2)

We assessed forest health based on two key sets of indicators, spatial configuration (or fragmentation) and ground survey data on disturbance and invasive species.

Forest Fragmentation. Forest data for the two time periods were resampled to 10-meter resolution; tree canopy outside forest was not included in this analysis. The classes that made up forest are Forest, Harvested Forest Barren, Harvested Forest Herbaceous, Tidal Wetlands Forest, Riverine Wetlands Forest and Terrene Wetlands Forest. Forest fragmentation metrics were estimated for 2013 and 2018 by applying a 100-meter forest edge using the CLEAR Forest Fragmentation Tool. The tool is based on a method developed by Vogt et al. (2007) for classifying forest spatial patterns and allows the process to be integrated with ArcGIS workflows (Vogt et al. 2007). This tool allows for quantifying landscape structure by categorizing patches, core forest, edges and perforations which can be tracked through time to assess trends in forest health. Patches indicate an area of forest that is distinct from the landscape around it. They can be surrounded by other land cover classes such as agricultural land or built environments and can act as islands of habitat. Edges represent the area between the boundary of patches to a distance into the interior of 100 meters in this report in order to account for edge effects. Edge effects are the tendency for forest along the perimeter of patches to be degraded or unique in quality compared with interior forest due to influence from surrounding land uses, as well as exposure to increased sunlight penetration, increased exposure to human and natural disturbances, including increased chance of introduction of invasive species. Forest edges usually have a different assortment of flora and fauna than interior forest. Edge effects tend to be more pronounced when the neighboring patch differs greatly, for example, when a forest patch borders a major road. Perforated areas are located along the edge of small forest gaps. Core areas are the interiors of patches that are far enough from the edge to be minimally affected by edge effects. The output includes patches, edges, small core forest (<250 acres), medium core forest (250-500) and large core (>500 acres). Fragmentation change metrics were calculated for each county and at the state level. Forests were fragmented based on any land use class that was not forest. Some natural fragmentation occurred from features like wide streams. When forested areas were bisected by streams that were wide enough to be picked up by 1m land use, natural fragmentation was introduced.

It should be noted that the high-resolution data used to perform these analyses rely on NAIP and LiDAR data, but there were not two LiDAR collections to create elevation data for every county throughout Maryland, which helps increase the accuracy of tree canopy change detection. In Anne Arundel, Calvert, Montgomery, Prince George's and St. Mary's counties, tree canopy change is more accurately observed as there are multiple LiDAR collections to support the analyses. In other counties, fine scale disturbance may not be as easily discerned. While the lack of two LiDAR collections in certain counties may have a fine scale visual impact or affect county-level change statistics somewhat, this probably does not have a big impact on statewide statistics reports.

Disturbance. We also assessed the level of disturbance observed in FIA forest plots in Maryland (USDA Forest Service FIA n.d.). For the 2019 FIA inventory in Maryland, estimates for variables such as forest extent, number of trees, volume and biomass are based on 982 plots (433 of which contained forest) collected from 2013-2019 (Bechtold and Patterson 2005). As part of these surveys, the level of disturbance is assessed. To be defined as disturbance, 25% of trees in a 1-acre plot need to have suffered damage or mortality from the specific cause since the last time the plot was visited. Major categories of disturbance include insect damage, disease, wildlife, tree suppression caused by vegetation, weather-induced and human-caused. Insect damage in this region is categorized as either uncategorized and alternately, "insect damage to trees or saplings." Generally, in these surveys, one acre of land could presumably suffer from more than one type of disturbance. Disturbed area was extrapolated to the total forest area in Maryland (Burrill et al. 2021). Subsequently, we graphed the FIA plot area by disturbance type to determine the major sources of disturbance to Maryland forests.

We also used data on IPS observations from FIA subplots in Maryland. For this, we obtained IPS data from 49 subplots collected from 2014-2019 and 75 subplots representing the years 2010-2014. We noted frequency of IPS observations and percent subplot area affected by each IPS (USDA Forest Service FIA n.d.; USDA Forest Service n.d.). Finally, we reviewed data from the FIA Forest Pest Impacts Portal for data on invasive insects and the National Insect and Disease Risk Map for Percent of Treed Area At Risk in Maryland (USDA Forest Service FIA 2019; USDA Forest Service 2018; Krist et al. 2014).

Progress (Task 3)

For this task, several datasets involving urban tree canopy were consulted. To observe urban tree canopy cover change from 2013-2013, we relied on tree canopy layers as classified by the high-resolution land use land cover dataset from CBPO. Urban areas within the state were identified using the Maryland Census Designated Areas - Urban Areas 2010 (CUAs) on Maryland's iMap. Using the high-resolution land cover change raster dataset, tree canopy gains and losses within the CUAs were tabulated and mapped. We complemented these observations with tree planting reports collected by the Harry Hughes Center for the years 2018-2019. Finally, we reviewed county-level best management practice certification reports from CAST that reflect the Phase III WIP and 2020 progress in the developed (urban) sector.

For the analysis of observed progress for riparian planting goals, we began with a comprehensive review of the 2014 Chesapeake Bay Agreement (CBWA 2014; State of Maryland 2019). From the review, several methodologies were considered for determining riparian buffers along streams. Based on Advisory Committee recommendations, we chose to follow a similar methodology to other riparian analysis projects occurring in the state. First, a high-resolution flow path dataset using a combination of 1) concentrated flow paths derived from elevation data, 2) channel width estimates predicted using USGS regional curves and 3) high-resolution land cover data produced by the CIC. We then buffered the flow paths by 100 feet and extracted high-resolution land cover values from that riparian buffer zone. Small bodies of water like ponds and lakes were included in this analysis. Then, to determine if Maryland counties have met tree canopy goals within their riparian areas, percent tree canopy coverage was summarized with the 100-foot riparian buffer zone, by jurisdiction, for the year 2018. Classes defined as tree canopy included Tree Canopy, Tree Canopy over Buildings, Tree Canopy over other Impervious and Tree Canopy over Roads. Water pixels were not included in calculations when they occurred within the 100-foot riparian zone; if we had included them, estimates of percent tree canopy coverage would have been more conservative than our estimate. Statewide totals of riparian buffer tree canopy coverage were calculated in addition to county-specific coverage. Tree canopy percent cover was then compared to the Chesapeake Bay Watershed-wide commitment of 70% forest coverage in riparian areas.

The aerial observations of riparian buffer tree canopy coverage for the year 2018 were complemented by a review of county-level best management practice certification reports for riparian areas available in CAST to the year 2020. We were unable to locate tree planting reports specific to riparian areas.

Land Cover and Forest Change (Tasks 4 and 5)

Short- and long-term land cover transitions were examined in this series of analyses at medium and high resolutions. To do this, we produced Sankey Diagrams in R, illustrating shifts between LULC categories based on aggregate classes in the NLCD (MRLCC n.d.) and high-resolution CBPO land use/land cover datasets.

The NLCD analysis was provided in the form of pivot tables by Sarah McDonald of USGS, CBPO. NLCD classes were intuitively combined with the purpose of visualizing trends; for example, the developed classes (low, medium and high intensity) were all combined into one Developed class. Woody wetlands were included in the Forest class. The Wetlands class only included emergent wetlands.

For the CBPO high-resolution land use/land cover data, we used a similar process to aggregate the generalized 18 classes into only six classes: Developed, Forest and other Tree Canopy, Natural, Production, Wetlands and Water. The Developed category includes roads, impervious structures and features, turf grass and pervious features within developed parcels. The Natural category includes areas of barren, herbaceous or shrubland that are in varying states of natural succession, including those used for timber harvest activities. The Production category includes agricultural and extractive land.

In a subsequent analysis, we used timber harvest permit data to make inferences about the distribution and intensity of timber harvest throughout the state. We obtained tabular data from Maryland DNR on timber harvest permits issued for private and state lands by county. Permit data overestimates the actual area harvested because in practice, timber companies selectively log and avoid high-risk areas such as riparian zones and steep slopes. We did not integrate satellite imagery into these estimates so were unable to determine the amount of actual tree loss and gain in these permitted areas.

We also conducted a series of analyses observing change by land cover class and conversion of forest and tree canopy outside forest to other land cover classes and uses. These are based on the 2013 and 2018 CBPO land use/land cover data, with results reported in a series of figures and tables.

Priority Funding Areas

We also calculated the extent of change in various conservation geographies and urbanizing areas. Urbanization and conservation geography datasets were the best available at the time; vintage may not line up exactly with the date(s) of the tree canopy change time frame. PFAs were used as a proxy for locally designated growth areas based on consultation with Advisory Committee members. While outreach was conducted with Maryland jurisdictions to acquire locally designated growth areas, due to the timeline of this project and variations in how localities define, maintain and share those datasets, it was determined that PFAs would be the best dataset to satisfy this particular task.

Core Forest Expansion (Tasks 4 and 5)

We identified plantable areas within 100 meters of forest edge as potential priorities for planting. We did this by overlapping out Plantable Areas dataset (Task 3) with a 100-meter buffer of forest edge derived from the CLEAR fragmentation analysis results (Task 2). We then calculated the percent of forest edge buffer area that is plantable.

Forest Change in Protection Priority Areas (Tasks 4 and 5)

We also looked at tree canopy cover and change within areas identified as having important ecological value, which may or may not have protective measures in place. These Priority Protection Areas included Green Infrastructure hubs and corridors, Targeted Ecological Areas (TEAs) and 100-year floodplains (MDNR [2005] 2021; FEMA [2017] 2017; MDNR [2011] 2019). The effective floodplain for the State of Maryland was selected by making a selection from the "description" field of the Maryland floodplain dataset where it contained "100." These datasets were merged into one region and converted to raster. Total forest and tree canopy outside forest as well as change from 2013-2018 was summarized statewide.

Projected Change (Tasks 4 and 5)

We projected forest cover change from 2025 to 2055 under a business-as-usual scenario using the Chesapeake Bay Land Change Model (CBLCM). The CBLCM forecast is based on projected changes in population and employment, while considering land use conditions, zoning, protected lands, slope and other factors affecting growth. The results in this report are based on the CBLCM 2021 Current Zoning scenario. For every county, the model estimates the portion of future population and jobs accommodated by infill and redevelopment and allocates the remaining portion to new development that would result in the conversion of forests and farmland (CBP 2020a).

Forest and Tree Canopy Commitments (Task 5)

We analyzed forest and tree canopy change in protected lands using high-resolution data from CBPO and GIS datasets available from MD iMap via the Maryland Protected Lands Dashboard. Data sources included the Department of Planning: Local Protected Lands, Maryland Agricultural Land Preservation Foundation Easements and TDR / PDR (MDNR, MDA, MDP 2022). We used Maryland Environmental Trust Easements, Rural Legacy Properties, DNR Owned Lands and Conservation Easements, Coastal and Estuarine Land Conservation Program, Private Conservation Lands, Protected Federal Lands and Forest Conservation Act Easements, all maintained by the Department of Natural Resources. Notably, we did not include Maryland Priority Funding Areas (which we looked at elsewhere in this report) or Rural Legacy Areas as part of this analysis. The vector layers were merged and converted to raster data to avoid double-counting in any overlapping areas. The protected raster layer was then tabulated against the defined forest dataset from Task 1a.

To assess the progress of afforestation, reforestation and other tree planting programs operating in the state, we reviewed ground based reports of trees planted from 2018-2020 by local to federal government programs (also see Task 7). We estimated potential future tree canopy acres based on projections made under the GGRA Plan (accumulating intended tree plantings across state programs from 2006-2030) and future tree planting goals to 2031 under the TSNA.

Forest Mitigation Banking (Task 6)

Through online queries and interviews with key forestry leaders, interns from the Hughes Center assembled a list of the names and contact information for the employees responsible for each county's mitigation banking program. This list was reviewed and updated in 2022. Each county was sent a survey by email of questions asking about the total and available number and acreage of banks, restrictions on the location of forest mitigation banks, minimum acreage for banks, fee-in-lieu rates and more, with follow-up phone calls to counties that were unreachable by email. Each county's forest conservation regulations were also reviewed and used as a further source of information about forest mitigation banking policies.

Forest and Tree Planting Programs (Task 7)

We used a survey methodology to conduct a programmatic and funding review of federal, state and local tree and forest planting programs operating in Maryland. Programmatic was interpreted to mean the number of trees planted, and funding was interpreted to mean expenditure amounts and funding sources.

In an effort to obtain the information requested in section 7.a.2.vii of H.B. 991, a survey containing a spreadsheet was created. This survey was then sent through email to the county planning departments, municipality offices, county forestry boards and county departments of the environment. In addition, the email containing the survey was sent to the municipalities through The Maryland Municipal League. Individuals on the state and federal level were not sent the survey and instead were sent questions specific to the known programs they administer.

The survey consisted of two questions and a link to the spreadsheet. Its purpose was to track the number of responses from counties and municipalities and gauge the spreadsheets' completeness. The spreadsheet itself contained five questions as well as a column for the counties and municipalities to identify their answers (Appendix B). The first two questions in the spreadsheet inquired about the tree and reforestation programs that existed and were employed within the jurisdictions asking for their title and a brief description (Appendix C). The next question asked about the number of trees planted in 2018 and 2019 through those programs. The number of trees planted in the year 2020 was not requested due to the unusual circumstances of the pandemic. The final two questions inquired about expenditures and funding sources, asking for dollar amounts of expenditures in 2018 and 2019 and funding from federal, state, local, private or fee-in-lieu sources.

Danial Rider, Marian Honeczy and Anne Hairston-Strang from Maryland DNR Forest Service were contacted on the state level. Similar to the questions asked in the survey, they were asked to provide tree and reforestation state program names and the number of trees planted and the annual expenditures for 2018 and 2019 for those programs.

On the federal level, Ramon Ortiz at Natural Resource Conservation Service (NRCS) was contacted regarding the Environmental Quality Incentives Program (EQIP) and Jason Keppler at MDA was contacted regarding the CREP program. Both individuals were asked about their respective program's tree planting numbers and annual expenditures for 2018 and 2019.

Appendices

Appendix A - GIS Data Sources

Table A1. *GIS Data Sources*

Feature Name	Dataset Description	Source Organization and Link*	Task(s)
Tree Canopy Cover, 1-m (2013/14 and 2017/2018)	**Chesapeake Bay High-Resolution Land Cover (2013/2014 and 2017/2018):** 1-Meter resolution land cover derived from NAIP, LiDAR and other inputs for the entire Chesapeake Bay Watershed. For this study we defined high-resolution Tree Canopy Cover as all tree canopy classes in the original dataset.	Chesapeake Bay Program	All Tasks
Airports	Airports	State of Maryland, iMap Data Catalog	1B
Beaches	**Maryland Land Use/Cover 2010** *Selected areas classified as as beach*	MDP Land Use/Cover Data (MDP n.d.)w	1B
Ecologically Sensitive Areas		DNR Internal Data	1B
Agriculture	Agricultural zones and areas suitable for agriculture	MDProperty View Land Use (MDP, n.d.) Maryland SSURGO Soils - SSURGO Soils (NRCS 2018) National Hydrography Dataset (NHD) (U.S. Geological Survey 2019)	1B
Important Bird Areas	Important bird areas	DNR Internal Data	1B
Powerlines	Electric Power Transmission Lines	Electric Power Transmission Lines- Homeland Infrastructure Foundation-Level Data (HIFLD 2021) MDProperty View MDP n.d.)	1B
Railroads	Railroads	TIGER/Line Shapefile, nation, U.S., Rails National Shapefile (U.S. Census Bureau 2019)	1B
CRAB - Climate Ready Action Boundary	Sea level rise predictions	Maryland Environmental Service (MES) in partnership with Maryland Department of Environment (MDE) and Coast Smart Council, under guidance of Maryland Department of Natural Resource (DNR)	1B
Cemeteries	Cemeteries	MDP Internal Data	1B
Golf Courses	Golf courses	MDP Internal Data	1B
Chesapeake Bay Land Change Model CBLCM	Model used to project future land use change and impacts on water quality	Chesapeake Bay Program (CBP n.d.)	
Census Block Groups	Maryland Census Boundaries - Census Block Groups 2010	State of Maryland iMap ESRI	1A

Feature Name	Dataset Description	Source Organization and Link*	Task(s)
Census Urbanized Areas	Maryland Census Designated Areas - Urban Areas 2010	State of Maryland, iMap data Catalog	3
Maryland Detailed County Boundaries	Maryland Physical Boundaries - County Boundaries (Detailed)	State of Maryland, iMap data Catalog	1A, 1B, 2, 4, 5
Protected Lands	Local Protected Lands MD Agricultural Land Preservation Foundation Easements TDR / PDR MD Environmental Trust Easements Rural Legacy Properties DNR Owned Lands and Conservation Easements Coastal and Estuarine Land Conservation Program Private Conservation Lands Protected Federal Lands Forest Conservation Act Easements	State of Maryland, iMap Data Catalog Maryland Protected Lands Dashboard (MDNR, MDA, MDP, 2022)	5
Maryland State Boundary	Maryland Political Boundaries - State Boundary	State of Maryland, iMap data Catalog	1A, 1B, 2, 4, 5
Property View Parcel	Land use Land use descriptions as defined by the Department of Assessments and Taxation	MDProperty View Land Use (MDP n.d.)	1A, 4
USFS National Insect and Disease Risk Map	Percent Treed Area at Risk	USDA Forest Service Forest Health & Protection	2
NHD Streams	Streams	National Hydrography Dataset (NHD) (U.S. Geological Survey 2019)	3?
Chesapeake Conservancy's Riparian Buffers	Internally created product from buffered enhanced flow paths and 1-meter resolution Chesapeake Bay land cover	Chesapeake Conservancy and partners National Hydrography Dataset (NHD) (U.S. Geological Survey 2019)	4
Sewer Service Areas	Sanitary sewer service areas	MDP Internal Data	4
Targeted Ecological Areas	Maryland Focal Areas - Targeted Ecological Areas	MD iMap	4
Priority Funding Areas	Priority Funding Areas (PFAs): Existing communities and places designated by local governments indicating where they want state investment to support future growth. *In this analysis, we used PFAs as a proxy for locally designated growth areas. PFA comment areas were included.*	Priority Funding Areas (MDP 2019)	4

**Datasets were shared or downloaded in their best current state in late 2021 or early 2022 unless otherwise noted.*

Appendix B - CAST Tables

Table B1. *BMP Credits by Type and Percent of WIP Implemented*

Geography, Sector and BMP Name	Phase III WIP, Sum of Total Amount Credited	CAST 2020 Progress, Sum of Total Amount Credited	Percent of WIP Implemented
Allegany, MD	**1,268.00**	**1,377.90**	**108.7**
Agriculture	**856.5**	**1,073.80**	**125.4**
Forest Buffer	595.4	678.5	114
Tree Planting	261.2	395.4	151.4
Developed	**411.4**	**304.1**	**73.9**
Forest Buffer	236.4	176.7	74.7
Forest Planting	48	0.4	0.8
Tree Planting - Canopy	127.1	127.1	100
Anne's Arundel, MD	**1,074.10**	**807.6**	**75.2**
Agriculture	**286.9**	**205.3**	**71.6**
Forest Buffer	77.6	25.3	32.6
Tree Planting	209.3	180	86
Developed	**787.2**	**602.3**	**76.5**
Forest Buffer	6.4	20.9	327.3
Forest Planting	689.6	345.2	50.1
Tree Planting - Canopy	91.2	236.2	259
Baltimore City, MD	**275.4**	**328.4**	**119.3**
Agriculture	**-**	**-**	**-**
Forest Buffer	-	-	-
Tree Planting	-	-	-
Developed	**275.4**	**328.4**	**119.3**
Forest Buffer	-	-	-
Forest Planting	237.8	13.5	5.7
Tree Planting - Canopy	37.5	314.9	839.1
Baltimore, MD	**1,599.80**	**1,196.90**	**74.8**
Agriculture	**383.7**	**210.6**	**54.9**
Forest Buffer	304.9	184.4	60.5
Tree Planting	78.7	26.2	33.3
Developed	**1,216.10**	**986.3**	**81.1**
Forest Buffer	63.3	104	164.3
Forest Planting	955.6	522.8	54.7
Tree Planting - Canopy	197.2	359.5	182.3

Geography, Sector and BMP Name	Phase III WIP, Sum of Total Amount Credited	CAST 2020 Progress, Sum of Total Amount Credited	Percent of WIP Implemented
Calvert, MD	**46.1**	**39.3**	**85.2**
Agriculture	**39.9**	**30.6**	**76.7**
Forest Buffer	18.2	12.1	66.1
Tree Planting	21.6	18.5	85.5
Developed	**6.2**	**8.7**	**139.6**
Forest Buffer	-	3.2	-
Forest Planting	5.5	5.5	100
Tree Planting - Canopy	0.7	-	-
Caroline, MD	**698.2**	**448.4**	**64.2**
Agriculture	**676.1**	**433**	**64**
Forest Buffer	217.4	204.9	94.3
Tree Planting	458.7	228.1	49.7
Developed	**22.1**	**15.4**	**69.7**
Forest Buffer	2.2	2.2	100
Forest Planting	19.7	13	65.9
Tree Planting - Canopy	0.2	0.2	100
Carroll, MD	**3,021.00**	**2,435.70**	**80.6**
Agriculture	**2,570.70**	**1,795.50**	**69.8**
Forest Buffer	2,325.10	1,668.40	71.8
Tree Planting	245.6	127.1	51.8
Developed	**450.3**	**640.1**	**142.2**
Forest Buffer	77.9	25.6	32.9
Forest Planting	314.4	313.9	99.8
Tree Planting - Canopy	58	300.6	518.1
Cecil, MD	**779.9**	**589.6**	**75.6**
Agriculture	**586.5**	**437.1**	**74.5**
Forest Buffer	431.3	293.2	68
Tree Planting	155.1	143.9	92.7
Developed	**193.4**	**152.5**	**78.9**
Forest Buffer	11.4	15.9	139.2
Forest Planting	175.7	13.5	7.7
Tree Planting - Canopy	6.3	123.1	1,957.80
Charles, MD	**995.5**	**872**	**87.6**
Agriculture	**553.4**	**608.3**	**109.9**
Forest Buffer	275.5	342.5	124.3
Tree Planting	277.9	265.8	95.7
Developed	**442.1**	**263.6**	**59.6**
Forest Buffer	-	-	-
Forest Planting	282.4	36.7	13
Tree Planting - Canopy	159.7	226.9	142.1

Geography, Sector and BMP Name	Phase III WIP, Sum of Total Amount Credited	CAST 2020 Progress, Sum of Total Amount Credited	Percent of WIP Implemented
Dorchester, MD	**1,369.90**	**996.5**	**72.7**
Agriculture	**1,344.00**	**973.4**	**72.4**
Forest Buffer	839.1	777.7	92.7
Tree Planting	504.9	195.8	38.8
Developed	**25.9**	**23**	**89.1**
Forest Buffer	8.8	12.5	141.9
Forest Planting	12.9	6.4	49.6
Tree Planting - Canopy	4.1	4.1	99.7
Frederick, MD	**4,551.80**	**3,207.70**	**70.5**
Agriculture	**3,346.70**	**2,414.50**	**72.1**
Forest Buffer	3,032.50	2,203.10	72.6
Tree Planting	314.2	211.4	67.3
Developed	**1,205.10**	**793.2**	**65.8**
Forest Buffer	70.5	36.4	51.7
Forest Planting	612.3	261.8	42.8
Tree Planting - Canopy	522.4	494.9	94.7
Garrett, MD	**210.2**	**844.3**	**401.8**
Agriculture	**207.9**	**838.7**	**403.4**
Forest Buffer	66.2	168	253.8
Tree Planting	141.7	670.7	473.3
Developed	**2.3**	**5.6**	**249**
Forest Buffer	0.3	5.6	1,856.40
Forest Planting	-	-	-
Tree Planting - Canopy	2	-	-
Harford, MD	**1,628.90**	**1,106.50**	**67.9**
Agriculture	**971.5**	**530.6**	**54.6**
Forest Buffer	713.6	318.4	44.6
Tree Planting	257.9	212.3	82.3
Developed	**657.4**	**575.8**	**87.6**
Forest Buffer	24.2	40	165.3
Forest Planting	422.2	76.7	18.2
Tree Planting - Canopy	210.9	459.1	217.7
Howard, MD	**2,165.00**	**1,250.30**	**57.8**
Agriculture	**535.5**	**333.6**	**62.3**
Forest Buffer	435.8	265.9	61
Tree Planting	99.7	67.8	68
Developed	**1,629.40**	**916.7**	**56.3**
Forest Buffer	5.4	9.9	182
Forest Planting	421.7	196.8	46.7
Tree Planting - Canopy	1,202.30	710	59.1

Geography, Sector and BMP Name	Phase III WIP, Sum of Total Amount Credited	CAST 2020 Progress, Sum of Total Amount Credited	Percent of WIP Implemented
Kent, MD	**649.3**	**672.5**	**103.6**
Agriculture	**560.5**	**576.4**	**102.8**
Forest Buffer	431.2	409.3	94.9
Tree Planting	129.3	167.1	129.2
Developed	**88.7**	**96.1**	**108.3**
Forest Buffer	-	4.7	-
Forest Planting	86.7	89.4	103.1
Tree Planting - Canopy	2	2	98.2
Montgomery, MD	**1,310.20**	**910.4**	**69.5**
Agriculture	**634.9**	**410.7**	**64.7**
Forest Buffer	510.7	322.5	63.1
Tree Planting	124.2	88.2	71.1
Developed	**675.3**	**499.7**	**74**
Forest Buffer	6.1	6.1	101.7
Forest Planting	477.2	285.6	59.8
Tree Planting - Canopy	192	207.9	108.3
Prince George's, MD	**1,812.60**	**2,373.90**	**131**
Agriculture	**228.6**	**228.6**	**100**
Forest Buffer	101.1	98.2	97.2
Tree Planting	127.5	130.3	102.2
Developed	**1,583.90**	**2,145.30**	**135.4**
Forest Buffer	165.4	1.1	0.7
Forest Planting	1,022.20	1,555.80	152.2
Tree Planting - Canopy	396.4	588.4	148.5
Queen Anne's, MD	**712.6**	**638.8**	**89.6**
Agriculture	**660.4**	**589.5**	**89.3**
Forest Buffer	558.4	483.3	86.6
Tree Planting	102	106.2	104.1
Developed	**52.2**	**49.3**	**94.4**
Forest Buffer	13.9	25.5	183.5
Forest Planting	33.9	19.4	57.3
Tree Planting - Canopy	4.4	4.4	99
Somerset, MD	**2,340.60**	**2,071.10**	**88.5**
Agriculture	**2,329.60**	**2,053.20**	**88.1**
Forest Buffer	2,210.60	2,027.40	91.7
Tree Planting	119	25.8	21.7
Developed	**11**	**17.9**	**162.5**
Forest Buffer	-	3.3	-
Forest Planting	9.4	13	138.1
Tree Planting - Canopy	1.6	1.6	99.8

Geography, Sector and BMP Name	Phase III WIP, Sum of Total Amount Credited	CAST 2020 Progress, Sum of Total Amount Credited	Percent of WIP Implemented
St. Mary's, MD	**846.8**	**720.4**	**85.1**
Agriculture	**731.6**	**701.3**	**95.9**
Forest Buffer	359.6	283.9	78.9
Tree Planting	372	417.4	112.2
Developed	**115.2**	**19.1**	**16.6**
Forest Buffer	7.3	4	54.8
Forest Planting	96.2	13	13.5
Tree Planting - Canopy	11.7	2.1	18
Talbot, MD	**592.8**	**438.3**	**73.9**
Agriculture	**552**	**398.9**	**72.3**
Forest Buffer	425	307.3	72.3
Tree Planting	127	91.6	72.1
Developed	**40.8**	**39.4**	**96.7**
Forest Buffer	3.3	7.9	238.1
Forest Planting	11.2	5.3	47.3
Tree Planting - Canopy	26.2	26.2	99.9
Washington, MD	**2,267.40**	**1,714.30**	**75.6**
Agriculture	**1,718.80**	**1,388.60**	**80.8**
Forest Buffer	1,418.10	1,107.00	78.1
Tree Planting	300.7	281.6	93.6
Developed	**548.7**	**325.7**	**59.4**
Forest Buffer	12.7	25.3	199.5
Forest Planting	500.7	14.5	2.9
Tree Planting - Canopy	35.3	285.9	810.5
Wicomico, MD	**2,054.30**	**1,960.00**	**95.4**
Agriculture	**1,879.50**	**1,902.20**	**101.2**
Forest Buffer	1,723.00	1,424.00	82.6
Tree Planting	156.5	478.3	305.6
Developed	**174.9**	**57.7**	**33**
Forest Buffer	6.7	12.9	192
Forest Planting	166.7	43.4	26
Tree Planting - Canopy	1.4	1.4	99
Worcester, MD	**2,128.90**	**3,244.60**	**152.4**
Agriculture	**2,116.20**	**3,216.90**	**152**
Forest Buffer	2,027.80	3,117.60	153.7
Tree Planting	88.4	99.3	112.3
Developed	**12.7**	**27.7**	**217.7**
Forest Buffer	-	4.4	-
Forest Planting	12.2	22.1	181.5
Tree Planting - Canopy	0.5	1.2	218.5
Grand Total	**34,399.20**	**30,245.30**	**87.9**

Appendix C - Forest Conservation Regulations

Table B1.*Forest conservation regulations for the Maryland counties that have forest mitigation banks (or the option for banks)*[18].

County	Relevant Regulations	Link
Anne Arundel	CC Article 17, Title 6, Subtitle 3	https://codelibrary.amlegal.com/codes/annearundel/latest/annearundelco_md/0-0-0-116562
Baltimore	CC Article 33, Title 6	https://library.municode.com/md/baltimore_county/codes/code_of_ordinances?nodeId=ART33ENPRSU_TIT6FOCO
Calvert	Zoning Ordinance Article 8-3	https://ecode360.com/29295339Z
Caroline	CC Part 3, Ch 109	https://ecode360.com/8724617
Carroll	CC Title XV, Ch 150	https://codelibrary.amlegal.com/codes/carrollcounty/latest/carrollcounty_md/0-0-0-20404
Cecil	Forest Conservation Regulations	https://www.ccgov.org/home/showpublisheddocument?id=1262
Charles	CC Division 2, Part II, Ch 298	https://ecode360.com/26905805
Dorchester	CC Part II, Ch 96	https://ecode360.com/10453712
Frederick	CC Ch 1-21	https://codelibrary.amlegal.com/codes/frederickcounty/latest/frederickco_md/0-0-0-9113
Howard	Forest Conservation Manual	https://www.howardcountymd.gov/sites/default/files/2021-03/HoCo%20Forest%20Con%20Manual_Feb%202021_0.pdf
Kent	CC Part III, Ch 185	https://ecode360.com/11475787
Montgomery	CC Ch 22A	https://montgomeryplanning.org/wp-content/uploads/2017/10/Montgomery-County-Forest-Conservation-Law-2-22-21.pdf
Prince George's	CC Subtitle 25, Division 2	https://library.municode.com/md/prince_george's_county/codes/code_of_ordinances?nodeId=PTIITI17PULOLAPRGECOMA_SUBTITLE_25TRVE_DIV2WOWIHACOOR
Queen Anne's	CC Part III, Ch 18:2	https://ecode360.com/7142512
Somerset	Forest Conservation Ordinance	https://cms7files1.revize.com/somersetcountymd/document_center/Department/Planning%20and%20Zoning/Zoning/2019/2015.11.17%20Forest%20Conservation%20Ordinance%20FINAL.pdf
Washington	Forest Conservation Ordinance	https://www.washco-md.net/wp-content/uploads/legal-FCO.pdf
Wicomico	CC Part II, Ch 126	https://ecode360.com/10169427
Worcester	CC Natural Resources Article, Subtitle NR1:IV	https://ecode360.com/14068104

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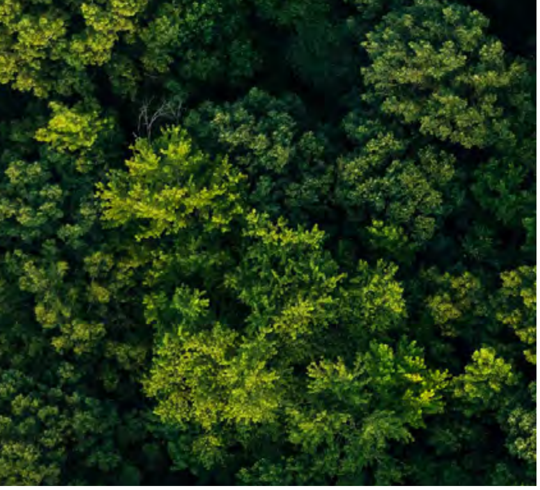



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