New England's Climate Imperative:

Our Forests as a Natural Climate Solution

Highstead

October 2022

New England's Climate Imperative:
Our Forests as a Natural Climate Solution

Authors

Spencer R. Meyer, *Highstead**
Kavita Kapur Macleod, *KKM Environmental Consulting*
Jonathan R. Thompson, *Harvard Forest, Harvard University*
David R. Foster, *Harvard Forest, Harvard University*
Robert Perschel, *New England Forestry Foundation*
Nicole St. Clair Knobloch, *Olifant, LLC*
Jon Leibowitz, *Northeast Wilderness Trust*
Brian Donahue, *Brandeis University*
Alec Giffen, *New England Forestry Foundation*
Tewosret Vaughn, *Highstead*
Tara Whalen, *Highstead*
Bill Labich, *Highstead*
Andrea Colnes, *New England Forestry Foundation*
Jeanne Ammermuller, *Highstead*

* Current Affiliation: *Natural Capital Exchange*

October 2022

Table of Contents

Glossary of Terms & Acronyms

BAU: Business as Usual

CO2: Carbon Dioxide

CO2e: Carbon Dioxide Equivalent — a measure used to compare emissions from various greenhouse gases on the basis of their global warming impact

GHG: Greenhouse Gas

IFM: Improved Forest Management

Tons: This report uses U.S. Customary Units, including acres and U.S. short tons (i.e., 2000 lbs)

1 acre = 0.4 hectares and 1 U.S. short ton = 0.91 metric tons

KEY FINDINGS

New England forests are a critical yet underutilized tool in fighting climate change. They store massive amounts of carbon—and each year they sequester more.

Despite the work our forests are already doing to keep CO2 out of the atmosphere, they could do substantially more. As New England states work to meet their 2050 goals for reducing emissions, the relative importance of forest-based mitigation will grow.

This report identifies five distinct but complementary pathways that illustrate how New England forests can do even more to tackle climate change. By implementing these five pathways, especially if done together, New England can advance conservation and increase the climate mitigation potential of forests:

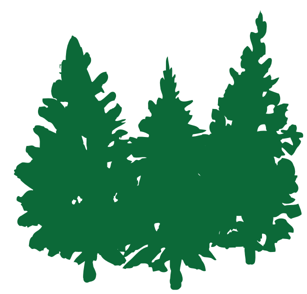
- **Avoided Deforestation:** Each year, 28,000 acres of forests are permanently converted to development, emitting their stored carbon and forgoing all future sequestration. We must reduce this rate of forest loss. If we reduce deforestation to 7,000 acres per year in New England, 74 million U.S. tons of Carbon Dioxide Equivalent (CO2e) would be kept out of the atmosphere by 2050.
- **Wildland Reserves:** Less than 4% of our forests are currently protected as wildland reserves. We need to ensure that a minimum of 10% of New England's forests are allowed to grow and mature without the influence of any extractive land uses. This would sequester an additional 50 million U.S. tons CO2e by 2050.
- **Improved Forest Management:** Society is heavily dependent on wood products, and New England is a great place to grow trees. By changing our management practices and stewarding timberlands to maximize carbon sequestration, we can maintain harvest volumes while increasing carbon storage in the forest. If just 50% of harvests employed climate smart techniques, an additional 203 million U.S. tons CO2e could be sequestered by 2050.
- **Mass Timber Construction:** Trees are a valuable climate solution inside and outside the forest. Using mass timber building materials is much less carbon intensive than steel or concrete and has the added benefit of storing carbon throughout the life of the building. If 50% of the eligible new buildings used mass timber construction, an additional 15 million U.S. tons CO2e could be stored.
- **Urban and Suburban Forests:** Expanding tree and forest cover within our communities has enormous benefits even beyond carbon, including shading, clean air, clean water, and recreational and employment opportunities. A 5% increase in urban tree canopy in New England could sequester an additional 17 million U.S. tons CO2e by 2050

New England's forests currently absorb roughly 27 million U.S. tons of CO2e each year—equal to 14% of the CO2 emitted through burning fossil fuels in the region in 2020. By adopting these pathways, even at a moderate pace, forests could sequester the equivalent of 21% of 2020 emissions. And if New Englanders choose to make the most of their incredible forest resources, they can do much more.

The relative importance of these pathways will increase over time. As New England states meet their specified goals for reducing emissions, and total emissions drop from 187 million U.S. tons CO2e to 40 million U.S. tons CO2e, forests will sequester the equivalent of 97% of remaining emissions.

14%
of CO2 emissions is absorbed by New England forests each year

Less than 4%
of forests are currently protected as ecological reserves



28,000 acres
of forests are permanently converted to development each year

21%
of current CO2 emissions could be sequestered by adopting these pathways

Executive Summary

Global greenhouse gas (GHG) emissions have increased dramatically over the past century, causing average annual temperatures to increase by just over 1°C. While there's no one clear threshold, scientists broadly agree that an increase beyond 1.5°C would lead to sea level rise, ocean acidification, heat waves, and drought, as well as more intense rainfall, hurricanes, and other natural disasters that would cause irreparable harm to society and the natural world. We are perilously close.

Addressing climate change requires aggressive and diverse strategies for maximizing mitigation, adaptation, and resilience. Mitigation reflects a critical step to bringing climate change under control by reducing the amount of GHGs in the atmosphere. To mitigate climate change we must both reduce emissions—particularly from the heavily emitting sectors of transportation, energy, and construction—and remove carbon dioxide (CO2)—the most prevalent GHG emitted by humans—from the atmosphere. As emissions reduction goals continue to pass unmet, governments and private actors are increasingly relying on future CO2 removal. While some technological approaches exist, nothing comes close to forests in terms of the magnitude of carbon removed.

This study estimates how New England's forests can better serve as a natural climate solution. New England's forests are a globally important carbon sink, cover approximately 75% of the region's landscape, and store 4.6 billion tons CO2 equivalent (CO2e)[1] above ground (trees, dead wood, and litter). Each year, these forests absorb around 27 million tons CO2e, or the equivalent of 14% of total annual emissions from New England states. In this study, five pathways are developed and assessed that could increase the climate mitigation potential of New England's forests:

- **Avoided Deforestation**
- **Wildland Reserves**
- **Improved Forest Management**
- **Mass Timber Construction**
- **Urban and Suburban Forests**

These pathways are examined separately and at low, medium, and high levels of adoption.[2] Overall, the pathways are highly complementary and additive—only if all the pathways were adopted at their highest tier would they interfere with each other. Estimates of the carbon benefit of each pathway are provided in terms of the *additional* CO2e absorption each could provide above the current condition and trend.

At the middle tier of adoption, the cumulative potential carbon benefits of the five pathways would lead to 358 million additional tons CO2e stored in the forest by 2050. This report breaks down the contribution of each pathway within each New England state and shows that the benefits are large, vary by pathway, and vary by state (Figures 1 and 2). The two greatest land uses affecting forest carbon—permanent forest loss and timber harvesting—vary considerably across the region and dictate the relative importance of the pathways in different states. Harvesting affects, by far, the most area of any land use in New England, and therefore Improved Forest Management (IFM) is the pathway that can make the most significant near-term contribution to regional climate mitigation. Together, the Avoided Deforestation and Wildland Reserves pathways provide a significant opportunity for each state in the region. As Figure 2, page 5, makes clear, the vast forestlands and forest industry present in Maine make IFM there the single largest contribution. (Maine makes up half of the New England land area.) IFM and Avoided Deforestation drive overall climate mitigation potential in Massachusetts, New Hampshire, and Vermont.

It is critical to note, however, that these pathways would provide all states with a significant increase in climate mitigation above the business-as-usual (BAU) scenario. For example, Rhode Island, while a small proportion of the entire region, could increase its carbon storage by almost one-third; Connecticut and Massachusetts show similar increases. Figure 3, on page 5,

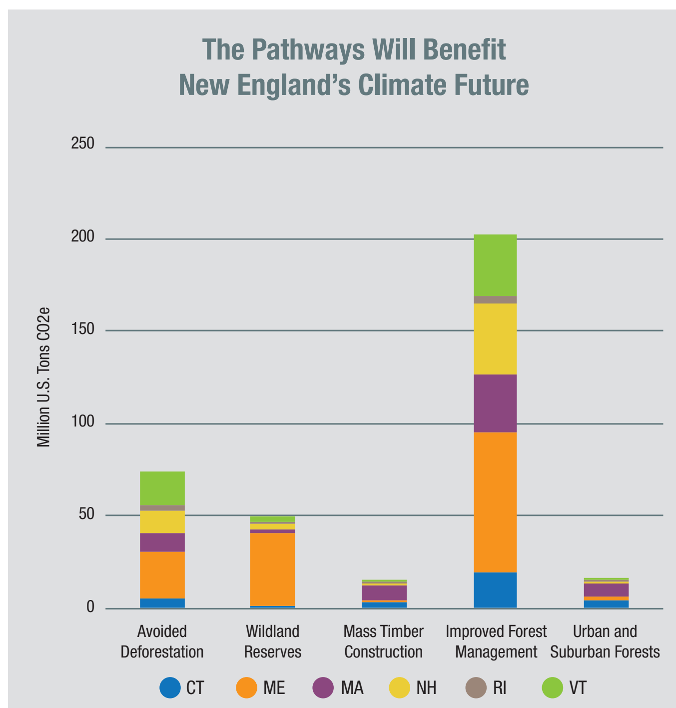


Figure 1: Additional CO2e sequestered by 2050 above the business-as-usual (BAU) scenario. Estimates shown are associated with the adoption of each pathway at its middle tier; see individual pathway sections for estimates at the low and high tier. See Figure 3 for estimates of low and high tiers.

shows the additional carbon stored and sequestered by each state's forests over the 30-year period from 2020 to 2050 as a result of the pathways.

Taken together, these pathways have the potential to reduce New England's near-term net annual emissions by 6.4%, boosting the total forest sequestration from a level equivalent to 14% of the region's emissions to an equivalent of 21% (Figure 4, page 6).

The relative importance of these pathways will increase over time. As New England states meet their specified goals for reducing emissions, and total emissions drop from 187 million tons CO2e to 40 million tons CO2e, the role of forests in sequestering emissions will grow to 97%: 30% from the five pathways and 67% from ongoing forest sequestration (Figure 5, page 6). So, while a 6.4% gain in the near term may seem relatively small, enacting these pathways now is essential to realizing a future in which forests mitigate nearly all annual emissions.

While the climate crisis is reason enough to implement these pathways, a redoubled commitment to forest conservation will provide many other benefits: clean water; clear air; shading; cooling; public access to open spaces, recreation, tourism; and natural resources across the region. These pathways will help New England achieve its goals for equity, environmental justice, and sustainable rural economies. If conserved and stewarded, the region's forests can be a major contributor to state climate goals and to adaptation, resilience, and reduced effects from climate change and extreme weather events.

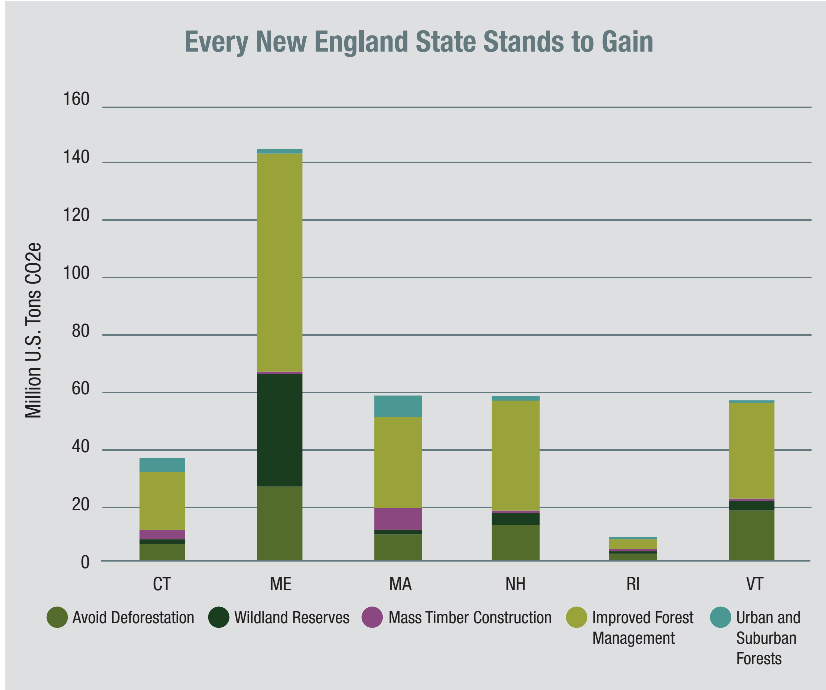


Figure 2: Additional CO2e sequestered above the BAU scenario in each New England state by 2050. Estimates shown are associated with the adoption of each pathway at its middle tier. See Figure 3 for estimates of low and high tiers.

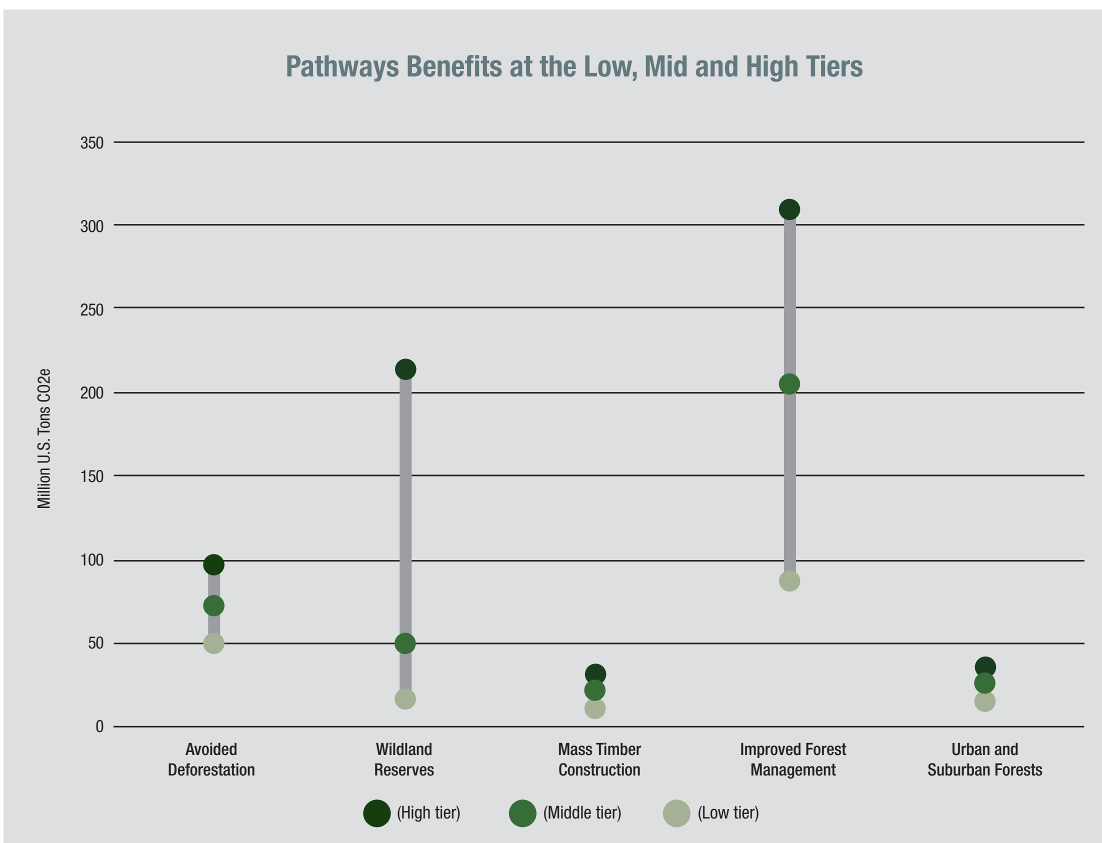


Figure 3: The accumulated carbon benefits of each pathway by 2050, shown at low, middle and high levels of adoption. Table 2 on page 15 provides details about the tiers.

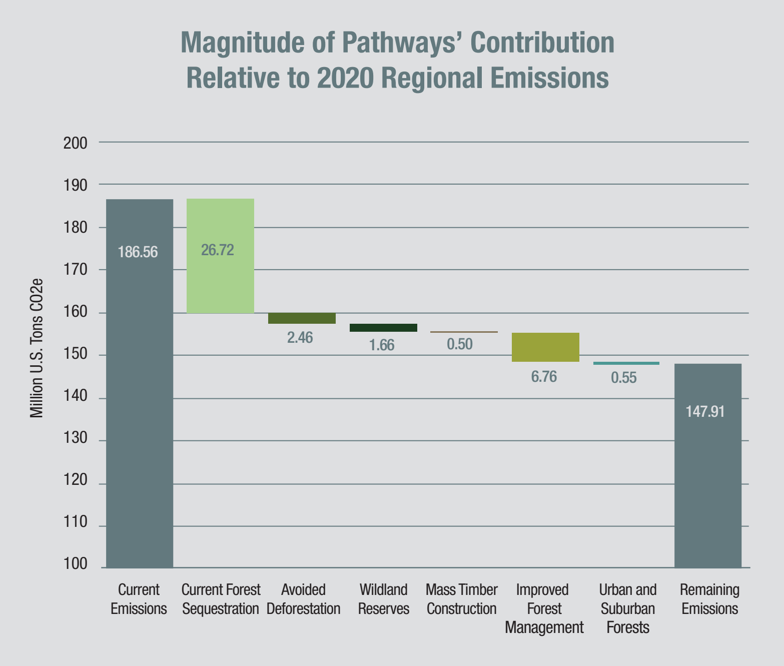


Figure 4: The adoption of each pathway (shown here at their average annual contribution when adopted at their middle tier) lowers New England's net emissions by sequestering more carbon in the forests. Please note, to show the detail associated with each pathway, the vertical axis has been scaled to start at 100 million tons C02e.

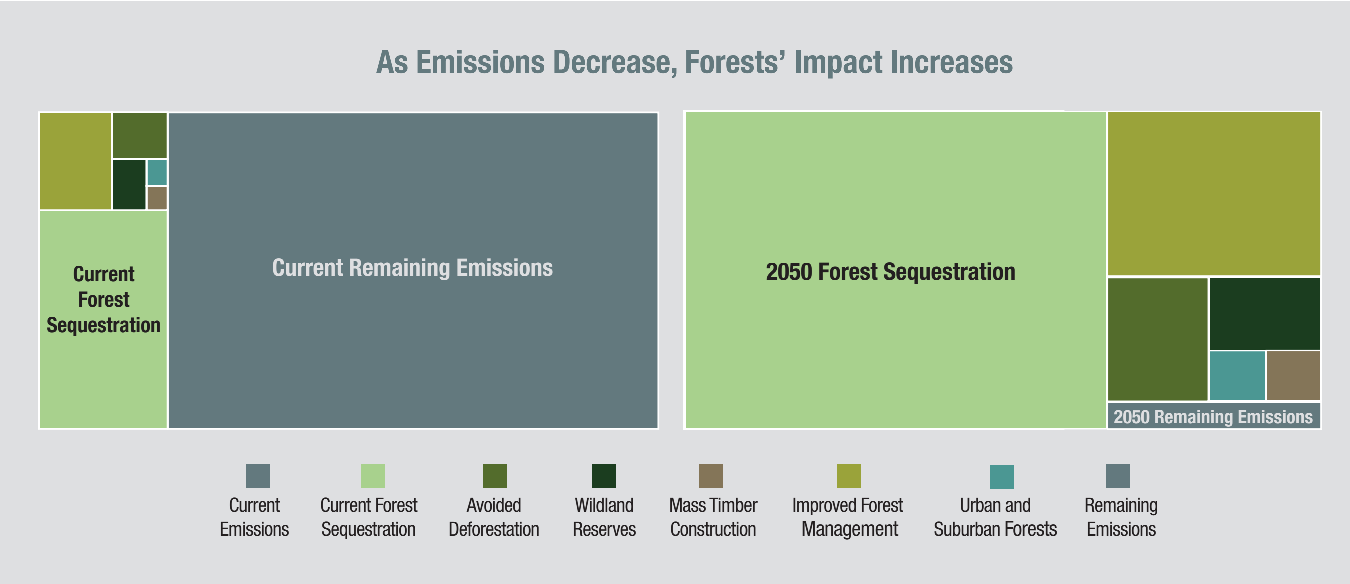


Figure 5: (Left) If the left rectangle represented the 187 million tons C02e that were New England's greenhouse gas emissions in 2020, current forests under the BAU land use scenario would sequester the equivalent of 14%. Adopting the five pathways at their moderate tier would sequester the equivalent of an additional 6.4%. **(Right)** By 2050 the role of forests will be even larger. As New England states meet their specified goals for reducing emissions, and total emissions drop from 187 million tons C02e to 40 million tons C02e, the role of forests in sequestering emissions will grow to 97%: 30% from the five pathways and 67% from ongoing forest sequestration.

FOOTNOTES

[1] CO2e (carbon dioxide equivalent) is a measure used to compare emissions from various greenhouse gases on the basis of their global warming impact. One ton of carbon stored in the forest is equal to 3.67 CO2e.

[2] Each pathway is assessed in a low, middle, and high tier, reflecting the degree of pathway implementation (e.g., the percentage of deforestation that is avoided or the percentage of additional Wildland Reserves that are designated). The estimates presented here represent the middle tier for each pathway. See Table 1 for definitions of the tiers.

Introduction

Global greenhouse gas (GHG) emissions have increased dramatically over the past century (Boden et al. 2017), driving climate change and its effects. Climate change is expected to accelerate ice melt, sea level rise, ocean acidification, heat waves, rainfall variability, and natural disasters, posing serious challenges to societies, economies, and the natural world. GHG emissions are localized within geographies and sectors (e.g., transportation in urban areas), but the impacts of climate change will be experienced globally. Attention to equity is critical, as many developing countries that have not substantially contributed to current GHG levels will be hit hardest. Momentum to address climate change is growing at all levels of government and across the economic and political spectrum. Almost every country signed the Paris Agreement in 2015, a global pact to reduce GHG emissions to keep temperature rise less than 1.5°C above pre-industrial levels. In the U.S., action is evident in the public and private sectors, with proposed legislation, net-zero commitments, and increased activity in carbon markets. The public is pushing for more action: A recent survey called "Climate Change in the American Mind" found that the majority of Americans think global warming is happening (Leiserowitz et al. 2019), and another survey found that nearly 70% of Americans don't think the federal government is doing enough to reduce the effects of global climate change (Pew Research Center 2019). Importantly, these surveys predated the fires, hurricanes, and floods of 2021.

The actions required to mitigate the climate crisis are known: Reduce GHG emissions from key sectors such as transportation, energy, and construction, and remove remaining emissions from the atmosphere using natural climate solutions and innovative carbon-removal technologies. Natural climate solutions are "conservation, restoration and improved land management actions that increase carbon storage or avoid greenhouse gas emissions in landscapes and wetlands across the globe" (Griscom et al. 2017).

Across natural climate solution options, forest-related actions have the highest potential due to their ability to absorb carbon out of the atmosphere through photosynthesis (carbon sequestration) and store it in their limbs, trunks, roots, and soils (carbon storage or stocks) (Griscom et al. 2017; Cook-Patton, S.C. et al 2020). In the U.S., forest-related actions could absorb up to the equivalent of 21% of current net annual U.S. emissions (Fargione et al. 2018). Currently, U.S. forests sequester approximately 14% of the country's annual carbon dioxide (CO2) emissions. (Domke et al. 2020). Recent legislative efforts related to the role forests can play in addressing climate change suggest a growing national understanding of the importance of these natural and working lands, including the 2020 Growing Climate Solutions Act focused on the agriculture and forestry sectors, the 2021 Rural Forests Market Act focused on family farms, and the 2021 Urban Forests Act that helps maintain urban forests.

This study provides an assessment of the climate mitigation potential of forests in the six-state New England region. New England is both one of the most densely forested regions in the United States, with 32 million acres of forest, and home to 15 million people (Figure 6). New England's landscape is 75% forested, most of which is privately owned (75%), predominantly by small landowners. Currently, these forests sequester approximately 28 million tons of CO2 equivalent (CO2e) annually, equal to 14% of total annual emissions from New England states.[3]

Despite their incredible value, New England's forests and the carbon they store and sequester are at risk. The region's forests are threatened by various land uses, including conversion to residential and commercial development, including alternative energy development,

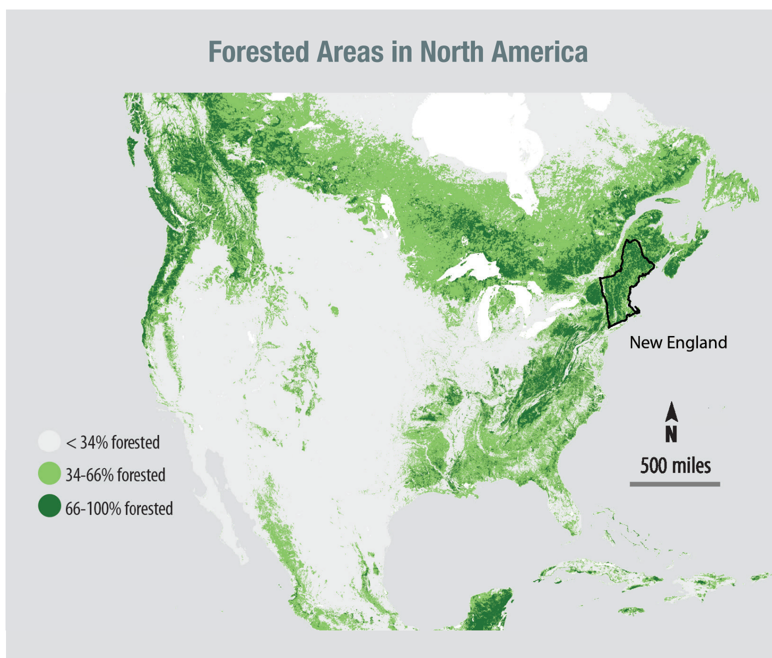


Figure 6: **Forested areas in North America**
Source: Wildlands & Woodlands, 2017

and poorly planned harvests. The primary effects on New England's forests considered in this study are conversion to development (forest loss) and harvest practices, which are especially concerning in the northern part of the region.[4] Estimates of forest loss range from 11,000 acres to almost 45,000 acres annually. Using a medium estimate of 28,000 acres, New England could lose 846,000 acres of forest by 2050, or 3% of the region's forested area. This would mean losing 2% of the current aboveground carbon storage, along with potential future carbon sequestration. (Note: based on Raciti et al. (2012), we estimate 70% of forest cover, and thus 70% of forest carbon, is emitted when an acre of forest is converted to another land use.)

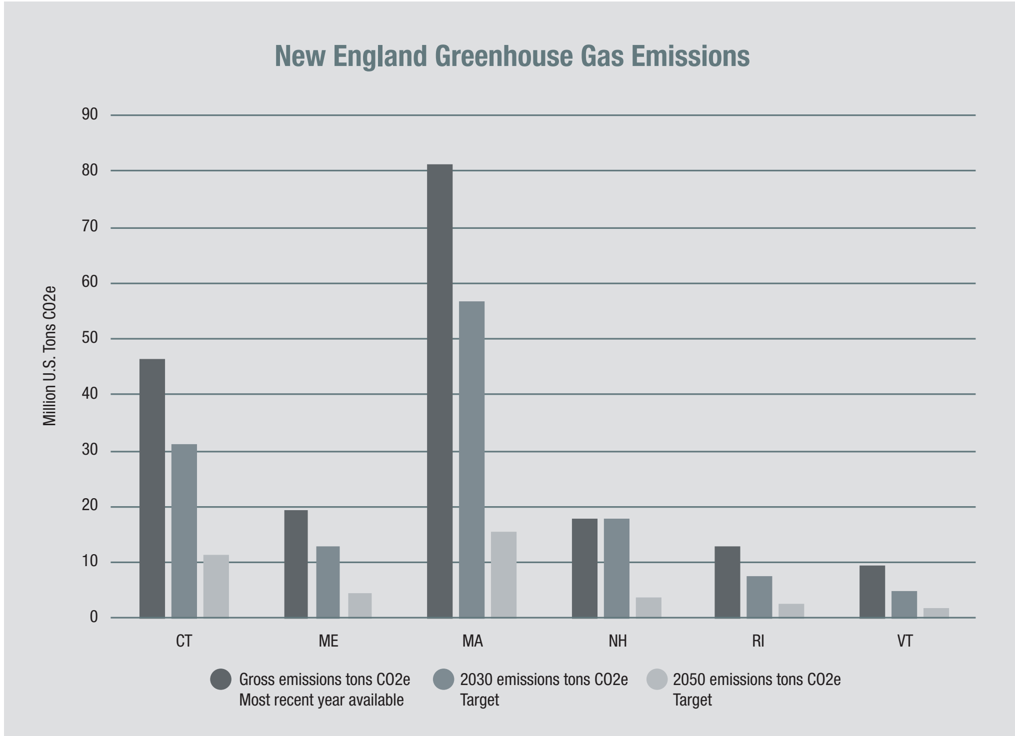
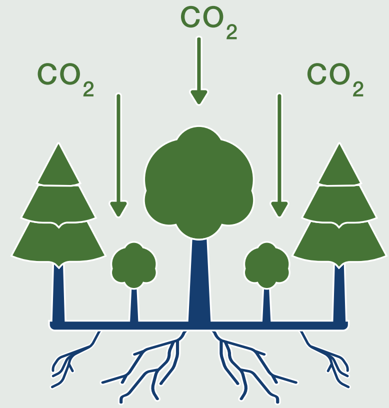


Figure 7: **Current greenhouse gas emissions profiles of New England states across sectors that are the primary sources of emissions**

New England states are leaders in state-level climate action planning: Most New England states have statutory requirements for reducing GHG emissions across sectors that are the primary sources of emissions (e.g., transportation, energy, buildings) (Figure 7). New England states also participate in regional and national initiatives such as the U.S. Climate Alliance, the Under2MOU, the Regional Greenhouse Gas Initiative, and the New England Governors and Eastern Canadian Premiers resolution on decreasing carbon pollution in the region. Supplement Two provides detailed information on each New England state's climate change planning process, including key recommendations, strategies, and plans.

While New England states are working to reduce emissions across all major economic sectors, they are also, to varying degrees, exploring how natural climate solutions, such as carbon storage and sequestration from the region's forests, may help them achieve their climate goals. In recent years, several New England states have crafted active, multisectoral climate change policies that considered forests as a natural climate solution (Supplement Two). Through this study, we try to close knowledge gaps and provide evidence that will support these efforts and facilitate policy and action around protecting and bolstering New England's forest resource for the important climate mitigation benefits it can bring.

Key Terms and Concepts



Carbon stock and sequestration. A carbon stock is the "quantity of carbon held within a pool at a specified time," while carbon sequestration is the "process of increasing the carbon content of a carbon pool other than the atmosphere" (IPCC Glossary 2000). In this report, we use the term "carbon sequestration" to refer to the process by which forests remove carbon from the atmosphere via photosynthesis and store it in the aboveground components of trees (e.g., trunks, limbs). We present our estimates for both carbon stocks and sequestration in tons CO2e, which allows direct comparison with GHG emissions.

Carbon pools. Forest carbon is distributed across many different pools, including forest biomass (i.e., leaves, branches, and stems of trees), wood products (e.g., lumber, paper), and soils. The base unit of measurement for carbon is mass, often expressed in tons of carbon, or tons CO2e when comparing directly to GHG emissions. **In this report, our estimates include the sum of the three aboveground forest carbon pools as defined by the Intergovernmental Panel on Climate Change: aboveground biomass, dead wood, and forest floor litter.** We do not include the two belowground pools: belowground biomass and soils. Although these pools are significant, adequate data is lacking to treat them effectively, and they are generally less affected by land use than are aboveground pools.

Additionality. Additionality refers to the carbon benefit gained from a deliberate adoption of a new approach that would not have occurred but for that approach. In other words, the carbon benefits we estimated in this analysis can be expected to occur in addition to any forest carbon benefits that would have occurred in a business-as-usual (BAU) approach to forest conservation and management in the New England states. Focusing on additionality ensures that the costs and benefits of alternative policies can be evaluated on a net-benefit basis.

Leakage. Leakage is an effect on carbon emissions or sequestration that is caused by activities in the analysis but not accounted for. For example, if the New England states declared that they would meet their carbon emissions reduction goals by ceasing all harvests in the forests of the region, demand for forest products would continue and would likely be met by forest products from another region. The same quantity of harvest may occur elsewhere in the world, with emissions to the atmosphere. Those emissions would have leaked out of the system of analysis (New England) to another region and could counteract most or all of the atmospheric benefit of the changes in New England.

Co-Benefits of Forests

While this study focuses on the climate mitigation benefits of New England's forests, it is critical to underscore that the climate benefits are just part of the overall story. Forests also provide widespread social, economic, and environmental co-benefits that we rely on for our very sustenance. While many of these benefits are invisible and out of mind for most people, they provide the foundation of our public health systems, major economic engines, jobs and livelihoods, and opportunities for recreation.

Clean water: Forests naturally help filter water for our drinking water systems, reducing the costs associated with water filtration and treatment. One study has estimated that every 10% increase in forest cover in a watershed leads to a 20% decrease in costs for water treatment downstream from the watershed (treeequityscore.org, 2020). For example, the intact forests of the Sebago Lake watershed in Maine provide clean water for one-sixth of Maine residents and saved the Portland Water District from building a $150-200 million water filtration plant (Sebago Clean Waters 2020). Forest management and conservation practices in the Quabbin watershed in Massachusetts provide drinking water to 40% of people in the state and has allowed the Massachusetts Water Resources Authority to avoid investing in filtration infrastructure. One estimate suggests that each acre of forest can filter 543,000 gallons of water every year.[5]

Clear air: Forests and trees positively affect human health by reducing air pollution, which reduces pollution-related respiratory diseases and other ailments. Trees in U.S. metropolitan areas and small towns absorb 822,000 metric tons of air pollutants, preventing 575,000 cases of acute respiratory symptoms annually (treeequityscore.org, 2020). New England's forests remove over 760,000 tons of air pollution each year, which is worth an estimated $550 million in health benefits (Foster et al. 2017).

Shading and cooling: New England states are warming faster than other parts of the country (Young and Young 2021), underscoring the need for shading and cooling, especially in urban areas. Recent research projects an increase in deaths related to heat in eastern U.S. cities by the 2050s (Wu et al. 2014). Trees provide shade and exert a cooling effect on nearby areas, reducing the health risks associated with the heat-island effects common in urban areas. In cities nationwide, trees prevent approximately 1,200 heat-related deaths and countless heat-related illnesses annually (American Forests 2020).

Recreation: New England's forests support significant recreation and recreation-based tourism, drawing large numbers of tourists each year for outdoor recreation, such as hiking, biking, and skiing. People benefit physically and mentally from being able to recreate and relax in forests. A 2007 study showed that contact with nature restores attention, and promotes recovery from mental fatigue and the restoration of mental focus (Frumkin and Louv 2007) and a 2015 study found time in nature can reduce rumination, the patternof repetitive thought associated with depression (Bratman 2015). Across New England, outdoor recreation, which relies heavily on conserved forests, contributes $52 billion in consumer spending and $7.6 billion directly in state and federal tax revenue annually (Holland and Meyer 2018).

Jobs and economic opportunity: Many New Englanders generate their livelihoods from forests, whether working directly in the forest products industry or indirectly in an industry that gets raw materials from trees or provides forest-dependent tourism services. For every $1 million invested in forest restoration, 39.7 forest-related jobs are created in rural U.S. areas alone (treeequityscore.org, 2020). Urban forestry will see a 10% increase in job openings for entry-level positions from 2020 to 2030, according to the U.S. Bureau of Labor Statistics. In 2016, the forestry sector in Maine was responsible for roughly $8.5 billion in economic output, while supporting 14,500 direct jobs in the industry and 33,500 total associated jobs (Maine Forest Products Council 2018). Across New England, the forest products sector has created more than 62,000 jobs and contributes $13.5 billion to the economy each year in product sales (Holland and Meyer 2018).

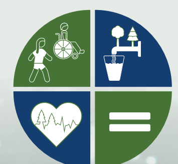
Continued on next page

Co-Benefits of Forests, Continued

Wood products and buildings: Northern New England is home to a large block of industrial forestland, which fuels local economies. For example, the Maine forest industry provides $8.5 billion in sales, nearly 34,000 jobs, and $1.8 billion in labor income. Roughly 69% of this economic impact comes from producing pulp and paper products; 23% comes from production of lumber, engineered wood, and other solid wood products; and the remaining 8% comes from logging, hauling, forestry, and bioelectric services (Maine Forest Products Council 2018).

Healthier people: Getting outside has many physical and mental health benefits. Studies show that access and exposure to forests and green spaces encourage healthier lifestyles and can boost immune function, in turn reducing the prevalence of obesity and related chronic diseases like heart disease, hypertension, and diabetes. For example, adults and adolescents who live closer to parks visit them and exercise more often than people who live farther away. And there is evidence that providing access to open spaces can help reduce health care costs for hypertension, heart disease, and diabetes by as much as 40%.[6]

Biodiversity: While 80% of land-dwelling species rely on forests to survive, populations of forest-dependent wildlife species declined 53% between 1970 and 2014 (treeequityscore.org, 2020). New England's forests serve as an important habitat that supports extensive biodiversity for both plant and animal species (Degraaf and Yamasaki 2001; Anderson et al. 2021).



Equitable access to the benefits of forests: Addressing climate change through forest-based solutions will also ensure many of these co-benefits are secure for generations. And while the benefits forests provide have not always been shared or experienced equitably (Center for American Progress 2020), policies that promote natural climate solutions can integrate climate benefits with environmental justice and equitable access to the outdoors, rural economic development, and the overall health of all people who call New England home.

FOOTNOTES

[3] Other sources of carbon storage and sequestration in New England forests include belowground portions of trees, soil, dead wood, litter, agricultural lands, and wetlands. This study focuses on aboveground forest carbon but notes that these other carbon stores are also significant.

[4] Forest insects and disease are also significant threats to forests in New England. Assessing these threats was beyond the scope of our research effort. Additional information on the effects of insects and disease on New England's forests is available in Lovett et al. 2016.

[5] Anderson, T. et al. 2015. Looking to the Future – Massachusetts Land and Parks Conservation and Their Future. Executive Office of Energy and Environmental Affairs. 21 pp.

[6] The scientific references for these health statistics are available from Stand Up for Forests: standupforforests.org

Purpose and Objectives

The purpose of this study is to provide policy relevant information about New England forests' current storage and sequestration of carbon, based on publicly available data and science, and to quantify and present five complementary pathways that will help decision-makers evaluate the potential of state climate policies to make meaningful contributions to climate change mitigation.

The specific objectives of this study are to:

- Provide information about the contributions of existing forests to mitigating climate change and how this will change under business-as-usual conditions through 2050.
- Through interviewing policymakers, advisers, scientists, and others, identify information gaps that remain for translating climate planning into climate policy action.
- Quantify and present the potential carbon opportunity of five complementary pathways that could conserve and enhance the climate benefits of forests in New England.

Data and Methods

Our analyses are informed by a review of forest carbon science and interviews with key stakeholders on forest carbon and policy in the region. In the review, we considered peer-reviewed and grey literature at different geographic scales: state-level, regional, national, and global. We prioritized uniform data that was available across all six New England states. We also conducted an inventory of forest and climate change policy, planning, and action for each New England state to assess how forests are being incorporated into state reports, policy, and legislation in the region. Finally, we held over 50 targeted interviews with scientists, state agency staff, policymakers, and legislators and their advisers working on forest carbon and policy in New England (Table 1). Our interviews assessed the type of information on forests, carbon, and climate that policymakers already have, and that which they lack but need to make the policy decisions.

Through this outreach, we built a database of literature, datasets, and reports on forests and climate change in New England. Links to supplementary documents describing our research in more detail are offered throughout the report.

Based on the results of our review of the available forest carbon data, we chose to rely primarily on U.S. Forest Service's Forest Inventory and Analysis (FIA) data, accessed in a number of ways as detailed in Supplement One. This resource provides consistent data across states as well as established, well-documented carbon-accounting standards that allowed us to conduct a consistent regional assessment of current and future conditions across the six New England states. We supplemented FIA data where possible and as necessary with peer-reviewed literature and state-specific reports. For our assessment of carbon potential in urban areas specifically, we used Urban FIA data (Nowak et al. 2013, Nowak and Greenfield 2018), which is a separate dataset. Using Urban FIA and FIA data together required additional analyses to avoid double-counting forest carbon. We partnered with USFS scientists to ensure we handled both datasets appropriately, as detailed in Supplements One and Eight.

TABLE 1: Summary of Interviews

Category	Completed Interviews
Scientists	17
Practitioners and advocates	17
Policymakers	13
Legislators	5
Total	**53**

Key Assumptions in These Analyses

In general, we strive for conservative estimates, and in some cases, we provide a range of estimates. Overall, the climate mitigation potential presented here is likely an underestimation of the true potential of New England's forests.

Forests are classified according to the USFS definition of forests. That definition states, in part: "Land of at least 10-percent canopy cover by trees of any size, including land that formerly had such tree cover and that will be naturally or artificially regenerated." Carbon storage and sequestration from trees and other forms of vegetation located outside of areas as defined by the USFS are not reflected in our results, including trees on cropland, wetlands, and urban areas, though we provide separate estimates for carbon in urban areas in this study.

Benefits are shown for aboveground carbon only. Forest soils and belowground vegetation (e.g., tree roots) store a significant amount of carbon. Indeed, as much as 60% of the total forest carbon stock is below ground (Domke 2020). Unfortunately, we have to exclude belowground carbon pools from our analysis, primarily because the data is not available at the scales needed for this study. Belowground carbon is much less understood. Despite this limitation, our focus on aboveground carbon captures the most relevant effects and dynamics. This is because the changes to belowground carbon resulting from the pathways would generally occur on a longer time horizon than the 30-year period of analysis and in general are less dynamic overall. Further, there is greater scientific uncertainty on how land use activities affect long-term changes in belowground pools. We provide results in later sections in relation to a BAU scenario, which also excludes belowground carbon, providing an unbiased comparison.

Carbon benefits reflect 30 years of storage and sequestration. We limit our analysis to the 2020-50 time period for the purposes of informing public policy and to align with emissions reductions goals in New England. Our carbon benefits therefore reflect only 30 years of additional sequestration, but this is just the blink of an eye from a forest's perspective, and so the forests will continue to absorb and store carbon throughout their much longer life cycle.

Quantified climate benefits of forests include climate mitigation only. This analysis focuses on the carbon storage and sequestration value of future pathways. However, each pathway also conveys innumerable co-benefits to our people, economy, and environment. See the co-benefit boxes on pages 10 and 11 for details.

We assume a consistent level of forest product harvest and consumption. We hold constant the net level of forest harvest and consumption over the 30-year period of our analysis. We do this to be able to isolate the effects of changes in forest practices, land use conversion, and wood utilization and substitution (e.g., for wooden buildings) and avoid the problem of leakage. For simplicity, and to isolate the difference between the alternatives we offer in this analysis and the BAU scenario, we assume a closed system with no significant leakage. That is, we presume the production of wood within the region will stay constant over the 30-year study period. As a result, we conceptually hold the consumption and quantity of wood harvested constant at a baseline level per year, though the number of acres and the intensity of harvest change through some of the pathways. That said, meeting the IFM goals will require a major shift in management practices, including implementing a "rest period" for some lands to recover from past overharvesting, shifting harvests to overstocked and/or forests at risk of disturbance (e.g., tree species affected by invasive insects), reducing the intensity of many harvests, and altering the types of wood products produced. We believe these IFM goals can be achieved while maintaining a regional net-constant harvest volume over the study period.

We do not include the potential benefits associated with reforestation. We have not considered reforestation as a specific pathway in this study because the opportunity for reforestation in New England is not as great as it is elsewhere in the country. Reforestation has been assessed as having the most climate mitigation potential across many natural climate solutions in the United States; however, the regional land cover regime in New England provides relatively few opportunities for reforestation compared with other regions of the U.S. (Fargione et al. 2018).

An Alternative Forest Future

The alternative forest future for New England described in this study is comprised of five separate but complementary and additive "pathways" (Table 2, page 15): ***Avoided Deforestation***, whereby the amount of forest lost to other land uses is reduced; increased area of ***Wildland Reserves***, where forests are protected and allowed to grow old; ***Improved Forest Management***, where silvicultural and other forestry practices are modified to increase the amount of carbon stored and sequestered within managed forests; ***Mass Timber Construction***, where mass timber buildings replace concrete and steel buildings and reduce carbon emissions and bring new forest products to support the region's working forests; and ***Urban and Suburban Forests***, where activities such as tree planting increase carbon stock and sequestration in urban areas.

In each pathway, we present three tiers of pathway implementation (Table 2, page 15), with greater carbon benefits resulting from higher levels of implementation. When we combine all five pathways to assess the overall regional carbon mitigation opportunity, we present the middle tier for each pathway. The potential carbon benefits and other co-benefits of these pathways are meant to be complementary and additive—they represent a portfolio of approaches that New England states can implement to bolster climate mitigation.

These five pathways increase the carbon stock and rate of sequestration on the landscape in different ways, interacting in ways that we capture in our analysis and in conceptual ways that we are not able to quantify. The uncertainty around potential future climate change effects to New England's forests underscores the importance of using multiple approaches: If one avenue to increase carbon storage and sequestration fails, diversified strategies compensate for losses elsewhere.

Alignment of Pathways and State Policy Proposals or Goals

Through an iterative process of literature review and interviews with expert stakeholders, we developed these five specific pathways to focus our analysis on the climate policies being considered at the state level throughout New England. The five pathways are composites of various policies put forth by experts and policymakers who were directly involved in each state's climate plans, which identified strategies to reduce carbon emissions and increase sequestration. During our study (2020 to 2021), three New England states were actively engaged in climate action planning: Connecticut through the Governor's Council on Climate Change (GC3); Maine through the Maine Climate Council; and Massachusetts through the 2050 Decarbonization Roadmap Process, facilitated by the GWSA Implementation Advisory Committee. In early 2021, these states released final reports and recommendations for reaching their respective goals for reducing emissions. Each report includes a prioritization and synthesis of recommendations received from multiple sector-based working groups (e.g., natural and working lands, buildings, energy, and equity and environmental justice) that contributed key data and expertise to the process. Massachusetts subsequently passed An Act Creating a Next-Generation Roadmap for Massachusetts Climate Policy in 2021. New Hampshire, Rhode Island, and Vermont were also engaged in various levels of climate change planning during the course of our study. Rhode Island passed An Act on Climate in 2021 and Vermont passed An Act Relating to Addressing Climate Change in 2020. For all states, we rely on the most recent state climate goals as established in legislation or in reports to identify their goals and/or climate focus areas.

Supplement Two provides a crosswalk table between our pathways and specific New England state policy proposals or goals. While the pathways identified in Supplement Two map to specific state-level recommendations and focus areas, we assess the potential carbon benefits of the five pathways for each New England state and for the region as a whole. We also assess the potential carbon benefits for some specific recommendations made in these state documents that are related to our five pathways; estimates of these carbon benefits are provided in the state briefs.

TABLE 2: The five forest carbon pathways and their parameters.

Pathway	Description and Carbon Benefit	Units and Tiers (Low/Middle/High)	Interaction with other Pathways
Avoided Deforestation	Reduce the current average number of acres of forestland converted to other land uses (e.g., residential development) to retain existing forest carbon storage and sequestration capacity.	Percent of business-as-usual (BAU) deforestation avoided: 50% 75% 100%	IFM and Wildland Reserves: Avoided Deforestation keeps forestland on the landscape, some of which is available for harvest or Wildland Reserves. Urban and Suburban Forests: Development that would have occurred on forestland may be pushed to suburban and urban areas.
Wildland Reserves	Designate additional Wildland Reserves to let trees grow old and accumulate and store more carbon.	Percent of forests designated as Wildland Reserves: 5% 10% 30%	IFM: Increasing Wildland Reserves area reduces the number of acres available for harvest in the IFM pathway.
Improved Forest Management (IFM)	Shift the location of harvesting to allow forest recovery, thin some forest areas to increase productivity, increase rotation ages, and shift some harvests to overstocked and at-risk stands.	Percent of forests that receive IFM practices: 20% 50% 85%	Wildland Reserves and Avoided Deforestation: Acres available for harvest in the IFM pathway are adjusted based on the number of acres designated for Wildland Reserves and the number of acres remaining as forest through the Avoided Deforestation pathway.
Mass Timber Construction	Substitute mass timber materials for concrete and steel to store more carbon and decrease carbon emissions associated with carbon-intensive building materials.	Percent of new buildings utilizing mass timber: 20% 50% 100%	The Mass Timber pathway assumes the regular, sustainable flow of appropriate wood products from the IFM pathway.
Urban and Suburban Forests	Increase tree cover and patches of forest in urban areas.	Increase in carbon density on urban acres: 3% 5% 8%	Urban land area is a function of forestland and other land conversion to development. We have adjusted our figures to minimize any double-counting of carbon benefit across forestland and urban areas.

Business as Usual (BAU)

Our relationship with our forests must change in acknowledgment of the tight linkages between the forests' future and our own. We cannot continue with business-as-usual forest land use. The pathways presented here offer alternative land use choices that can help protect the climate. To measure how much additional climate mitigation benefit the five pathways can offer, we compare them to an estimate of forest carbon stock and sequestration in New England over the next 30 years (2020-50) under a business-as-usual (BAU) scenario. Our BAU projection assumes a linear continuation of observed trends in forest carbon stock during the past 30 years (1990-2020). The historical data used to derive these trends comes from the U.S. Forest Service's Forest Inventory and Analysis (FIA) program (Walters et al. 2021; Supplement Three). The observed trends in the FIA data integrate the effects of continued forest growth, land use including harvesting, and natural disturbances such as insects, disease, wind, and drought. Because we use historical data to project future carbon trends, our BAU estimate does not account for any changes in future forest growth or natural disturbances, including those resulting from future climate change. For the BAU scenario, we assume consistent levels of growth, land conversion, natural disturbance, and/or harvest on forested acres in New England states. The data projects increasing carbon stock over time in the states, suggesting that new biomass from growth exceeds losses from disturbance, conversion, and harvest (Figure 8, page 17). Importantly, the results from the five mitigation pathways represent the additional carbon stored above what we project under the BAU scenario.

The BAU assumption that historical trends will continue unchanged for the coming 30 years is a simplification that could over- or underestimate future carbon stocks. For example, if, as some studies suggest (e.g., Walker et al. 2020), warmer temperatures and increased carbon dioxide (CO2) concentrations in the atmosphere cause forests to grow at a faster rate in the future than they did in the past, then our 2050 carbon stock projection will be an underestimate (Duveneck and Thompson 2019). Alternatively, if there is an increase in number or magnitude of damaging weather events and/or other disturbances, then our projections will be an overestimate. Indeed, there are myriad unpredictable reasons that the next 30 years of forest carbon accrual may not resemble the past 30 years. As such, the BAU scenario offers just one plausible future among many. Nonetheless, it is a useful reference.

In 2020, we estimate that New England forests contain 4.6 billion tons CO2 equivalent (CO2e). Under the BAU scenario—where forest dynamics observed during the past 30 years continue through the next 30 years—carbon stocks are expected to increase by 28% to 5.8 billion tons CO2e by 2050. The expected 30-year increase ranges from a low of 18% in Maine to a high of 37% in Connecticut (Figure 9, page 17). The projected benefits under BAU scenario are the baseline; the pathways are how we can do better.

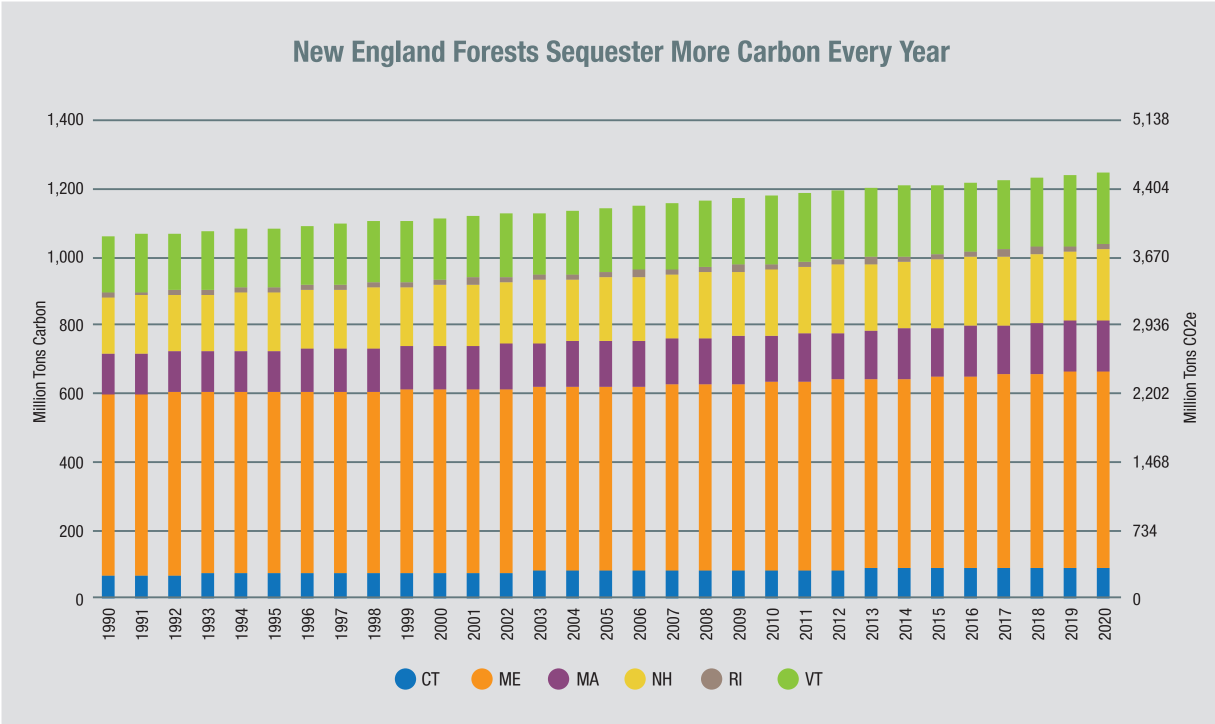


Figure 8: Aboveground carbon stocks have increased steadily in New England during the past thirty years, even under BAU practices. Here, we show change in live aboveground forest carbon estimated from the U.S. Forest Service Forest Inventory and Analysis data. (Source: Walters et al. 2021)

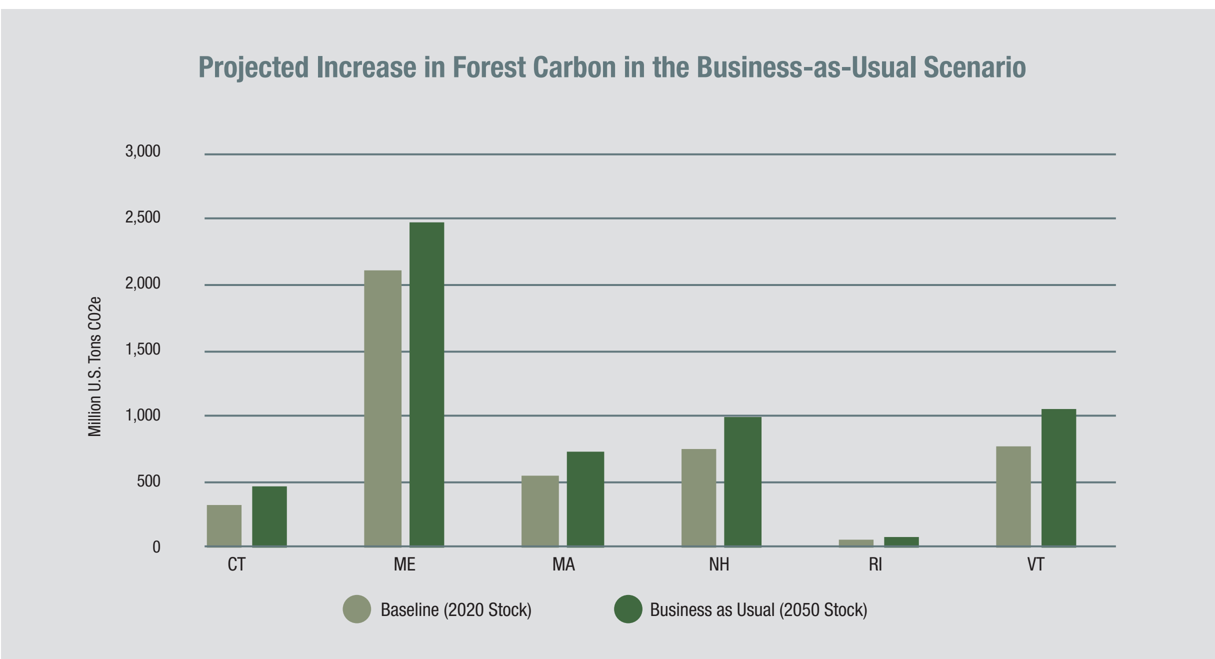


Figure 9: If the rate of forest growth continues as it has in the past thirty years, and we continue business as usual, carbon stocks are expected to increase by 28%. By adopting the pathways, we can greatly increase these stocks.

Avoided Deforestation

PATHWAY 1

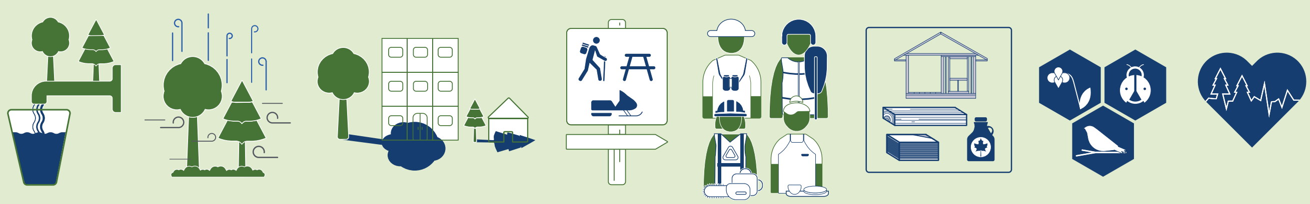
Problem: New England is losing 28,000 acres of forest a year and could lose up to 846,000 acres of forest over the next 30 years.

Pathway: Reduce forest loss in New England by implementing policies that regulate development.

Potential Policy Actions: Adopt "No Net Loss of Forests" policies; adopt "smart-growth" and open-space zoning policies; site alternative energy infrastructure outside of forestland; create incentives for densification of housing and conservation restrictions.

Carbon Benefit: Over 30 years, New England's forests could absorb the equivalent of an additional 1.3% (74 million tons CO2e) of the region's current carbon emissions through Avoided Deforestation (middle tier estimate).

Co-Benefits: Clean water, clean air, shading and cooling, recreation, jobs and economic opportunity, wood products and buildings, biodiversity, and healthier people.



Trade-offs: Reducing forest loss while maintaining the same rate of development (e.g., settlements) will require redevelopment, densification, cluster development, and smart-growth.

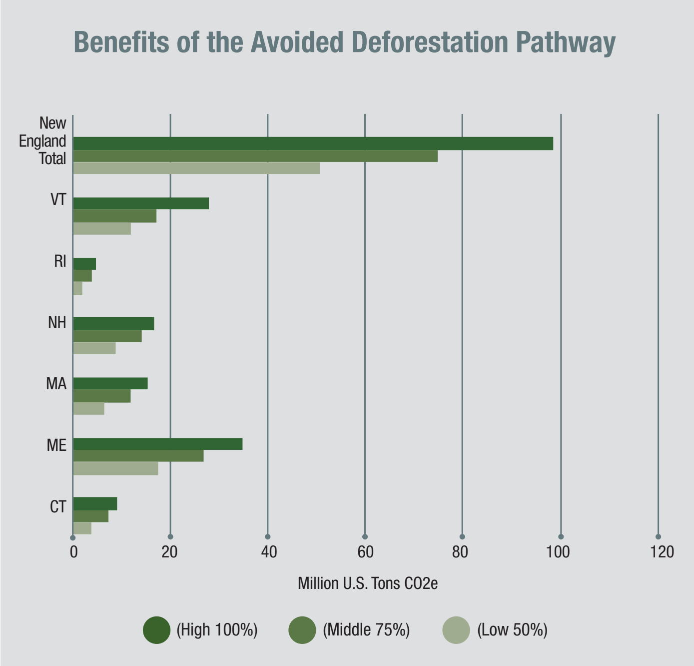


Figure 10: Accumulated carbon benefits of the Avoided Deforestation Pathway at three tiers of adoption by 2050

Background

Increasing population and continued urban expansion in New England are key factors in forest loss in the region. Development pressure in urban and suburban areas is increasing throughout much of the region, especially in southern New England (Thompson et al. 2017).Throughout the region, energy development (e.g., pipelines, powerlines, solar farms, and wind turbines) is also a major driver of forest loss. Deforestation results in the loss of the stored carbon and the capacity to sequester carbon on that site into the future.

Estimates of forest loss in New England vary widely, depending on the data and methodology employed—e.g., whether the estimates are field- or remote sensing-based, and the geography and period of analysis (Supplement Four offers a detailed discussion of forest loss estimates from different sources). Among the published estimates, we use forest loss and conversion estimates from a recent national report completed to meet the United Nations Framework Convention on Climate Change's reporting requirements that are based on the FIA database (EPA 2022; Domke 2021). We focus our forest loss analysis on the 28,000 acres per year that are lost to conversion. Using this estimate over 30 years, we estimate that New England could lose almost 846,000 acres of forestland, or nearly 3% of the existing forest area, by 2050. The carbon implications of this forest loss would be a reduction in the aboveground carbon stock of New England's forests of 90 million tons CO2e, or 2% of the current carbon stock. We estimate the lost forest acres would cause an additional loss of future aboveground forest carbon sequestration of 8 million tons CO2e over 30 years.

Methodology

To estimate the carbon benefits that could be realized if a policy reduced annual forest loss caused by development in New England, we multiply state-level forest loss estimates by the average carbon stock and sequestration estimates per acre of forestland in each New England state (Supplement Four). We then estimate the carbon benefits of avoiding deforestation of 50%, 75%, or 100% of ongoing forest loss in New England.

Results

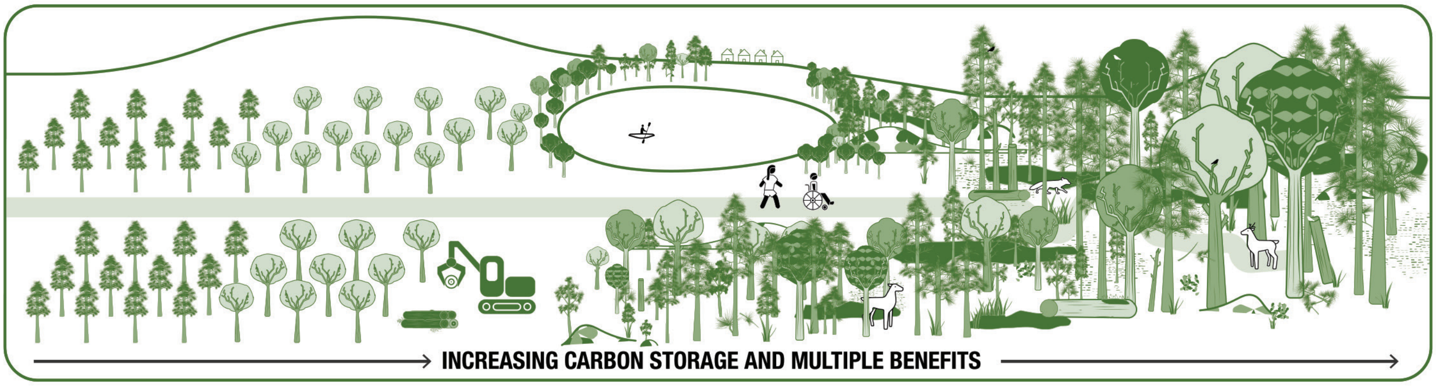
The carbon benefit of Avoided Deforestation, including the avoided loss of the existing carbon stocks and the future sequestration, across the three tiers ranges from 49.2 million tons CO2e (low tier) to 98.4 million tons CO2e (high tier). At the middle tier, we estimate a net carbon benefit of 74 million tons CO2e for the Avoided Deforestation pathway (Figure 10 and Table 3).

TABLE 3: Carbon benefits of Avoided Deforestation in New England (2020-2050)

State	Current Forest Area (million acres)	Forest Area Converted to Settlements 2020-50 (acres, %)	Carbon Benefit of Avoided Deforestation (30 years, million tons CO2e)		
			Low	Middle	High
Connecticut	1.76	50,000, 3%	3.8	5.7	7.6
Maine	17.4	371,000, 2%	17.0	25.0	33.9
Massachusetts	3.0	86,000, 3%	6.3	9.5	12.7
New Hampshire	4.7	138,000, 3%	8.6	12.9	17.2
Rhode Island	0.36	28,000, 8%	1.9	2.8	3.8
Vermont	4.5	173,000, 4%	11.7	17.5	23.3
New England – Total	**31.7**	**846,000, 3%**	**49.2**	**73.8**	**98.4**

Wildland Reserves

PATHWAY 2



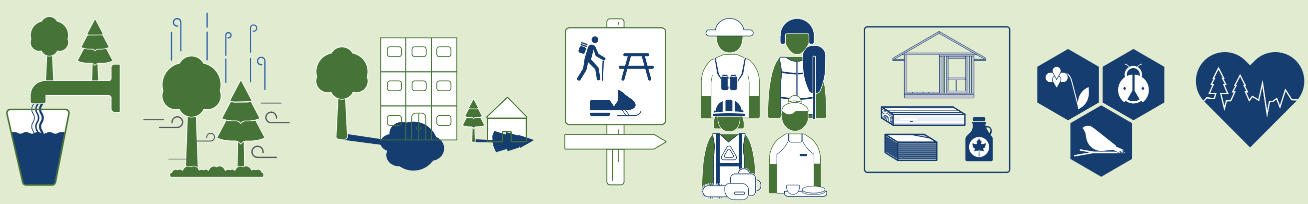
Problem: Less than 4% (~1.2 million acres) of New England's forests are protected as wildland reserves with all their benefits for biodiversity science and society.

Pathway: Increase the area of forestland across New England designated as Wildland Reserves that is protected from development and timber harvest and allowed to grow old.

Potential Policy Actions: Designate additional existing state-owned lands as Wildland Reserves, incentivize "Forever Wild" easements, revise states' current-use property tax reduction policies to include Wildland Reserves-style management.

Carbon Benefit: Increasing New England's Wildland Reserves to 10% of the forest, an additional 1.76 million acres above the BAU, could absorb an additional 0.9% (50 million tons CO2e) of the region's current carbon emissions over 30 years (middle tier).

Co-Benefits: All the co-benefits of Avoided Deforestation, with significant additional benefits for biodiversity, recreation, tourism-dependent jobs, and economic opportunity.



Trade-offs: Increasing Wildland Reserves to the highest tier examined would reduce the forest area available for harvesting, thereby potentially putting additional pressure on the remaining acres to increase the productivity to meet a similar regional demand for forest products.

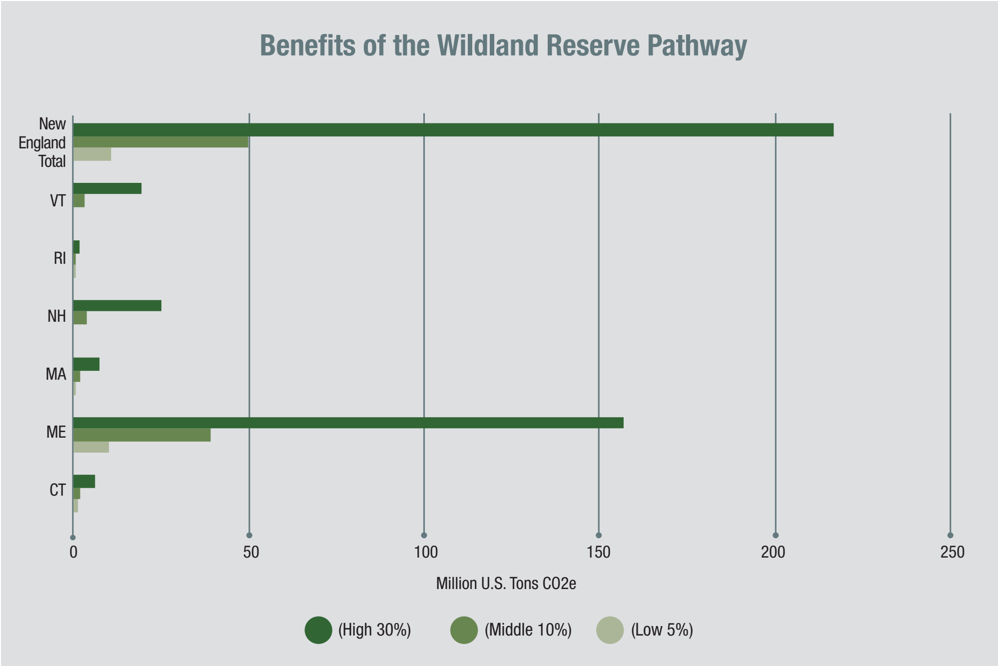


Figure 11: Accumulated carbon benefits of the Wildland Reserve Pathway at three tiers of adoption by 2050

Background

In this study we use a definition of Wildland Reserves[7] set forth by the Wildlands, Woodlands, Farmlands & Communities initiative: "forested areas where natural patterns of variation and ecosystem functions prevail at a landscape scale and support the diversity of plants and animals that thrive on an array of habitats that only develop over centuries of growth, natural disturbance, and recovery" (*Wildlands & Woodlands* 2017). From a policy and land use perspective, Wildland Reserves are permanently protected from any active management and extractive natural resource use, including harvest, and cannot be converted for developed uses. We used the USFS FIA "reserved forest" category to estimate that about 1.2 million acres, or 3.7% of New England's forests, meet the criteria for Wildland Reserves (Figure 11). Reserved forest is defined in the FIA database as "land permanently reserved from wood products utilization through statute or administrative designation." [8]

A Wildland Reserves designation, in and of itself, does not change the forest or its carbon dynamics, but by eliminating the potential for future land use, Wildland Reserves have the potential to continue to grow and store more carbon than a forest subject to harvesting. For example, Baxter State Park in Maine contains some of New England's most carefully protected Wildland Reserves. The core of the park was created in 1931 from former industrial forestland that was heavily cut. Over the past 80 years, these areas have transitioned into maturing forest and will eventually exhibit old-growth ecological characteristics and ecosystem function.

The Biodiversity Co-Benefit of Wildland Reserves

In addition to carbon storage and sequestration, Wildland Reserves provide many ecological co-benefits. For example, they often develop relatively species-rich tree canopies and greater structural complexity over time, including greater numbers of large live and dead standing trees, coarse woody material on the forest floor, and taller canopies (Zlonis and Niemi 2014). Structurally complex and species-diverse forests provide more habitat niches, which often result in relatively high abundance and diversity of plant, animal, and fungal species. This complexity and diversity brings adaptive capacity to these forests in the face of natural disturbances such as disease and storms that may accelerate due to climate change. Severe disturbances can lead to temporary losses in aboveground carbon; however, aboveground carbon is more resilient in Wildland Reserves, as much of it is transferred from live stems to downed woody debris and stored on the forest floor until it decomposes (D'Amato et al. 2017). Severe disturbances result in habitat for "area-sensitive" early successional birds (e.g., yellow breasted chats, golden-winged warblers, and prairie warblers) and other species that do not occur in smaller canopy gaps created by less severe disturbances (King and Schlossberg 2014).

Wildland Reserves can store a great deal of carbon accumulated over time, and they continue to sequester carbon as they grow old and recover from past land use disturbances. Forests over 170 years of age in the Northeast contain the largest carbon pools and carbon storage and have high levels of tree growth and species diversity (Thom et al. 2019). In some conditions, younger forests may grow more rapidly and sequester carbon at a faster rate. However, older forests have already accumulated large stores of carbon that we cannot afford to release. From a carbon perspective, creating Wildland Reserves from forests that are already old is important precisely because of these large stores: Harvesting at this stage would result in an immediate carbon reduction that would be impossible to replace in the short to medium term.

Methodology

A Wildland Reserves designation only increases carbon sequestration or stocks if it prevents an impact that would have occurred but for that designation. Therefore, to estimate the potential additional carbon benefits that an increase in Wildland Reserves could provide, it is necessary to evaluate what might have happened in BAU, had a given area of forest not been designated as a Wildland Reserve (i.e., the "counter-factual"). To do this, we use the BAU trends in forest loss and forest harvesting to calculate the probability that any given acre of forestland would have been converted or harvested. We then calculate the difference in expected carbon storage and sequestration between those alternative actions. We evaluate the probability of harvest and conversions to settlements, cropland, and other lands as potential disturbances to forests. For parsimony, we assume that Wildland Reserves and non-Wildland Reserves have the same susceptibility to natural disturbances such as disease, insects, and fire in New England. In practice and especially in a changing climate, this assumption likely will not hold, and further consideration is warranted. The Wildland Reserves pathway interacts with the Improved Forest Management IFM pathway: Acres designated as Wildland Reserves are removed from the IFM analysis because Wildland Reserves acres cannot be harvested. See Supplement Five for details on our methodology.

Table 4, on page 23, summarizes the quantity of Wildland Reserves in each New England state. Using the Forest Service's category of "Reserved Forestland" as a proxy for Wildland Reserves shows that they range from 1.4% in Connecticut to 5.7% in New Hampshire. We consider potential carbon benefits at a 10% Wildland Reserves goal (an additional 1.76 million acres above what is assumed in the BAU), reflective of the Wildlands, Woodlands, Farmlands & Communities vision of securing at least 10% of the forests in the region in wildlands, and at lower and higher tiers of 5% and 30%. We calculate the number of acres required to reach the percentage goals (5%/10%/30%) in each New England state (Table 4). For example: the gap to achieve 10% of the forest designated as Wildlands Reserves from an additional 4.3% required in New Hampshire ranges to an additional 8.6% required in Connecticut. The amount of wildland is proportionate to a state's forestland. Maine will therefore contribute the most acreage in reaching the Wildland Reserve goal. For New England as a whole, reaching the goal of 10% of forestland in Wildland Reserves would require an additional 1.76 million acres of new reserves.

Results

Our analysis shows that northern New England states, especially Maine, have the largest potential carbon benefit (on a per-unit area basis) from increased Wildland Reserves designation, largely due to the more intensive levels of forest harvesting, which increase the probability that a forest would have otherwise been harvested in the 30-year study period. While areas in southern New England have a higher (but still low) probability of being converted, they have a very low probability of being harvested, leading to less expected *additional* carbon benefit from increased Wildland Reserves designation. We estimate the carbon benefit of Wildland Reserves may range from 10.6 million tons CO2e over 30 years (low tier) to 217.1 million tons CO2e over 30 years (high tier). Reaching the 10% goal (middle tier) would yield a carbon benefit of 50 million tons CO2e over 30 years.

FOOTNOTES

[7] We use the term Wildland Reserves exclusively to reference a land-use zoning policy that limits extractive uses, such as timber harvesting, while still allowing various other human uses.

[8] A forthcoming census of Wildland Reserves (Foster et al. 2022) provides an updated and much improved estimate of Wildlands and includes a census of privately owned Wildlands. Despite the improvement, we used the FIA estimate here because it is coupled with the FIA forest plot data, which allows us to estimate the carbon stores therein. The FIA estimate is based on public land, and using looser criteria for defining Wildlands than does Foster et al. Coincedentally, both estimate roughly 1.2M acres of wildlands in New England, therefore the overall estimates we give here are robust to either datasource.

TABLE 4: Additional Wildland Reserves acres required at each tier

Wildland Reserves Analysis	CT	ME	MA	NH	RI	VT	New England Total
Forestland (acres)	1,763,460	17,372,795	2,966,472	4,686,704	358,617	4,508,984	31,657,031
Timberland (acres)* — "not reserved"	1,737,978	16,873,315	2,848,785	4,420,004	343,736	4,273,598	30,497,416
Reserved forestland (acres)	25,481	499,480	117,687	266,700	14,881	235,386	1,159,615
% forestland reserved (current Wildland Reserves)	1.4%	2.9%	4.0%	5.7%	4.1%	5.2%	3.7%
% needed to achieve 5%	3.6%	2.1%	1.0%	0.0%	0.9%	0.0%	1.3%
Additional Wildland Reserves acres @ 5% [1]	**59,085**	**278,280**	**13,378**	**-**	**810**	**-**	**233,192**
% needed to achieve 10%	8.6%	7.1%	6.0%	4.3%	5.9%	4.8%	6.3%
Additional Wildland Reserves acres @ 10% [1]	**145,984**	**1,121,946**	**155,818**	**150,643**	**17,997**	**171,327**	**1,758,063**
% needed to achieve 30%	28.6%	27.1%	26.0%	24.3%	25.9%	24.8%	26.3%
Additional Wildland Reserves acres @ 30% [1]	**493,580**	**4,496,609**	**725,575**	**1,034,644**	**86,744**	**1,026,047**	**7,857,546**

Note:

[1] The additional Wildland Reserves acres required at each tier have been reduced by our estimated BAU Wildland Reserves designation over the 30-year period. At the 5% tier, some states (NH and VT) already meet the acres of Wildland Reserves designation required to meet the goal. **Source:** Acres of forestland, timberland, and reserved forestland extracted from FIA Evalidator database.

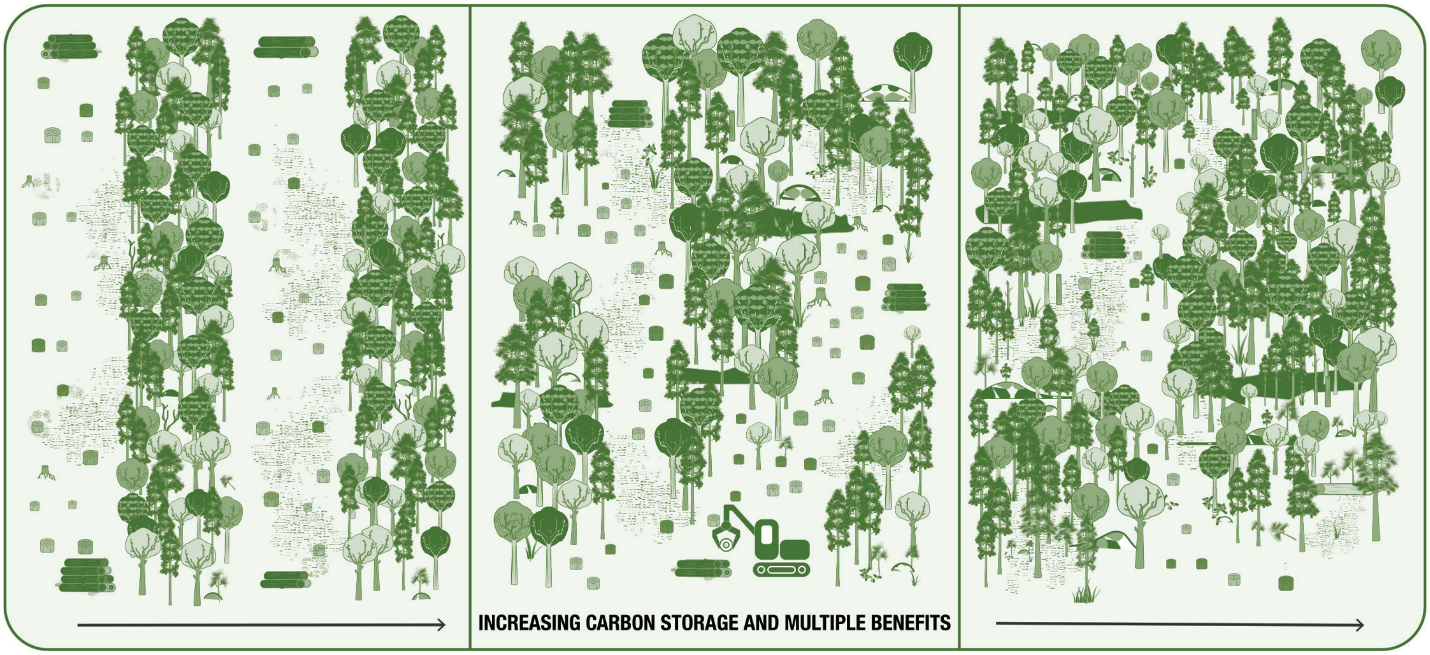
* Timberland refers to forest that is available for wood product utilization, per US Forest Service designation.

TABLE 5: Wildland Reserves pathway carbon benefits

State	Carbon Benefit of Closing the Wildland Reserves Gap (30 years, million tons CO2e)		
	5%	**10%**	**30%**
Connecticut	0.72	1.8	6.0
Maine	9.7	39.2	157.3
Massachusetts	0.15	1.7	7.7
New Hampshire	0.0	3.6	25.0
Rhode Island	0.011	0.37	1.8
Vermont	0.0	3.3	19.4
New England – Total	**10.6**	**50.0**	**217.1**

Improved Forest Management

PATHWAY 3



Problem: New England's forests yield valuable wood-based products, such as dimensional lumber for buildings, and support an important sector of the region's economy. At the same time, tree harvesting emits more carbon than any other forest activity in the region. Often, past forest management practices have left the land below its capacity to store and sequester carbon. The goal of the Improved Forest Management (IFM) pathway is to increase the carbon storage and sequestration of the region's managed forests, while also producing the forest products that we rely on.

Pathway: Incentivize "climate smart" forestry practices including: longer rotations between harvests, increases to productivity (growth per acre per year), and/or thinning overstocked stands.

Potential Policy Actions: Provide payments for ecosystem services that incentivize improved silviculture to allow some areas to recover from past management, increase productivity and/or harvesting on longer rotations, and to thin overstocked stands.

Carbon Benefit: Over 30 years, IFM practices to increase forest stocking in New England would absorb an additional 3.6% (203 million tons CO2e) of current carbon emissions in the middle tier scenario.

Co-Benefits: Clean water, clearer air, jobs and economic opportunity, wood products and buildings, and biodiversity.

Trade-offs: Sequestering and storing more carbon in a managed forest will require shifting harvests to overstocked stands and, in some areas, cutting fewer trees in the short term. This will require altering landowners' harvest regimes. Maintaining harvest regimes at their highest tier would preclude our ability to achieve the highest tier of the Wildlands Pathway.

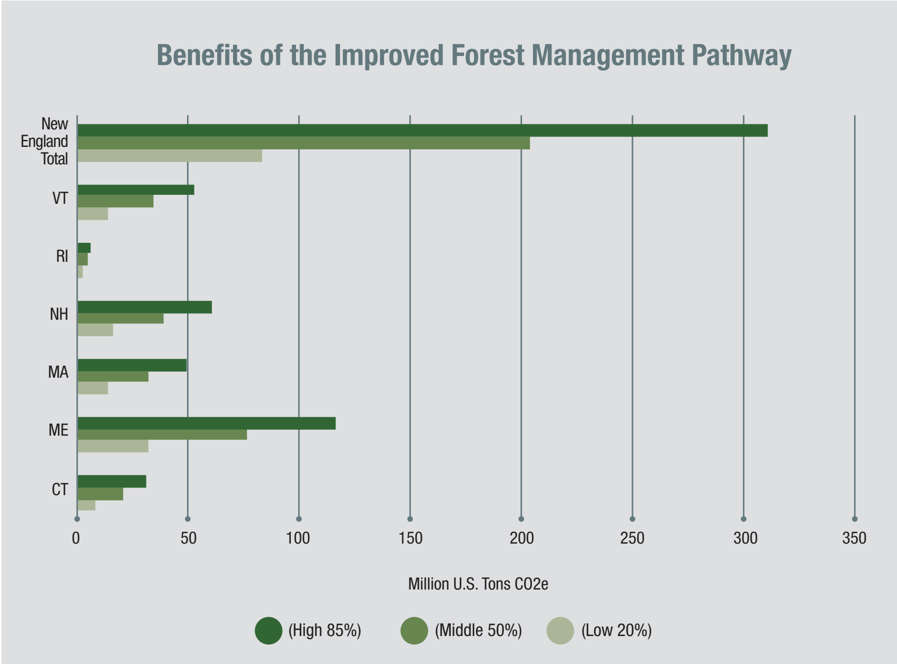


Figure 12: Accumulated carbon benefits of the Improved Forest Management Pathway at three tiers of adoption by 2050

Background

Tree harvesting in New England is the largest source of carbon emissions from the forest landscape. One study estimated that harvest accounts for between 68% (Connecticut) and 96% (Vermont) of forest carbon loss in New England states (Harris et al. 2016). While on a per-acre basis, carbon loss during conversion to non-forest uses (e.g., settlements or croplands) may be larger, total carbon loss from forest harvesting is far larger because it occurs over a much larger area of New England's forests (Duveneck and Thompson 2019). Past management practices on industrial timberlands in New England have impacted many forests, such that their growth rates are now well below their potential (Gunn et al. 2019). Supplements Three and Six provide additional detail on these estimates, in both the BAU and IFM sections.

Improved Forest Management is a broad term that encompasses a wide variety of silvicultural practices. We use the term to denote a portfolio of silvicultural approaches that, when applied across much of New England, could collectively increase carbon stocks and sequestration rates by increasing the productivity of the forests. Examples of IFM include increasing the interval between treatments or harvests and the overall age of the forest (i.e., extended rotations), uneven-aged stand management that encourages stand complexity and retention of species key to long-term objectives, pre-commercial thinning to improve the growth of residual trees, and focusing harvests in areas that are at higher risk of disturbance (e.g., areas prone to insects, ice, or wind). The larger trees that result from such practices can be harvested for durable wood products that store carbon for longer periods of time, such as the mass timber buildings we discuss elsewhere in this report. For an in-depth discussion of how some IFM practices can be used to increase carbon and what questions remain, see Kaarakka et al. (2021).

The effects of timber harvest on forest carbon stocks and sequestration are complex and vary by forest type and forestry practice. However, all forest harvests, by definition, reduce the carbon stock of a particular area as trees are removed from the forest. The principles underpinning IFM techniques all seek to minimize the harvest effects on carbon stocks and when possible bolster rates of sequestration, while also acknowledging that society needs wood products and that wood is among the least carbon-intensive building materials. The IFM pathway incorporates these underpinnings into an approach to forest management that focuses on increasing regional forest productivity (i.e., growth rates) while maintaining flows of wood products.

IFM can increase forest productivity in three ways: maintaining enough leaf area to fully capture sunlight, thinning some stems to ensure maximal growth rates on residual trees, and retaining high-quality individual trees to maximize growth rates. The science of silviculture has developed multiple techniques to achieve these goals, but depending on available markets and landowner objectives, these goals are not applied to all harvests or forest management in New England. The climate crisis demands that IFM be a regional goal that incorporates all forestland, which means that policy, social context, and economic incentives need to be structured to make that possible.

Consider these three mechanisms in order. First, some forestland, particularly in northern New England, is harvested heavily enough that there is not enough volume of tree leaves remaining to fully capture the sunlight reaching the site. Sunlight that could drive tree growth is either wasted or captured by non-woody vegetation near the ground. Sequestration is reduced, and storage levels are low. By managing for longer rotations and harvesting in ways that do not reduce tree leaf volume as much, landowners can keep sequestration at high levels while also maintaining more carbon storage on a site. This may require a shift in markets and financial incentives to make such management feasible for landowners.

Second, forestland is often managed not with a long-term goal of maximizing productivity, but rather with a short-term goal of financial gain. Therefore, investments that could increase carbon stocks significantly, such as early thinning to allow individual trees to maximize their growth rates, may not be used widely. This is particularly true on small family forest holdings but may also be true on commercial lands if the landowner does not intend to maintain management for a long enough period to reap the benefits of such investments. Existing government programs such as Natural Resources Conservation Service subsidies can help with the financial cost of such approaches, and new markets are emerging that pay landowners for storing carbon instead of harvesting it.

Finally, too much forestland in New England is subject to a type of harvest that simply prioritizes cutting all valuable trees over a certain size. Selective approaches that retain high-quality growing stock for regeneration and future harvest can increase productivity over time (Belair and Ducey 2018).

Recent research suggests that forests in the eastern U.S. have capacity for additional sequestration (Keeton 2018) through changes in forest management and allowing trees to grow older (Nunery and Keeton 2010). We examine the potential of IFM within New England's managed forests, given the evidence that they could be storing and sequestering more carbon. As much as 40% of forestland in northern New England (Vermont, New Hampshire, and Maine) is understocked due to past management (Gunn et al. 2019), where stocking is defined as the density of trees in a particular area compared with the capacity of that area to grow trees. Another study of harvesting in New England more broadly concluded that nearly one-third of harvests in the region involve commercial clear-cuts and high-grading (Belair and Ducey 2018); these practices are considered exploitative because of their singular focus on removing high-value trees. Stands are left with dynamics that result in reduced overall biomass growth rates and timber values.

Methodology

We apply the concept of IFM to New England's managed forests, which exhibit a significant capacity to store and sequester additional carbon through increased *stocking*, defined by the USFS as the percent of total tree density that is required to fully use the growth potential of the land. A poorly stocked stand has unfulfilled growing capacity that could be storing more carbon, whereas a fully stocked stand has little capacity left for more trees to store more carbon. The USFS FIA data reports five classes of stocking, from non-stocked (0-9%) to overstocked (>100%). This study looks at the non-stocked (0-9%), poorly stocked (10-34%) and medium-stocked (35-59%) categories, as they represent the forest conditions where IFM practices could increase stocking, and therefore carbon storage. We do not attempt to prescribe any particular suite of IFM approaches; instead, we acknowledge that a diversity of approaches could be used, and the best approach will be determined by the site and the landowner's objectives. According to FIA data, roughly 35-40% of New England's forests are inadequately stocked, which we define as the combined non-stocked, poorly stocked, and medium-stocked FIA categories.

To estimate the carbon additionality of the IFM pathway, we first estimate the number of acres of timberland New England is expected to have in 2050. From the total current acres of timberland, we subtract

A No-Leakage Assumption

This study assumes that the supply of forest products flowing from New England forests remains constant during the 30-year period. We make this assumption because society's demand for wood products is increasing, and we don't want to simply shift harvesting to forests outside of New England. There is great benefit from local wood. Of course, stopping all timber harvesting—in effect, making all of New England's forests into Wildland Reserves—would maximize forest carbon storage and sequestration in New England. However, unless this were associated with a corresponding decline in wood consumption, stopping harvesting here would just shift harvests elsewhere, with no benefit to the climate. Our assumption of no-leakage in harvesting while increasing forest carbon stocks is reasonable because harvesting occurs on a small percentage of the landscape each year and there are ample opportunities to shift where harvests occur to maximize landscape-scale forest productivity. Forest growth, and therefore the wood available to harvest, is influenced by the total volume of trees on a given area of land, as well as how that volume is distributed across different sizes of trees. Depending on these considerations, productivity per acre—defined as the amount of wood grown per acre per year—across New England can vary sixfold or more. IFM principles are not intended to reduce the availability of wood products over the long term, but rather to increase the productivity of the forest, so more products can be harvested later while maintaining a higher stocking level in the future.

the middle-tier estimates for existing and future Wildland Reserves and the Avoided Deforestation pathway that adjusts forest loss estimates across New England. We use the midpoint acre estimate between 2020 timberland acres from our baseline data and these 2050 projected timberland acres to account for not knowing when an acre will be designated a Wildland Reserve over the 30-year period. With this approach, we estimate a total of 29.4 million timberland acres, to which we apply the IFM pathway (representing a loss of 846,000 acres to development and 1.76 million acres to the Wildland Reserves pathway over 30 years). We distribute the projected timberland acres across the stocking categories according to proportions in the current stocking classes from our baseline FIA data. We then model the reallocation of forested acres from their current stocking levels to one class higher. We do this at three different tiers, where 20%, 50%, or 85% (low, middle, and high tiers) of inadequately stocked acres of timberland (i.e., nonreserved forests in which harvest is allowed) in New England move up to the next stocking class through IFM practices. For example, in the middle tier, we move 50% of forested acres that allow harvest to the next stocking class: half of non-stocked acres move to poorly stocked, half of poorly stocked acres move to medium stocked, and half of medium-stocked acres move to fully stocked (Table 6).

TABLE 6: Number of Acres Moving Stocking Categories

State	Medium-stocked -> Full	Poorly stocked -> Medium	Non-stocked -> Poor
Connecticut	256,372	51,882	13,380
Maine	2,309,461	509,136	22,220
Massachusetts	429,749	91,259	5,523
New Hampshire	669,548	91,885	8,775
Rhode Island	52,976	11,660	317
Vermont	576,828	114,881	4,574

To estimate the climate mitigation opportunity of IFM, we apply estimates of carbon stock for each stocking class from the FIA data to the acres in each of our reallocated stocking classes. Therefore, the carbon additionality from IFM for any given acre is calculated as the increased carbon storage from moving up one stocking class. For example, an acre of timberland moving from a non-stocked to poorly stocked class in Maine experiences a gain of roughly 8 tons of carbon per acre; in Massachusetts an acre of timberland moving from a non-stocked to a poorly stocked state experiences a gain of 12 tons per acre. Gains per acre from moving from a poor to medium state are smaller but still significant, and from medium to full stocking smaller still but also significant. Overall, our data suggests that moving up a stocking class (e.g., from poor to medium stocking) through certain IFM practices increases the carbon stock per acre of forestland by approximately 60% to over 100% in some instances. Supplement Six provides summary tables for each state and stocking category considered in the study.

Results

By applying the carbon benefit that results from moving up a stocking class to the number of acres we assume move up at each tier level, we estimate the total carbon benefits associated with moving inadequately stocked acres to higher stocking classes across New England.

At the middle tier, we estimate a carbon benefit of an additional 203 million tons CO_2e over 30 years (Figure 12, page 25). This is equivalent to 3.6% of New England's annual GHG emissions today (Table 7, page 28).

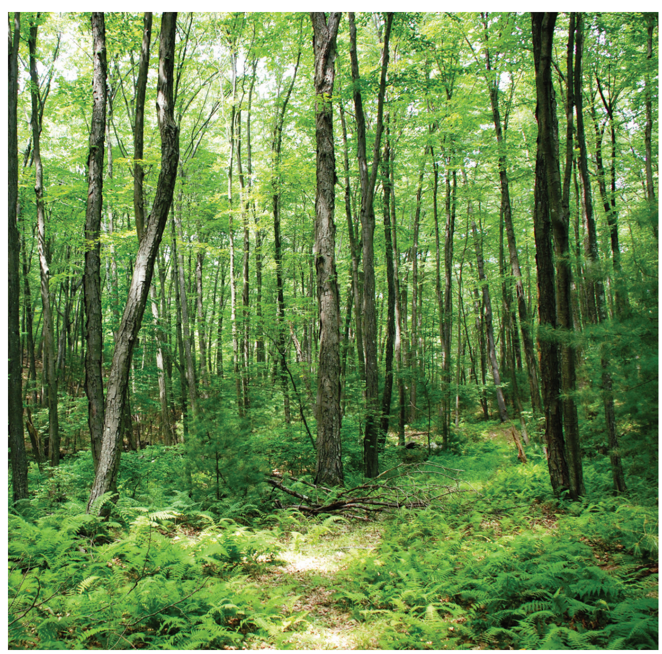


TABLE 7: IFM Pathway Carbon Benefits

State	Projected 2050 Timberland Acres (milions) [1]	Total Carbon Benefit of Shifting Acres by One Stocking Class (30 years, million tons CO2e) [2]		
		20%	50%	85%
Connecticut	1.7	8.0	19.6	30.1
Maine	16.2	31.0	75.7	115.7
Massachusetts	2.8	12.8	31.4	48.0
New Hampshire	4.3	15.7	38.7	59.4
Rhode Island	0.33	1.5	3.6	5.6
Vermont	4.1	13.6	33.6	51.5
New England – Total	**29.4**	**82.7**	**202.8**	**310.3**

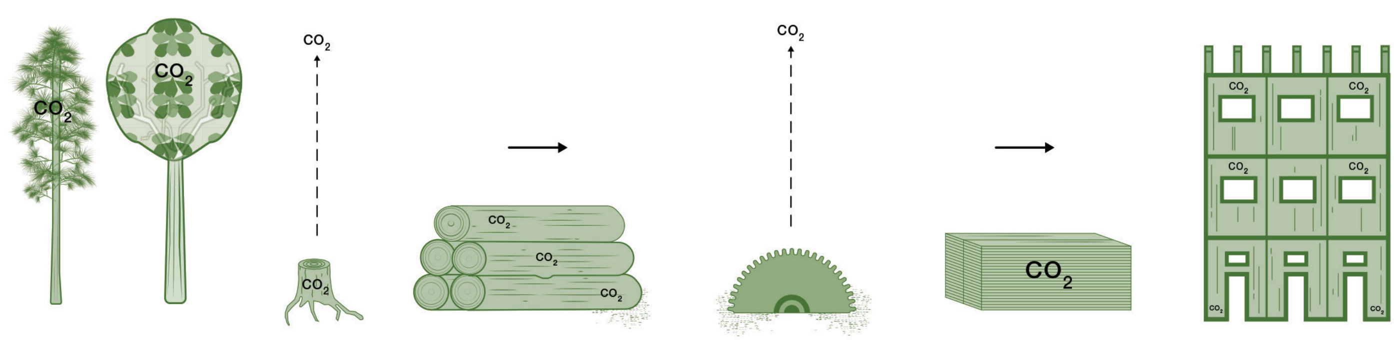
Notes:

[1] Timberland acres in 2050 are net of Wildland Reserves introduced in the Wildland Reserves pathway, BAU Wildland Reserves designation, and the Avoided Deforestation pathway that determines forest loss. In this table, the timberland acres are net of the 10% Wildland Reserves pathway, which removes 1.7 million acres of forestland from the timberland category from 2020-50 across New England. Timberland acres in 2050 here reflect the midpoints of acres in 2020 and 2050 because we do not know when an acre of Wildland Reserve will be designated over the 30-year period of our analysis.

[2] The carbon benefit reflects the additional carbon that is realized when moving up a stocking class.

Mass Timber Construction

PATHWAY 4



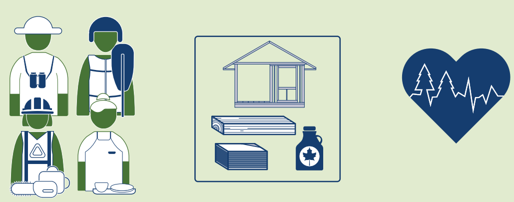
Problem: The construction industry is a significant source of GHG emissions and will become more so if carbon-intensive steel and concrete construction is used to meet increasing housing needs.

Pathway: Replace carbon-intensive building materials, such as concrete and steel, with regionally sourced mass timber materials for new large multifamily and commercial buildings in New England.

Potential Policy Actions: Adopt the IBC 2021 building code, which allows tall wood buildings; incentivize developers to use mass timber; adopt new net-zero stretch codes, which include embodied carbon reduction targets; incentivize mass timber manufacturing facilities in New England; create low-interest financing based on climate benefits of construction materials.

Carbon Benefit: At the middle tier, the construction of 6,400 new mass timber buildings in New England over the next 30 years could mitigate an additional 15 million tons CO2e of regional carbon emissions (0.3% of regional annual emissions).

Co-Benefits: Jobs and economic opportunity; buildings constructed from new, long-lived forest products; and healthier people.



Trade-offs: This pathway could increase the prices paid for certain sizes of logs, potentially incentivizing landowners to hold trees longer. Maintaining timber harvest regimes at their highest tier would preclude our ability to achieve the highest tier of the Wildlands Pathway.

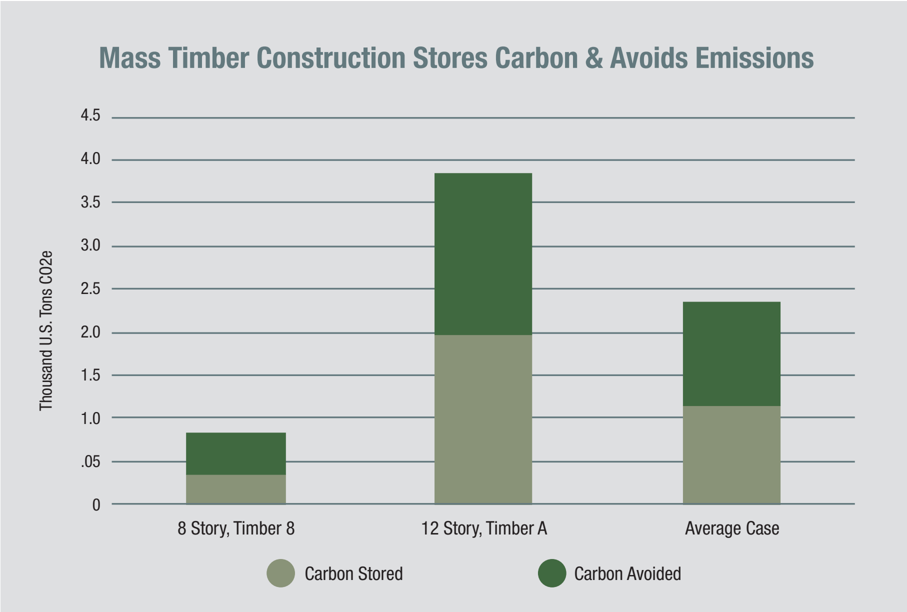


Figure 13: By building with wood, instead of steel or concrete, we can store carbon and avoid emissions. Here we show the per building carbon benefits for eight- and twelve-story buildings (source: LCA by Olifant, LLC, Generate Technologies, LLC and building designs [e.g., "Timber 8" and "Timber A"] by MIT and Buro Happold Engineering.) Note: Benefits are relative to the concrete and steel reference building.

Background

Urbanization is a growing trend globally, with nearly 70% of people expected to live in cities by 2050 (UN DESA 2018). Most of southern New England's population lives within urban areas at rates higher than the national average: 88%, 92%, and 91% for Connecticut, Massachusetts, and Rhode Island, respectively (U.S. Census Bureau 2010).

New England's urban populations and areas are growing (Federal Reserve Bank of Boston 2019), requiring significant construction of new buildings. In Massachusetts alone, another 1.4 billion square feet of new construction is expected by 2050, a 23% increase over the total today. Sixty-four percent of this new wave of construction is expected to come by 2030 (MA Buildings Sector Report 2020), with additional construction slowing for the subsequent two decades. Given its heavy reliance on concrete and steel, the building sector today is a significant source of GHG emissions. For this reason, it is critical to align urgent demand for new buildings with climate smart building materials coming from climate smart supply chains, including mass timber.

Mass timber yields carbon benefits in two primary ways: (1) by displacing the full life cycle of carbon emissions associated with concrete and steel construction, the so-called embodied carbon; and (2) by storing carbon in the building itself; i.e., carbon in wood removed from the forest is not released to the atmosphere but locked up over a long term as building components (stored CO2e). Our estimate of carbon benefits focuses on the stored and embodied carbon associated with mass timber construction, including substitution benefits once the wood needed for construction has already left the forest. An assessment of the in-forest effects of this construction and the potential regional economic impacts (e.g., regional wood economy) is beyond the scope of this study. However, we expect there are additional carbon benefits of increasing market demand for mass timber in the supply chain and forest. Such benefits would be implied through our IFM pathway but cannot be enumerated separately here without risk of double-counting. Only the carbon storage in the building and the benefit of displacing steel and concrete emissions is counted here.

Methodology

To estimate the carbon benefit of increased mass timber construction in New England, we envision a future in New England where mass timber buildings expand to broad use for the multifamily housing, affordable housing, and mixed-use real estate the region will need as urbanization increases and development in and around cities requires greater density. We leverage embodied and stored carbon data for mass timber buildings that are code variant or code compliant and are likely to be accepted by developers due to their cost and design profile. Specifically, we rely on life-cycle assessments (LCA) conducted by Olifant, LLC and Generate Architecture and Technologies. Those LCAs are for eight- and 12-story buildings, which were designed collaboratively by Generate Architecture and Technologies and Buro Happold Engineering. Details on this data and our methodology is provided in Supplement Seven.

We use the embodied and stored carbon components from the LCAs to calculate the total carbon benefit of a representative mass timber building. We estimate the carbon benefit of this building is 2,350 tons CO2e, comprised of just over 1,000 tons CO2e stored in each building and 1,000 tons CO2e avoided in the LCA of each building as compared to a steel and concrete reference case (Figure 13).

We then apply the average carbon benefit per building to a market analysis we conducted on the potential for new mass timber buildings in New England over the next

30 years. Our market analysis looks at two building market segments over the 30-year period: (1) the "institutional" sector, representing the kinds of buildings already being constructed with mass timber in New England as summarized above; and (2) the potential capture of a percentage of the multifamily market by mass timber construction. For both markets, we develop estimates for three tiers of market capture: 20%, 50%, and 100%. Within the multifamily market, the subcategory of affordable housing is a promising market for mass timber construction because, in addition to carbon benefits, it can be less expensive and constructed more quickly than typical steel and concrete construction. We assess tiers of mass timber adoption to demonstrate the relative scale of the opportunity presented by potential policy changes to incentivize more mass timber adoption.

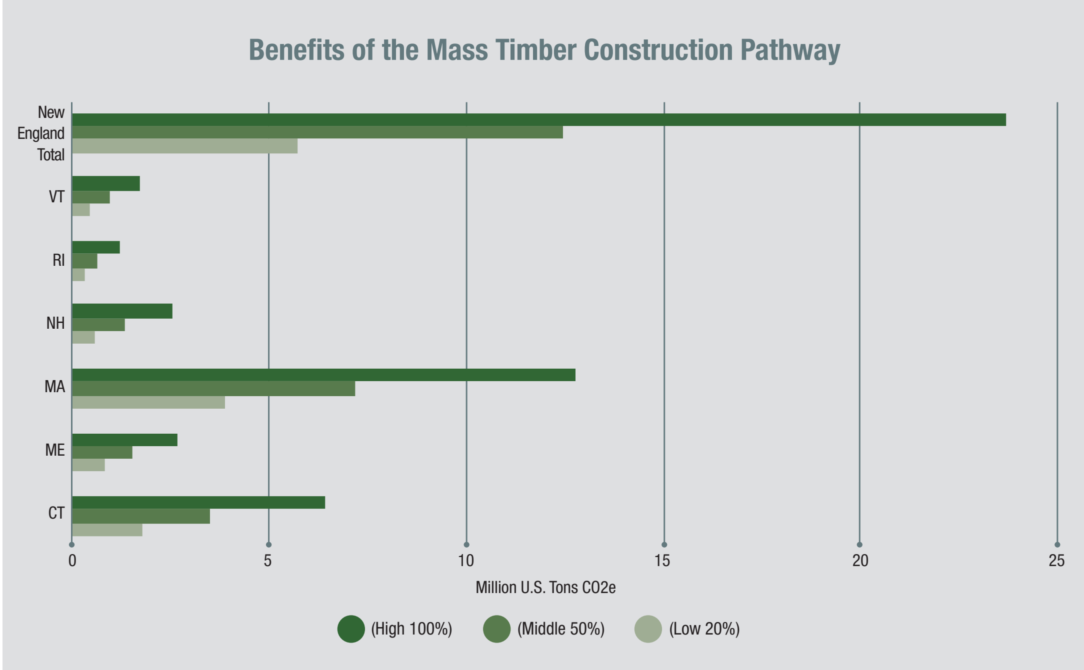


Figure 14: Accumulated carbon benefits of the Mass Timber Construction Pathway at three tiers of adoption by 2050

Results

Our data and market analysis suggest that Massachusetts and Connecticut are likely to experience the greatest growth in the mass timber building market from 2020-50 (Figure 14). At the middle tier, we show roughly 3,000 new mass timber buildings could be constructed in Massachusetts over the 30-year period of analysis, and roughly 1,500 in Connecticut. This level of Mass Timber Construction would yield 7.2 million

What is Mass Timber?

Mass timber refers to a set of large solid engineered wood materials, including panels, posts, and beams for wall, supporting structure, and floor construction, to be used in mid- to high-rise construction. Mass timber is currently allowed by the International Building Code in buildings from six to eighteen stories and can be used in place of conventional structural materials such as concrete and steel, or in hybrid structures. Mass timber products differ considerably from dimensional lumber normally used to build homes. Mass timber is fabricated prior to the building construction by joining dimensional lumber (most frequently with glue) together in perpendicular layers. While mass timber beams, called glulam, have been in use since the 1930s, mass timber's utility for use in larger structures was revolutionized with the development of cross-laminated timber, or CLT, panels, which allow for its use for walls and floor structures. Mass timber is most promising for constructing mid-rise (6 to 12 stories) multifamily and commercial buildings (e.g., offices, public/institutional buildings, schools, hotels); it is not a likely substitute for low-rise residential and commercial buildings where light wood framing is more cost competitive. Softwood species found in New England — including pine, spruce and fir — are used in the manufacture of mass timber components. Harvest for CLT-grade wood is the same as dimensional lumber, with mass timber being made of high grade two-by pieces.

TABLE 8: Mass Timber Construction Pathway Carbon Benefits

State	2050 Mass Timber Buildings (20%/50%/100%) [1]	Total Carbon Benefit of Mass Timber Construction (30 years, million tons CO2e) [2]		
		20%	50%	100%
Connecticut	749 / 1,490 / 2,725	1.8	3.5	6.4
Maine	355 / 641 / 1,117	0.84	1.5	2.6
Massachusetts	1,638 / 3,059 / 5,429	3.8	7.2	12.8
New Hampshire	241 / 558 / 1,085	0.6	1.3	2.6
Rhode Island	125 / 267 / 503	0.3	0.6	1.2
Vermont	191 / 386 / 713	0.45	0.91	1.7
New England – Total	**3,299 / 6,401 / 11,572**	**5.7**	**12.4**	**23.7**

Notes:

[1] Estimated number of mass timber buildings constructed at each tier from 2020-50.

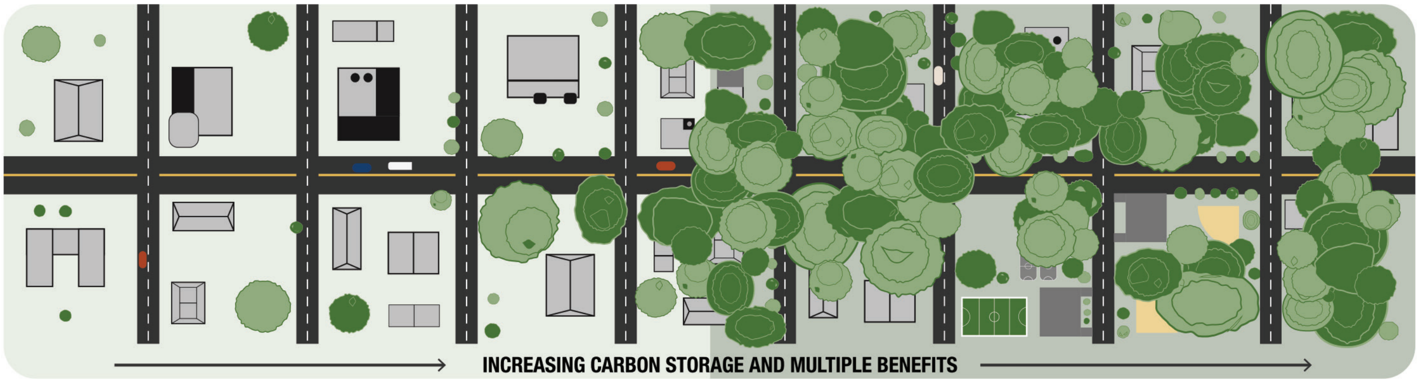
[2] Carbon benefit reflects carbon avoided in Mass Timber Construction as compared to the concrete and steel reference case, and carbon stored in mass timber buildings.

tons CO2e and 3.5 million tons CO2e of carbon benefit (from carbon stored and avoided) in Massachusetts and Connecticut, respectively. At the middle tier, we estimate that over 6,000 new mass timber buildings would be built in New England by 2050, absorbing an additional 15 million tons CO2e. For mass timber, it is important to remember that the wood supply for these buildings could come from other New England states than where the buildings are constructed.

The parameters of our analysis mean we assume constant production of wood products from New England's forests and no leakage in this study (i.e., all of the wood required for Mass Timber Construction in New England will come from New England). While these are simplifying assumptions, growth-versus-harvest data for New England (Supplement Seven) shows capacity for increased harvest in the region. Further, because the engineered wood manufactured for mass timber will be drawn from the same dimensional lumber pool of products used for building construction, it is possible that mass timber will displace dimensional lumber used for other wood-based products and/or encourage the production of more dimensional lumber by encouraging timberland owners to let trees grow older before harvesting them. If this is the case, Mass Timber Construction may result in significant additional positive effects related to forests and the supply chain. For example, our IFM pathway analysis assumes some delayed harvests that would effectively shift harvests from younger, lower-valued products (e.g., biomass for electrical production) to larger, older forest products, such as feed stocks for mass timber, thereby increasing stocking (and consequently carbon storage and sequestration) in the forest. We do not count these in-forest benefits in the Mass Timber Construction pathway to avoid double-counting with the IFM pathway. It is also important to note that many economic factors could influence the potential effectiveness of mass timber buildings as a climate mitigation solution in New England. In addition, given the limited number of CLT manufacturing facilities in the U.S., achieving the level of mass timber building construction we describe will depend on an increase in manufacturing capacity.

Urban and Suburban Forests

PATHWAY 5



Problem: New England's urban areas (including suburban areas) are increasing, but urban tree cover is declining.

Pathway: Increase urban canopy and suburban forest cover in New England to increase carbon storage and sequestration in the region's urban areas.

Potential Policy Actions: Provide bond funding and other incentives for city and town tree-planting efforts. Fund the maintenance of existing urban and suburban trees.

Carbon Benefit: Over 30 years, Urban and Suburban Forests enhancement activities to increase carbon density in New England's urban areas would absorb an additional 0.30% (16.5 million tons CO_2e) of current carbon emissions in the middle tier scenario.

Co-Benefits: Clean water, reduced flooding, clean air, shading and cooling, recreation, jobs and economic opportunity, biodiversity, and healthier people.

Trade-offs: Good urban design and planning will be needed to simultaneously increase urban density (to prevent rural forest loss) and increase urban forest cover. To be respectful, impactful, and sustainable, planting trees on private and public land in urban and suburban areas must be driven and directed by neighborhoods and communities, not governments or nonprofits.

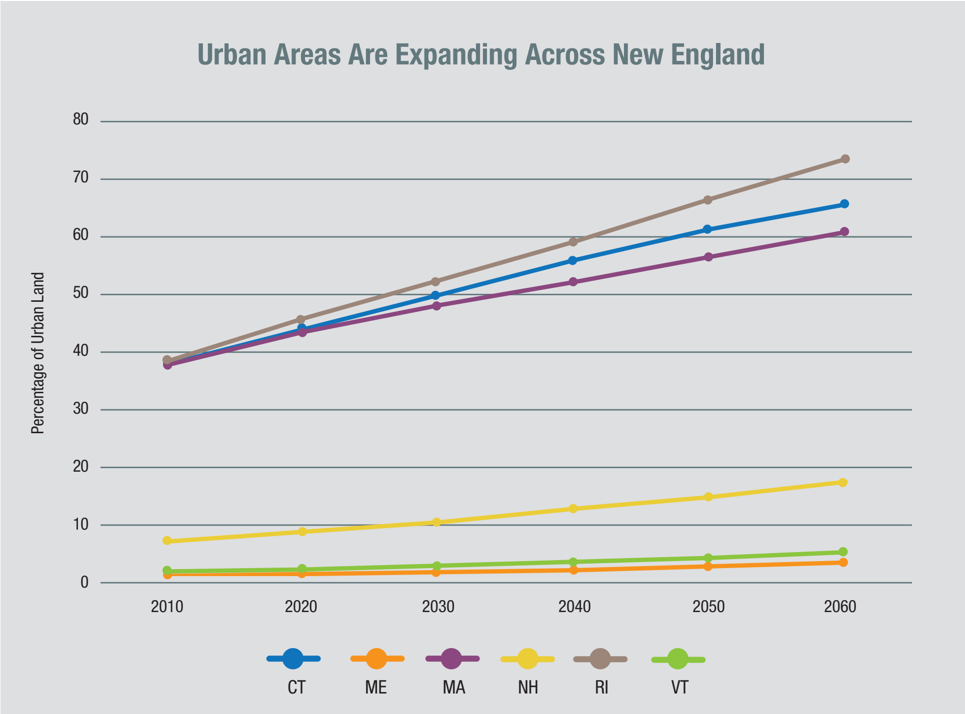


Figure 15: Projected urban land growth in New England states, 2010-60. (Source: Nowak and Greenfield 2018)

Background

Urban and Suburban Forests in New England are at an important nexus of human health, equity and environmental justice, and climate mitigation for the region. They provide ecosystem services that support vital environmental and social goals. While the focus of our research is on the climate mitigation potential of forests, it is hard to overstate the importance of increasing urban forests, especially for climate adaptation. The effects of climate change are widely expected to accentuate existing inequities in access to clean air and water, mental and physical health, susceptibility to flooding and dwelling displacement, and resource-based economic opportunity (Mearns, Robin, and Andrew Norton, eds. *Social dimensions of climate change: Equity and vulnerability in a warming world*. World Bank Publications, 2009). Therefore, it is critical that investments in natural climate solutions are made across the urban-rural gradient, both to increase sequestration in trees and forests and to ensure that the health and environmental co-benefits of forest conservation are realized equitably.

Climate-related benefits of urban trees are derived both from the carbon storage and sequestration function of trees and through the cooling effect they provide through shade and evapotranspiration, which can reduce the carbon implications of energy use in buildings (e.g., from air conditioning). Trees exert a powerful cooling effect in urban areas, thereby reducing the health risks associated with the urban heat-island effect. The cooling effect is especially important, as recent research projects an increase in deaths related to heat in eastern U.S. cities by the 2050s (Wu et al. 2014). Trees also positively affect human health by reducing air pollution, which reduces pollution-related respiratory diseases and other ailments. Trees in U.S. metropolitan areas and small towns absorb 822,000 metric tons of air pollutants, preventing 575,000 cases of acute respiratory symptoms annually (treeequityscore.org, 2020). In a national study of 27 cities, forest declines from 2004-14 negatively affected particulate removal, leading to a decline in inhalable particulate matter (PM10) removal by the urban canopy, and leading to an increase in summer air temperatures on average by 0.1°C (32°F) (Kroeger 2018). A recent USFS study of the benefits of investment in trees in five U.S. cities concluded that $1.37 to $3.09 in annual benefits were generated from every $1 invested in trees (USFS 2018).

For this analysis, we use a more expansive definition of *urban* trees, driven by our reliance in this section on Urban FIA data (Nowak et al. 2013, Nowak and Greenfield 2018), which uses a population density-based criteria from the U.S. census to define urban areas.[9] Using this definition means that our use of the term *urban* actually includes both urban and suburban areas, and that our urban trees analysis includes both core urban areas (e.g., individual trees along roads and in densely developed residential areas, groups of trees in urban parks, and urban forests or contiguous patches of dense tree cover that may cover an extensive area) as well as trees and forests in surrounding suburban areas. We note that our estimates may overlap with the FIA data we use for the other parts of the analysis to the extent that some urban and community areas meet the FIA definition of forestland. We have accounted for this overlap and have adjusted our carbon storage and sequestration estimates for the urban tree benefits analysis (Supplement Eight).

Using this definition of urban, the three southern New England states (Connecticut, Massachusetts and Rhode Island) exhibit the highest percentage of urban area in the U.S.: each around 36% of total land area in the state. Urban areas in New England are also expanding: Projections of urban area growth in the U.S. place three New England states in the top five for overall urban area growth from 2010-60 (Figure 15, page 34). Rhode Island is the highest across all 50 states at 34.8% projected increase in percentage of urban land; Connecticut is projected at 27.6% and Massachusetts at 22.7% (Nowak and Greenfield 2018). Urbanization will have effects on edge and rural forests as it expands outward from urban centers.

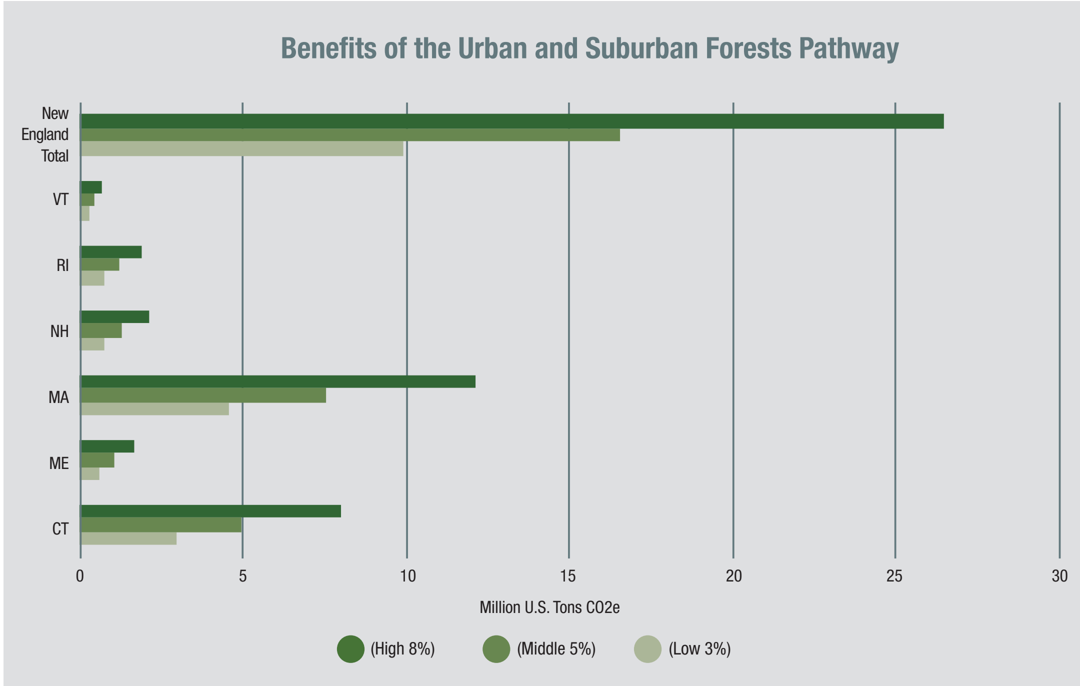


Figure 16: Accumulated carbon benefits of the Urban and Suburban Forests Pathway at three tiers of adoption by 2050

Southern New England states also exhibit higher tree canopy coverage than other states— roughly 67% of the area classified as urban in Connecticut is covered with trees, 65% in Massachusetts, and 54% in Rhode Island as compared to a national average of 34% (Nowak and Greenfield 2012 as cited in Butler et al. 2015). However, urban tree cover in New England is declining. Recent research showed declines in urban/community tree cover over a five- to seven-year period around 2010 for Massachusetts (-1.3%, -4,930 acres per year), New Hampshire (-1.4%, -1,650 acres per year), Rhode Island (-2.2%, -1,260 acres per year), and Vermont (-0.9%, -370 acres per year), and notes a corresponding increase in impervious cover in these urban areas (Nowak and Greenfield 2018). Using an average estimate of 207 trees per acre of tree cover means that these New England states lost 1.7 million trees annually from urban areas over this time period.[10] Drivers for the loss of urban tree cover include: “development, old age, storms, insects and diseases, land owner choices and fire” (Nowak and Greenfield 2018).

Trends showing declining urban tree cover but expanding urban land area suggest that it will be critical for New England states to retain and improve upon tree cover trends in urban areas, and efforts in many states are underway. For example, in Massachusetts,

TABLE 9: Urban and Suburban Forests enhancement pathway benefits

State	2020 Urban Acres / % [1]	2020 Adjusted Urban Acres [2]	Total Carbon Benefit of Urban and Suburban Forests Enhancement (30 years, million tons CO2e) [3]		
			3%	5%	8%
Connecticut	1,400,000 (44%)	925,000	3.0	5.0	8.0
Maine	318,000 (2%)	217,000	0.63	1.04	1.7
Massachusetts	2,301,000 (44%)	1,500,000	4.5	7.6	12.1
New Hampshire	529,000 (9%)	277,000	0.79	1.31	2.1
Rhode Island	360,000 (46%)	277,000	0.71	1.2	1.9
Vermont	129,000 (2%)	103,500	0.26	0.43	0.68
New England – Total	**5,037,000 (12%)**	**3,300,000**	**9.9**	**16.5**	**26.4**

Notes:

[1] The percentage reflects the percent of the state's total land area that is categorized as urban.

[2] Urban acres are adjusted to remove the portion of urban areas that would be included in the FIA forest data we use in the other pathways to avoid double-counting (see Supplement Eight). The carbon benefits summarized here reflect carbon improvements on these adjusted acres.

[3] Total carbon benefit reflects the 30-year additional stock and sequestration associated with increasing carbon density on urban acres by 3%, 5%, and 8%.

the Department of Conservation and Recreation "Urban and Community Forestry Greening the Gateway Cities Program" is a tree-planting program aiming to increase urban tree cover by 5% over 30 years in Environmental Justice Neighborhoods to reduce household energy use and mitigate the suffering associated with heat waves in treeless neighborhoods. In Rhode Island, the recent "Urban Forests for Climate and Health" partnership is addressing both climate and human health within the state's Health Equity Zones through increasing urban tree canopy cover. The partnership will focus on tree canopy improvements in areas with the most vulnerability to heat-related illness by developing and disseminating a number of tools, such as: a tree equity score; a climate and health forestry action guide; a tree-planting tool to prioritize areas where trees will have the greatest benefits to the resident population; and city forest credits, a voluntary carbon-plus credit market (American Forests 2019). Connecticut and Rhode Island have Urban Forestry Programs to advance better urban forestry practices; Connecticut has also included a recommendation for urban tree planting and other measures to address human and ecological health in dense urban areas in its recent GC3 report (GC3 Phase 1 Report 2021). In addition to state-level efforts, some New England cities have tree-planting goals. For example, Speak for the Trees Boston is a nonprofit that aims to help the city increase tree canopy cover from 27% to 35% by 2030. New Haven, Connecticut, plants about 500 street trees per year, with a goal of simply keeping up with the loss of trees to storm damage and invasive species, such as the emerald ash borer (Urban Resources Institute).

Methodology

We estimate the potential benefit of urban tree planting and other activities to increase tree cover (e.g., natural reforestation of nonforested areas) as an increase in the carbon density per acre in New England's existing urban areas. Our study relies on carbon storage and sequestration by urban trees data assessed by the Urban FIA program. Urban FIA data differs from the FIA data referenced in other sections of this report in several important methodological ways that are explained in

Supplement Eight, which also provides detail on how we collaborated with USFS scientists to adjust the urban carbon storage and sequestration data to account for potential overlap with FIA data and avoid double-counting, as some urban areas may contain enough forest to meet FIA's definition of forestland.

We estimate the benefits associated with carbon density improvements of 3%, 5%, and 8% per acre in existing urban areas of New England states in 2020. This range of potential increases in carbon density in urban areas is based on our review of the literature and proposed state actions (e.g., the Greening the Gateway Cities tree-planting program in Massachusetts discussed above). A recent study estimates that urban tree cover in the U.S. could be increased to a total potential of 6.7 to 10 million acres, equivalent to roughly 300-430 million trees or 7% to 11% of the existing U.S. tree population of 4 billion (Fargione et al. 2018). As noted, Massachusetts' Greening the Gateway Cities Program has a goal of increasing urban tree cover by 5% over 30 years. The 3% to 8% range of carbon density improvement across urban acres in this study is therefore in line with the estimated total potential urban tree increase found in these recent studies and considers that within urban areas, much of the available space is not suitable for additional tree planting due to development restrictions.

Results

The total benefit of Urban and Suburban Forests enhancement changes substantially across the low, middle, and high tiers. The carbon benefit grows from an additional 10 million tons CO2e absorbed over 30 years if urban tree density is increased by 3% per acre to an additional 26 million tons CO2e absorbed over 30 years if urban tree density is increased by 8% per acre. Massachusetts and Connecticut show the greatest potential gains from improvements in urban tree density (Table 9, page 36, Figure 16, page 35). By 2050, we estimate that around half the land area of all southern New England states will be classified by USFS as urban (which includes area commonly considered to be suburban, as well), underscoring the importance of mechanisms to protect and improve the urban tree canopy in these areas.

FOOTNOTES

[9] In 2010, the U.S. Census Bureau defined urban areas as comprising "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 as well as 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 identified according to criteria must encompass at least 2,500 people, at least 1,500 of which reside outside institutional group quarters" (U.S. Census Bureau 2010). This is the urban definition employed in the Urban FIA data we use for the analysis.

[10] Estimate of 207 trees per acre of urban tree cover is from Nowak, D.J., Greenfield, E.J., 2018. U.S. urban forest statistics, values, and projections. J. For. 116, 164–177.

Putting It All Together

The five pathways assessed in this report can inform climate change planning processes underway in New England. The quantification of the carbon benefits associated with each pathway is meant to provide policymakers and practitioners with practical information on the size and urgency of the opportunities in each state to support their decision making. Previous sections have provided information on the carbon benefits associated with each pathway at different tiers; this section provides information on the carbon benefit of all pathways together. The cumulative estimates in this section reflect the middle tier for each pathway (Table 10, page 39); it is important to note that the relative size of each pathway will shift at lower or higher tiers.

The cumulative potential carbon benefits (Figures 17 and 18, pages 38 and 39) of the five pathways amount to 358 million tons carbon dioxide equivalent (CO2e) over 30 years, or the equivalent of displacing the total 30-year energy consumption of nearly 1.3 million households in New England. The opportunity on an individual state basis ranges from 8.7 million tons CO2e in Rhode Island to 143 million tons CO2e in Maine, a 20-fold variation across states.

Two primary lessons emerge from these results: (1) business-as-usual (BAU) patterns of harvesting and development fail to capture the full climate mitigation potential of New England's forests, such that the greatest carbon benefit would come from the Improved Forest Management (IFM), Wildland Reserves, and Avoided Deforestation pathways; and (2) the long history of intense harvesting throughout the vast timberlands of Maine has depleted forest carbon stocks, and there is a huge opportunity to increase the carbon stocks and rate of sequestration in the state.

While the five pathways are meant to be additive and complementary, certain pathways and states stand out for their relative potential impact. IFM is a leading pathway to climate mitigation in the region. The Avoided Deforestation pathway assumes policy interventions that reduce forest loss by two-thirds. Creating more Wildland Reserves is also highly impactful for carbon storage. Maine alone could contribute 40% of the total regional climate mitigation benefit from implementing these

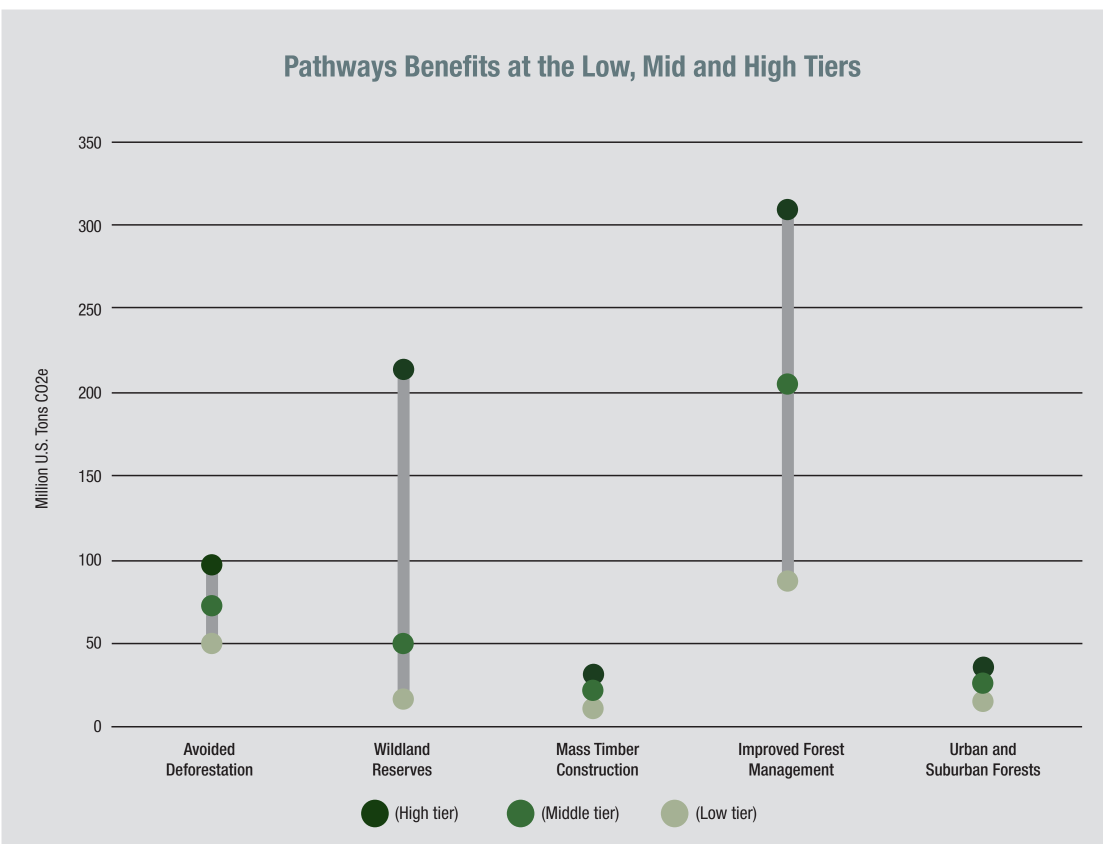


Figure 17: The accumulated carbon benefits of each pathway by 2050, shown at low, middle and high levels of adoption. Table 2 on page 15 provides details about the teirs.

TABLE 10: Summary of the Five Pathways

Pathway	Middle Tier Selection	Description
Avoided Deforestation	75%	Reduce annual rates of forest conversion by 75%.
Wildland Reserves	10%	Increase total Wildland Reserves area to 10% of forest area.
Improved Forest Management	50%	Apply IFM practices to 50% of forest area.
Mass Timber Construction	50%	Build 50% of new institutional and multifamily homes from mass timber.
Urban and Suburban Forests	5%	Increase tree canopy and forest cover by 5% in urban and suburban areas.

five pathways, with IFM and Wildland Reserves playing particularly important roles, given the state's vast forestland. Massachusetts, New Hampshire and Vermont (16% each) are the next largest potential contributors.

It is important to remember that these pathways have been constructed to count only carbon that would be additional to a BAU scenario, and thus reflect potential additional carbon stocks in 2050.

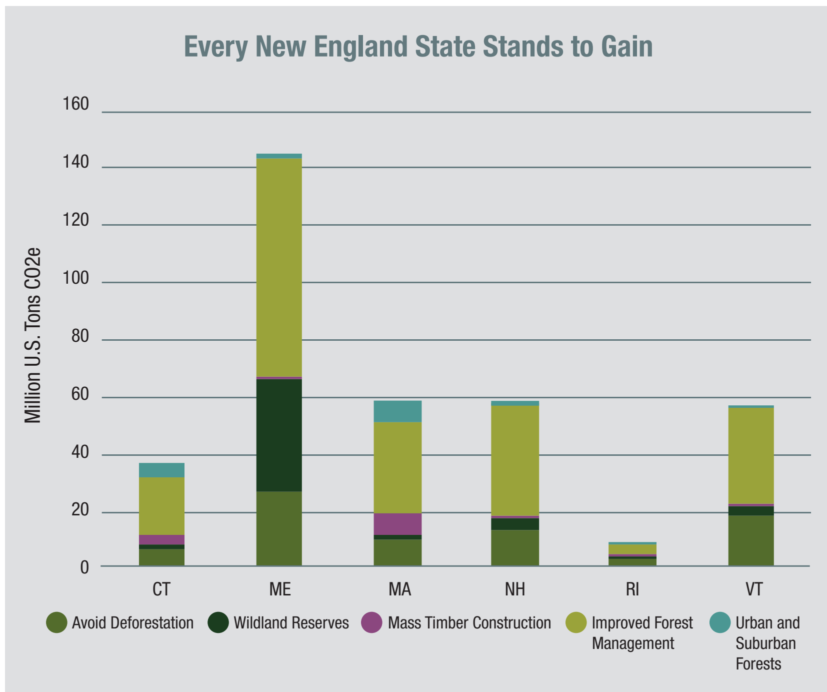


Figure 18: The carbon benefits for each state by 2050, showing the relative contributions from each pathway

Impact of Pathways on Regional Emissions

The most recent emissions data available for New England states shows that the region's total carbon emissions are currently around 187 million tons CO2e. Taken together, the carbon opportunity of the pathways assessed in this report have the potential to reduce New England's net emissions by almost 12 million tons CO2e per year, or an additional 6.4% of current annual emissions on top of the 14% of emission that our forests are already sequestering per year (Figure 19, page 40). With the implementation of these five pathways, New England's forests can sequester the equivalent of nearly 21% of the region's total current emissions. If New England states meet their 2050 emissions reductions goals, and total emissions drop from 187 million tons CO2e to 40 million tons CO2e, then the role of forests in sequestering emissions would grow to 97%: 30% from the five pathways and 67% from ongoing forest sequestration (Figure 201, page 40).

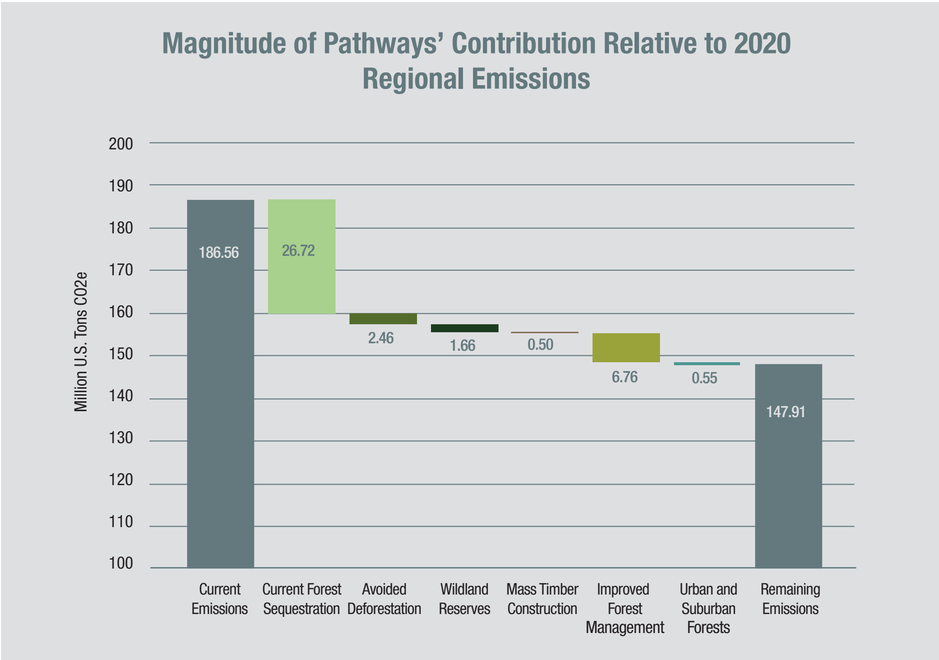


Figure 19: The adoption of each pathway (shown here at their average annual contribution when adopted at their middle tier) lowers New England's net emissions by sequestering more carbon in the forests. Please note, to show the detail associated with each pathway, the vertical axis has been scaled to start at 100 million tons CO2e.

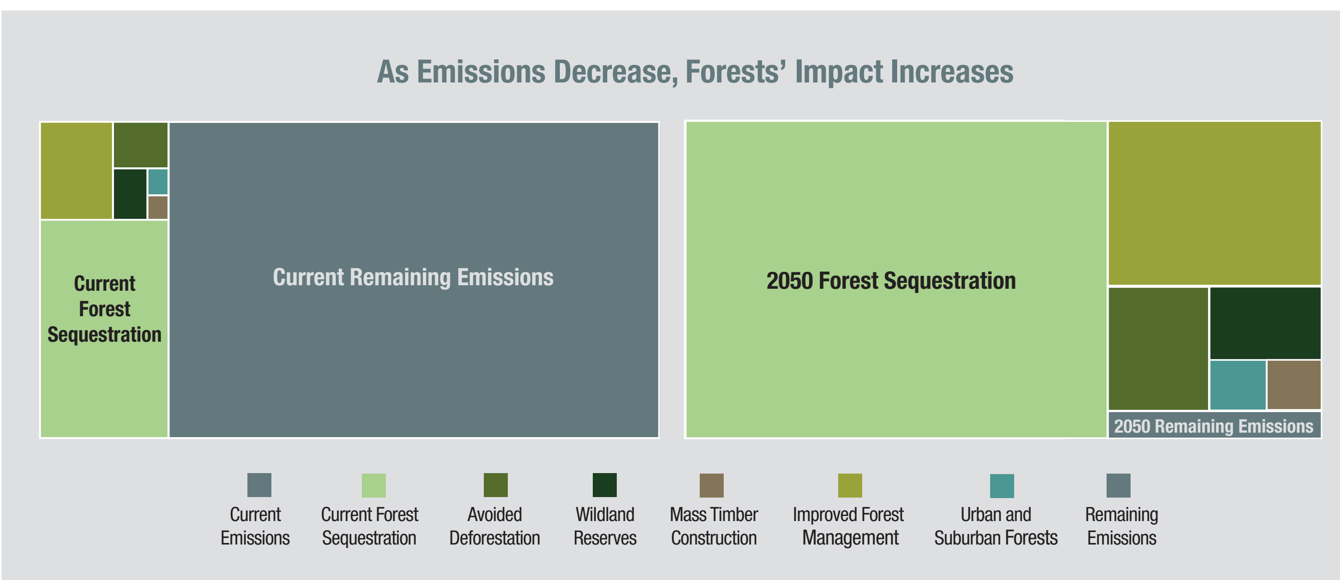


Figure 20: (Left) If the left rectangle represented the 187 million tons CO2e that were New England's greenhouse gas emissions in 2020, current forests under the BAU land use scenario would sequester the equivalent of 14%. Adopting the five pathways at their moderate tier would sequester the equivalent of an additional 6.4%. **(Right)** By 2050 the role of forests will be even larger. As New England states meet their specified goals for reducing emissions, and total emissions drop from 187 million tons CO2e to 40 million tons CO2e, the role of forests in sequestering emissions will grow to 97%: 30% from the five pathways and 67% from ongoing forest sequestration.

Recommendations

Avoided Deforestation:

Adopt "No Net Loss of Forests" policies, adopt "smart-growth" zoning policies; site alternative energy infrastructure outside of forestland; incentivize densification of housing and conservation restrictions.

Wildland Reserves:

Provide funding for public and private Wildland Reserves, convert additional existing state-owned lands to Wildland Reserves, incentivize "Forever Wild" easements, revise states' current-use property tax reduction policies to include Wildland Reserves-style management.

Improved Forest Management:

Pay landowners for ecosystem services that incentivize "climate smart" forestry, including: longer rotations, increases to productivity (growth per acre per year), and/or thinning overstocked stands.

Mass Timber Construction:

Adopt the IBC 2021 building code, which allows tall wood buildings; incentivize developers to use mass timber; adopt new net-zero stretch codes, which include embodied carbon; incentivize mass timber manufacturing facilities in New England; create low-interest financing reductions based on climate benefits of construction materials.

Urban and Suburban Forests:

Provide bond funding and other incentives for city and town tree-planting efforts. Fund support to maintain existing urban and suburban trees.

Acknowledgements

This study benefited from extensive outreach to many individuals and organizations working tirelessly in New England for the benefit of the region's forests for the climate and people. The authors thank the staff and researchers at Highstead and the Harvard Forest, and the Wildlands, Woodlands, Farmlands & Communities Strategic Working Group for their engagement and input throughout the research, analysis, and writing of this report. The authors also extend thanks to the many scientists and researchers, policy makers and legislators, and other colleagues in New England who supported this work through engaging with us during the study. We want to especially recognize the engagement of U.S. Forest Service researchers, including Grant Domke, Brian Walters, David Nowak, Eric Greenfield, Chris Woodall, and Mark Nelson, who helped us to understand the Forest Service data that we relied on for many parts of the analysis. We also want to recognize the significant inputs of other researchers and practitioners who helped us understand the current state of carbon science and policy in the region, including Meghan Graham Maclean, Laura Marx, Ed Faison, Steve Long, Frank Lowenstein, Buzz Constable, Aaron Weiskettel, Adam Daigneault, Ivan Fernandez, and Bill Keeton.

Millennia of Indigenous stewardship and knowledge formed the foundation of the ecosystems in this region. We recognize the vital role of Indigenous community members in shaping these ecosystems into the future and encourage decision-makers acting on the recommendations in this report to include the perspectives and contributions of Indigenous nations in that work.

References

American Forests. "Rhode Island Urban Forests for Climate and Health Initiative," August 2019. https://www.americanforests.org/wp-content/uploads/2019/09/Rhode-Island-Urban-Forests-for-Climate-and-Health-Initiative.pdf.

"Tree Equity Score." Accessed August 13, 2020. https://www.treeequityscore.org.

Anderson et al. "Conserving Plant Diversity in New England." Native Plant Trust and The Nature Conservancy, 2021. https://www.nativeplanttrust.org/documents/827/ConservingPlantDiversity_FullReport_Final_6.19.21.pdf.

Belair, Ethan P., and Mark J. Ducey. "Patterns in Forest Harvesting in New England and New York: Using FIA Data to Evaluate Silvicultural Outcomes." *Journal of Forestry* 116, no. 3 (May 4, 2018): 273–82. https://doi.org/10.1093/jofore/fvx019.

Boden, T., R. Andres, and G. Marland. "Global, Regional, and National Fossil-Fuel CO2 Emissions (1751 - 2014) (V. 2017)." Environmental System Science Data Infrastructure for a Virtual Ecosystem; Carbon Dioxide Information Analysis Center (CDIAC), Oak Ridge National Laboratory (ORNL), Oak Ridge, TN (United States), 2017. https://doi.org/10.3334/CDIAC/00001_V2017.

Bratman, G. N., Hamilton, J. P., Hahn, K. S., Daily, G. C., & Gross, J. J. (2015). Nature experience reduces rumination and subgenual prefrontal cortex activation. Proceedings Visit standupforforests.org for more information. 8 of the National Academy of Sciences, 112(28), 8567-8572. doi:10.1073/pnas.1510459112

Butler, Brett J., Susan J. Crocker, Grant M. Domke, Cassandra M. Kurtz, Tonya W. Lister, Patrick D. Miles, Randall S. Morin, Ronald J. Piva, Rachel Riemann, and Christopher W. Woodall. "The Forests of Southern New England, 2012." Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station, 2015. https://doi.org/10.2737/NRS-RB-97.

Cook-Patton, Susan C., Sara M. Leavitt, David Gibbs, Nancy L. Harris, Kristine Lister, Kristina J. Anderson-Teixeira, Russell D. Briggs, et al. "Mapping Carbon Accumulation Potential from Global Natural Forest Regrowth." *Nature* 585, no. 7826 (September 24, 2020): 545–50. https://doi.org/10.1038/s41586-020-2686-x.

CT DEEP, Governor's Council on Climate Change. "Taking Action on Climate Change and Building a More Resilient Connecticut for All: Phase I Report: Near-Term Actions," January 2021. https://portal.ct.gov/-/media/DEEP/climatechange/GC3/GC3_Phase1_Report_Jan2021.pdf.

Daigneault, Adam, and Aaron Strong. "An Economic Case for the Sebago Watershed Water & Forest Conservation Fund." University of Maine, November 2018. https://www.sebagocleanwaters.org/wp-content/uploads/2020/03/Sebago-Lake-Report.pdf.

D'Amato, Anthony W., John B. Bradford, Shawn Fraver, and Brian J. Palik. "Forest Management for Mitigation and Adaptation to Climate Change: Insights from Long-Term Silviculture Experiments." *Forest Ecology and Management* 262, no. 5 (September 1, 2011): 803–16. https://doi.org/10.1016/j.foreco.2011.05.014.

DeGraaf, Richard M., and Mariko Yamasaki. *New England Wildlife: Habitat, Natural History, and Distribution*. Hanover, NH: University Press of New England, 2001.

Domke, Grant M., Sonja N. Oswalt, Brian F. Walters, and Randall S. Morin. "Tree Planting Has the Potential to Increase Carbon Sequestration Capacity of Forests in the United States." *Proceedings of the National Academy of Sciences* 117, no. 40 (October 6, 2020): 24649–51. https://doi.org/10.1073/pnas.2010840117.

Domke, Grant M., Brian F. Walters, David J. Nowak, James E. Smith, Stephen M. Ogle, J.W. Coulston, and T.C. Wirth. "Greenhouse Gas Emissions and Removals from Forest Land, Woodlands, and Urban Trees in the United States, 1990-2018." Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station, April 16, 2020. https://doi.org/10.2737/FS-RU-227.

Duveneck, Matthew J., and Jonathan R. Thompson. "Social and Biophysical Determinants of Future Forest Conditions in New England: Effects of a Modern Land-Use Regime." *Global Environmental Change* 55 (March 2019): 115–29. https://doi.org/10.1016/j.gloenvcha.2019.01.009.

Fargione, Joseph E., Steven Bassett, Timothy Boucher, Scott D. Bridgham, Richard T. Conant, Susan C. Cook-Patton, Peter W. Ellis, et al. "Natural Climate Solutions for the United States." *Science Advances* 4, no. 11 (November 2, 2018): eaat1869. https://doi.org/10.1126/sciadv.aat1869.

Foster et al. *Wildlands and Woodlands: Farmlands and Communities: Broadening the Vision for New England*. Petersham, Massachusetts: Harvard Forest, Harvard University, 2017.

Foster et al. 2022

Frumkin, Howard, and Richard Louv. "The Powerful Link Between Conserving Land and Preserving Health." Land Trust Alliance Special Anniversary Report, 2007. http://arachnid.biosci.utexas.edu/courses/thoc/Readings/Nature-Health.pdf.

Griscom, Bronson W., Justin Adams, Peter W. Ellis, Richard A. Houghton, Guy Lomax, Daniela A. Miteva, William H. Schlesinger, et al. "Natural Climate Solutions." *Proceedings of the National Academy of Sciences* 114, no. 44 (October 31, 2017): 11645–50. https://doi.org/10.1073/pnas.1710465114.

Gunn, John S., Mark J. Ducey, and Ethan Belair. "Evaluating Degradation in a North American Temperate Forest." *Forest Ecology and Management* 432 (January 15, 2019): 415–26. https://doi.org/10.1016/j.foreco.2018.09.046.

Harris, N. L., S. C. Hagen, S. S. Saatchi, T. R. H. Pearson, C. W. Woodall, G. M. Domke, B. H. Braswell, et al. "Attribution of Net Carbon Change by Disturbance Type across Forest Lands of the Conterminous United States." *Carbon Balance and Management* 11, no. 1 (December 2016): 24. https://doi.org/10.1186/s13021-016-0066-5.

Holland, Isabel, and Spencer R. Meyer. "The Economic Case for Conservation: A Synthesis of the Economic Impacts of Natural Resources and Conservation in New England," 2018. https://www.wildlandsandwoodlands.org/sites/default/files/The%20Economic%20Case%20for%20Conservation.pdf.

Intergovernmental Panel on Climate Change. "Land Use, Land-Use Change and Forestry, Appendix III Glossary," 2000. https://archive.ipcc.ch/ipccreports/sres/land_use/index.php?idp=13.

Kaarakka, Lilli, Meredith Cornett, Grant Domke, Todd Ontl, and Laura E. Dee. "Improved Forest Management as a Natural Climate Solution: A Review." *Ecological Solutions and Evidence* 2, no. 3 (July 2021). https://doi.org/10.1002/2688-8319.12090.

Keeton, William S. "Source or Sink? Carbon Dynamics in Eastern Old-Growth Forests and Their Role in Climate Change Mitigation." In *Ecology and Recovery of Eastern Old-Growth Forests*, edited by Andrew M. Barton and William S. Keeton, 267–88. Washington, DC: Island Press/Center for Resource Economics, 2018. https://doi.org/10.5822/978-1-61091-891-6_14.

King, David I., and Scott Schlossberg. "Synthesis of the Conservation Value of the Early-Successional Stage in Forests of Eastern North America." *Forest Ecology and Management* 324 (July 2014): 186–95. https://doi.org/10.1016/j.foreco.2013.12.001.

Kroeger, Timm, Robert I. McDonald, Timothy Boucher, Ping Zhang, and Longzhu Wang. "Where the People Are: Current Trends and Future Potential Targeted Investments in Urban Trees for PM10 and Temperature Mitigation in 27 U.S. Cities." *Landscape and Urban Planning* 177 (September 2018): 227–40. https://doi.org/10.1016/j.landurbplan.2018.05.014.

Leiserowitz, A et al. "Climate Activism: Beliefs, Attitudes, and Behaviors, November 2019." Yale University and George Mason University. New Haven, CT: Yale Program on Climate Change Communication, 2019. https://climatecommunication.yale.edu/publications/climate-activism-beliefs-attitudes-and-behaviors-november-2019/.

Lovett, Gary M., Marissa Weiss, Andrew M. Liebhold, Thomas P. Holmes, Brian Leung, Kathy Fallon Lambert, David A. Orwig, et al. "Nonnative Forest Insects and Pathogens in the United States: Impacts and Policy Options." Edited by Y. Pan. *Ecological Applications* 26, no. 5 (July 2016): 1437–55. https://doi.org/10.1890/15-1176.

MA EEA. "Buildings Sector Report: A Technical Report of the Massachusetts 2050 Decarbonization Roadmap Study." Massachusetts Executive Office of Energy and Environmental Affairs, December 2020. https://www.mass.gov/doc/building-sector-technical-report/download.

Maine Forest Products Council. "Maine's Forest Economy," 2018. https://maineforest.org/wp-content/uploads/2022/08/Maines-Forest-Economy.pdf.

Nowak, David J., and Eric J. Greenfield. "Declining Urban and Community Tree Cover in the United States." *Urban Forestry & Urban Greening* 32 (May 2018): 32–55. https://doi.org/10.1016/j.ufug.2018.03.006.

Nowak, David J., Eric J. Greenfield, Robert E. Hoehn, and Elizabeth Lapoint. "Carbon Storage and Sequestration by Trees in Urban and Community Areas of the United States." *Environmental Pollution* 178 (July 2013): 229–36. https://doi.org/10.1016/j.envpol.2013.03.019.

Nunery, Jared S., and William S. Keeton. "Forest Carbon Storage in the Northeastern United States: Net Effects of Harvesting Frequency, Post-Harvest Retention, and Wood Products." *Forest Ecology and Management* 259, no. 8 (March 31, 2010): 1363–75. https://doi.org/10.1016/j.foreco.2009.12.029.

Pew Research Center. "U.S. Public Views on Climate and Energy," 2019. https://www.pewresearch.org/fact-tank/2020/04/21/how-americans-see-climate-change-and-the-environment-in-7-charts/ft_2020-04-21_earthday_01/.

Raciti, Steve M., Lucy R. Hutyra, and Adrien C. Finzi. "Depleted Soil Carbon and Nitrogen Pools beneath Impervious Surfaces." *Environmental Pollution* 164 (May 2012): 248–51. https://doi.org/10.1016/j.envpol.2012.01.046.

Rowland-Shea, Jenny, Sahir Doshi, Shanna Edberg, and Robert Fanger. "The Nature Gap: Confronting Racial and Economic Disparities in the Destruction and Protection of Nature in America." Center for American Progress, July 2020. https://www.americanprogress.org/wp-content/uploads/2020/07/The-Nature-Gap4.pdf.

Sullivan, Riley. "Aging and Declining Populations in Northern New England: Is There a Role for Immigration?" New England Public Policy Center Regional Briefs. Federal Reserve Bank of Boston, 2019. https://www.bostonfed.org/publications/new-england-public-policy-center-regional-briefs/2019/aging-and-declining-populations-in-northern-new-england.aspx.

Thom, Dominik, Marina Golivets, Laura Edling, Garrett W. Meigs, Jesse D. Gourevitch, Laura J. Sonter, Gillian L. Galford, and William S. Keeton. "The Climate Sensitivity of Carbon, Timber, and Species Richness Covaries with Forest Age in Boreal–Temperate North America." *Global Change Biology* 25, no. 7 (July 2019): 2446–58. https://doi.org/10.1111/gcb.14656.

Thompson, Jonathan R., Joshua S. Plisinski, Pontus Olofsson, Christopher E. Holden, and Matthew J. Duveneck. "Forest Loss in New England: A Projection of Recent Trends." Edited by Robert F. Baldwin. *PLOS ONE* 12, no. 12 (December 14, 2017): e0189636. https://doi.org/10.1371/journal.pone.0189636.

U.N. DESA. "World Urbanization Prospects: The 2018 Revision." United Nations Department of Economic and Social Affairs, 2018. https://population.un.org/wup/Publications/Files/WUP2018-Report.pdf.

U.S. Census Bureau. "Decennial Census 2010," 2010. https://www.census.gov/programs-surveys/decennial-census/decade.2010.html#list-tab-SCKSX2FFUDT26LP6AR.

U.S. EPA. "Inventory of U.S. Greenhouse Gas Emissions and Sinks, 1990-2020," 2022. https://www.epa.gov/ghgemissions/draft-inventory-us-greenhouse-gas-emissions-and-sinks-1990-2020.

Walker, Anthony P., Martin G. De Kauwe, Ana Bastos, Soumaya Belmecheri, Katerina Georgiou, Ralph F. Keeling, Sean M. McMahon, et al. "Integrating the Evidence for a Terrestrial Carbon Sink Caused by Increasing Atmospheric CO_2." *New Phytologist* 229, no. 5 (March 2021): 2413–45. https://doi.org/10.1111/nph.16866.

Walters, Brian F., Grant M. Domke, David J. Nowak, James E. Smith, and Stephen M. Ogle. "Greenhouse Gas Emissions and Removals from Forest Land, Woodlands, and Urban Trees in the United States, 1990-2019: Estimates and Quantitative Uncertainty for Individual States." Accessed October 9, 2022. https://doi.org/10.2737/RDS-2021-0035.

Wu, Jianyong, Ying Zhou, Yang Gao, Joshua S. Fu, Brent A. Johnson, Cheng Huang, Young-Min Kim, and Yang Liu. "Estimation and Uncertainty Analysis of Impacts of Future Heat Waves on Mortality in the Eastern United States." *Environmental Health Perspectives* 122, no. 1 (January 2014): 10–16. https://doi.org/10.1289/ehp.1306670.

Young, Stephen S., and Joshua S. Young. "Overall Warming with Reduced Seasonality: Temperature Change in New England, USA, 1900–2020." *Climate* 9, no. 12 (December 6, 2021): 176. https://doi.org/10.3390/cli9120176.

Zlonis, Edmund J., and Gerald J. Niemi. "Avian Communities of Managed and Wilderness Hemiboreal Forests." *Forest Ecology and Management* 328 (September 2014): 26–34. https://doi.org/10.1016/j.foreco.2014.05.017.

Highstead

About Highstead

Highstead is a regional conservation non-profit based in Redding, Connecticut, that is dedicated to increasing the pace of land protection in New England and beyond through science, sound stewardship and collaboration with diverse partners.

highstead.net

Report Graphics: Tewosret Vaughn
Report Design: RavenMark, LLC

Photos:
Covers: Adobe stock
Page 6: David R. Foster
Page 8: Brian O'Connor
Page 9: Linda Mirabile
Page 11: Adobe stock
Page 14: Adobe stock
Page 16: Charlie Reinertsen Photography
Page 23: Rob Lilieholm
Page 27: David R. Foster
Page 28: David Kittredge
Page 35: Adobe stock
Page 37: Adobe stock
Page 41: Nina Mirabile

ISBN: 979-8-218-09736-3