Rhode Island
Department of
Environmental
Management
OFFICE OF AIR RESOURCES

2019 Rhode Island Greenhouse Gas Emissions Inventory

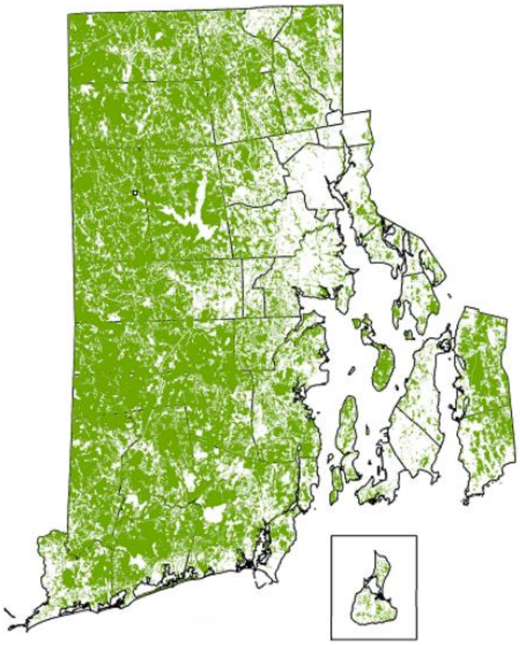
Accounting Carbon Sequestration from LULUCF

The Executive Climate Change Coordinating Council (EC^4) sharing session on March 16, 2022 highlighted the need for a carbon-sequestration sector in Rhode Island's annual greenhouse gas (GHG) emissions inventory. According to the U.S. Geological Survey, carbon sequestration is the process of capturing and storing atmospheric carbon dioxide. The state's 1990 GHG inventory and 2010 GHG inventory account for seven GHG emission sectors and one GHG sequestration sector, known as Land-Use, Land-Use Change, and Forestry (LULUCF). The presence of this sector in 1990 and 2010 prevents an apples-to-apples comparison to inventory years 2011 - 2018. To meet the 2021 Act on Climate's emission reduction mandates and achieve net-zero in 2050, all new inventories must include a LULUCF sector.

Background

Rhode Island's small and diverse landscape is inherently difficult to account for carbon sequestration. The 1990 LULUCF estimate was calculated through a one-time contract with the Northeast States for Coordinated Air Use Management (NESCAUM) and is not replicable. Additionally, the 2010 LULUCF estimate was calculated through the Long-range Energy Alternatives Planning (LEAP) model used in the *Rhode Island Greenhouse Gas Emissions Reduction Plan (2016)* and is not replicable.

RIDEM can estimate LULUCF through the EPA's State Inventory Tool (SIT), which is used for most of the statewide GHG emissions inventory. The SIT is preloaded with default LULUCF data that is nationally apportioned to Rhode Island. Default inputs are listed below and ranked by their share of the total. Asterisks indicate inputs already provided by RIDEM's Division of Forest Environment (DFE) annually.



Extent of Forests in Rhode Island

Forest Carbon Flux

1. Aboveground Biomass (30%)
2. Deadwood (19%)
3. Mineral Soil (7%)
4. Belowground Biomass (6%)
5. Litter (5%)
6. Organic Soil (1%)
7. Wood Products/Landfills (<1%)

Additional Inputs

1. Carbon Sequestration from Urban Trees (28%) *
2. Carbon Stored in Yard Trimmings (3%)
3. Agricultural Soil Carbon Flux (1%)
4. Carbon Emissions from Forest Fires (<1%) *
5. N_2O From Settlement Soils (<1%)

Quantitative estimates may be subject to change. Annual inventories allow the Department to track progress towards Act on Climate mandates but are not considered official until published in a triennial summary.

Since the SIT's default data is nationally apportioned to states, it may not be accurate for the New England region. Connecticut, Massachusetts, and Vermont have also felt the SIT's default LULUCF data is unreliable. For this reason, RIDEM decided to omit LULUCF from the inventory between 2011 and 2018.

Estimating Carbon Sequestration from Aboveground Biomass

To ensure Rhode Island's carbon sequestration estimate reflects the local landscape, RIDEM replaced the SIT's aboveground biomass estimate with RI-specific data from DFE's *2020 Forest Action Plan*. Every ten years, DFE is required to submit a forest action plan to the U.S. Forest Service (USFS). Within the action plan, estimates for the **total forest land in RI**, **percentages of each forest type**, and **sequestration factors for each forest type** are provided by USFS's Forest Inventory and Analysis (FIA) program. RIDEM can use this information to estimate carbon sequestration from aboveground biomass, the largest subsector of LULUCF. The following example calculation demonstrates how carbon sequestration is estimated for oak/hickory forest:

- Oak/hickory sequesters an average of 1.46 $MTCO_2$/acre/year
- Oak/hickory covers ~61.0% or 220,287.47 acres of RI forest
- 1.46 $MTCO_2$/acre * 220,287.47 acres / 1,000,000 = 0.32 $MMTCO_2$/year

This calculation is repeated for all nine forest types, summed, and substituted into the SIT. Tee Jay Boudreau, DFE Deputy Chief, reiterated that the *2020 Forest Action Plan's* FIA data is reliable for Rhode Island. New **percentages of each forest type** and **total forest land in RI** can be requested annually from DFE. When the next forest action plan is published in 2030, **sequestration factors for each forest type** will be updated. Boudreau mentioned the current sequestration factors are adequate for the next ten years. With DFE's data, 94% of LULUCF would originate from local sources and 6% would originate from the SIT's default data.

RIDEM recognizes this methodology update has small drawbacks. When a specific input (such as aboveground biomass) is replaced in the SIT, the possibility of using any default forest carbon flux data is eliminated. The six remaining forest carbon flux inputs (deadwood, mineral soil, belowground biomass, forest litter, organic soil, and wood products) would be omitted from the inventory. Additionally, since the definition of forest land and urban area could slightly overlap, a small amount of overcounting sequestration between subsectors is possible.

Conclusion

Rhode Island requires an accurate LULUCF sector to meet the Act on Climate's 2050 'net-zero' emissions mandate. Additionally, an apples-to-apples comparison between 1990 and new inventories is impossible without a carbon sequestration sector. To recap, the following subsectors are now included in Rhode Island's LULUCF sector estimate:

- Aboveground Biomass
- Carbon Sequestration from Urban Trees
- Carbon Stored in Yard Trimmings
- Agricultural Soil Carbon Flux
- Carbon Emissions from Forest Fires
- N_2O From Settlement Soils

2019’s LULUCF estimate represents a **first step** towards a reliable carbon sequestration sector for Rhode Island and should not be compared with other state’s sequestration sectors at this time. In the future, RIDEM will work towards achieving a more precise picture of carbon sequestration in Rhode Island. Partners such as the U.S. Climate Alliance, NESCAUM, and other state environmental agencies will help facilitate this growth.

Comments Received

RIDEM held a public comment period on this technical document between September 15, 2022 and October 14, 2022. The responses RIDEM received are listed here:

1. Greg Gerritt
2. Barbara Walsh
3. Jamie Matthews
4. Sue AnderBois

Greg Gerritt

RI absolutely needs ot account for carbon stored in the land, above ground in vegetation and below ground. Land conversions are a big loss for Rhode Island, as we contnue to lose forest land to parking lots and roads. In addition to counting the carbon stored that is lost when land is converted, we should also be including in this measure the additional GHG's that are created by the expansion of driving that coes about when we create additional roads and parking lots.

Barbara Walsh

It is about time that DEM would recognize the value of undisturbed forests, soil practices, etc. to address climate change. This now needs to be strongly converted into state policies and practices, legislation and advocacy. For example, DEM has not taken strong enough positions on the need to conserve all state forests - not just 'core' forests over 250 acres per a recent legislative effort. DEM's position should be to conserve all forests regardless of size. DEM should also embrace preserving old growth forests instead of denigrating such proposals. DEM should be stronger advocates and educators to the governor's office and his policies. The state should never support solar farms on any forested areas, nor should DEM have been silent on the legislation giving solar farms a tax advantage that other corporations do not receive after destroying woodlands and building solar farms. DEM should have advised the governor not to sign this bill. There should be far more support given to roof top solar and canopies on all state properties; there should be more support and advocacy to municipalities to do the same. DEM should no longer keep a 'hands off' position on the rights of owners and municipalities to destroy any woodlands - you should educate and advocate for alternatives, e.g., destroying 5 acres of open space in Pawtucket for a parking lot is outrageous. Destroying 50 acres in Cranston, Johnston, Warwick, etc. is outrageous. DEM should have a stronger advocacy role and provide more funds and information to protect these parcels. If we simply leave woodlands alone, they will help to combat climate change, allowing DEM to focus more on managing other sectors that address carbon emissions.

Jamie Matthews

Dear Joseph,

I feel that is extremely important when counting areas of carbon sequestration, that you continue to look towards coastal carbon sinks, such as salt marshes and sea grass beds, and kelp production. These areas of blue carbon are extremely important to consider when measuring our ability to sequester carbon amidst the Act on Climate goals.

Restoration and protection of salt marshes and sea grass beds are essential in its ability store carbon and should not be left out of this important report. Kelp farming is on the rise in the state, and the role that kelp plays in capturing carbon should also be included.

I have attached a link to article that outlines the importance of Blue Carbon in the work of carbon mitigation and sequestrations.

Many thanks,
Jamie Matthews

https://www.frontiersin.org/articles/10.3389/fclim.2021.710546/full

Sue AnderBois

Dear Joseph,

I hope that this note finds you well. I am submitting these comments on behalf of The Nature Conservancy. (The pulldown only had the option for individual, but I am submitting on behalf of an organization).

Thank you for the opportunity to provide comments and input on the Land Use, Land Use Change and Forestry components of Act on Climate implementation. Partnering with TNC Northeast Regional Science-staff, we respectfully submit the following three primary comments.

1. We have attached an updated report created for the U.S. Climate Alliance by Clark University that includes datasets designed to address the questions that DEM has raised about Land Use and Land Use Change. The report has a link to all of the data sets that were used, referenced on page 26. We are happy to help connect you with the researchers at Clark, with whom our science team has worked closely, if that is a helpful connection.

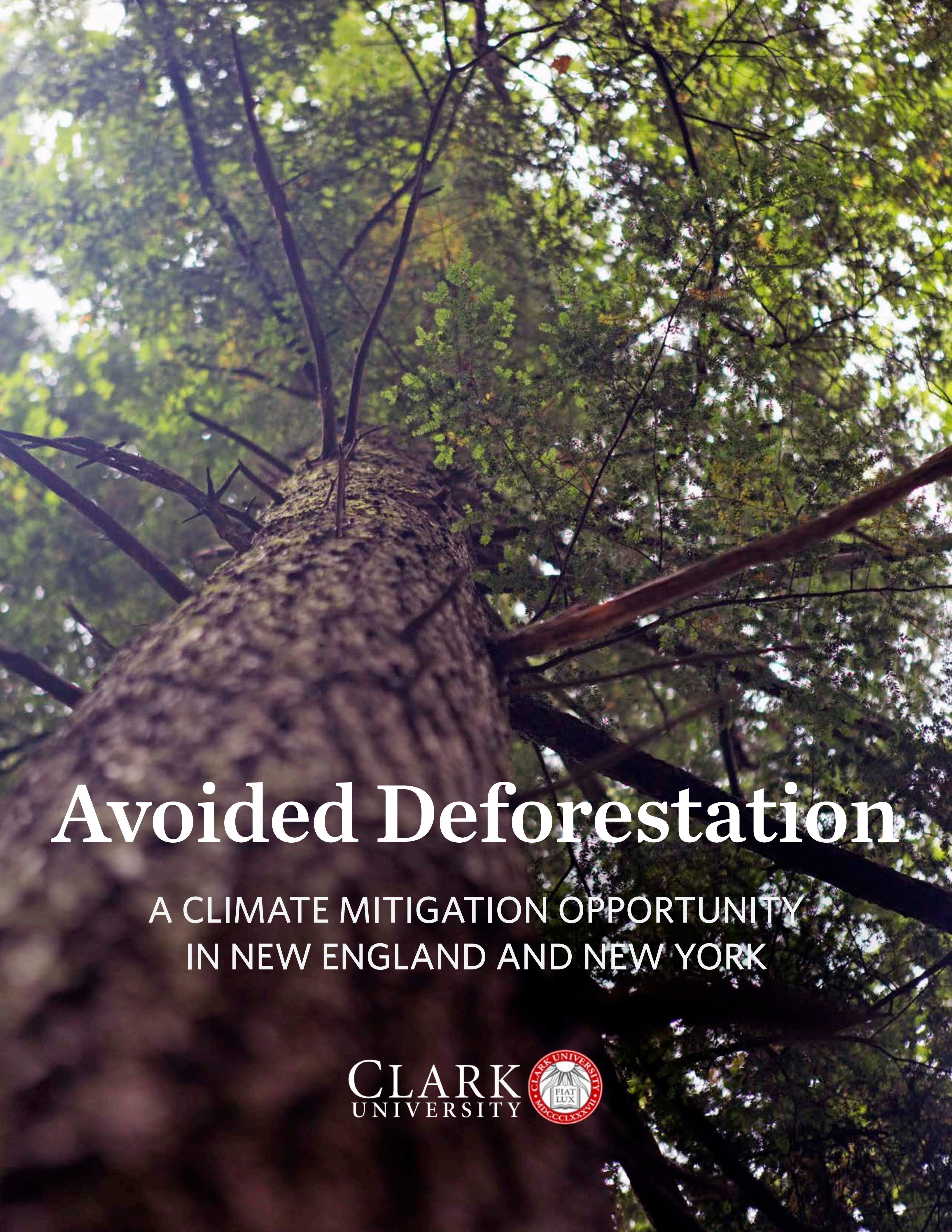
2. Rhode Island could benefit from harmonizing our approach with our neighboring states who have similarly aggressive climate goals and fairly similar types of forests and open space. Our Massachusetts staff have been working with staff at the Executive Office of Energy and Environmental Affairs in MA on similar issues - and they recently hired Dunbar Carpenter as their new carbon inventory guru. If this is not someone with whom DEM has a relationship and you feel it would be beneficial to connect, we are happy to make the connection.

3. While we believe strongly in the importance of data and metrics, we also urge at this moment to focus most of our time and energy on taking action and enacting policy that we know will help us achieve our climate goals on land use. As LIDAR and remote sensing technology improves in efficiency and lowers in cost, we will be able to increase our granularity of the data over time. However, we know now many of the things that move us in the direction we need to go: land protection, reforestation, climate smart forest management. These are no regrets strategies that we need to aggressively implement now to ensure we are on the path to achieving our carbon goals, regardless of small potential modeling differences between different methodologies.

Thank you so much for the opportunity to provide these comments. We are available any time to answer any questions or to help direct to additional resources or be helpful in any way we can.

With Gratitude,

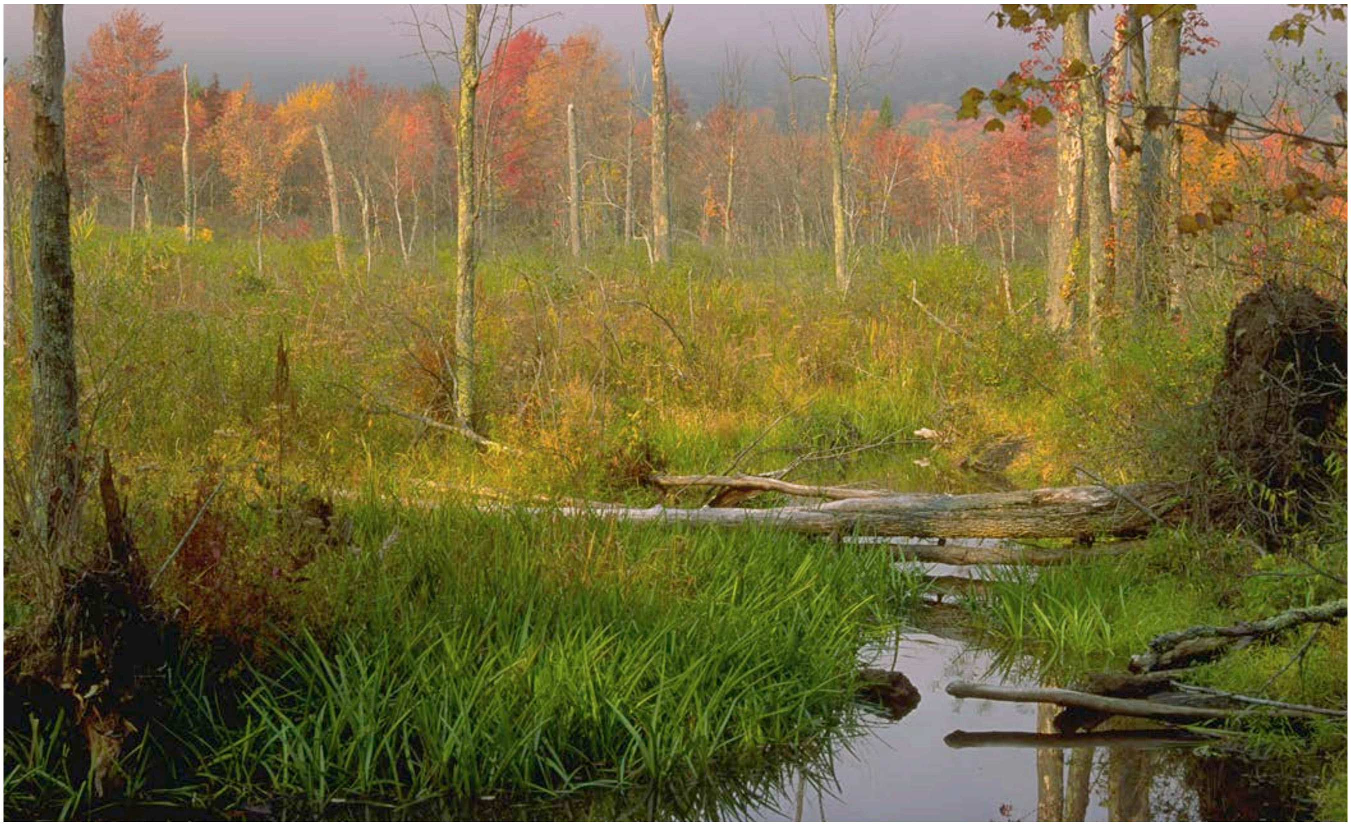
Sue AnderBois
The Nature Conservancy
Susan.AnderBois@tnc.org



Avoided Deforestation

A CLIMATE MITIGATION OPPORTUNITY IN NEW ENGLAND AND NEW YORK

CLARK
UNIVERSITY



This report was prepared by the research group of Dr. Christopher A. Williams at Clark University for the United States Climate Alliance Grant Program for Natural and Working Lands Research, and for The Nature Conservancy in Massachusetts.

Dr. Christopher A. Williams
Dr. Natalia Hasler
Li Xi (doctoral student)

CLARK UNIVERSITY

Graduate School of Geography
Clark University
950 Main Street
Worcester, MA 01610 USA

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WE ARE IN THE MIDST OF A CLIMATE CRISIS. A steadily increasing excess of carbon dioxide and other greenhouse gases in the Earth's atmosphere, predominantly from fossil fuel use by humans, is driving rapid changes in the global climate system. To avoid catastrophic climate change, it is imperative that we bring atmospheric carbon dioxide levels back down to below 350 parts per million (ppm), yet in 2021, the amount of carbon dioxide in the atmosphere topped 420 ppm.

The most important way to address this climate crisis is to reduce greenhouse gas emissions to zero, principally by switching from fossil fuels to low-carbon alternatives such as renewable energies. Avoiding carbon emissions from deforestation is important as well. However emissions reductions alone will not be enough. We also need to remove excess carbon dioxide from the atmosphere with negative emissions technologies, several of which are provided by nature. Protecting and expanding the carbon stored in forests belongs to a suite of "natural climate solutions" — defined as protecting, restoring, and better managing forests, grasslands, farms and wetlands to reduce and remove carbon emissions and safeguard the climate system.

Deforestation — primarily for residential, commercial and infrastructural development — is a major threat to forests in the northeastern United States. Unlike many other threats to our forests, deforestation is almost always permanent. Deforestation is a direct source of carbon emissions, releasing the carbon stored in trees and roots into the atmosphere as carbon dioxide. It also negates one of the best tools we have for drawing carbon dioxide back out of the atmosphere (forest carbon sequestration). Thus, **slowing the pace of forest loss (avoiding deforestation) is an important instrument in the fight against climate change**.
w

The size of the avoided deforestation opportunity and its spatial distribution had previously been poorly quantified. This study fills that gap with detailed spatial analysis (30 m resolution) that shows where forests have been lost in recent decades, and the carbon impacts of that loss. We found that the states of **New England and New York are releasing a cumulative 4.9 million metric tons of CO2 equivalent into the atmosphere each year due to forest loss. And they are losing out on a cumulative 1.2 million metric tons of CO2 equivalent in carbon sequestration** each year due to that loss. This reduces the region's intact forest carbon sink by about 10%, or amounts to about 2% of the region's CO2e emissions from fossil fuel combustion across all sectors in 2018 (EPA 2020).

In this report you will find detailed descriptions of the methods used, regional maps, and tables and summaries at the state level (informed by multiple meetings with state agency staff throughout the study). The data are free and available on the web (see links in the report) or by contacting the study's authors. Our intent is to deliver actionable information that can assist states with greenhouse gas emissions and removals inventories, as well as with actions that avoid deforestation as a possible component of climate mitigation. The details of forest carbon stocks and sequestration and of forest loss vary by state, but the necessary conclusions do not. **Every state stands to gain by reducing their rate of deforestation, and those benefits compound over time**.

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INTRODUCTION

This study quantifies the climate mitigation that could be achieved by avoiding deforestation in seven states across the northeastern US. Forest losses to development, agriculture and other land uses release carbon to the atmosphere, contributing to greenhouse gas emissions and associated climate change. These forest to non-forest conversions also halt carbon sequestration that would have occurred if the forests had remained intact. Slowing the rate of forest loss presents a climate mitigation opportunity that is of interest to states in the region, and states are interested in more detailed quantification of this opportunity. This study aims to fill that gap by documenting the locations of forest loss in recent decades, assessing the associated carbon emissions and foregone carbon sequestration, and providing summaries at state and county levels along with statewide maps at a 30 m resolution. The intent is to provide actionable information that can inform the general public, and assist states with greenhouse gas emissions and removals inventories as well as with plans to explore avoided deforestation as a possible component of climate mitigation initiatives.

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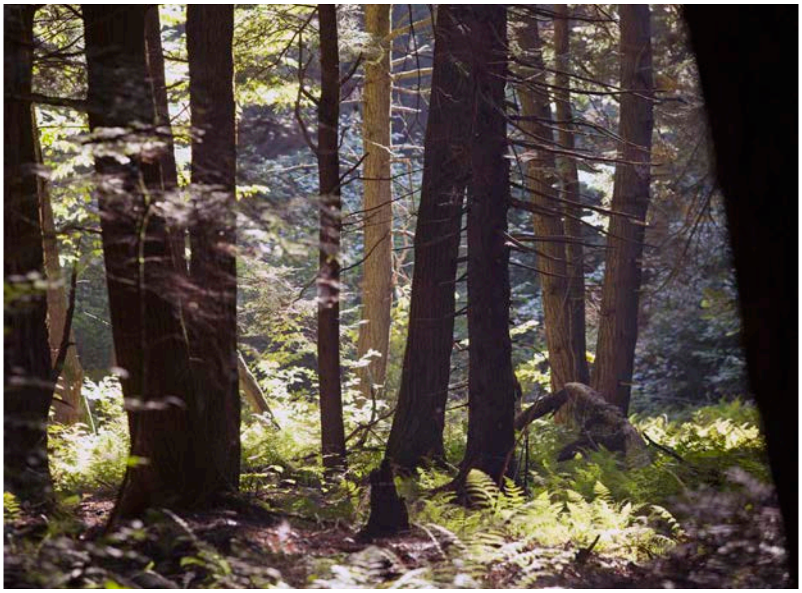

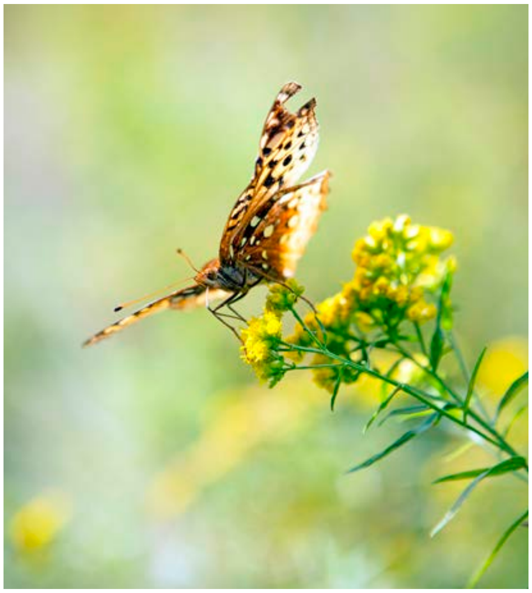

METHODOLOGY

In this study we estimate the *potential emissions* that would occur if areas of present-day forest were to be converted to non-forest, as well as the *actual emissions* associated with forested areas that were converted to non-forest during the 1990s and the 2000s. Also, we estimate the *potential foregone carbon sequestration* that would be lost if forestlands were to be converted in the future, as well as the *actual foregone carbon sequestration* associated with areas of deforestation in the 1990s and 2000s. The combination of greenhouse gas emissions that are avoided, and potential foregone carbon sequestration that is maintained, when deforestation is prevented is referred to here as the *climate mitigation opportunity*.

A number of spatially explicit datasets of land cover and forest carbon were developed for this study. Methods are described in detail below. Section 2.1 explains the combination of satellite and field plot data sets used to map **forest cover**, and to estimate forest **carbon stocks**. Section 2.2 details the equations that estimate the **carbon emissions** caused by conversion of a given forest. Section 2.3 explains how **wood products** were considered since some of the wood from land clearing for conversion is used in long-lived wood products. Section 2.4 covers the amount of **potential carbon sequestration**, or the carbon stock added each year that the forest remains forest and continues to grow without a natural disturbance or harvest. Section 2.5 shows how **actual forest conversion** was mapped using satellite data from two different points in time to look for forested areas that were converted to non-forest and stayed non-forest for at least a decade. Finally, Section 2.6 details the **cost per metric ton of carbon dioxide** if avoided deforestation is used as a climate mitigation strategy.

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2.1 Forest Carbon Stocks

We use our National Forest Carbon Monitoring System (NFCMS) 30-m resolution dataset, published on Oak Ridge National Laboratory DAAC (**https://doi.org/10.3334/ORNLDAAC/1829**) (Williams et al. 2012, Williams et al. 2014, Gu et al. 2016, Gu et al. 2019a, Gu et al. 2019b, Williams et al. 2021b), as a base for estimating forest carbon stocks in 2010, and for any specific year from 1990 to 2010 for which a particular forest tract was marked as having been converted to non-forest. The NFCMS is a comprehensive dataset of pixel-level carbon stocks and fluxes derived from a combination of an inventory-constrained carbon cycle model, satellite-based aboveground biomass, satellite-based forest disturbance mapping, and a set of ancillary datasets characterizing additional forest attributes.

The essence of the NFCMS methodology involves training an ecosystem carbon cycle model, the Carnegie-Ames-Stanford Approach model (CASA, (Potter et al. 1993, Randerson et al. 1996)), to match forest biomass yield curves sampled from the Forest Inventory and Analysis (FIA) database to produce a suite of curves characterizing forest carbon stocks and fluxes with stand age that are uniquely defined for a range of forest type group and site productivity conditions. We then apply these curves to assign forest carbon values for each 30m pixel based on the pixel's attributes, most importantly forest type and stand age. An illustrative example of resulting curves is provided in Figure 1.

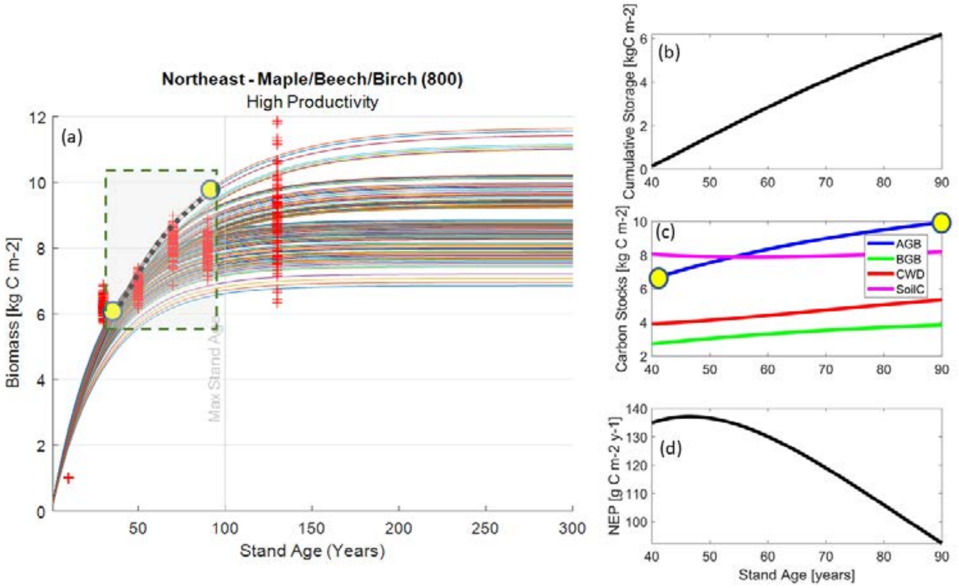

FIGURE 1. Carbon stocks with stand age shown for high productivity stands of the Maple / Beech / Birch forest type group in the northeastern U.S. shown with: (a) individual curves of stand-level aboveground biomass from the NFCMS trained to match statistical samples of FIA data (red plus signs); (b) cumulative carbon storage from 40 to 90 years; (c) carbon stock changes from 40 to 90 years for aboveground biomass (AGB), belowground biomass (BGB), coarse woody debris (CWD), and total soil carbon (SoilC); and (d) annual net ecosystem productivity (NEP) from 40 to 90 years with positive values representing net uptake of carbon from the atmosphere.

We assign forest type to pixels with a USFS dataset (Ruefenacht et al. 2008). We determine each pixel's stand age in the year 2000 with a look-up of the pixel's biomass indexed into the biomass versus stand age yield curve for the pixel's forest type and site productivity class. We define the pixel's biomass in 2000 with the National Biomass Carbon Dataset (NBCD) of Kellndorfer et al. (2013). We increment stand age backwards or forwards in time to represent any year from 1990 to 2010. We reset stand age to one year for all pixels identified as experiencing a stand-replacing disturbance in a given year from 1986 to 2010 according to the North American Forest Dynamics dataset (NAFD, (Goward et al. 2015b), (Zhao et al. 2018)). We also use NAFD to define forest areal extent at the 30 m pixel level. The forest conversion losses described in this work, as well as the results from our grow-only scenarios that are described in section 2.4, provide extensions to our published NFCMS datasets. Forest carbon stocks of present-day forests, as well as stocks expected by 2050 under a grow-only scenario, can be explored at the 30 m resolution in the interactive web-mapping interface of The Nature Conservancy's Resilient Land Mapping Tool (**http://maps.tnc.org/resilientland/**).

2.2 Emissions from Forest to Non-Forest Conversion

We estimate total carbon emissions that resulted from forest conversions that occurred from 1990 to 2010 conversion events, and the emissions that would result from conversion of lands that were forested in 2010 with the following procedure. Put into words, the amount of carbon emitted from forest conversion is composed of (1) a portion of the aboveground biomass carbon in the forest, which varies based on what percentage of the wood from land clearing is turned into wood products (and how long those products last) and what percentage of the wood is immediately emitted through decay or burning, plus (2) an estimate of the remaining carbon pools (belowground wood, coarse woody debris (downed trees), fine roots, and leaves and leaf litter), which are assumed to decay entirely within 20 years of forest loss. Estimates account for emissions from aboveground woody biomass carbon (*AGB*) removed from a forest stand as wood products ("removals"), emissions from all other *AGB* and belowground woody biomass carbon (*BGB*) that is not part of the wood product removals, and emissions from decomposition (or burning) of coarse woody debris (*CWD – both above and below ground*), fine roots (FR), and foliar plus litter carbon (*L*) within forestlands according to the following equation:

$$F_{CO2e} = AGB * f_r * EF_{wp} + [AGB * (1-f_r) + BGB + CWD + FR + L] * EF_{\text{non-wp}} \qquad (1)$$

We assume that all of the biomass carbon not removed for wood products, plus all of the site's coarse woody debris, root and litter carbon is emitted to the atmosphere as CO_2 within 20 years of conversion ($EF_{\text{non-wp}}$ = 100%). We assume that mineral soil carbon is not vulnerable to prompt emission as a result of forest to non-forest conversion, consistent with reports of equivocal findings for conversions to residential lands (Milesi et al. 2005, Campbell et al. 2014). We estimate the fraction of woody biomass removed for wood products (f_r averaging 72% for hardwoods to about 74% for softwoods) for each specific forest type group using data from the USFS Timber Product Output (TPO) online database (USDA 2012).

We estimate the proportion (EF_{wp}) of biomass removals that is emitted from the wood products stream over time with methods detailed below (see section 2.3). This proportion varies by forest type as described in the timber products output tables of the US Forest Service combined with the WOODCARB2 model of the US Forest Service. We estimate the fraction emitted within 40 years as CO_2e, including accounting for the chemical nature of the emissions as either CO_2 or CH_4, and using a 100-year global warming potential (GWP-100) for CH_4 equal to 28 times that of CO_2 (Myhre et al. 2013). This corresponds to the timeframe of committed emissions commonly used in studies of the carbon consequences of land conversion.

Using equation 1 as above, emissions from forestlands are calculated for each pixel individually according to the ecosystem's pre-conversion carbon pools (i.e. carbon stocks). For actual conversions detected with satellite data products, emissions from all pixels converted in the same decade are reported in a single map, i.e. emissions from forestlands converted from 1990 to 1999 are reported on the 1990s maps, emissions from forestlands converted from 2000 to 2009 are reported on the 2000s map, etc., regardless of the year of conversion within the decade. This approach estimates the actual emissions for each pixel accumulated for 40 years post-conversion, as described below, regardless of when that conversion occurred within the decadal interval. For emissions from potential future conversions, year 2010 carbon stocks are used as the baseline.

2.3 Emissions from Wood Harvested During Conversion

To calculate carbon emissions from biomass removals during conversion, we use the NFCMS-adapted version of the US Forest Service WOODCARB2 model (Skog 2008). This model tracks the fate of harvest removals with associated emissions for a range of wood products and including emissions that occur when wood products are discarded and enter the waste stream. A detailed description of the adapted version can be found in supplements of both Zhou et al. (2021) and Gu et al. (2019a). Briefly, we use data from the USDA Forest Service Timber Product Output (TPO) online database (USDA 2012) to estimate the forest-type-specific proportion of wood entering each Harvested Wood Product (HWP) category. For each year after harvest, the model uses exponential decay functions, with half-lifes specific to each HWP category, to calculate the proportion of wood that remains in use. Portions no longer in use are either burned, composted or discarded in Solid Waste Disposal Sites (SWDS). Some of the carbon entering SWDS is stored indefinitely and some is decomposed and released to the atmosphere as either carbon dioxide (CO2) or methane (CH4). To account for methane, we use CO2e units with a standard 100-years global warming potential of 28 (Myhre et al. 2013). We use WOODCARB2's default assumption that half of landfill emissions are released as methane. The disposition and fate of harvest removals varies by forest type as seen in Table 1, unfolds over time as seen in Table 2, and yields carbon storage distributions and cumulative emissions as characterized in Table 3.

TABLE 1. Percent of all NAFD disturbances in the northeast by forest type, as well as the initial (year 1) disposition of harvest removals into harvested wood products of various types, or emitted to the atmosphere from different processes as reported by the USFS Timber Products Output.

	All Forests	Maple / Beech / Birch	Oak / Hickory	Spruce / Fir
Percent of all disturbance by forest type	**100**	**47**	**35**	**10**
Removals stored in HWPs (%)				
Construction	29	22	36	40
Other wood uses	14	11	16	17
Paper	19	24	7	28
Wood in SWDS	1	1	1	1
Paper in SWDS	4	5	1	5
Total removals stored in HWPs (%)	**66**	**62**	**61**	**91**
Removals emitted to the atmosphere (%)				
Burning	33.5	36.9	38.5	7.8
Composting	0.7	0.9	0.4	1.1
CO_2 from Solid Waste Disposal Sites	0.1	0.1	0.0	0.1
CH_4 from Solid Waste Disposal Sites	0.0	0.1	0.0	0.1
Total removals emitted to the atmosphere (%)	**34**	**38**	**39**	**9**

TABLE 2. Fate of harvest removals over time including storage in harvested wood products (HWPs) and emissions to the atmosphere expressed as percent of total harvest removals. Results are from the average across all forest types weighted by their respective material contributions.

	Years after harvest				
	1	10	30	50	100
Percent of removals stored in HWPs					
Construction	29	25	19	15	9
Other wood uses	14	8	3	2	0
Paper	19	2	0	0	0
Wood in SWDS	1	8	15	18	21
Paper in SWDS	4	12	9	7	7
Total of all HWPs	**66**	**54**	**46**	**42**	**37**
Percent of removals released in accumulated flux					
Burning & Composting	34	43	46	48	50
C fluxes from SWDS	0	3	8	10	14
Cumulative release of carbon to the atmosphere	**34**	**46**	**54**	**58**	**63**

TABLE 3. Illustrative example of pre- and post-conversion carbon stocks and cumulative emissions to the atmosphere for a representative case in the northeastern U.S., including stocks and emissions within forests and within the wood products sector and reporting emissions in units of carbon mass and in CO2 equivalents. The example assumes that 72% of aboveground biomass is removed from the forest and delivered to the wood products stream.

	pre-conversion	Year 1	Year 30	Year 100
Forest Stocks [kg C m^{-2}]				
Aboveground Biomass Carbon (AGB)	8.00			
Other Forest Carbon (BGB + CWD + FR + L)	7.92			
Forest Cumulative Emissions [kg C m^{-2}]				
Aboveground Biomass Carbon (AGB)			2.24	2.24
Other Forest Carbon (BGB + CWD + FR + L)			7.92	7.92
HWP Stocks [kg C m^{-2}]				
AGB Removals		5.76		
Removals stored in HWPs [kg C m^{-2}]				
Construction		1.67	1.09	0.50
Other wood uses		0.81	0.17	0.02
Paper		1.09	0.00	0.00
Wood in SWDS		0.06	0.86	1.22
Paper in SWDS		0.23	0.52	0.38
Total removals stored in HWPs		3.80	2.65	2.12
HWP Cumulative Emissions				
Removals emitted to the atmosphere C units [kg C m^{-2}]				
Burning & Composting		1.97	2.67	2.86
C as CO_2 from Solid Waste Disposal Sites		0.01	0.22	0.39
C as CH_4 from Solid Waste Disposal Sites		0.00	0.22	0.39
Total removals emitted to the atmosphere		1.98	3.12	3.64
Removals emitted to the atmosphere CO_2e units [kg CO_2e m^{-2}]				
Burning & Composting		7.22	9.80	10.49
CO_2 from Solid Waste Disposal Sites		0.02	0.81	1.43
CH_4 from Solid Waste Disposal Sites		0.00	8.27	14.58
Total removals emitted to the atmosphere		7.24	18.88	26.50
Total Emissions				
Total Cumulative Emissions C units [kg C m^{-2}]			13.25	13.80
Total Cumulative Emissions CO_2e units [kg CO_2e m^{-2}]			28.96	36.66

Though forest conversions are year-specific events, the resulting committed emissions legacy occurs over decades to centuries. We report the accumulated emission occurring within 40 years after conversion to represent the emissions impact of a conversion event that occurred within a given decade. This 40 year time horizon is long enough to capture the majority of emissions while being short enough to be relevant for climate and land use policies. When summarizing emissions over areas larger than a single pixel, we report the accumulated emissions over 40 years from conversions that occurred within a given decade, and averaged over years within that decade. Materially, the accumulated emissions represent the difference between the forest carbon in aboveground biomass that was removed as harvest during conversion and the proportion that remains stored either in long-term use as a wood product (e.g. in construction) or in solid waste disposal sites, while also accounting for the chemical nature of emissions as CO2 or CH4 and reported as CO2e.

2.4 Foregone Carbon Sequestration

We estimate the carbon sequestration that would occur within 40 years in the absence of forest conversion assuming sustained forest growth and maturation consistent with the FIA yield curves. This "grow-only" scenario represents forest maturation in the absence of a stand-replacing disturbance during the 40 year timeframe, thus being free of forest harvest, forest conversion or a major natural disturbance from severe pest or pathogen attack. We base this on our group's prior work that quantified the net ecosystem productivity and associated carbon storage for forestlands as they vary with a range of stand-level attributes, principally forest type group, site productivity class, and stand age. As described above, the technique first identifies carbon release or uptake as a function of stand age for a wide range of forest types unique to different regions of the US based on forest inventory and analysis (FIA) data combined with a carbon cycle model. We then map carbon stocks to forestlands at a 30 m resolution based on maps of forest type, and stand-level biomass and disturbance histories which are used together to approximate stand age. This well-published method (Williams et al. 2012, Gu et al. 2016, Williams et al. 2016, Gu et al. 2019a, Zhou et al. 2021) is applied here to estimate forest carbon stock accumulation with ensuing forest growth and maturation at an average rate representative for each forest type group and productivity class setting.

We estimate the potential foregone carbon sequestration for all present-day forestlands (forested in 2010) by calculating the difference between the current forest carbon stocks and the carbon stocks expected after 40 years. This quantifies the carbon uptake that would be lost, or foregone, if present-day forestland was to be converted accumulated over 40 years. Results of grow-only sequestration can be explored at the 30 m resolution in the interactive web-mapping interface of the TNC Resilient Land Mapping Tool (**http://maps.tnc.org/resilientland/**).

We estimate the foregone carbon sequestration for each location of actual forest to non-forest conversion during the 1990s and 2000s by calculating the difference between the total ecosystem carbon stocks prior to conversion and the total ecosystem carbon that the forest would have had 40 years later if the forest conversion had not occurred. The difference between the stocks 40 years after conversion and those pre-conversion quantifies the potential carbon sequestration that would occur with sustained forest growth and maturation. For sites of actual forest conversion, results for all pixels converted in the same decade are reported in a single dataset.

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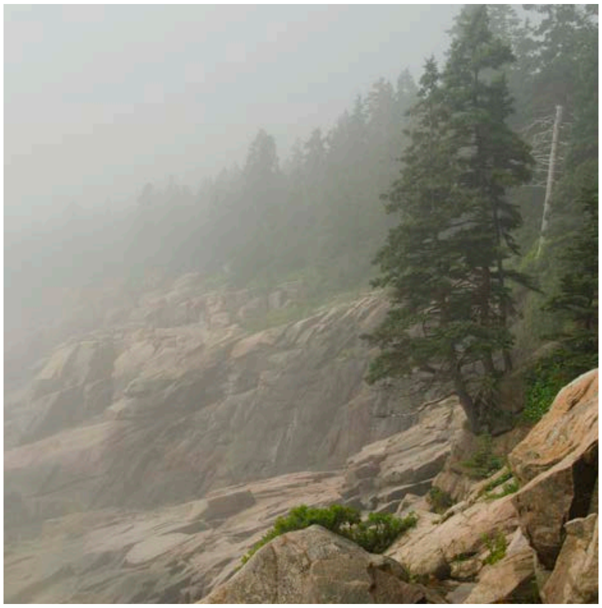
2.5 Mapping of Forest Conversions



We mapped areas of actual forest conversion with a forest disturbance data product filtered to retain only those pixels that persist as non-forest according to the 2016 NLCD (Homer et al. 2020), and restricted to select non-forest land cover classes that most confidently represent lasting forest loss (deforestation). We adopted the widely-used North American Forest Dynamics (NAFD, (Goward et al. 2015a, Zhao et al. 2018)) forest disturbance dataset to identify forested pixels that experienced a stand-replacing disturbance in a given year. The NAFD dataset reports annual forest disturbance and regrowth dynamics from 1986 to 2010 for the conterminous US at a 30 m resolution. It is based on a vegetation change detection algorithm applied to Landsat spectral data (Huang et al. 2009a, Huang et al. 2009b, Huang et al. 2010).

For forest pixels marked with a disturbance in NAFD either in the 1990s (1990 to 1999) or in the 2000s (2000 to 2009), we found the corresponding land cover class in the 2016 NLCD. We considered deforested pixels to be those with a NLCD land cover class of “developed” (NLCD classes 21-24) or “cultivated crops” (NLCD class 82). Restricting the deforestation mapping to only those areas classified as developed or agricultural leads to a conservative, and more confident mapping of forest conversions resulting from human action with a persistent, non-forest land cover. Results for other non-forest classes were recorded as well, such as pasture, grassland, shrubland, wetland, water or bare land, however we did not consider such cases to involve permanent conversion because they often involve either land cover class confusion (e.g. classification algorithms trained on Landsat spectral data often confuse forests with wetlands or woody wetlands) or ensuing forest regrowth (e.g. the land cover mapped for post-harvest forest regrowth often appears as pasture, grassland, savanna or shrubland for several years after harvest). Excluding apparent forest losses to these other classes is important in areas with an active forest harvest industry where disturbed forests often return to forest with ensuing regrowth over decades but that may appear in a satellite-based land cover classification dataset as a non-forest class for the intervening years. Careful filtering in this way is especially important for the most recent disturbances in the record because even when forests regrow after harvest clearing, it can take several years to even a decade for a land cover classification dataset to mark it as returning to forest.

2.6 Cost per Tonne of Mitigation

We estimate the cost of per tonne (metric ton) of CO_2e mitigation with a ratio of land values and the potential climate mitigation (emissions plus foregone sequestration) of avoided deforestation. We adopt the land values dataset of Nolte (2020), representing the cost of purchasing land for conservation interventions based upon the fair market value for all lands determined from analysis of 6 million actual land sales of properties greater than 1 acre from 2000 to 2019 across the contiguous United States. The computation is simply land cost per area divided by potential climate mitigation per area. We note that this analysis was outside the original grant scope and is presented as a courtesy to states, at their request, but may benefit from additional analysis and refinement.

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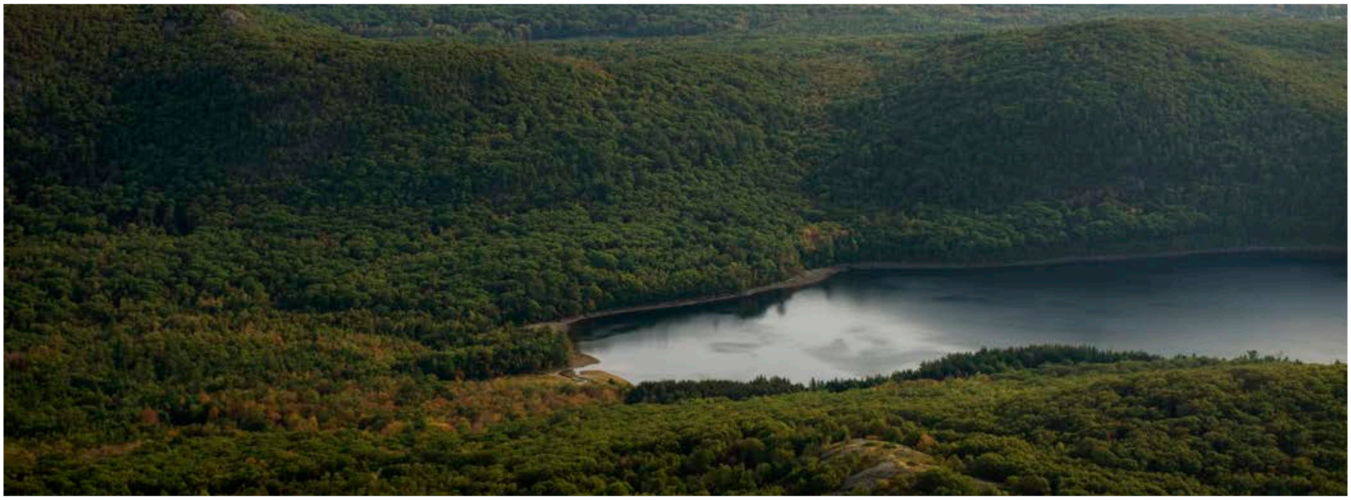

RESULTS AND DISCUSSION

3.1 Findings in This Study

States in the region saw a combined forest loss averaging about 9,500 hectares (23,500 acres) per year in the early 2000s, committing 6 million metric tons of CO_2e to the atmosphere each year (Table 4). Foregone sequestration contributed about 20% of the total carbon burden from avoided deforestation, with the remainder (80%) contributed by carbon emissions. We emphasize in this section the results for the 2000s, being the more recent of the two decadal intervals that are studied, but note that results from the 1990s are very similar in magnitude.

Forest losses are most densely concentrated around urban centers and their suburban sprawl fronts (Figure 2). However, losses are widely spread, including across exurban landscapes where forests tend to have higher biomass (Figure 3) leading to larger CO_2e emissions impacts (Figure 4). Foregone sequestration is larger in areas with younger, lower biomass forests (Figure 5). However, the largest CO_2e mitigation opportunities are in areas with higher, present-day biomass (Figures 6 and 7). Carbon stocks are generally higher in older forests, while the amount of carbon stock added in a given year is higher in younger forests (see growth curves in Figure 1).

The CO_2e impact of forest conversions equates to 3% to 28% of the statewide carbon sequestration occurring within forestlands remaining forestlands (Table 5). Variation across states is related more to the proportion of forestland being converted than to the magnitude of carbon sequestration within forestlands.

The CO_2e impact of forest conversions equates to 9% to 151% of the harvested wood products emissions resulting from state-wide forest harvesting (Table 5). Variation across states is related to both the amount of forest harvesting in each state and the amount of forest conversion. We note that the emissions from harvest removals extracted in a particular state do not necessarily occur within that state given the way harvested materials and wood products cross state lines in response to the locations of mills, markets, and even landfills.

The CO_2e impact of forest conversions equates to about 2% of region-wide fossil fuel emissions across all sectors (Table 5), but is as high as 7% in Maine and 5% in New Hampshire.

The cost per ton of CO_2e associated with purchasing forestland to avoid deforestation varies widely (Figure 8), and is largely driven by the cost of land.

We note that our maps of potential emissions, potential foregone sequestration, and the cost of mitigation show results for the entire landscape, and that they do not account for things like protected lands or other lands that may not be at risk of deforestation.

State-specific summaries are provided in Appendix A.

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TABLE 4. Carbon emissions, foregone carbon sequestration, and total carbon opportunity from avoided deforestation as well as the area of forest converted to developed or agricultural lands by state in the 1990s and 2000s. Emissions and foregone sequestration include 40 years of committed emissions or lost removals resulting from a single year of forestland conversion, including emissions from solid waste disposal sites.

	Carbon Emissions		**Foregone Sequestration**		**Total Opportunity**		**Area Converted**	
	[MMT CO_2e per year]		[MMT CO_2e per year]		[MMT CO_2e per year]		[ha per year]	
	1990s	**2000s**	**1990s**	**2000s**	**1990s**	**2000s**	**1990s**	**2000s**
ME	0.80	0.91	0.19	0.20	0.99	1.11	1,700	1,873
NH	0.46	0.59	0.10	0.12	0.56	0.71	825	1,041
VT	0.14	0.15	0.03	0.03	0.16	0.18	237	252
NY	1.67	1.70	0.42	0.42	2.09	2.12	3,180	3,227
MA	0.99	1.05	0.26	0.26	1.25	1.31	2,023	2,074
CT	0.35	0.42	0.08	0.09	0.43	0.51	675	782
RI	0.11	0.11	0.03	0.03	0.14	0.15	229	239
All	4.52	4.94	1.11	1.15	5.62	6.08	8,869	9,490

TABLE 5. State-level assessment of forest area, annual average disturbed or converted area, carbon stocks and carbon fluxes representative of the 2000s. Estimates are drawn from the NFCMS platform which serves as the base for this study, augmented by this study's estimation of the area and emissions associated with forest to non-forest conversions. Cumulative HWP emissions from total harvest and from conversion-derived harvest have the same assumptions regarding wood products fates and include the same 40 year time horizon.

	ME	NH	VT	NY	MA	CT	RI	All
Area [thousands of hectares]								
Forestland*	7,469.9	2,141.8	2,004.1	8,825.0	1,631.0	1,005.5	199.2	23,276.5
Annual Disturbed Forest*	808.0	144.3	55.9	307.1	75.4	36.7	1.0	1,428.4
Annual Conversion to Agri. or Devel. [#]	1.9	1.0	0.2	3.2	2.1	0.8	0.2	9.4
C Stocks in Forests [MMT C]								
Live Biomass[†]	558	215	201	851	164	103	18	2,110
Forest Carbon[†]	1,399	496	477	2,030	361	220	39	5,022
C Fluxes [MMT CO_2e per year]								
Carbon Sequestration in Forestlands[†]	-16.0	-5.2	-5.3	-25.0	-4.6	-3.1	-0.7	-59.9
Harvest Removals from Forests[†]	11.0	2.4	0.9	4.4	0.9	0.5	0.1	20.2
Harvest HWP Cumulative Emissions[†]	11.8	2.5	1.0	4.7	0.9	0.4	0.1	21.4
Conversion Cumulative Burden[#]	1.1	0.7	0.2	2.1	1.3	0.5	0.2	6.1
Fossil Fuel Emissions All Sectors[§]	15.3	14.5	6.2	172.2	64.7	38.2	11.7	322.8
C Flux Ratios								
Conversion Burden / C Sequestration	7%	14%	3%	8%	28%	16%	22%	10%
Conversion Burden / Harvest Emissions	9%	28%	18%	45%	151%	116%	136%	10%
Conversion Burden / Fossil Fuel Emissions	7%	5%	3%	1%	2%	1%	1%	28%

Sources: *NAFD; [†]NFCMS; [#]this study; [§]EPA (2020) for the year 2018

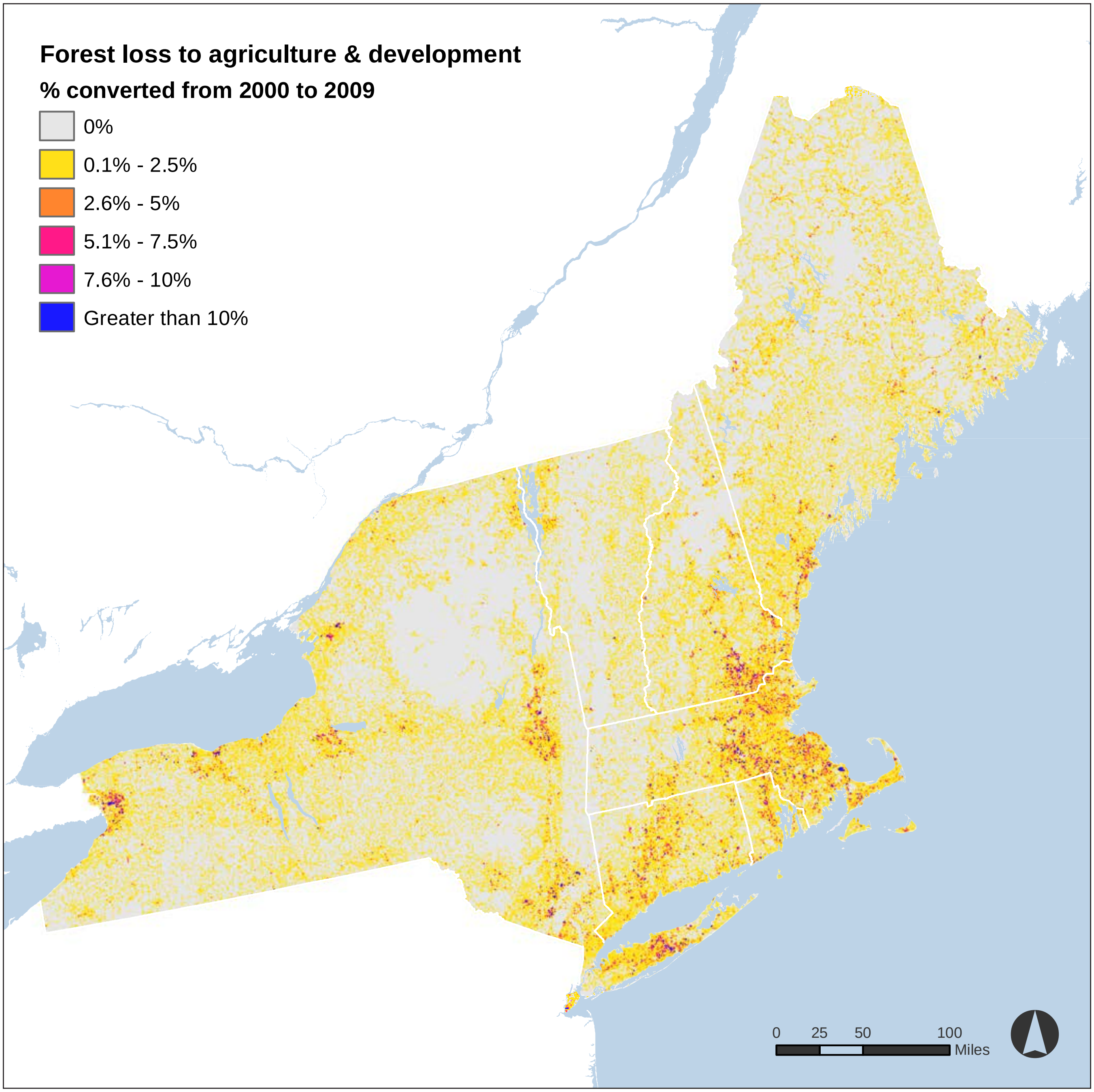

FIGURE 2. Forest loss to agriculture and development from 2000 to 2009 within 990 m x 990 m pixels as percent of total forest in 1999.

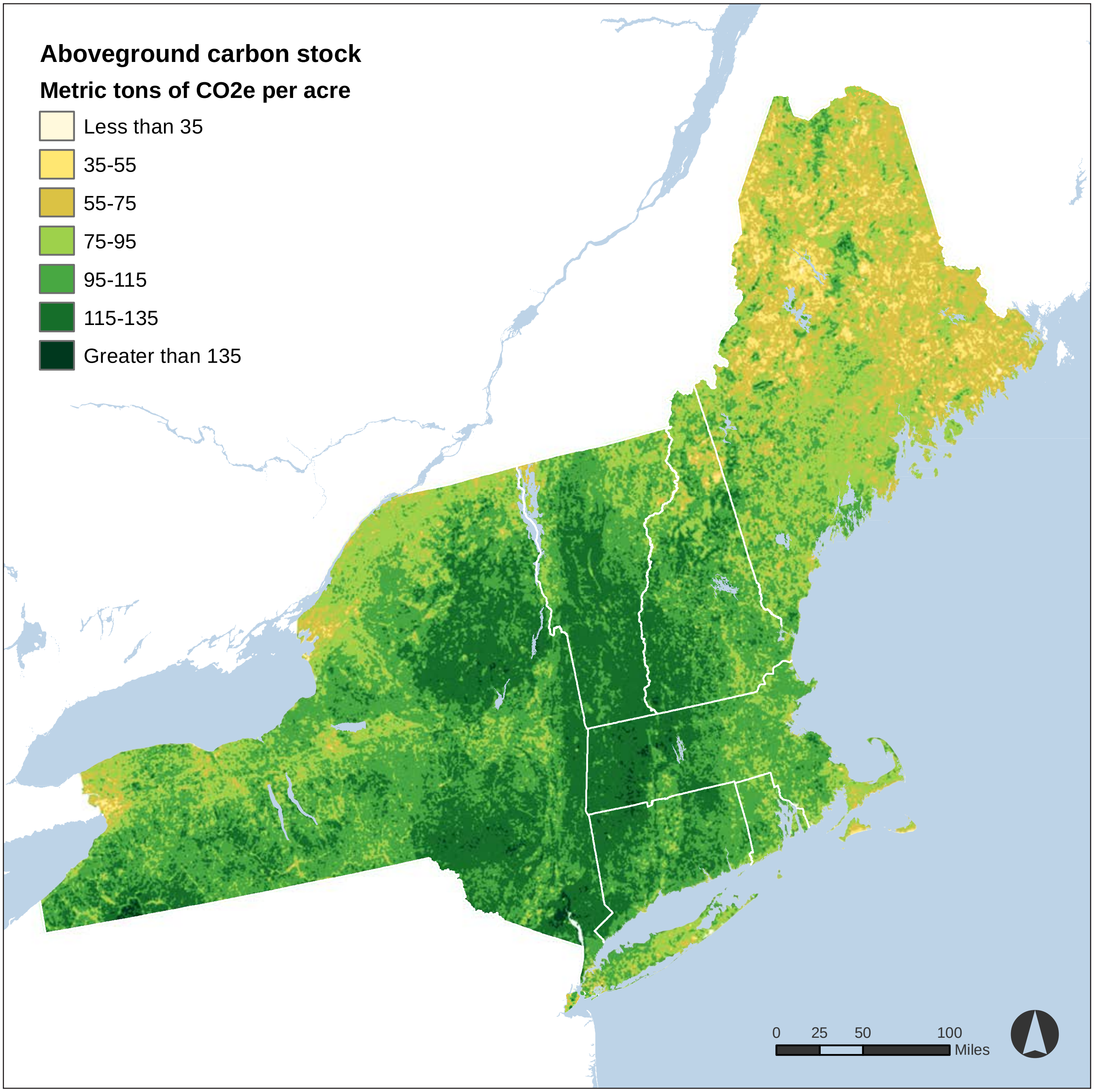

FIGURE 3. Above ground carbon stocks, expressed in metric tons of CO_2e per acre, smoothed from the original dataset with focal statistics that average over a 1 km x 1 km block. The highest value in the original, 30 m resolution map is 210 metric tons of CO_2e per acre.

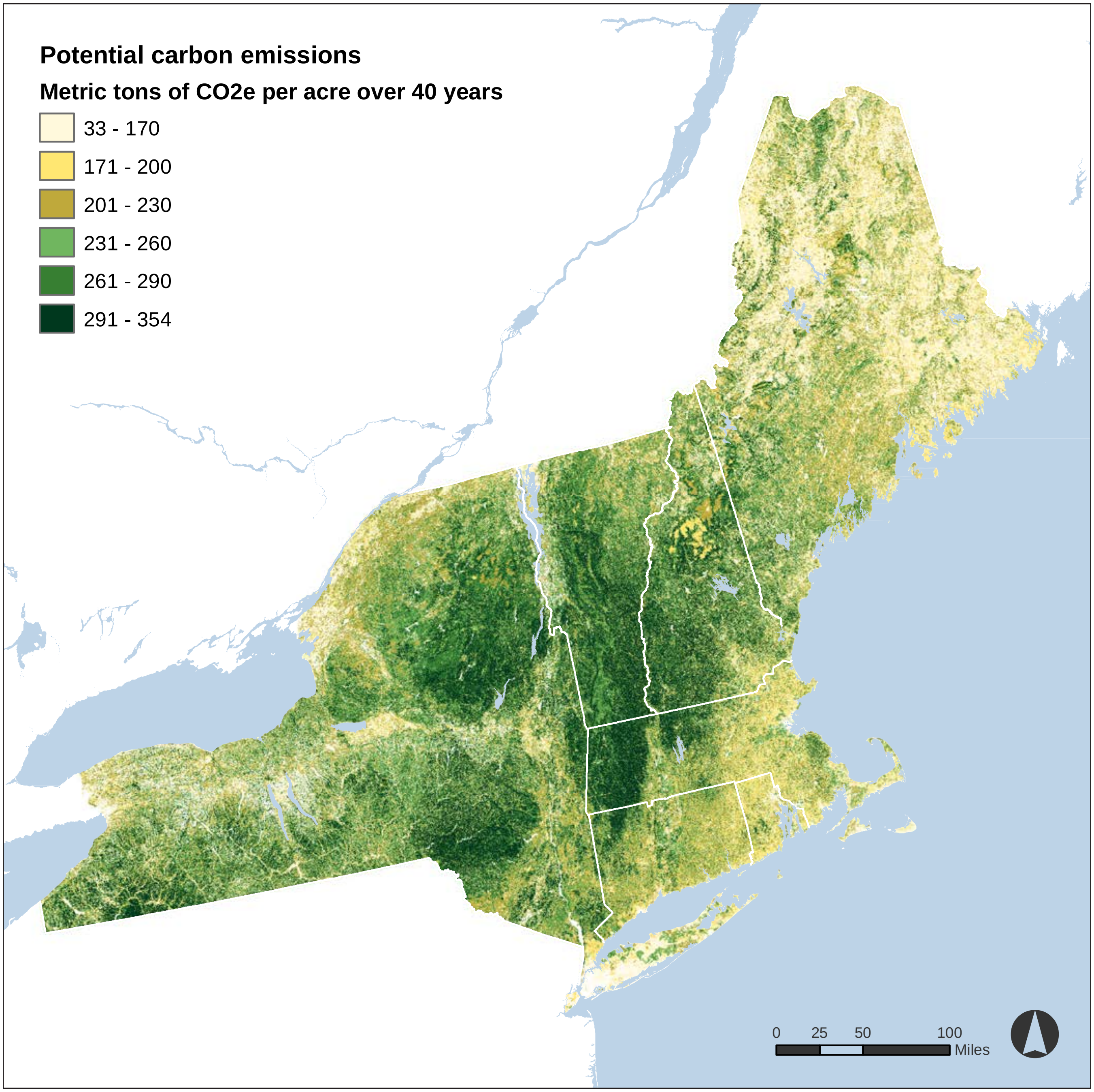

FIGURE 4. Potential CO2e emissions from forest to non-forest conversion of present-day forestland.

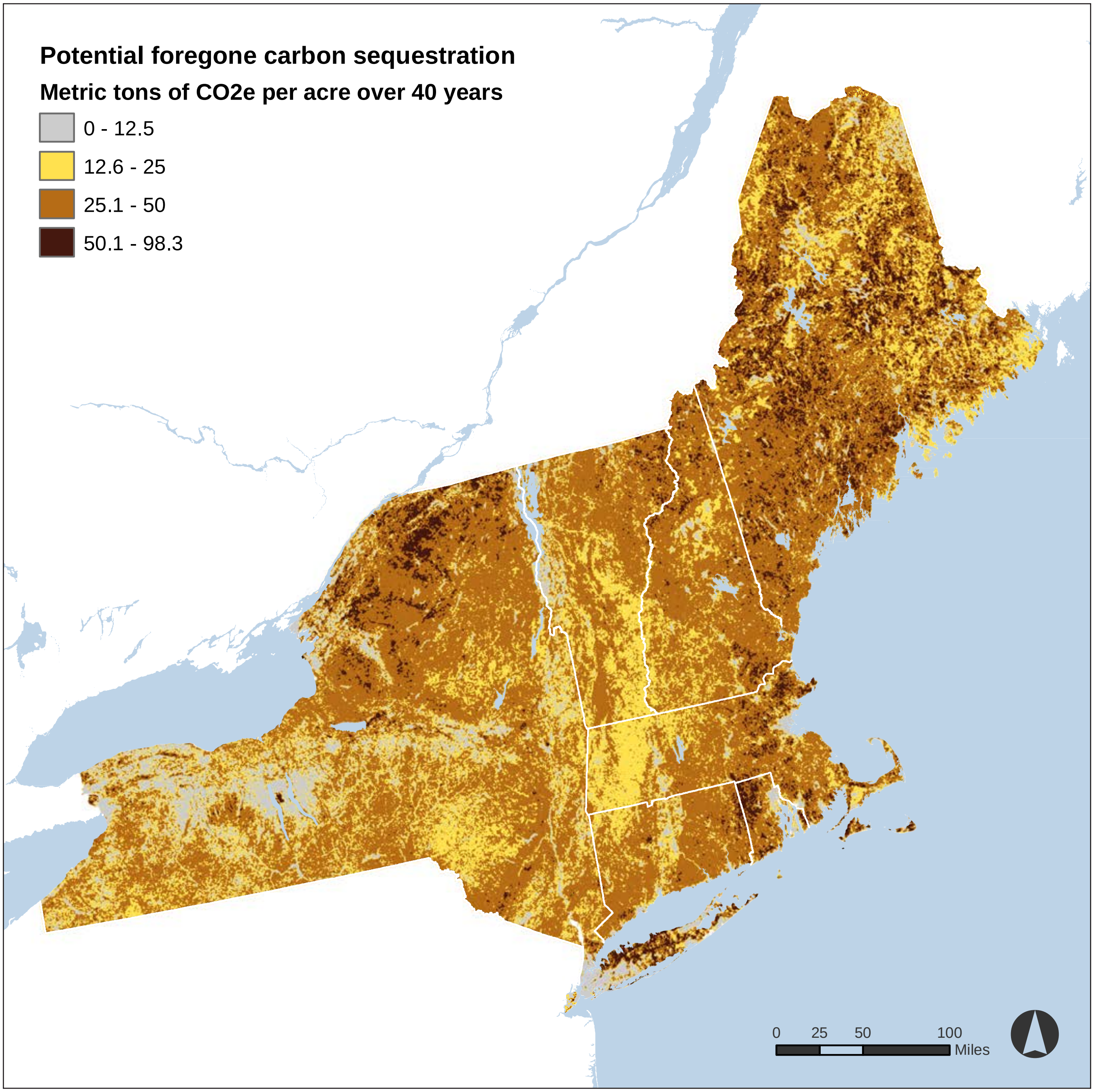

FIGURE 5. Potential foregone carbon sequestration from forest to non-forest conversion accumulated over 40 years from present-day conditions with a grow-only scenario, smoothed from the original dataset with focal statistics that average over a 1 km x 1 km block.

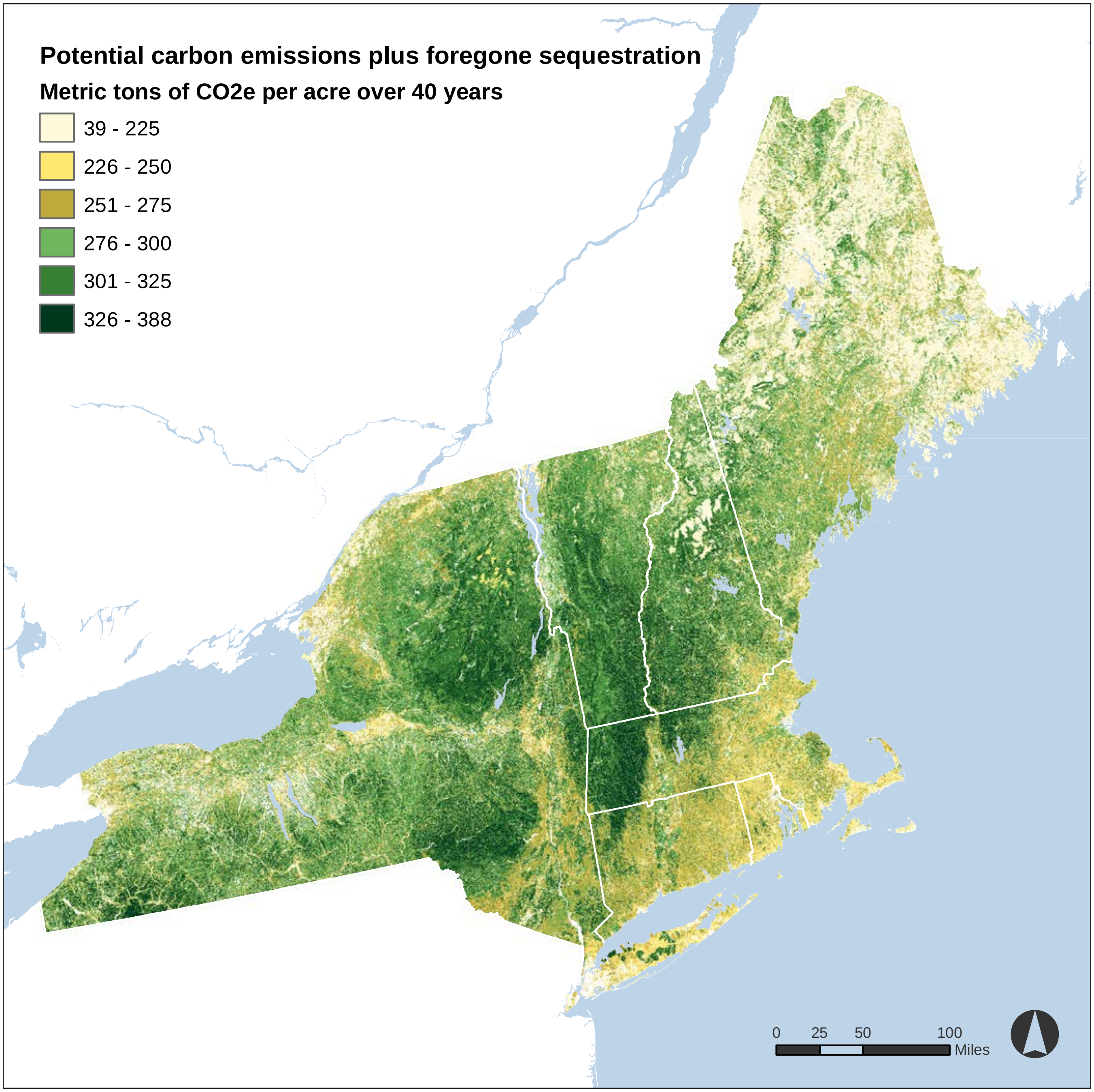

FIGURE 6. Total CO2e burden from emissions and foregone sequestration that would result from forest to non-forest conversion and accumulated over 40 years.

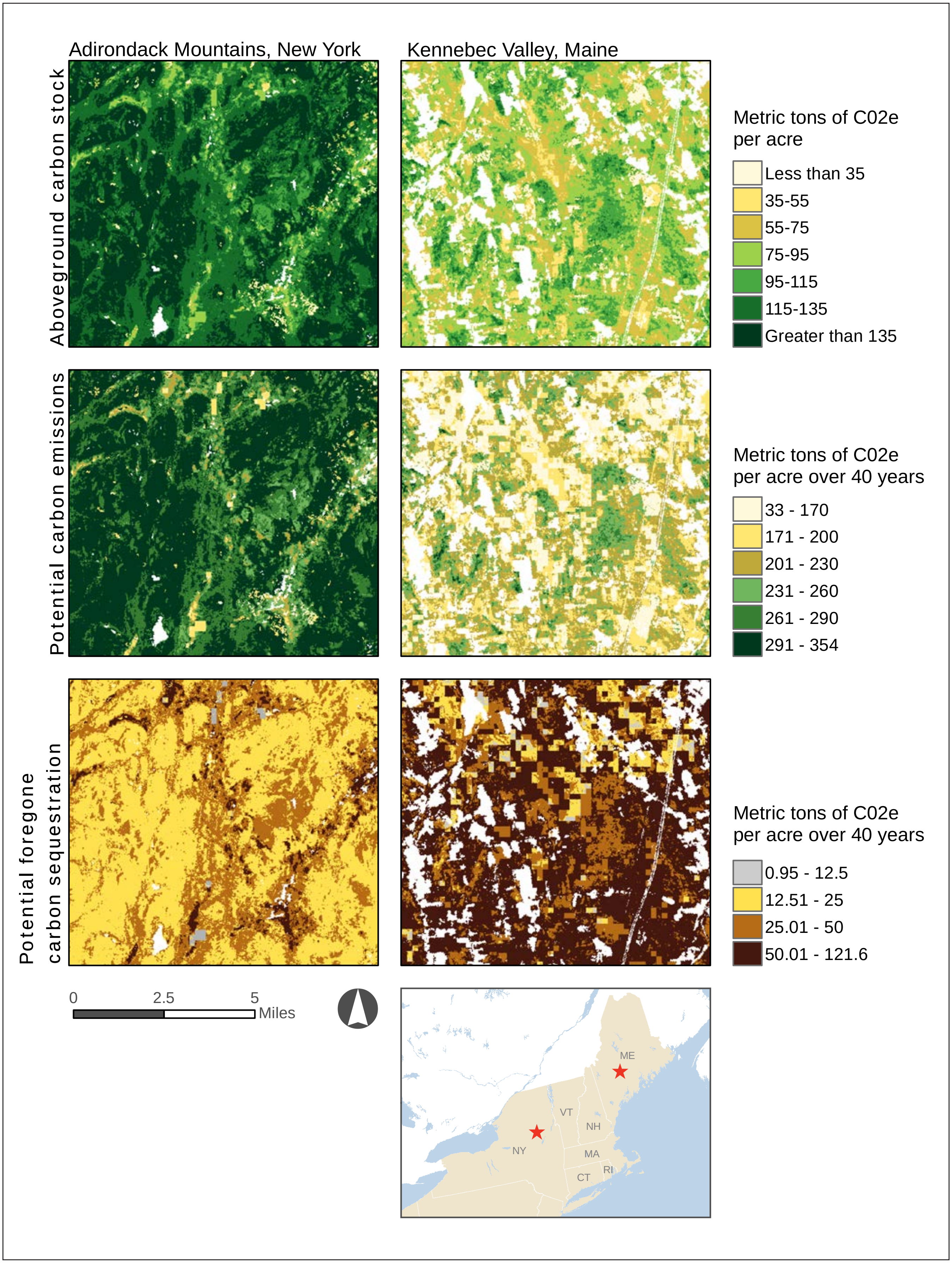

FIGURE 7. Example regions of interest displaying fine-scale detail and correspondences of carbon stocks, potential carbon emissions, and potential foregone sequestration.

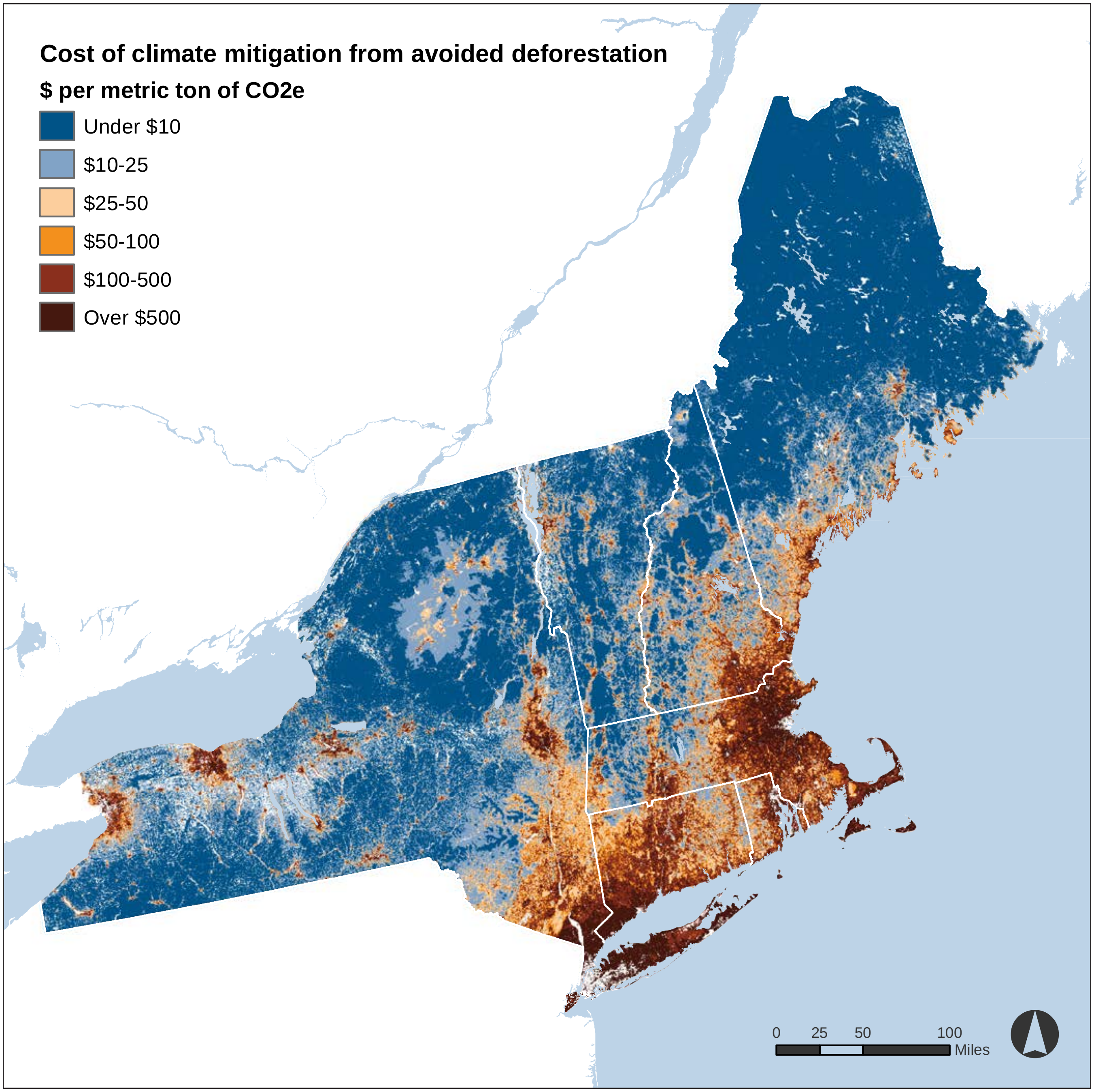

FIGURE 8. Cost of mitigation, in US Dollars per metric ton of CO2e, that could be achieved by avoiding deforestation of present-day forestland. The cost per acre is derived from the detailed conservation land values described by Nolte (2020).

3.2 Comparisons to Other Estimates

The state-level forest conversion rates we estimate agree well with those obtained from the NLCD (Table 6), both on an area basis and as a percent of initial forested area. Disagreement is largest for Maine where active forest harvesting and, in some cases, slower forest regrowth, can make it challenging to confidently map forest losses. Conversion rates also agree well with the Losing Ground 6 (LG6) dataset for Massachusetts (Pasquarella and Holden 2019), a dataset that offers a powerful point of comparison because it has involved a sophisticated land cover change detection algorithm (Zhu and Woodcock 2014) as well as detailed training and validation. The LG6 dataset was obtained through our correspondences with the New England Landscape Futures (NELF) team centered at the Harvard Forest, who have provided valuable points of comparison throughout this study.

State-level forest area, forest carbon stocks, net CO2 exchange with the atmosphere, harvest removals, and forest to non-forest conversion rates compare favorably between this report's results and those reported by the US Forest Service (Table 7). Our NFCMS estimates tended to be higher than for the USFS for forest area (5% to 37%), aboveground biomass (12% to 29%) and total ecosystem carbon (0% to 18%), but were generally lower for carbon sequestration (i.e. net CO2 exchange with the atmosphere), though not for ME. Harvest removals are generally close in magnitude but somewhat higher than those reported by the USFS. Conversion emissions are also generally close in magnitude with a slight tendency for larger emissions estimated by the USFS. This high degree of agreement overall is almost surprising given widely differing methods, and we think this lends a certain degree of credibility to both.

TABLE 6. Average annual forest loss per year in the 1990s and 2000s by state, with estimates from a range of data products.

	ME	NH	VT	NY	MA	CT	RI
Forestland [1000s of ha]	7,469.9	2,141.8	2,004.1	8,825.0	1,631.0	1,005.5	199.2
1990 to 1999							
hectares per year							
NAFD	1,701	825	237	3,180	2,023	675	229
LG6	--	--	--	--	1,388	--	--
percent per year							
NAFD	0.02	0.04	0.01	0.04	0.13	0.07	0.12
LG6	--	--	--	--	0.10	--	--
2000 to 2009							
hectares per year							
NAFD	1,873	1,041	252	3,227	2,074	783	239
NLCD	371	716	110	2,093	2,132	1,011	242
LG6	--	--	--	--	1,880	--	--
percent per year							
NAFD	0.03	0.05	0.01	0.04	0.14	0.08	0.13
NLCD	0.01	0.04	0.01	0.03	0.19	0.13	0.17
LG6	--	--	--	--	0.14	--	--

Sources: NAFD is for this study, NLCD is estimated from conversion of any forest to the same agriculture and developed classes as used to filter and screen NAFD disturbances to select those involving conversion as described in the methods section.

TABLE 7. Comparison of NFCMS and USFS reported forest areas, carbon stocks, harvest removals, and conversion emissions by state and representative of 2010.

	ME	NH	VT	NY	MA	CT	RI
Forested Area [1000s of hectares]							
This Report	7,470	2,142	2,004	8,825	1,631	1,006	199
USFS RU FS-227	7,114	1,925	1,826	7,643	1,224	732	150
Live Biomass [MMT C]							
This Report	563	216	209	891	170	107	19
USFS RU FS-227	407	162	159	636	121	71	14
Aboveground Biomass [MMT C]							
This Report	383	151	149	640	121	77	13
USFS RU FS-227	339	135	133	533	101	60	12
Total Carbon [MMT C]							
This Report	1,405	502	488	2,081	370	226	40
USFS RU FS-227	1,399	468	460	1,853	313	183	37
Carbon Sequestration [MMT CO_2e y^{-1}]							
This Report	15.3	4.6	4.9	23.9	4.3	2.8	0.7
USFS RU FS-227	11.7	5.5	5.9	24.2	4.8	2.9	0.4
Harvest Removals during the 2000s [MMT CO_2e y^{-1}]							
This Report	11.0	2.4	0.9	4.4	0.9	0.5	0.1
USFS RPA 2001, 2006, 2011 average	10.0	1.8	1.4	3.4	0.3	0.2	0.04
Conversion Emissions during the 2000s [MMT CO_2e y^{-1}]							
This Report	1.1	0.7	0.2	2.1	1.3	0.5	0.2
USFS RU FS-227	1.5	0.8	0.9	3.1	0.7	0.4	0.1

Sources: USFS RU FS-2227 (Domke et al. 2020)

3.3 Additional Considerations Regarding Scope, Use and Reliability

This study did not consider the additional climate impacts caused by changes in surface albedo imposed by forest to non-forest conversion. The surface albedo effect tends to cause a net cooling that opposes the net warming effect from carbon emissions and foregone sequestration (Williams et al. 2021a). The magnitude of this cooling varies geographically depending on the local climate and the specific land cover conversion that occurred, but in the northeastern U.S. it typically amounts to about one quarter to one third of the net warming effect from the carbon burden ((Williams et al. 2021a) see supplement Figure S12).

This study does not explore how states, NGOs, or other agents might design policy, market or regulatory mechanisms to facilitate avoidance of forest loss in the region. The map we provide displaying the cost per tonne of CO_2 mitigation may provide useful information as context. We note, however, that there may be several additional considerations important to such a cost assessment. For example, it is conceivable that there would be costs associated with buying out land uses foregone due to land conservation. Also, there is the challenge of "leakage" whereby conservation in one area displaces property development or use to another area. Furthermore, there could be financial value associated with additional ecosystem service benefits of preserving forestland and its natural capital, including enhanced biodiversity, clean air, clean water, healthy soils, and others. These and other considerations are beyond the scope of the current study but surely relevant to associated decision making, land management, and policy design.

This study does not predict the locations of future forest conversions but rather uses the recent past as an indicator of the expected size of the climate mitigation opportunity from avoiding forest losses. The forest losses we detected for the 1990s and 2000s provide an initial baseline which serves as a useful reference point. While forests today are facing new threats from novel and expanding pests and pathogens (e.g. Williams et al. 2016), new centers of urban to exurban development, and new land uses such as solar farms, the baseline results presented in this study still provide a valuable benchmark for the size of the opportunity which seems poised to grow rather than shrink with these new threats. Users are encouraged to apply other sources of information about threats to forestland as available, for example from permitting and zoning databases. Our maps of the potential CO_2e emissions and foregone sequestration readily enable users to explore the climate impacts of future forest losses wherever they may occur. As a simplified example, our datasets and findings could be used as a look-up table for non-spatial accounting of potential emissions and foregone sequestration associated with deforestation in the region.

This study's grow-only scenario estimates the potential sequestration within forests if they are able to continue to mature with tree-level but not stand-clearing disturbance events. While forests are of course vulnerable to a wide range of natural disturbances, such as windthrow and insect outbreaks, the impacts of these disturbances on stand-level biomass are partially embedded within the FIA yield curves used in this study to train the forest carbon cycle model. A trend of increasing natural disturbances would jeopardize not only the future sequestration but even the current carbon stocks contained within forests. This study did not attempt to assess the impacts of such a trend. Instead we simply underscore that this is an additional pathway by which contemporary carbon stocks and future carbon uptake could be impaired.

This study reports potential CO_2e emissions from biomass removed during forest conversion as it enters the harvested wood products stream, which we understand to be the typical fate. Some of the associated emissions will occur in other accounting sectors such as energy or waste, and users should think carefully about attribution to avoid double counting. We cannot make a general recommendation for how to address this because the design of a seamless solution will vary by application and accounting system. If desired, it should be possible to use the information provided in this report to parse the total emissions into portions occurring within forestlands, as fuelwood at wood processing facilities or elsewhere, and from landfills.

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We note that our analysis is based on satellite imagery (such as NAFD, NBCD, NLCD) and field plot data (USFS FIA) that are updated consistently over time. The datasets and conclusions reported here can be validated and extended over time as more recent data on land use and cover change and on forest growth and carbon stocks become available. Similarly, for individual states or regions that have LiDAR or other satellite datasets, a new forest carbon stock (biomass) base layer can be substituted for our biomass layer to generate additional estimates.

Map outputs from this study may include pixels that are presently not forested, and users should consider filtering our datasets to remove such areas. This is particularly important in areas with significant recent development, as well as on forest edges adjacent to non-forest land cover types. Our NAFD-derived forest extent tends to over-estimate forested area, as we have shown in the report. This is partly because we include all 30 m pixels marked as forest in the year 1986 of the NAFD dataset as forested in 2010 without removal of forests that may have been lost. We recommend screening of our datasets with the NLCD 2016 or more recent land cover dataset for a more conservative filtering and removal of areas that may presently be non-forest.

Application of this study's maps represent an average expectation within strata of a given forest type group, site productivity class, and stand age. While the maps were initialized with information derived from satellite remote sensing with methodical training on in situ field data, there is inevitably a smoothing to the mean in such applications. Individual tracts of land may have more or less forest carbon or growth potential than can be captured with state-of-the-science methods applied over large areas such as in this study. Users are encouraged, whenever possible, to blend our data with local information, whether from the field, aerial photography, higher resolution remote sensing, or another source to spot-check and correct the estimates provided here.

While we hope that our data are useful to a range of audiences, the focus of the US Climate Alliance is on providing technical assistance and resources to states, and our primary audience in this work was state agency staff and decision-makers. We worked closely with staff from various states' natural resources and environmental agencies throughout the course of this grant, including by receiving support letters from six of the seven New England and New York states at the time of the grant application. States expressed a need for more accessible and customized presentations of forest carbon stock and sequestration data, and shared their frustration with the difficultly in comparing across data sets from different sources. We have included in Appendix A paraphrased excepts from the support letters each state provided for this grant, as a starting point for how states might use the products of this report.

The questions from New England and New York echo those we have heard in work across the country, compiled into the six questions below. While this project does not provide answers to all of these questions, bold text indicates maps or data provided here that can provide partial answers.

1. What is the **current carbon stock**, how much is protected, and where would additional protection be most effective?
2. What is the current **rate of C sequestration**, how big is the **unfilled C stock potential**, and will it be sustained?
3. What is the **baseline rate of forest loss** and associated carbon emission?
4. What is the **cost of implementation** and are there significant savings from co-benefits?
5. How big are the risks from natural disturbances, leakage, etc.?
6. Can we **measure policy success** over time? How exactly?

We appreciate the time and thoughtful questions and suggestions from all of the New England and New York states, especially through meetings at the US Climate Alliance Regional Learning Lab in Rhode Island in 2019 and through the New England Landscape Futures Working Group meeting in 2020. The final maps, data tables, incorporation of a subset of our data into The Nature Conservancy Resilient Land Mapping Tool, and associated communications tools are better because of this collaboration, and we've worked to make them useable in informing future land use and climate change actions and programs. There will likely be continued needs for technical assistance, and we are looking forward to continuing to work to refine, update, and communicate our results as states' needs change over time.

SOURCE DATA SETS

Datasets and Maps From This Report
https://tnc.box.com/s/2yvv1ypjl2cln2qjzvl1iyejznmwrgmg

FIA Forest Inventory and Analysis
https://apps.fs.usda.gov/Evalidator/evalidator.jsp

NAFD North American Forest Dynamics Project: Forest Disturbance and Regrowth Data
http://dx.doi.org/10.3334/ORNLDAAC/1077

NFCMS National Forests Carbon Monitoring System
https://doi.org/10.3334/ORNLDAAC/1829

NLCD National Land Cover Database
https://www.mrlc.gov/

TPO Timber Product Output
http://srsfia2.fs.fed.us/php/tpo_2009/tpo_rpa_int1.php

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REFERENCES

Campbell, C., J. Seiler, P. Wiseman, B. Strahm, and J. Munsell. 2014. Soil Carbon Dynamics in Residential Lawns Converted from Appalachian Mixed Oak Stands. Forests 5:425.

Domke, G. M., B. F. Walters, D. J. Nowak, J. E. Smith, S. M. Ogle, J. W. Coulston, and T. C. Wirth. 2020. Greenhouse gas emissions and removals from forest land, woodlands, and urban trees in the United States, 1990-2018. Resource Update FS-227. U.S. Department of Agriculture, Forest Service, Northern Research Station, Madison, WI, **https://doi.org/10.2737/FS-RU-227**.

EPA. 2020. Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2018. U.S. Environmental Protection Agency, Washington, D.C. April 2019. EPA 430-R-18-003.

Goward, S. N., C. Huang, F. Zhao, K. Schleeweis, K. Rishmawi, M. Lindsey, J. L. Dungan, and A. Michaelis. 2015a. NACP NAFD Project: Forest Disturbance History from Landsat, 1986-2010. ORNL DAAC, Oak Ridge, Tennessee, USA. **http://dx.doi.org/10.3334/ORNLDAAC/1290**.

Goward, S. N., C. Huang, F. Zhao, K. Schleeweis, K. Rishmawi, M. Lindsey, J. L. Dungan, and A. R. Michaelis. 2015b. NACP NAFD Project: Forest Disturbance History from Landsat, 1986-2010. ORNL Distributed Active Archive Center.

Gu, H., C. A. Williams, B. Ghimire, F. Zhao, and C. Huang. 2016. High-resolution mapping of time since disturbance and forest carbon flux from remote sensing and inventory data to assess harvest, fire, and beetle disturbance legacies in the Pacific Northwest. Biogeosciences **13**:6321-6337.

Gu, H., C. A. Williams, N. Hasler, and Y. Zhou. 2019a. The Carbon Balance of the Southeastern U.S. Forest Sector as Driven by Recent Disturbance Trends. Journal of Geophysical Research: Biogeosciences **124**:2786-2803.

Gu, H., C. A. Williams, N. Hasler, and Y. Zhou. 2019b. Forest Carbon Stocks and Fluxes After Disturbance, Southeastern USA, 1990-2010. ORNL Distributed Active Archive Center.

Homer, C., J. Dewitz, S. Jin, G. Xian, C. Costello, P. Danielson, L. Gass, M. Funk, J. Wickham, S. Stehman, R. Auch, and K. Riitters. 2020. Conterminous United States land cover change patterns 2001–2016 from the 2016 National Land Cover Database. ISPRS Journal of Photogrammetry and Remote Sensing **162**:184-199.

Huang, C., S. N. Goward, J. G. Masek, F. Gao, Vermote, E.F., N. Thomas, K. Schleeweis, R. E. Kennedy, Z. Zhu, J. C. Eidenshink, and J. R. G. Townshend. 2009a. Development of time series stacks of Landsat images for reconstructing forest disturbance history. International Journal of Digital Earth **2**:195-218.

Huang, C., S. N. Goward, J. G. Masek, N. Thomas, Z. Zhu, and J. E. Vogelmann. 2010. An automated approach for reconstructing recent forest disturbance history using dense Landsat time series stacks. Remote Sensing and the Environment **114**:183-198.

Huang, C., S. N. Goward, K. Schleeweis, N. Thomas, J. G. Masek, and Z. Zhu. 2009b. Dynamics of national forests assessed using the Landsat record: Case studies in eastern U.S. Remote Sensing and the Environment **113**:1430-1442.

Kellndorfer, J., W. Walker, K. Kirsch, G. Fiske, J. Bishop, L. LaPoint, M. Hoppus, and J. Westfall. 2013. NACP Aboveground Biomass and Carbon Baseline Data, V. 2 (NBCD 2000), U.S.A., 2000. Dataset Available on-line [**http://daac.ornl.gov**] from ORNL DAAC, Oak Ridge, Tennessee, U.S.A. **http://dx.doi.org/10.3334/ORNLDAAC/1161**.

Milesi, C., S. W. Running, C. D. Elvidge, J. B. Dietz, B. T. Tuttle, and R. R. Nemani. 2005. Mapping and Modeling the Biogeochemical Cycling of Turf Grasses in the United States. Environmental Management **36**:426-438.

Myhre, G., D. Shindell, F.-M. Bréon, W. Collins, J. Fuglestvedt, J. Huang, D. Koch, J.-F. Lamarque, D. Lee, B. Mendoza, T.

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REFERENCES CONT.

Nakajima, A. Robock, G. Stephens, T. Takemura, and H. Zhang. 2013. Anthropogenic and Natural Radiative Forcing Pages 659-740 in T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley, editor. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, US.

Nolte, C. 2020. High-resolution land value maps reveal underestimation of conservation costs in the United States. Proceedings of the National Academy of Sciences 117:29577-29583.

Pasquarella, V. J., and C. E. Holden. 2019. Losing Ground 6, Annual Land Cover Products for Massachusetts, version 1.0. Zenodo, https://doi.org/10.5281/zenodo.**3531893**.

Potter, C. S., J. T. Randerson, C. B. Field, P. A. Matson, P. M. Vitousek, H. A. Mooney, and S. A. Klooster. 1993. Terrestrial ecosystem production: a process model based on global satellite and surface data. Global Biogeochemical Cycles **7**:811-841.

Randerson, J. T., M. V. Thompson, C. M. Malmstrom, C. B. Field, and I. Y. Fung. 1996. Substrate limitations for heterotrophs: Implications for models that estimate the seasonal cycle of atmospheric CO2. Global Biogeochemical Cycles **10**:585-602.

Ruefenacht, B., M. V. Finco, M. D. Nelson, R. Czaplewski, E. H. Helmer, J. A. Blackard, G. R. Holden, A. J. Lister, D. Salajanu, D. Weyermann, and K. Winterberger. 2008. Conterminous U.S. and Alaska Forest Type Mapping Using Forest Inventory and Analysis Data. Photogrammetric Engineering and Remote Sensing **74**:1379-1388.

Skog, K. 2008. Sequestration of carbon in harvested wood products for the United States. Forest Products Journal **58**:56-72. USDA, F. S. 2012. Timber Product Output (TPO) Reports. U.S. Department of Agriculture Forest Service, Southern Research Station., Knoxville, TN.

Williams, C. A., G. J. Collatz, J. G. Masek, and S. Goward. 2012. Carbon consequences of forest disturbance and recovery across the conterminous United States. Global Biogeochemical Cycles **26**:GB1005.

Williams, C. A., G. J. Collatz, J. G. Masek, C. Huang, and S. Goward. 2014. Impacts of disturbance history on forest carbon stocks and fluxes: merging satellite disturbance mapping with forest inventory data in a carbon cycle model framework. Remote Sensing and the Environment **151**:57-71.

Williams, C. A., H. Gu, and T. Jiao. 2021a. Climate impacts of U.S. forest loss span net warming to net cooling. Science Advances **7**:eaax8859.

Williams, C. A., H. Gu, R. MacLean, J. G. Masek, and G. J. Collatz. 2016. Disturbance and the carbon balance of US forests: a quantitative review of impacts from harvests, fires, insects and droughts. Global Planet Change. **143**.

Williams, C. A., N. Hasler, H. Gu, and Y. Zhou. 2021b. Forest Carbon Stocks and Fluxes from the NFCMS, Conterminous USA, 1990-2010. ORNL Distributed Active Archive Center.

Zhao, F., C. Huang, S. N. Goward, K. Schleeweis, K. Rishmawi, M. A. Lindsey, E. Denning, L. Keddell, W. B. Cohen, Z. Yang, J. L. Dungan, and A. Michaelis. 2018. Development of Landsat-based annual US forest disturbance history maps (1986–2010) in support of the North American Carbon Program (NACP). Remote Sensing of Environment **209**:312-326.

Zhou, Y., C. A. Williams, N. Hasler, H. Gu, and R. Kennedy. 2021. Beyond biomass to carbon fluxes: application and evaluation of a comprehensive forest carbon monitoring system. Environmental Research Letters **16**:055026.

Zhu, Z., and C. E. Woodcock. 2014. Continuous change detection and classification of land cover using all available Landsat data. Remote Sensing of Environment **144**:152-171.

MAINE

Deforestation (forest loss) is a direct source of carbon emissions, releasing the carbon stored in trees and roots into the atmosphere as carbon dioxide. It also removes one of the best tools we have for pulling carbon dioxide from the atmosphere (carbon sequestration). Thus, slowing the pace of forest loss (avoiding deforestation) is an opportunity to both reduce and remove carbon emissions in the fight against climate change.

A 2021 study by Clark University quantifies the size of the avoided deforestation opportunity and its spatial distribution in New England and New York. Collectively, these states are releasing 4.9 million metric tons of CO_2 equivalent into the atmosphere each year due to forest loss, and losing out on 1.2 million metric tons of CO_2 equivalent in carbon sequestration each year due to that loss. The numbers vary by state. However, every state stands to gain by reducing their rate of deforestation, and those benefits compound over time. Here are some of the study's conclusions for Maine:

1.1 MILLION

METRIC TONS OF CO_2e PER YEAR

Forest loss in Maine averaged about 1,873 hectares (4,628 acres) per year in the early 2000s, committing 1.1 million metric tons of CO_2e to the atmosphere as carbon emissions plus foregone sequestration each year.

80%

FROM CARBON EMISSIONS

20%

FROM FOREGONE SEQUESTRATION

Foregone sequestration contributes about 20% of the total carbon burden from deforestation, while 80% comes from carbon emissions.

CO_2e
IMPACT

THIS CO_2e IMPACT OF FOREST CONVERSIONS IS EQUAL TO:

7% of statewide carbon sequestration occurring within remaining forestlands

9% of the harvested wood products emissions resulting from forest harvesting

7% of the state's fossil fuel emissions across all sectors (2018)

There are many uses of these data, particularly in considering land use and climate change policies and actions. Maine state agencies wrote in their letter of support for this project that they "need updated and state-specific data on the size, location, and mechanics of natural climate solutions", and that this project complements another US Climate Alliance grant project "which includes an array of management options in both forestry and agriculture."

The full report, including a link to download the data, is here: **https://tnc.box.com/s/apncszy7yrsknlk0hix9n2bt7n6n3f9k** Many of these carbon data are also available in the interactive **Resilient Land Mapping Tool** from The Nature Conservancy.

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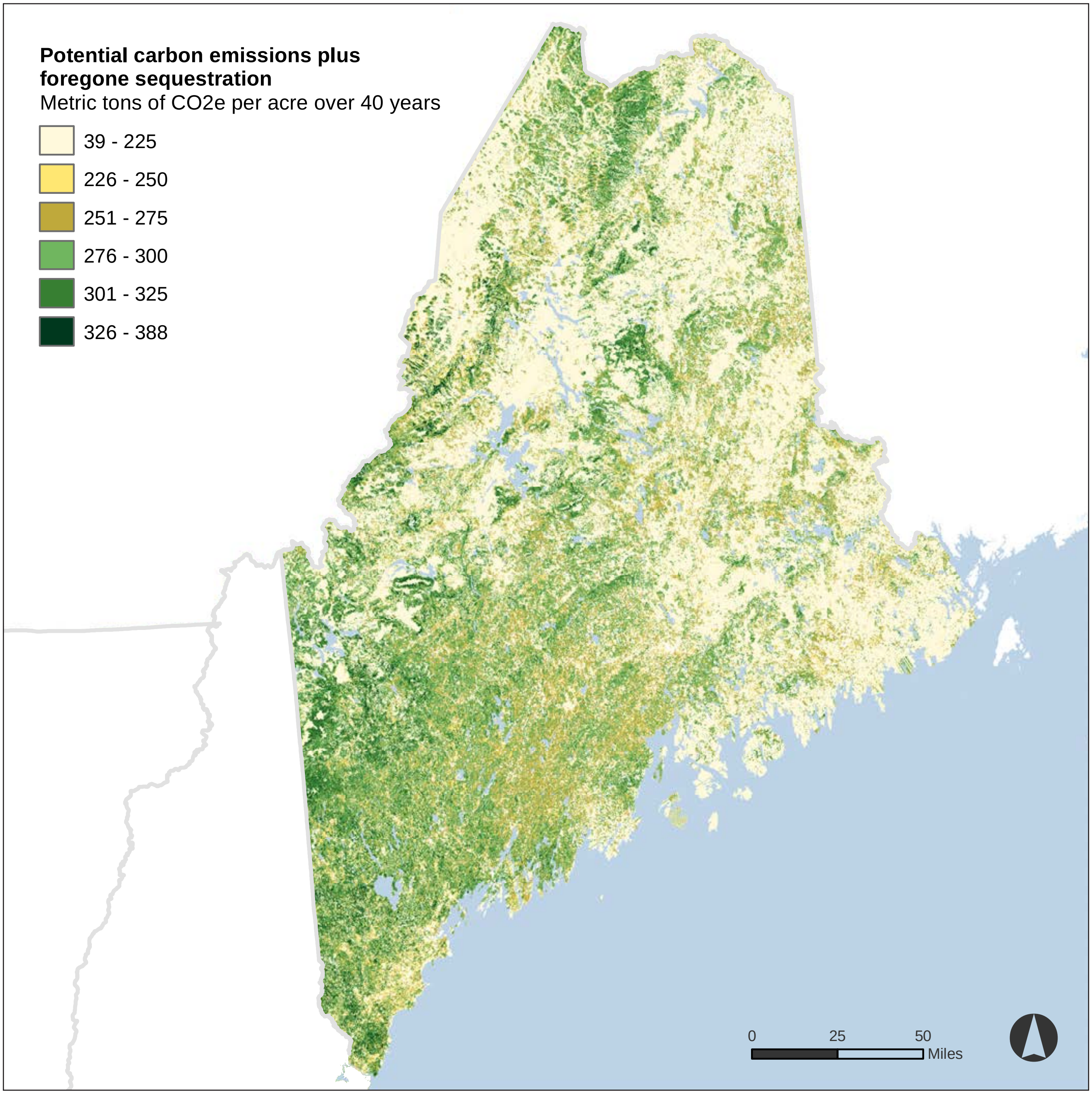
An Opportunity in Maine

If any given point on the map is deforested, the carbon consequences are shown as the carbon that would be emitted plus foregone carbon sequestration, over 40 years. Conversely, this map shows the size of the opportunity represented by avoided deforestation.



NEW HAMPSHIRE

Deforestation (forest loss) is a direct source of carbon emissions, releasing the carbon stored in trees and roots into the atmosphere as carbon dioxide. It also removes one of the best tools we have for pulling carbon dioxide from the atmosphere (carbon sequestration). Thus, slowing the pace of forest loss (avoiding deforestation) is an opportunity to both reduce and remove carbon emissions in the fight against climate change.

A 2021 study by Clark University quantifies the size of the avoided deforestation opportunity and its spatial distribution in New England and New York. Collectively, these states are releasing 4.9 million metric tons of CO2 equivalent into the atmosphere each year due to forest loss, and losing out on 1.2 million metric tons of CO2 equivalent in carbon sequestration each year due to that loss. The numbers vary by state. However, every state stands to gain by reducing their rate of deforestation, and those benefits compound over time. Here are some of the study's conclusions for New Hampshire.

0.7 MILLION

METRIC TONS OF CO_2e PER YEAR

Forest loss averaged about 1,041 hectares (2572 acres) per year in the early 2000s, committing 0.7 million metric tons of CO2e to the atmosphere as carbon emissions plus foregone sequestration each year.

80%

FROM CARBON EMISSIONS

20%

FROM FOREGONE SEQUESTRATION

Foregone sequestration contributes about 20% of the total carbon burden from deforestation, while 80% comes from carbon emissions.

CO_2e IMPACT

THIS CO_2e IMPACT OF FOREST CONVERSIONS IS EQUAL TO:

14% of statewide carbon sequestration occurring within remaining forestlands

28% of the harvested wood products emissions resulting from forest harvesting

5% of the state's fossil fuel emissions across all sectors (2018)

There are many uses of these data, particularly in considering land use and climate change policies and actions.

The full report, including a link to download the data, is here: **https://tnc.box.com/s/apncszy7yrsknlk0hix9n2bt7n6n3f9k**
Many of these carbon data are also available in the interactive **Resilient Land Mapping Tool** from The Nature Conservancy.

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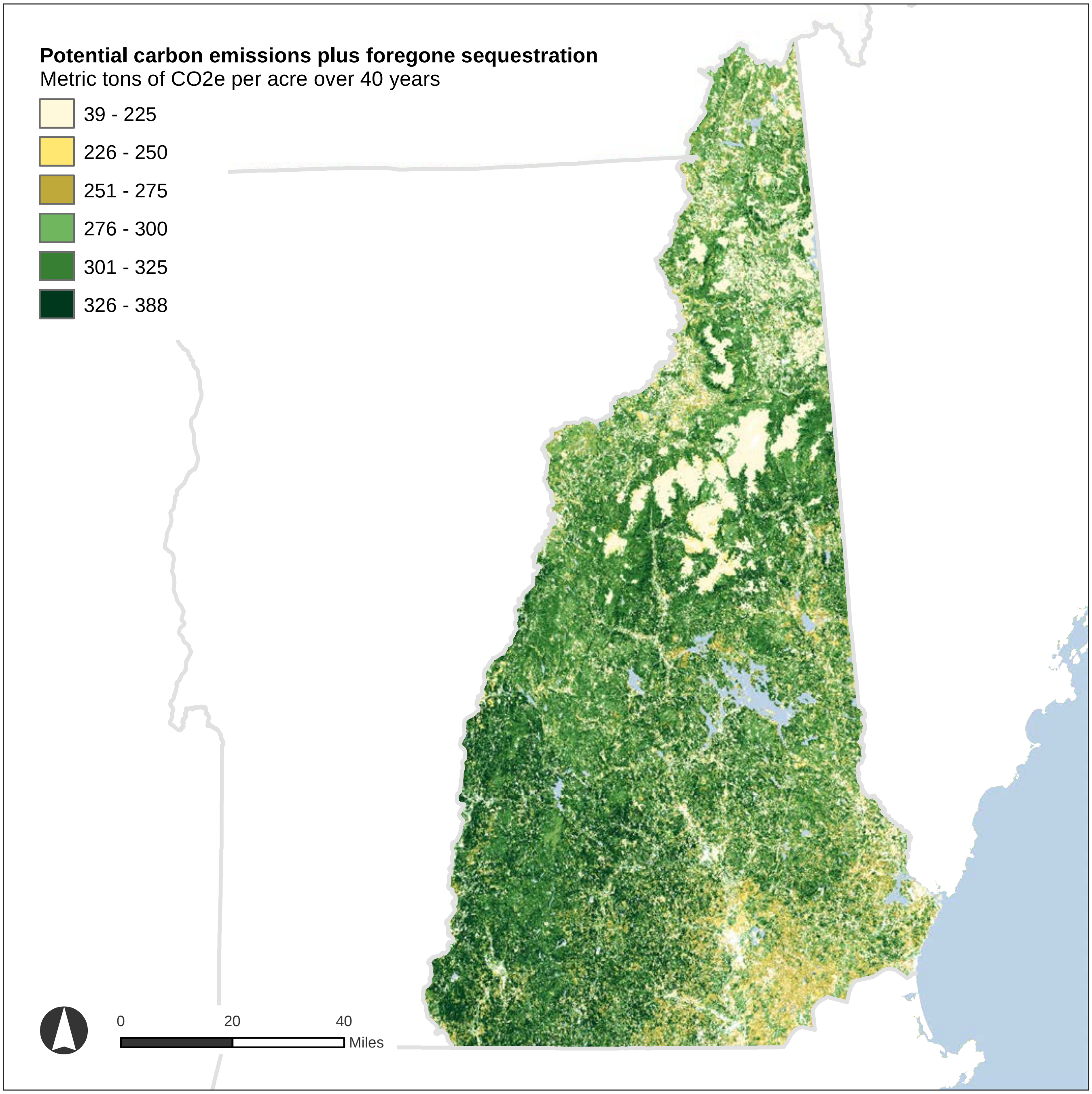
An Opportunity in New Hampshire

If any given point on the map is deforested, the carbon consequences are shown as the carbon that would be emitted plus foregone carbon sequestration, over 40 years. Conversely, this map shows the size of the opportunity represented by avoided deforestation.



VERMONT

Deforestation (forest loss) is a direct source of carbon emissions, releasing the carbon stored in trees and roots into the atmosphere as carbon dioxide. It also removes one of the best tools we have for pulling carbon dioxide from the atmosphere (carbon sequestration). Thus, slowing the pace of forest loss (avoiding deforestation) is an opportunity to both reduce and remove carbon emissions in the fight against climate change.

A 2021 study by Clark University quantifies the size of the avoided deforestation opportunity and its spatial distribution in New England and New York. Collectively, these states are releasing 4.9 million metric tons of CO2 equivalent into the atmosphere each year due to forest loss, and losing out on 1.2 million metric tons of CO2 equivalent in carbon sequestration each year due to that loss. The numbers vary by state. However, every state stands to gain by reducing their rate of deforestation, and those benefits compound over time. Here are some of the study's conclusions for Vermont.

0.2 MILLION

METRIC TONS OF CO_2e PER YEAR

Forest loss averaged about 252 hectares (623 acres) per year in the early 2000s, committing 0.2 million metric tons of CO2e to the atmosphere as carbon emissions plus foregone sequestration each year

80%

FROM CARBON EMISSIONS

20%

FROM FOREGONE SEQUESTRATION

Foregone sequestration contributes about 20% of the total carbon burden from deforestation, while 80% comes from carbon emissions.

CO_2e
IMPACT

THIS CO_2eIMPACT OF FOREST CONVERSIONS IS EQUAL TO:

3% of statewide carbon sequestration occurring within remaining forestlands

18% of the harvested wood products emissions resulting from forest harvesting

3% of the state's fossil fuel emissions across all sectors (2018)

There are many uses of these data, particularly in considering land use and climate change policies and actions. Vermont state agencies wrote in their letter of support for this project that "improved carbon maps and compatibility with emerging satellite data will help us improve our greenhouse gas accounting, identify priority landscapes, and increase support and funding for conservation."

The full report, including a link to download the data, is here: **https://tnc.box.com/s/apncszy7yrsknlk0hix9n2bt7n6n3f9k**
Many of these carbon data are also available in the interactive **Resilient Land Mapping Tool** from The Nature Conservancy.

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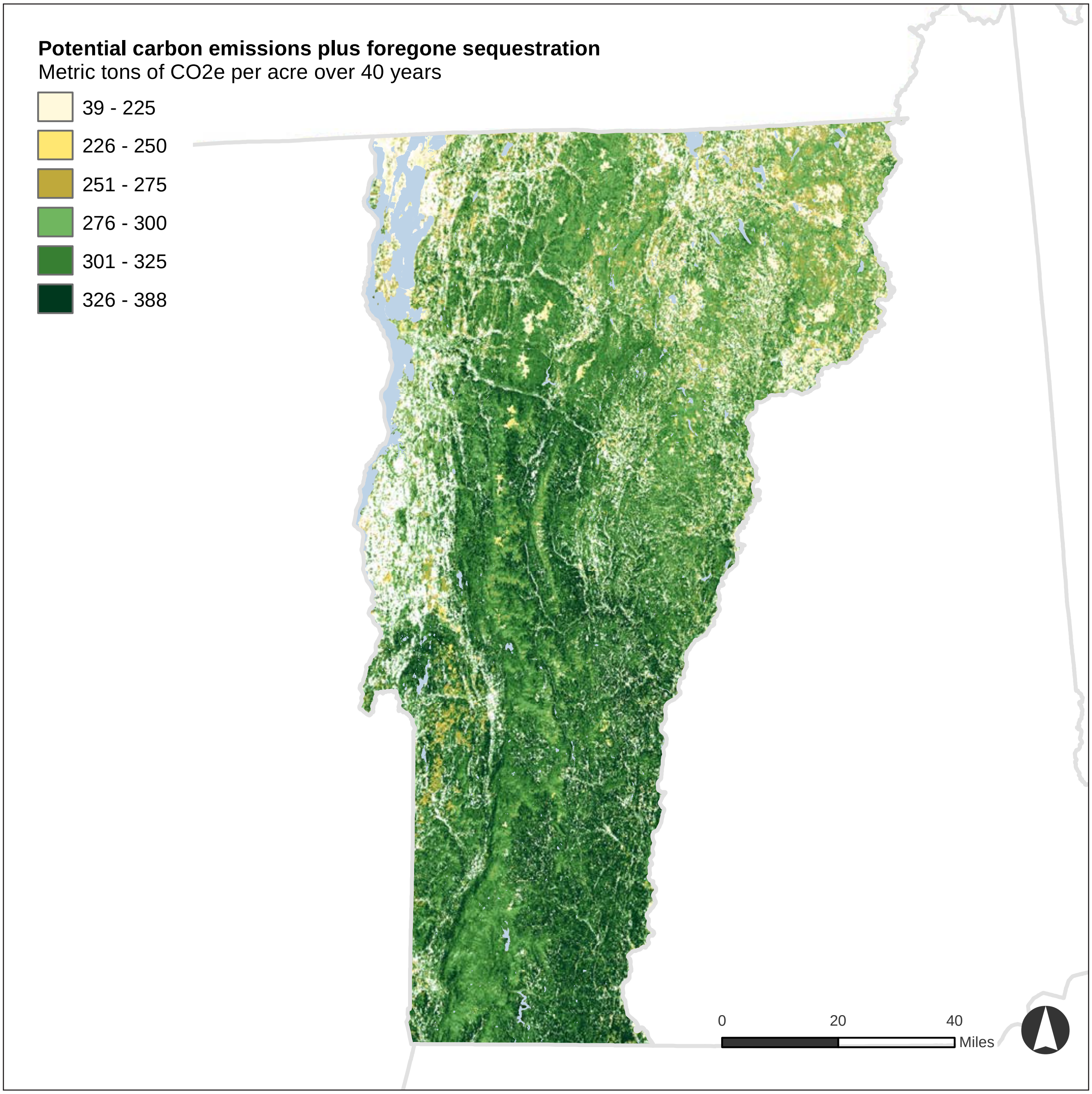
An Opportunity in Vermont

If any given point on the map is deforested, the carbon consequences are shown as the carbon that would be emitted plus foregone carbon sequestration, over 40 years. Conversely, this map shows the size of the opportunity represented by avoided deforestation.



NEW YORK

Deforestation (forest loss) is a direct source of carbon emissions, releasing the carbon stored in trees and roots into the atmosphere as carbon dioxide. It also removes one of the best tools we have for pulling carbon dioxide from the atmosphere (carbon sequestration). Thus, slowing the pace of forest loss (avoiding deforestation) is an opportunity to both reduce and remove carbon emissions in the fight against climate change.

A 2021 study by Clark University quantifies the size of the avoided deforestation opportunity and its spatial distribution in New England and New York. Collectively, these states are releasing 4.9 million metric tons of CO2 equivalent into the atmosphere each year due to forest loss, and losing out on 1.2 million metric tons of CO2 equivalent in carbon sequestration each year due to that loss. The numbers vary by state. However, every state stands to gain by reducing their rate of deforestation, and those benefits compound over time. Here are some of the study's conclusions for New York.

2.1 MILLION

METRIC TONS OF CO_2e PER YEAR

Forest loss averaged about 3,227 hectares (7974 acres) per year in the early 2000s, committing 2.1 million metric tons of CO2e to the atmosphere as carbon emissions plus foregone sequestration each year.

80%

FROM CARBON EMISSIONS

20%

FROM FOREGONE SEQUESTRATION

Foregone sequestration contributes about 20% of the total carbon burden from deforestation, while 80% comes from carbon emissions.

CO_2e IMPACT

THIS CO_2e IMPACT OF FOREST CONVERSIONS IS EQUAL TO:

8% of statewide carbon sequestration occurring within remaining forestlands

45% of the harvested wood products emissions resulting from forest harvesting

1% of the state's fossil fuel emissions across all sectors (2018)

There are many uses of these data, particularly in considering land use and climate change policies and actions. New York state agencies wrote in their letter of support for this project that they "need improved methodologies and estimates of forest cover and carbon sequestration, as well as insight into the trends of forest health in forest health, land cover change and land ownership that will determine the future of carbon sequestration in the region," and "how land use change can affect the attributes of land cover that the State values, including carbon sequestration."

The full report, including a link to download the data, is here: **https://tnc.box.com/s/apncszy7yrsknlk0hix9n2bt7n6n3f9k**
Many of these carbon data are also available in the interactive **Resilient Land Mapping Tool** from The Nature Conservancy.

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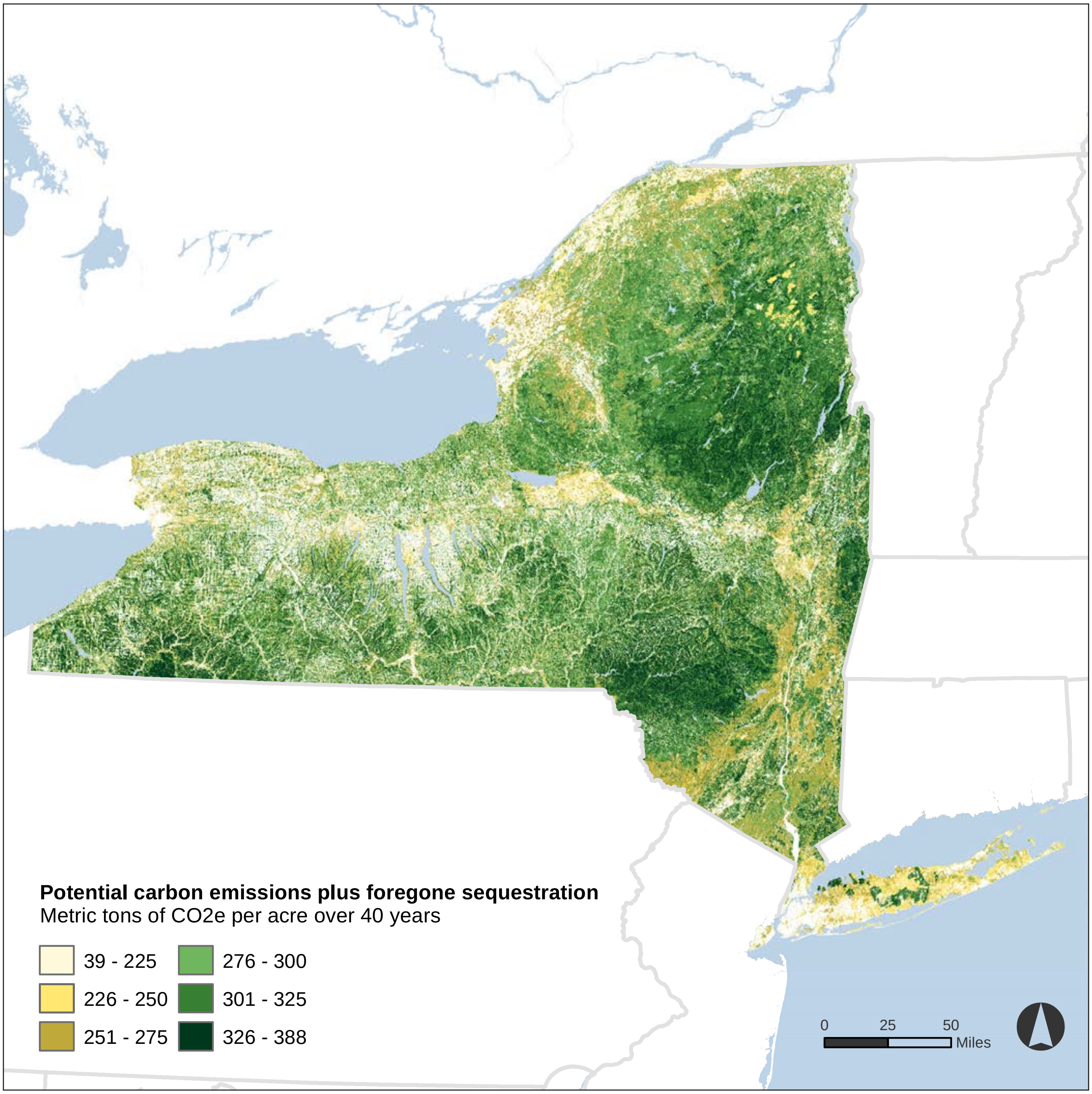
An Opportunity in New York

If any given point on the map is deforested, the carbon consequences are shown as the carbon that would be emitted plus foregone carbon sequestration, over 40 years. Conversely, this map shows the size of the opportunity represented by avoided deforestation.



MASSACHUSETTS

Deforestation (forest loss) is a direct source of carbon emissions, releasing the carbon stored in trees and roots into the atmosphere as carbon dioxide. It also removes one of the best tools we have for pulling carbon dioxide from the atmosphere (carbon sequestration). Thus, slowing the pace of forest loss (avoiding deforestation) is an opportunity to both reduce and remove carbon emissions in the fight against climate change.

A 2021 study by Clark University quantifies the size of the avoided deforestation opportunity and its spatial distribution in New England and New York. Collectively, these states are releasing 4.9 million metric tons of CO2 equivalent into the atmosphere each year due to forest loss, and losing out on 1.2 million metric tons of CO2 equivalent in carbon sequestration each year due to that loss. The numbers vary by state. However, every state stands to gain by reducing their rate of deforestation, and those benefits compound over time. Here are some of the study's conclusions for Massachusetts.

1.3 MILLION

METRIC TONS OF CO$_2$e PER YEAR

Forest loss averaged about 2,074 hectares (5,125 acres) per year in the early 2000s, committing 1.3 million metric tons of CO2e to the atmosphere as carbon emissions plus foregone sequestration each year.

80%

FROM CARBON EMISSIONS

20%

FROM FOREGONE SEQUESTRATION

Foregone sequestration contributes about 20% of the total carbon burden from deforestation, while 80% comes from carbon emissions.

CO$_2$e
IMPACT

THIS CO$_2$eIMPACT OF FOREST CONVERSIONS IS EQUAL TO:

28% of statewide carbon sequestration occurring within remaining forestlands

150% of the harvested wood products emissions resulting from forest harvesting

2% of the state's fossil fuel emissions across all sectors (2018)

There are many uses of these data, particularly in considering land use and climate change policies and actions. Massachusetts state agencies wrote in their letter of support for this project that this study would "complement and support several emerging state initiatives including: the launching of an extensive project to evaluate options for Massachusetts to meet its legally mandated goal of {a net zero} reduction in greenhouse gas emissions by 2050," and "further expansion of climate mitigation and adaptation funding."

The full report, including a link to download the data, is here: **https://tnc.box.com/s/apncszy7yrsknlk0hix9n2bt7n6n3f9k** Many of these carbon data are also available in the interactive **Resilient Land Mapping Tool** from The Nature Conservancy.

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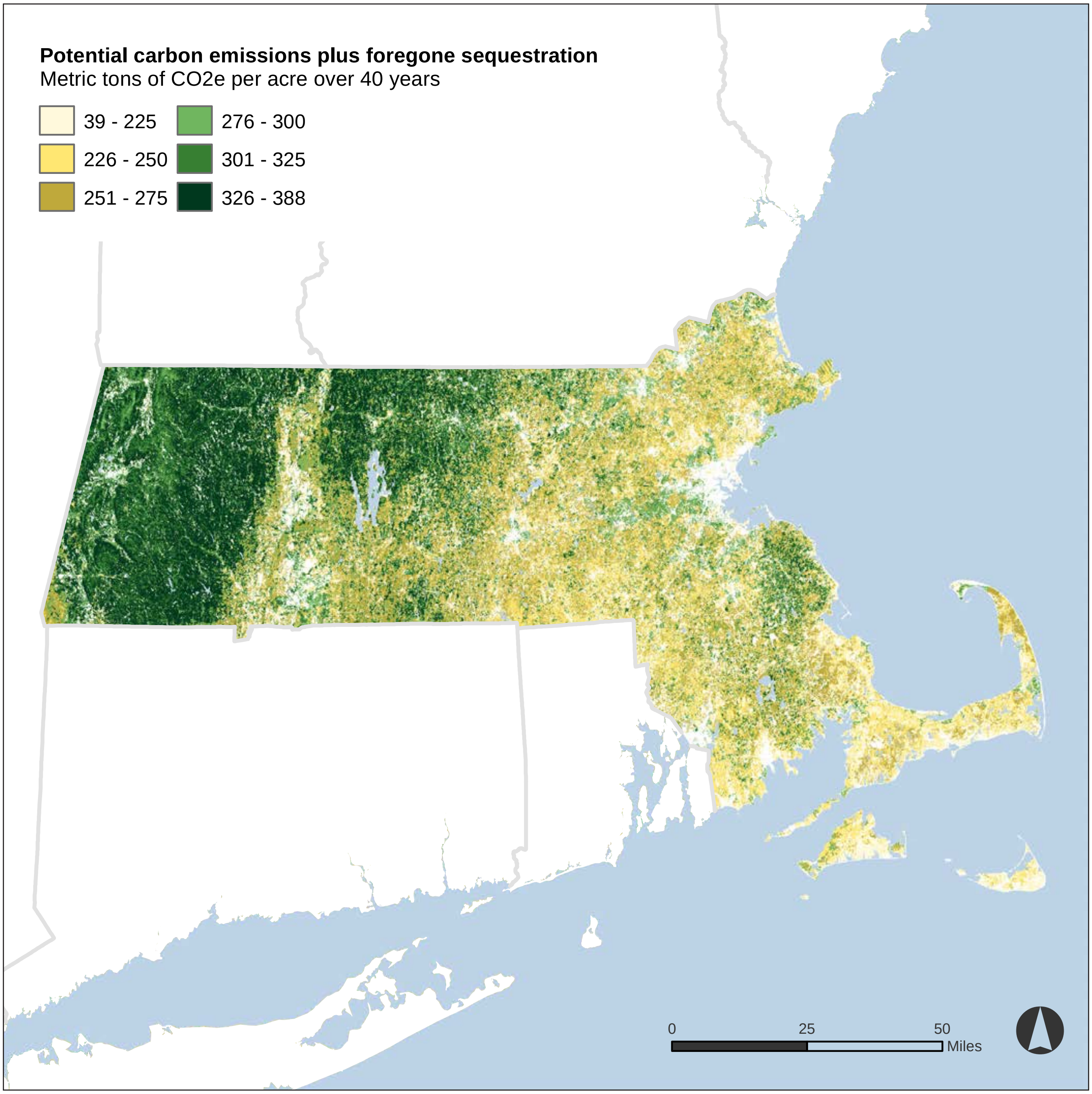
An Opportunity in Massachusetts

If any given point on the map is deforested, the carbon consequences are shown as the carbon that would be emitted plus foregone carbon sequestration, over 40 years. Conversely, this map shows the size of the opportunity represented by avoided deforestation.



CONNECTICUT

Deforestation (forest loss) is a direct source of carbon emissions, releasing the carbon stored in trees and roots into the atmosphere as carbon dioxide. It also removes one of the best tools we have for pulling carbon dioxide from the atmosphere (carbon sequestration). Thus, slowing the pace of forest loss (avoiding deforestation) is an opportunity to both reduce and remove carbon emissions in the fight against climate change.

A 2021 study by Clark University quantifies the size of the avoided deforestation opportunity and its spatial distribution in New England and New York. Collectively, these states are releasing 4.9 million metric tons of CO2 equivalent into the atmosphere each year due to forest loss, and losing out on 1.2 million metric tons of CO2 equivalent in carbon sequestration each year due to that loss. The numbers vary by state. However, every state stands to gain by reducing their rate of deforestation, and those benefits compound over time. Here are some of the study's conclusions for Connecticut.

0.5 MILLION

METRIC TONS OF CO_2e PER YEAR

Forest loss averaged about 782 hectares (1,932 acres) per year in the early 2000s, committing 0.5 million metric tons of CO2e to the atmosphere as carbon emissions plus foregone sequestration each year.

80%

FROM CARBON EMISSIONS

20%

FROM FOREGONE SEQUESTRATION

Foregone sequestration contributes about 20% of the total carbon burden from deforestation, while 80% comes from carbon emissions.

CO_2e IMPACT

THIS CO_2e IMPACT OF FOREST CONVERSIONS IS EQUAL TO:

16% of statewide carbon sequestration occurring within remaining forestlands

116% of the harvested wood products emissions resulting from forest harvesting

1% of the state's fossil fuel emissions across all sectors (2018)

There are many uses of these data, particularly in considering land use and climate change policies and actions. Connecticut state agencies wrote in their letter of support for this project that "improved data would help increase the focus on land protection/avoided conversion as a climate strategy as forest loss and fragmentation remain one of the highest concerns for residents regarding CT woodlands," and "improved data collection will complement state efforts to reduce emissions through energy policy with efforts to remove emissions through land policy."

The full report, including a link to download the data, is here: **https://tnc.box.com/s/apncszy7yrsknlk0hix9n2bt7n6n3f9k**
Many of these carbon data are also available in the interactive **Resilient Land Mapping Tool** from The Nature Conservancy.

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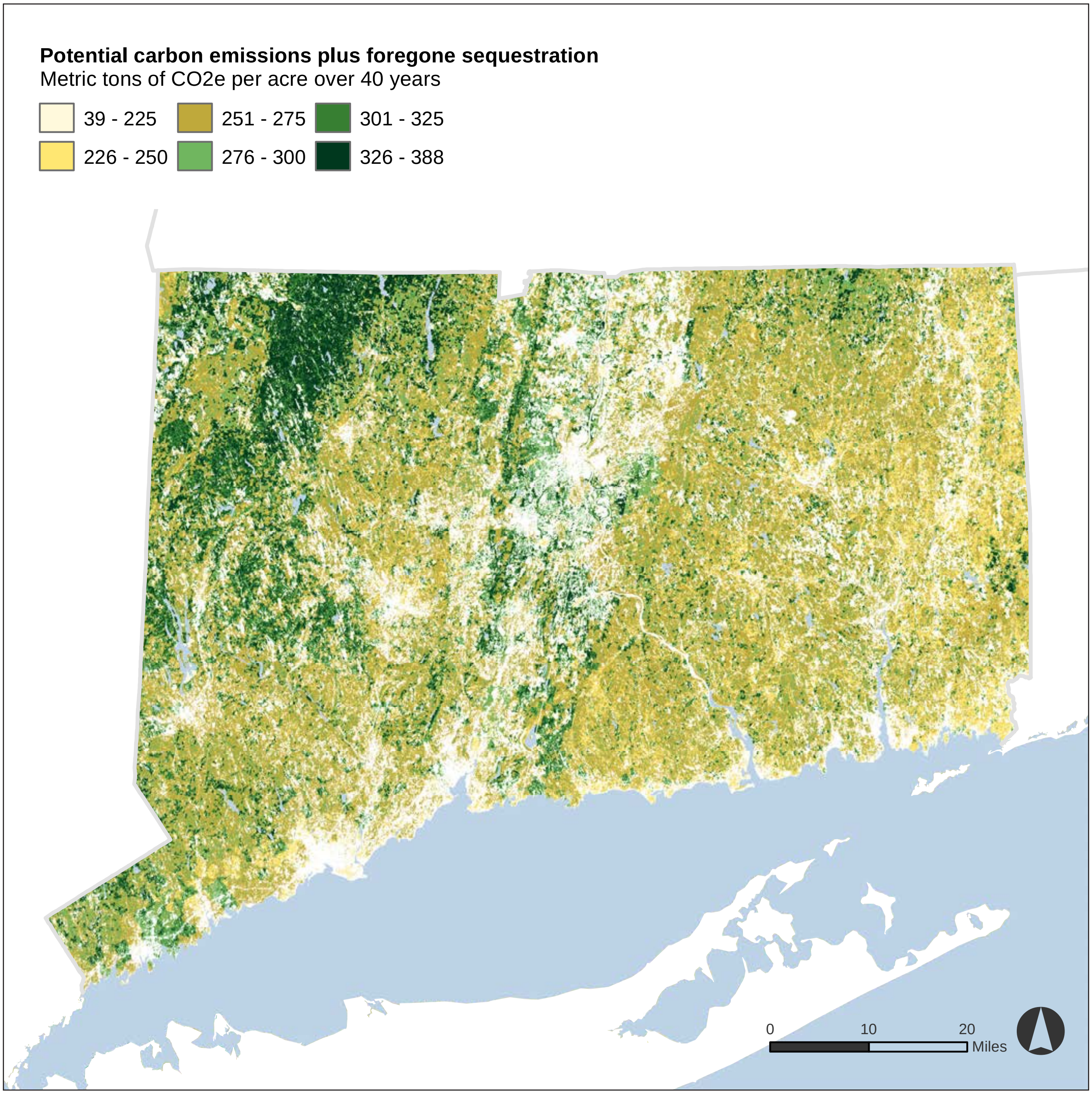
An Opportunity in Connecticut

If any given point on the map is deforested, the carbon consequences are shown as the carbon that would be emitted plus foregone carbon sequestration, over 40 years. Conversely, this map shows the size of the opportunity represented by avoided deforestation.



RHODE ISLAND

Deforestation (forest loss) is a direct source of carbon emissions, releasing the carbon stored in trees and roots into the atmosphere as carbon dioxide. It also removes one of the best tools we have for pulling carbon dioxide from the atmosphere (carbon sequestration). Thus, slowing the pace of forest loss (avoiding deforestation) is an opportunity to both reduce and remove carbon emissions in the fight against climate change.

A 2021 study by Clark University quantifies the size of the avoided deforestation opportunity and its spatial distribution in New England and New York. Collectively, these states are releasing 4.9 million metric tons of CO2 equivalent into the atmosphere each year due to forest loss, and losing out on 1.2 million metric tons of CO2 equivalent in carbon sequestration each year due to that loss. The numbers vary by state. However, every state stands to gain by reducing their rate of deforestation, and those benefits compound over time. Here are some of the study's conclusions for Connecticut.

0.15 MILLION

METRIC TONS OF CO_2e PER YEAR

Forest loss averaged about 239 hectares (591 acres) per year in the early 2000s, committing 0.15 million metric tons of CO2e to the atmosphere as carbon emissions plus foregone sequestration each year.

80%

FROM CARBON EMISSIONS

20%

FROM FOREGONE SEQUESTRATION

Foregone sequestration contributes about 20% of the total carbon burden from deforestation, while 80% comes from carbon emissions.

CO_2e
IMPACT

THIS CO_2e IMPACT OF FOREST CONVERSIONS IS EQUAL TO:

22% of statewide carbon sequestration occurring within remaining forestlands

136% of the harvested wood products emissions resulting from forest harvesting

1% of the state's fossil fuel emissions across all sectors (2018)

There are many uses of these data, particularly in considering land use and climate change policies and actions. Rhode Island state agencies wrote in their letter of support for this project that "identifying forest carbon capture realities... will be used in discussions with communities in fully understanding their forest land carbon sequestration numbers. This data will be used to encourage the development of community climate resiliency plans."

The full report, including a link to download the data, is here: **https://tnc.box.com/s/apncszy7yrsknlk0hix9n2bt7n6n3f9k**
Many of these carbon data are also available in the interactive **Resilient Land Mapping Tool** from The Nature Conservancy.

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An Opportunity in Rhode Island

If any given point on the map is deforested, the carbon consequences are shown as the carbon that would be emitted plus foregone carbon sequestration, over 40 years. Conversely, this map shows the size of the opportunity represented by avoided deforestation.