Vermont Forest Carbon Inventory

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Summary

Forests play a crucial role in the global carbon cycle by absorbing carbon dioxide (CO_2) from the atmosphere and storing the carbon in trees, both living and dead, as well as in the soil. Climate change is driven by atmospheric CO_2 levels, for which the balance between carbon sequestration and emissions is key. When sequestration exceeds emissions, additional carbon is withheld from the atmosphere and storage within forests increases; when emissions surpass sequestration, carbon is lost from the land and released back into the atmosphere.

The Vermont Forest Carbon Inventory aims to communicate and monitor the carbon benefits of Vermont's forest sector. This inventory incorporates carbon stored in forests, as well as carbon gains and losses across the forest sector—including sequestration by existing forests, urban trees, newly established forest land, and harvested wood products in use and in landfills, alongside emissions from when a forest is converted to another type of land use, such as development or agriculture. Emissions from harvested wood products in the form of bioenergy and decay are accounted for in existing forests (see Key Information for more details). The forestland-based estimates in this inventory are based on data from the U.S. Forest Service[i,ii] which follows guidelines established by the Intergovernmental Panel on Climate Change[iii]. The *Agency of Natural Resources Vermont Greenhouse Gas Emissions Inventory and Forecast*[iv] is the official accounting source for statewide fluxes, including those from the land use sector.

Key Findings

1. **Vermont's forests remain a carbon sink.**
   Each year, the State's forests absorb more carbon than they emit. As of 2023, Vermont's forests held an estimated **1.9 billion metric tons of CO_2-equivalent (CO_2e)**. If all this carbon were released tomorrow, it would equal more than **200 years' worth of Vermont's fossil fuel, industrial, and agricultural greenhouse gas emissions**. The increase in stored carbon each year represents sequestration. In 2022, Vermont's forests sequestered approximately **-6.1 million metric tons of CO_2e**.

2. **In 2022, the forest sector offset about 79% of the Vermont's fossil fuel, industrial, and agricultural greenhouse gas emissions.**
   When considering the combined carbon fluxes of existing forests, urban trees, land-use changes (both to and from forest), and harvested wood products, Vermont's net sequestration benefit in 2022 was **-6.6 million metric tons of CO_2e**.

3. **Vermont's forest sequestration rate is gradually declining.**
   Each year, forests are absorbing slightly less CO_2 than the year before. This decline is due to **natural forest aging** (older forests sequester CO_2 at a slower rate) and **net forestland loss from land-use conversion**. Since 1997, Vermont has lost an average of **5,904 acres of forestland per year**. Loss of forestland not only reduces the State's forest sector sequestration benefit, but results in emissions of stored carbon.

4. **Land use change has resulted in net emissions to the atmosphere.**
   Combining emissions from forest land converted to other land uses and sequestration from land converted back to forest reveals overall net emissions to the atmosphere of **+0.96 MMt CO_2e** in 2022.
5. **Projections suggest Vermont's forests will continue to be a carbon sink, though at a lower rate.**
   However, these forecasts do not account for potential future changes, such as **climate change impacts or socioeconomic factors** that could alter forest growth and carbon sequestration. Ongoing monitoring is essential to track these dynamics and ensure that forests continue to provide climate benefits.

Key Information:

→ Data and trends presented in this inventory are intended for educational purposes only, and caution should be observed when interpreting these data for other uses:

Forest carbon fluxes, including those from land conversion, are estimates with inherent uncertainty, often in the range of 20-50%. Estimating carbon storage and flux is imprecise due to the methods used for assessment and the variability across the landscape. The forest carbon data presented here are derived from a set of ground-based plots that have been extrapolated to the entire state.

This inventory is provided for outreach purposes and does not replace the official accounting source for statewide fluxes: the *Agency of Natural Resources Vermont Greenhouse Gas Emissions Inventory and Forecast*[v].

→ There are two types of carbon benefits included in this inventory:

1. **Carbon Storage**: the total amount of carbon in an entity. For example, storage can refer to the carbon contained in a tree, an acre of forestland, or a cord of wood. Sometimes, it is referred to as carbon stock.

2. **Carbon Flux**: the rate of change in carbon storage, usually expressed as an amount of change per year.

   Carbon flux is comprised of two components:

   A. **Carbon Sequestration**: the rate at which carbon dioxide (CO_2) is absorbed from the atmosphere and stored. Sequestration occurs when plants and trees photosynthesize and use these carbon compounds to grow larger. These carbon compounds can then be transferred to other parts of the forest, such as the forest floor and soil.

   B. **Carbon Emissions**: the rate at which CO_2 is released back into the atmosphere. In a forest, carbon emissions occur because of respiration (the metabolic process of living organisms), decomposition, and combustion (fire). Emissions can increase due to natural and human-caused disturbances, such as forest fires, conversion of forestland to other land uses, or timber harvesting.

   The balance between sequestration and emissions determines whether a forest or other entity gains or loses carbon over time.

   - If sequestration is greater than emissions, the net flux is negative. This means that CO_2 is removed from the atmosphere and stored on land, which is called a **carbon sink**.

   - If sequestration is smaller than emissions, the net flux is positive. This means that CO_2 is added to the atmosphere, and less is stored on land. This is called a **carbon source**.

→ **There are two units used to describe forest carbon benefits in this inventory:**

Carbon is expressed both as **carbon (C)** and as the **equivalent amount of carbon dioxide (CO_2-equivalent, CO_2e)**. This is because forests store carbon but absorb and emit carbon dioxide. To convert from carbon to CO_2-equivalent, multiply by 3.67.

Carbon and carbon dioxide are both measured in weight. The units are metric tons (Mt), which is equal to 2,205 lb. In some cases, the units are expressed in million metric tons (MMt).

→ **In this inventory, the forest sector is comprised of five components:**

1. **Forests remaining forest (Forests):** land area with established or newly growing trees.

   Forest carbon storage and flux reflect both natural processes and human activities, including tree mortality from natural causes and removals due to timber harvesting. This measures the net change in carbon storage within forests over time. If a timber harvest occurs between measurement periods, the carbon removed through harvesting is initially treated as if it's immediately released back into the atmosphere. Carbon that continues to be stored in harvested wood products is accounted for separately (see data details below).

   In forests, carbon is stored in different pools or reservoirs. The **forest carbon pools** are:

   1. **Aboveground biomass**: live trees and shrubs
   2. **Belowground biomass**: living roots > 2 mm diameter
   3. **Forest floor**: litter layer comprised of leaves, needles, twigs
   4. **Dead wood**: standing dead trees, downed logs, and branches
   5. **Soil**: organic carbon measured to a 1 m depth

2. **Forestland converted to another land use (From Forest):** land with trees that has been converted to a different land use type (cropland, grassland, wetlands, settlements, or other lands) since the last inventory period.

3. **Land converted to forestland (To Forest):** non-forested land that has been converted to forest by allowing trees to regrow or through active planting since the last inventory period.

4. **Settlement trees:** trees in developed land, including transportation infrastructure and human settlements of any size[vi].

5. **Harvested wood products**: about 30% of the carbon in harvested trees remains stored in long-lasting wood products, such as houses and furniture. To reflect this, the carbon retained in these durable products is added back into the overall carbon balance. This includes carbon stored in both **wood products still in use** and those in **landfills**. See Forests Remaining Forests above for more details about carbon accounting of harvested wood products.

→ **Data on forestland stocks and fluxes used in this inventory were derived from the US Forest Service's Forest Inventory and Analysis (FIA) Program. Harvested wood product stocks and fluxes were derived from Dugan et al. (2021).**

The FIA program has about 1,400 permanent plots arranged in a hexagonal grid across Vermont. A subset of these plots is measured each year, with each plot being measured every 7 years. These data are robust estimates, but they contain uncertainty because they cannot capture every acre of land across Vermont.

Harvested wood products (HWP) provide sequestration (negative flux) due to the transfer of harvested carbon to products in use and landfill. HWP also produces emissions (positive flux) due to the combustion of wood for bioenergy and the decay of retired products. However, HWP emissions are included in Forests Remaining Forests. This is because the net carbon flux of forests is computed as a change in carbon stock over time that accounts for harvest removals. In this way, carbon removed in harvests is considered emissions, and the proportion of harvested wood that is not emitted (whether in use or landfill) can be added back.

The data sources include:

1. Walters BF, Domke GM, Greenfield EJ, Smith JE, Ogle SM. 2024. Greenhouse gas emissions and removals from forest land, woodlands, and urban trees in the United States, 1990-2022: Estimates and quantitative uncertainty for individual states, regional ownerships, National Forests, and Tribal Ownership. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2024-0065
2. US Forest Service. 2024. Forest Inventory and Analysis (FIA) EVALIDator [DB Version: FIADB_1.9.3.00]. Accessed via https://apps.fs.usda.gov/fiadb-api/evalidator
3. Dugan, A.J., Lichstein, J.W., Steele, A., Metsaranta, J.M., Bick, S. and Hollinger, D.Y., 2021. Opportunities for forest sector emissions reductions: a state-level analysis. *Ecological Applications*, *31*(5), p.e02327.[1]

→ Additional Notes:

- Carbon values in this inventory should not be compared to the previous version (Kosiba 2021), as methodologies for computing forest carbon storage have changed. This has resulted in more accurate estimates of the carbon benefits of Vermont's forests compared to the previous estimates, which has accounted for more of the carbon stored within forests – mostly in the aboveground biomass pool.
- A comparison to the State of Vermont's Greenhouse Gas Inventory in Figure 5 is provided for context, but it is important to note that this analysis does not include all land use fluxes, forest carbon fluxes are estimates, and carbon stored and sequestered by forests is owned by the landowner and may be sold to another entity in carbon offset markets. Therefore, caution should be made when interpreting these data relative to the State's net zero goals.

[1] Note that EPA state level estimates for harvested wood product carbon were not available at the time of this inventory.

Each year, Vermont's 4.5 million acres of forests store more carbon than they did in the year prior.

The amount of carbon stored in Vermont's forests has steadily increased since 1990, the first year of available data. In 1990, Vermont's forests stored an estimated 449 MMt C (1646 MMt CO_2e). By 2023, this amount was 510 MMt C (1872 MMt CO_2e), or an increase of 61 MMt C (226 MMt CO_2e) absorbed from the atmosphere. This increase is the equivalent of removing 1.4 million cars off the road per year[2]. Adding in carbon stored in harvested wood products, both in use and landfill, there is an additional 34.7 MMt C (127.3 MMt CO_2e) stored in 2022.

Most of the increase in carbon storage has occurred in the aboveground biomass pool, which is the most dynamic of the forest carbon pools (see Figure 2). This is because in most of Vermont's forests, trees are growing larger and thus, storing more carbon. Although carbon is constantly relocating from trees to other carbon pools, this process is slow. Soils store more than half of the carbon contained in Vermont's forests: 297 MMt C (1024 MMt CO_2e) compared to 213 MMt C (847 MMt CO_2e) in the four other pools combined. Soils are critical in their ability to store large amounts of carbon, sometimes for very long periods (centuries to millennia).

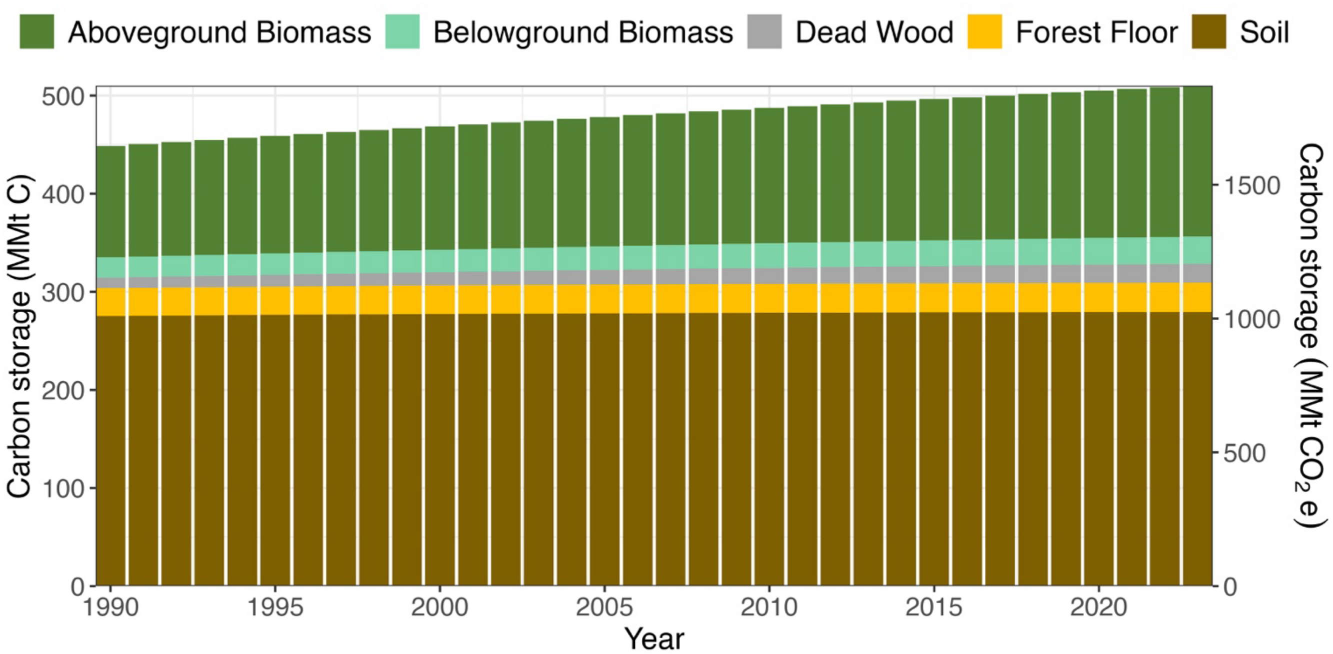


Figure 1. Estimated total carbon storage for forests that have remained forests in Vermont, shown by carbon pool and year. Carbon is expressed as a million metric tons of carbon (left axis, MMt C) and of carbon dioxide equivalents (right axis, MMt CO_2e). Carbon estimates from Walters et al. (2024).

[2] Assuming a passenger car emits 4.6 Mt CO_2e per year (https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle)

Vermont's 4.5 million acres of forests are a carbon sink. However, over time, the rate of sequestration has declined.

Since 1990, the net flux rate of the five carbon pools in forests that have remained forests has been negative since 1990. A negative carbon flux value indicates that more CO_2 has been sequestered from the atmosphere than emitted (refer to Key Information for further details). In other words, Vermont's forests function as a carbon sink. Most of this carbon sequestration benefit is attributed to the aboveground biomass pool. In the most recent year of data (2022), the aboveground biomass pool sequestered over two and a half times as much carbon as the combined total of the other four pools, with values of -4.38 MMt CO_2e compared to -1.68 MMt CO_2e. The values presented in Figure 2 are estimates, and there is a 43% uncertainty surrounding the total annual flux rate, which means that the total carbon flux could be as much as 43% higher or lower (see Figure 6).

One trend evident in Figure 2 is that the rate of carbon sequestration in Vermont's forests has declined since 1990, indicating that these forests are now storing carbon at a slower rate. In 1990, Vermont's forests sequestered -7.7 MMt CO_2e, whereas in 2022, this amount decreased to -6.1 MMt CO_2e. This translates to an average annual reduction of approximately 45,800 Mt CO_2e compared to the previous year. The decline in sequestration is primarily observed in the dead wood, forest floor, and soil carbon pools. This reduction is likely a result of the natural maturation processes of Vermont's forests; while older forests tend to store more carbon overall, they do so at a slower sequestration rate[vii]. Another contributing factor may be climate change: increased air temperatures and wetter conditions can accelerate decomposition rates and carbon emissions. The annual flux rates of the dead wood, forest floor, and soil pools are influenced by the balance between new inputs—such as dead plant and animal matter—and the rate at which these materials are decomposed by fungi, insects, and bacteria. Additionally, Vermont is experiencing a net loss of forest land over time, as more forested areas are converted to other uses than are restored. This land conversion accounts for approximately 20% of the annual decline in carbon sequestration (see Figure 3).

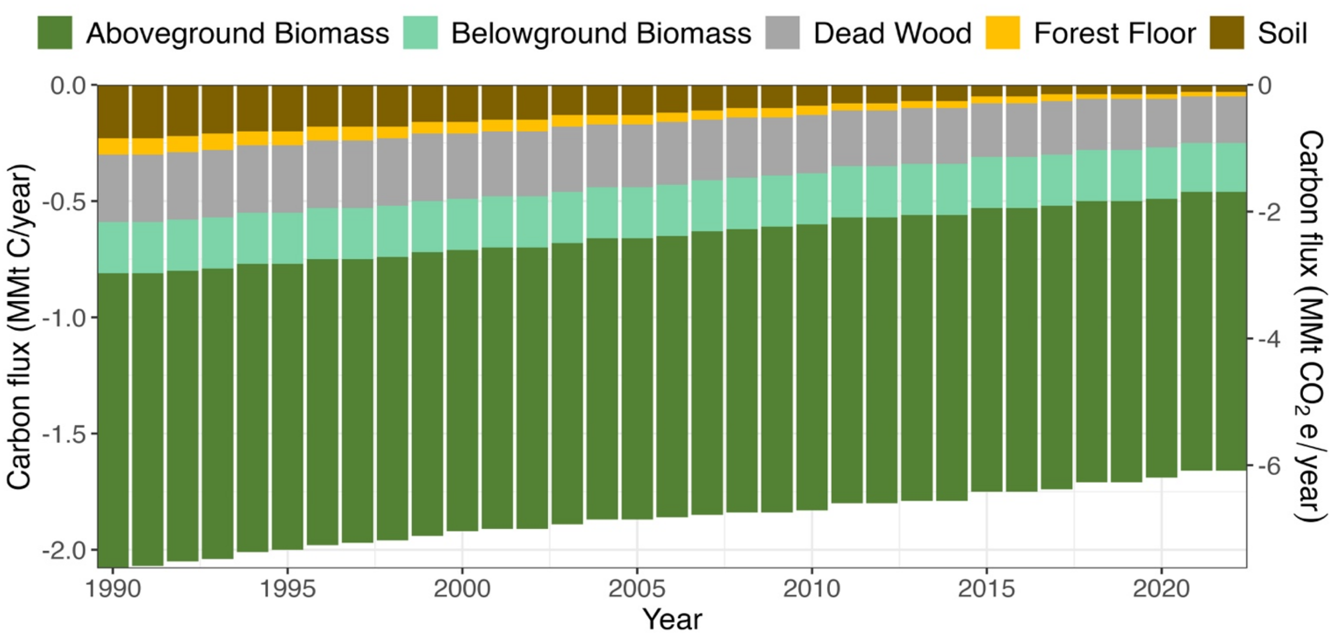


Figure 2. Estimated annual carbon flux for forests that have remained forests in Vermont, shown by carbon pool and year. Carbon is expressed as a million metric tons of carbon (left axis, MMt C) and of carbon dioxide equivalents (right axis, MMt CO_2e). Negative flux values indicate net carbon uptake, or sequestration, and positive values indicate net emissions (net carbon release to the atmosphere). Carbon estimates from Walters et al. (2024).

The extent of Vermont's forestland is a critical determinant of the total carbon benefits provided. In 2022, forests covered 76% of Vermont's total land area, or about 4.5 million acres.

The amount of forestland in Vermont has undergone significant changes over the past two hundred years. In the 20th century, Vermont witnessed a remarkable recovery of forest area, primarily due to the natural regrowth of trees on abandoned agricultural land, alongside active tree planting efforts. However, since the mid-1990s, this trend of increasing forest cover has reversed, leading to ongoing losses. As of 2022, Vermont had an estimated 4,487,566 acres of forestland, which constitutes 76% of the state's total land area. With an uncertainty of ±43,465 acres, this estimate ranges between 4,444,101 and 4,531,031 acres. This variation highlights the challenges in obtaining precise yearly estimates of forest cover, as depicted in Figure 3, which illustrates significant year-to-year fluctuations. A linear model applied to these estimates reveals that Vermont has lost on average 5,904 acres of forestland annually since 1997.

Most of the carbon stored in the lost forests is emitted into the atmosphere. However, about 30% of this carbon remains stored in wood products. When forestland is repurposed for other uses, it ceases to provide the carbon sequestration benefits it previously offered. This phenomenon is known as *foregone sequestration*. The annual loss of forestland in Vermont results in an estimated 8,088 Mt CO_2e that are no longer sequestered, which accounts for approximately 20% of the observed decline in statewide carbon sequestration (see Figure 2). Over the 25 years since 1997, this foregone sequestration totals about 202,212 Mt CO_2e.The amount of forestland in Vermont has changed dramatically over the past two hundred years. Starting in the 20th century, Vermont experienced a dramatic recovery of forest area when trees naturally regrew on unused agricultural land, and in other places, people actively planted trees. However, since the mid-1990s, the trend of increasing forest cover has reversed, and the state is experiencing losses.

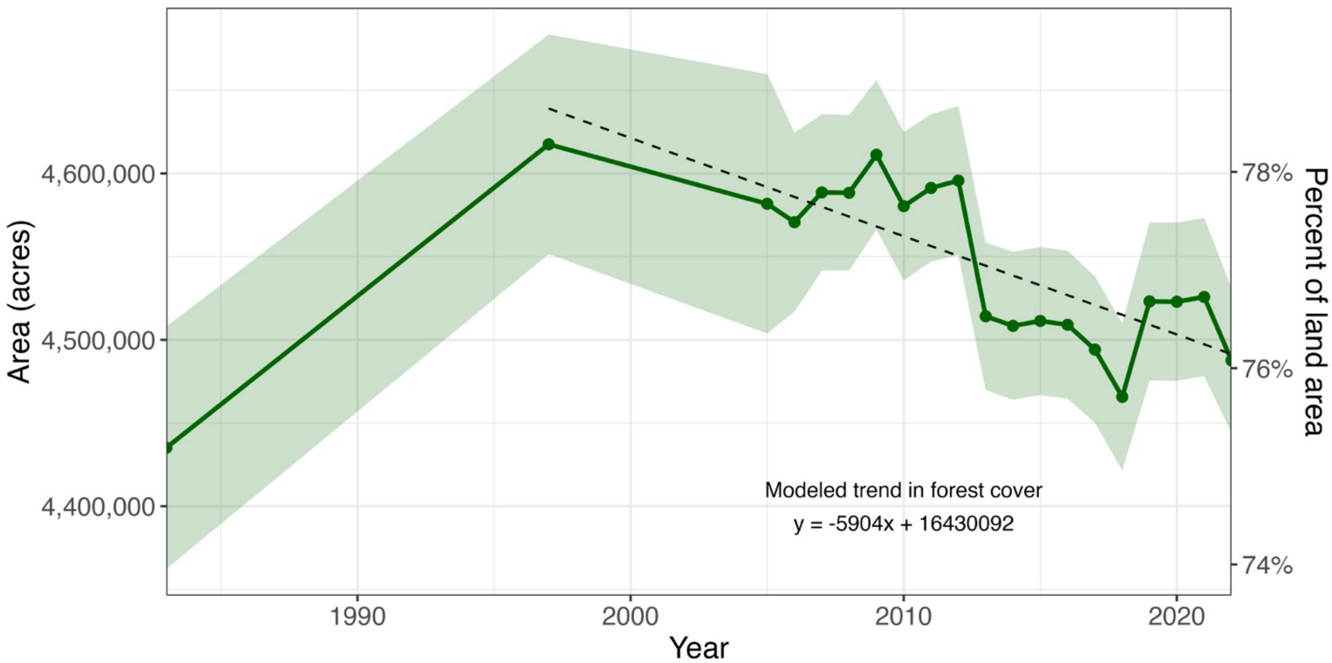


Figure 3. Estimated Vermont forest cover over time. Forest area is expressed as acres (left axis) and as the percentage of total land area in the state (right axis). Green shading indicates uncertainty estimates (standard error). Dashed black line depicts a linear model of forest cover since 1997. Forest area estimates from USDA et al. (2024).

Vermont's forestland sector includes land use changes, both the conversion of forest to other land uses and the creation of new forests. When summed, land use change is a net emitter of carbon dioxide to the atmosphere.

Each year, some forestland in Vermont is converted to other land uses, such as agriculture and development. This conversion can occur due to natural factors; for example, beavers may transform forests into wetlands. Conversely, forests are also regrowing in various areas, often when agricultural fields are no longer cultivated or when lands are actively replanted with trees.

When forestland is converted for other uses, the carbon flux is positive, indicating increased carbon dioxide emissions to the atmosphere. In contrast, the regrowth of forests results in negative carbon flux, as this process sequesters carbon dioxide from the atmosphere. Considering all these land use changes—both the conversion from forests and the reversion to forests—the net carbon flux for Vermont in 2022 is positive at +0.96 MMt CO_2e. This indicates that land use changes have contributed to overall emissions in the state[3].

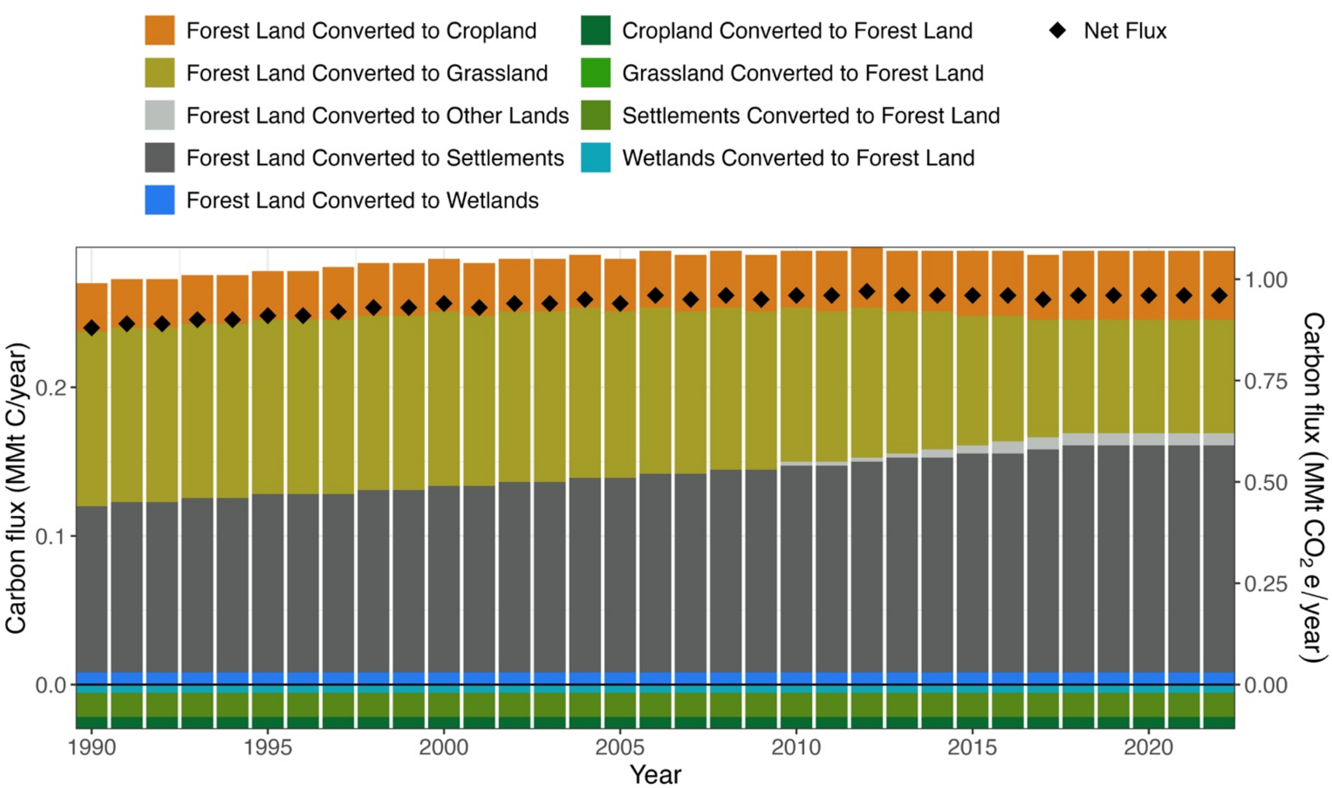


Figure 4. Estimated annual carbon flux due to forest-based land use change in Vermont, shown by type of conversion and year. Carbon is expressed as a million metric tons of carbon (left axis, MMt C) and of carbon dioxide equivalents (right axis, MMt CO_2e). Negative flux values indicate sequestration of carbon dioxide from the atmosphere, and positive values indicate emissions to the atmosphere. Carbon estimates from Walters et al. (2024).

[3] Note that this analysis only considers land use change to/from forests and does not include fluxes caused by other land use conversions, such as croplands to settlements.

Comparing Vermont's forest sector carbon sinks and sources with Vermont's Statewide estimate of greenhouse gas emissions suggests that the total forest sector compensated for about 79% of the State's emissions.

Vermont's forest sector encompasses both carbon sinks (such as the growth of forests, settlement trees, and land converted to forests, as well as carbon stored in harvested wood products in use and landfills) and carbon sources (primarily the conversion of forest land to other uses). In 2022, this sector recorded a net carbon flux of -6.6 MMt CO_2e. In contrast, Vermont emitted +8.3 MMt CO_2e in 2021 from transportation, heating, industry, and agriculture[viii]. When comparing the forest sector's net flux to the state's overall greenhouse gas emissions, it resulted in a total net flux of +1.7 MMt CO_2e, indicating that Vermont's forest sector compensated for approximately 79% of the state's anthropogenic greenhouse gas emissions.

This percentage is higher than reported in the previous Vermont Forest Carbon Inventory due to three primary factors: methodological changes in forest carbon accounting that have led to a greater negative carbon flux value, the previous inventory's double counting of emissions in harvested wood products (HWP), and a decline in the state's overall greenhouse gas emissions. However, it's essential to acknowledge that actual statewide net emissions may vary from this estimate for several reasons. One significant source of uncertainty is the accuracy of the carbon flux estimates related to forests and land use. Another uncertainty arises from the number of acres of forestland enrolled in carbon offset markets. When landowners sell the carbon benefits of their forests to another entity in a carbon offset market, those benefits cannot be counted towards offsetting state-level greenhouse gas emissions, as they have already been allocated to reduce emissions elsewhere.

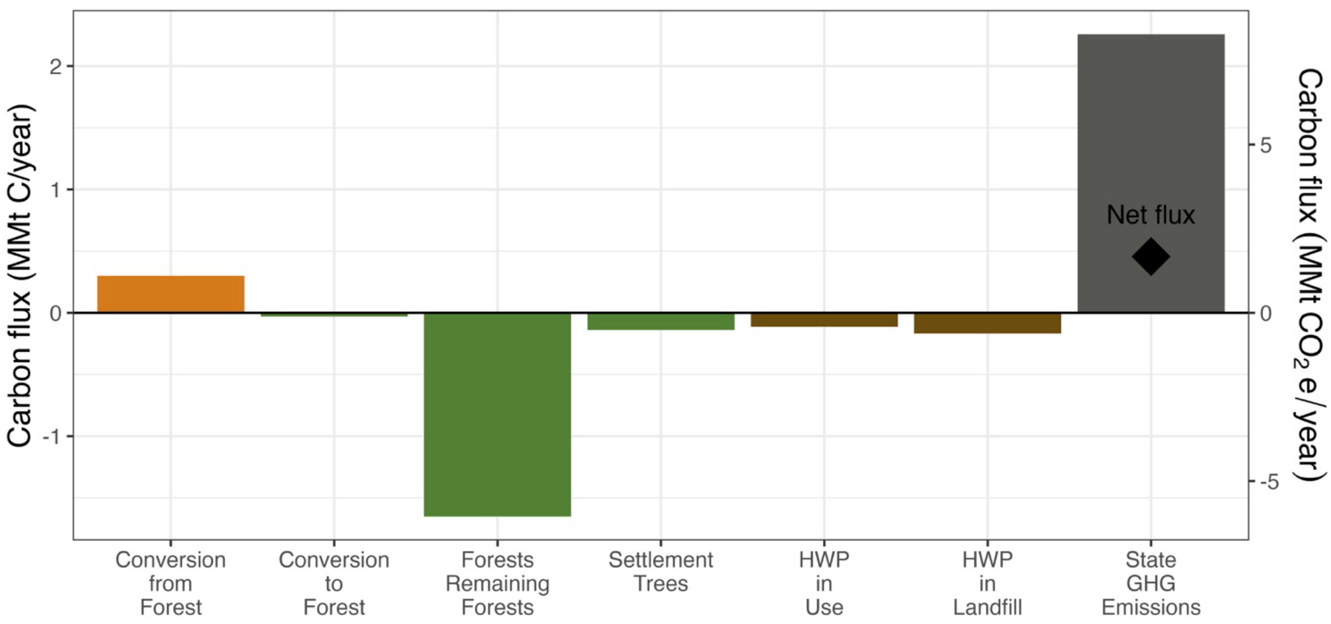


Figure 5. Estimated forest sector carbon fluxes in 2022 compared to the State of Vermont's Greenhouse Gas Emissions. Carbon is expressed as a million metric tons of carbon (left axis, MMt C) and of carbon dioxide equivalents (right axis, MMt CO2e). Negative flux values indicate sequestration of carbon dioxide from the atmosphere (a carbon sink), and positive values indicate emissions to the atmosphere (a carbon source). Estimates of fluxes for forests remaining forests, settlement trees, and land-use conversion (net conversion to and from forest) were extracted from Walters et al. (2024). Estimates for harvested wood products (HWP), including flux to wood products in use and landfills, were derived from Dugan et al. (2021), which are modeled estimates from harvesting patterns. Note that the net flux of forests remaining forests includes carbon removals as harvested wood products, thus accounting for emissions from bioenergy and decay. Statewide total greenhouse gas emissions for 2021 were extracted from the Vermont Greenhouse Gas Emissions Inventory and Forecast (Vermont Agency of Natural Resources, 2024). The net flux across all these sources and sinks is indicated with a black diamond.

Over time, the net sequestration benefit of the forest sector has declined. Forecasting this trend into the future shows a 37% decline in carbon sequestration by 2050.

Analyzing the four sources of carbon flux in Vermont's forest sector—conversion from forests, conversion to forests, forests remaining forests, settlement trees, and harvested wood products (HWP)—reveals a negative overall carbon flux of -6.6 MMt CO_2e in 2022, despite emissions from land use change. Since 1990, however, the sequestration benefits of the forest sector have diminished, primarily due to declining sequestration rates in forests that remain forests and a reduction in HWP.

Looking ahead, we can forecast the trend of the forest sector's net flux, assuming that historical patterns from 1990 to 2022 persist. This projection estimates a total net flux of -5.4 MMt CO_2e by 2030, with an upper bound of -7.7 and a lower bound of -3.1 MMt CO_2e. By 2050, the estimated net flux is expected to decline further to -3.4 MMt CO_2e, with an upper bound of -4.9 and a lower bound of -1.9 MMt CO_2e. While these estimates indicate that Vermont could achieve its net zero emissions targets, they do not account for all sources of land use flux. Additionally, they overlook potential environmental, climatic, and socioeconomic changes that could significantly impact forest sector fluxes, such as increased disturbances and stress from climate change or variations in land conversion and timber harvesting rates.

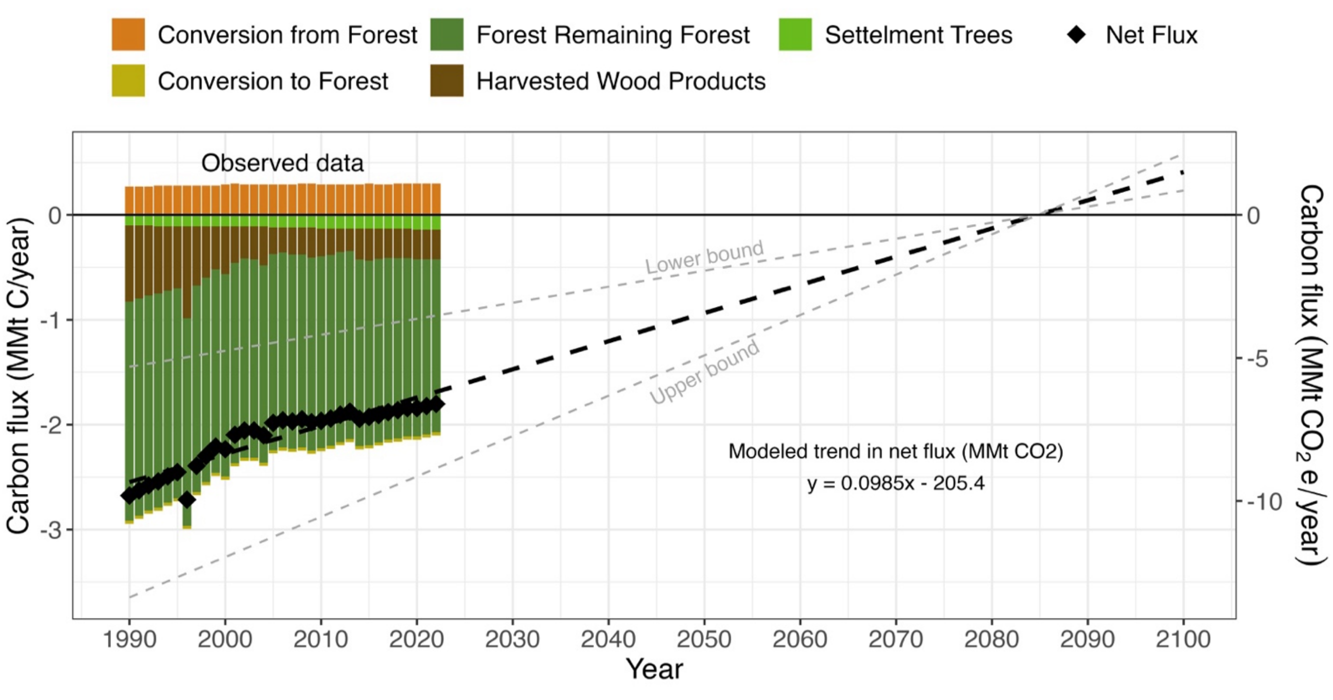
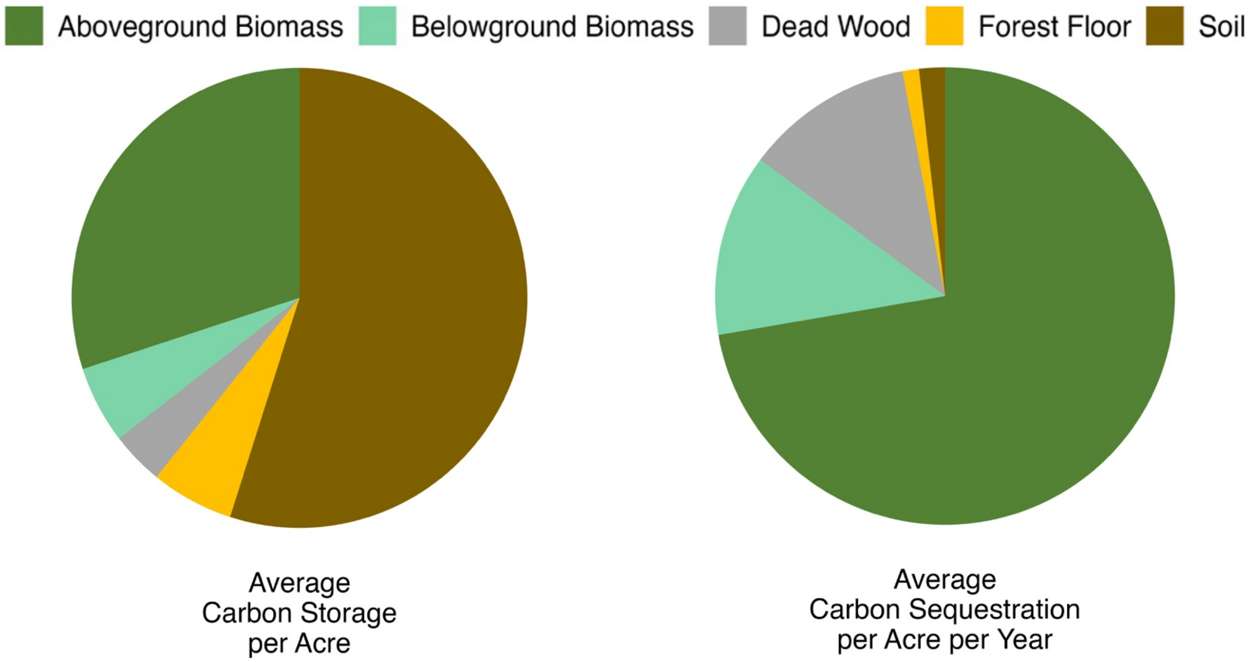


Figure 6. Estimated observed and modeled annual carbon flux across Vermont's forest sector, shown by year. Carbon is expressed as a million metric tons of carbon (left axis, MMt C) and of carbon dioxide equivalents (right axis, MMt CO_2e). Negative flux values indicate sequestration of carbon dioxide from the atmosphere, and positive values indicate emissions to the atmosphere. Land use changes are grouped into conversion to forest land and from forest land (refer to Figure 4 for individual land use change classifications). 'Settlement trees' are trees in developed land, including transportation infrastructure and human settlements of any size (IPCC 2006). Harvested wood products (HWP) include sequestration in products in use and landfill. It does not include emissions of HWP from bioenergy and decay because those emissions are factored into the net flux of forests remaining forests[ix]. The modeled linear trend in the overall forest sector net flux is shown for MMt CO_2e, is based on 1990-2022 net flux values, and does not factor in changes in forest condition due to climate-induced disturbances, increased rates of land conversion, or other changes. Lower and upper bounds are provided to illustrate uncertainty around net flux estimates using the percent uncertainty provided for the 2022 carbon flux of forests remaining forests. Carbon estimates from Walters et al. (2024) and Dugan et al. (2021).

In 2022, Vermont's forests stored 112 Mt C per acre (413 Mt CO_2e/ac) and sequestered -0.37 Mt C per acre per year (-1.37 Mt CO_2e/ac/yr) on average.

Analyzing the average carbon storage and sequestration per acre in 2022 highlights the varying contributions of different carbon pools within Vermont's forests. On average, soils store more than half of the total carbon, whereas the live biomass pool—comprised of both aboveground and belowground biomass—accounts for approximately 35% of total carbon storage. When considering the rate of carbon uptake, the live biomass pool is particularly significant, sequestering around 85% of the carbon. Over time, carbon captured by trees and other plants is gradually transferred to other pools as branches, leaves, and eventually entire trees die. Although soils represent the largest carbon storage pool in a forest, they accumulate carbon at a much slower rate compared to live biomass. This slow accumulation means that any loss of soil carbon can take a considerable amount of time to recover. It is important to note that these figures reflect the estimated average carbon storage and sequestration per acre in Vermont. Actual values can vary significantly; individual acres may store and sequester more or less carbon, and the ratios among the different carbon pools can differ as well.



	Average carbon storage per acre in 2022			Average carbon flux per acre in 2022		
Carbon Pool	*Mt C*	*Mt CO_2e*	*Percent*	*Mt C*	*Mt CO_2e*	*Percent*
Aboveground Biomass	33.8	123.8	30%	-0.266	-0.969	72%
Belowground Biomass	6.1	22.5	5%	-0.046	-0.173	13%
Dead Wood	4.2	15.4	4%	-0.044	-0.159	12%
Forest Floor	6.6	24.2	6%	-0.004	-0.015	1%
Soil Organic Carbon	61.8	226.6	55%	-0.007	-0.024	2%

Figure 7. Estimated average carbon storage per acre (left) and the annual average rate of carbon sequestration per acre (net flux, right) for forest remaining forest in 2022. The corresponding values and percent of the total for each pool is shown in the table. Carbon data expressed as a metric tons of carbon (Mt C) and of carbon dioxide equivalents (Mt CO_2e). Negative flux values indicate net uptake, or sequestration. Carbon estimates from Walters et al. (2024).

Carbon density (amount of carbon stored per acre) increases as forests age, mostly due to the larger trees and greater amount of aboveground biomass found in older forests, but the rate that carbon accrues slows down as forests age.

The dynamics of carbon storage in forest ecosystems demonstrate an important relationship between forest age and carbon density. As forests mature, carbon density generally increases, particularly in the aboveground biomass pool, which is composed of live trees. In young forests (ages 0-20 years), nearly all of the carbon is held in the soil. However, as forests grow older, the dynamics shift, leading to a change in the relative proportions of carbon stored in various pools. The decline in soil carbon seen in the oldest age class in Figure 8 (121-140 years) is likely due to a lack of stands of this age in Vermont, resulting in greater variability within this age class. Consequently, this variability may skew perceptions of carbon dynamics at these advanced age stages.

In terms of carbon sequestration rates, younger stands exhibit faster rates of carbon uptake compared to older forest stands. For instance, when forests transition from the 0-20 year age class to the 21-40 year age class, the average increase in carbon stored is 18 Mt C per acre. As forests continue to mature into the 41-60 year age class, the increase in carbon storage tapers off to about 9 Mt C per acre, reflecting a slowing rate.

Figure 8. Estimated average carbon storage per acre for forests remaining forests in Vermont, shown by stand age class. Data are averaged for years 2005 to 2023. Carbon is expressed as a metric tons of carbon (left axis, Mt C) and of carbon dioxide equivalents (right axis, Mt CO_2e). Percentages depict the relative contribution of each carbon pool to the total carbon storage for the age class. Error bars show the standard error of the mean total forest carbon storage per age class. Carbon estimates from USFS 2024.

Comparing the carbon density (amount of carbon stored per acre) in similarly aged forests that differ by community type reveals that some types store more carbon than others and there is variation in carbon stored in each of the five carbon pools.

The amount of carbon stored per acre of forest, also referred to as carbon density, varies slightly with the mix of tree species that make up the forest community. This is because different tree species have different wood properties, growth forms, maximum size, and mortality rates. Additionally, there are differences in soil properties and decomposer communities, along with differences in climate and disturbances.

Looking only at forests that are 81-100 years old, Figure 9 shows that the total amount of carbon, as well as the proportion in each carbon pool, varies by forest type. For example, spruce-fir forests tend to have more carbon in the dead wood pool compared to other forest types. This is likely due to a combination of factors unique to this forest type. For example, spruce-fir forests are often in higher elevation and colder locations where decomposition of wood is slower. At these locations, trees can by toppled by strong winds and heavy snow loading. Plus, once dead, spruce and fir wood decays more slowly than hardwoods like oak. Oak-pine forests on the other hand store the most carbon in the aboveground biomass pool. This reflects the fact that oak and pine trees are typically the largest trees found in Vermont's forests.

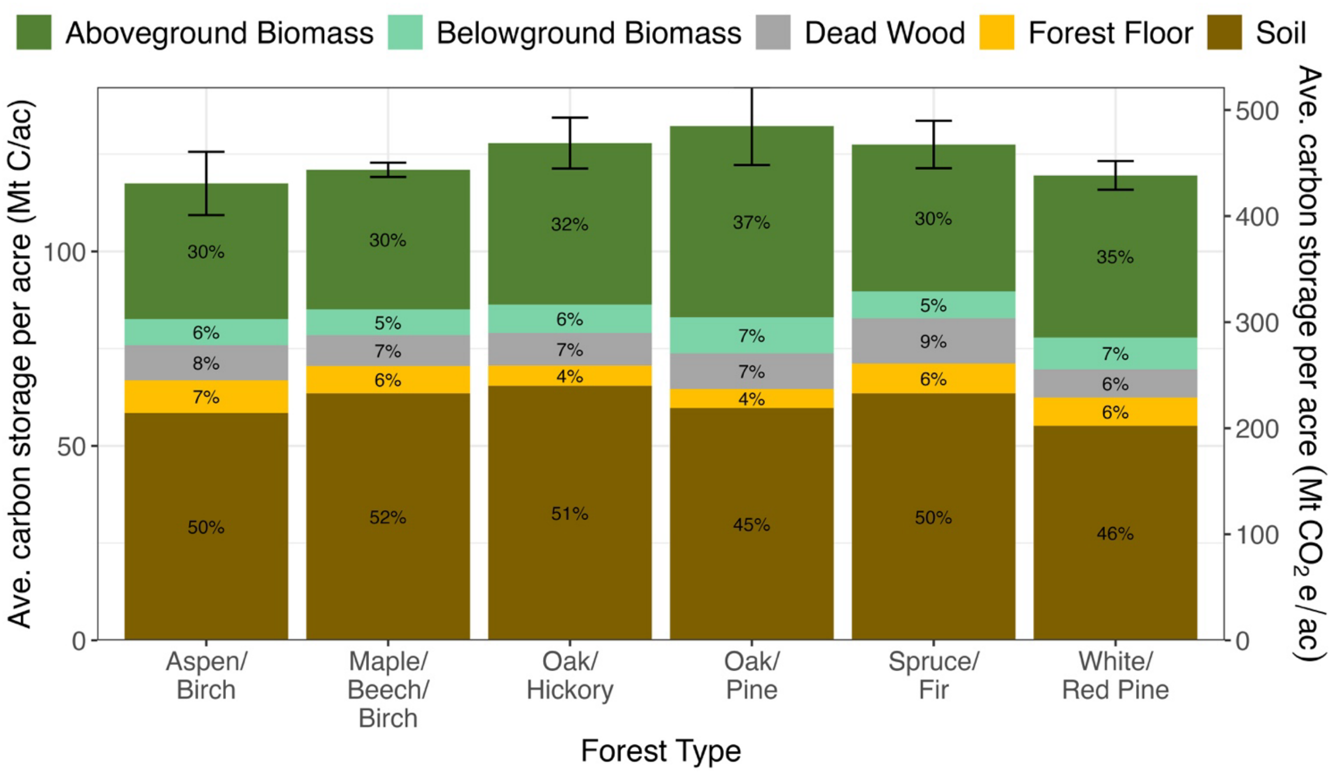


Figure 9. Estimated average carbon storage per acre (stands 80-100 years old) for forests remaining forests in Vermont, shown by forest type. Data are averaged for years 2005 to 2023. Carbon is expressed as a metric tons of carbon (left axis, Mt C) and of carbon dioxide equivalents (right axis, Mt CO_2e). Percentages depict the relative contribution of each carbon pool to the total carbon storage for that forest type. Error bars show the standard error of the mean total forest carbon storage per forest type. Carbon estimates from USFS 2024.

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