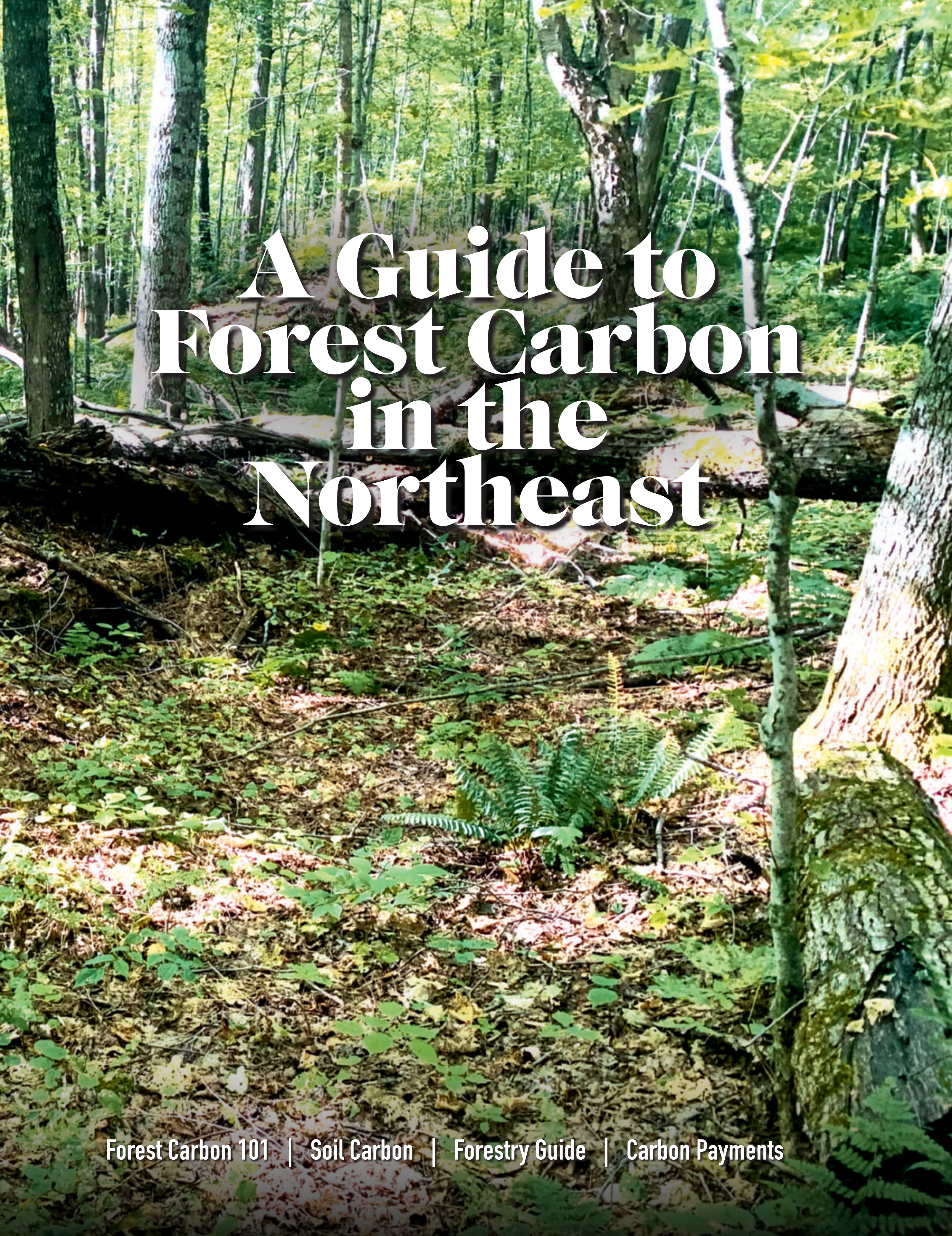
A Guide to Forest Carbon in the Northeast



Forest Carbon 101 | Soil Carbon | Forestry Guide | Carbon Payments

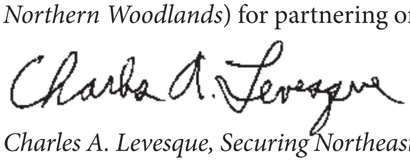
THE PURPOSE OF THIS GUIDE

Prior to 2019, forest carbon offset opportunities in the Northeast were limited; only landowners who owned very large forest parcels were able to build carbon payments into their forestry plans. However, in that year, several companies introduced carbon offset programs for northeastern forest parcels less than 5,000 acres. This sudden expansion of opportunities to most forest landowners coincided with public policy discussions and ultimately, new state laws in New England and New York that reflected increasing public concern about climate change, and growing awareness of forests' important role in sequestering and storing carbon.

In 2020, The North East *State* Foresters Association (www.nefainfo.org), a nonprofit of the state foresters from New England and New York, decided that the time was right for a regional collaboration to focus on educating key audiences about forest carbon and to provide technical assistance. The state foresters recognized that they could enhance their educational impact by working together to provide information about the latest science, management, and markets of forest carbon to forest landowners, foresters, land trusts, and other key decision makers.

USDA Forest Service provided a grant to the association, and the *Securing Northeast Forest Carbon Program* was born. The idea was simple: to use all education and outreach forms, from publications, to webinars, to live meeting presentations to one-on-one consultations, to assure that people could make informed decisions about forest carbon and their woods. The program also prompted all of the seven states' top forest carbon staffers to collaborate, sharing methods, materials, and learnings.

A key step to make all this work was finding a forest carbon expert who could lead the development of educational content for the program. That individual was Dr. Alexandra (Ali) Kosiba. Initially as the State of Vermont's first Climate Forester, and then as the University of Vermont's Extension Forester, Ali has been the linchpin of the whole *Securing Northeast Forest Carbon Program* educational effort. Her four *Northern Woodlands* magazine articles on forest carbon, which appear together in this publication, are the culmination of hundreds of in-person and video presentations around the region. They reflect the input of the state forest carbon staffers in the program, and of the topic experts listed in the acknowledgments page at the back of this guide. Ali has written about this important topic in a way that is relevant both to today and tomorrow. We hope this compilation will be available for years to come as a key source of information about forest carbon in the Northeast. Thanks go to the Center for Northern Woodlands Education (the publisher of *Northern Woodlands*) for partnering on this effort.



Charles A. Levesque, Securing Northeast Forest Carbon Program Coordinator and Executive Director,
North East State Foresters Association, Spring 2024

INTRODUCTION

In recent years, there has been a remarkable surge in interest in forests, a trend that fills me with enthusiasm and hope. This interest largely stems from a heightened awareness of forests' crucial role in mitigating climate change as "natural climate solutions." With this comes a pressing need for science-based information on forest carbon dynamics. As many states and organizations set net-zero targets and carbon offset markets expand, landowners are increasingly seeking guidance on the best practices for managing forests for carbon benefits.

In 2020, when I was the Climate Forester for the State of Vermont and beginning to address these information gaps, Charlie Levesque approached me about a new regionwide collaborative: the *Securing Northeast Forest Carbon Program*. This program brought together a state leader from each of the seven states, with me representing Vermont and leading the development and delivery of the educational content. Through this program, we have educated thousands of landowners, foresters, and decision makers in New England, New York, and beyond.

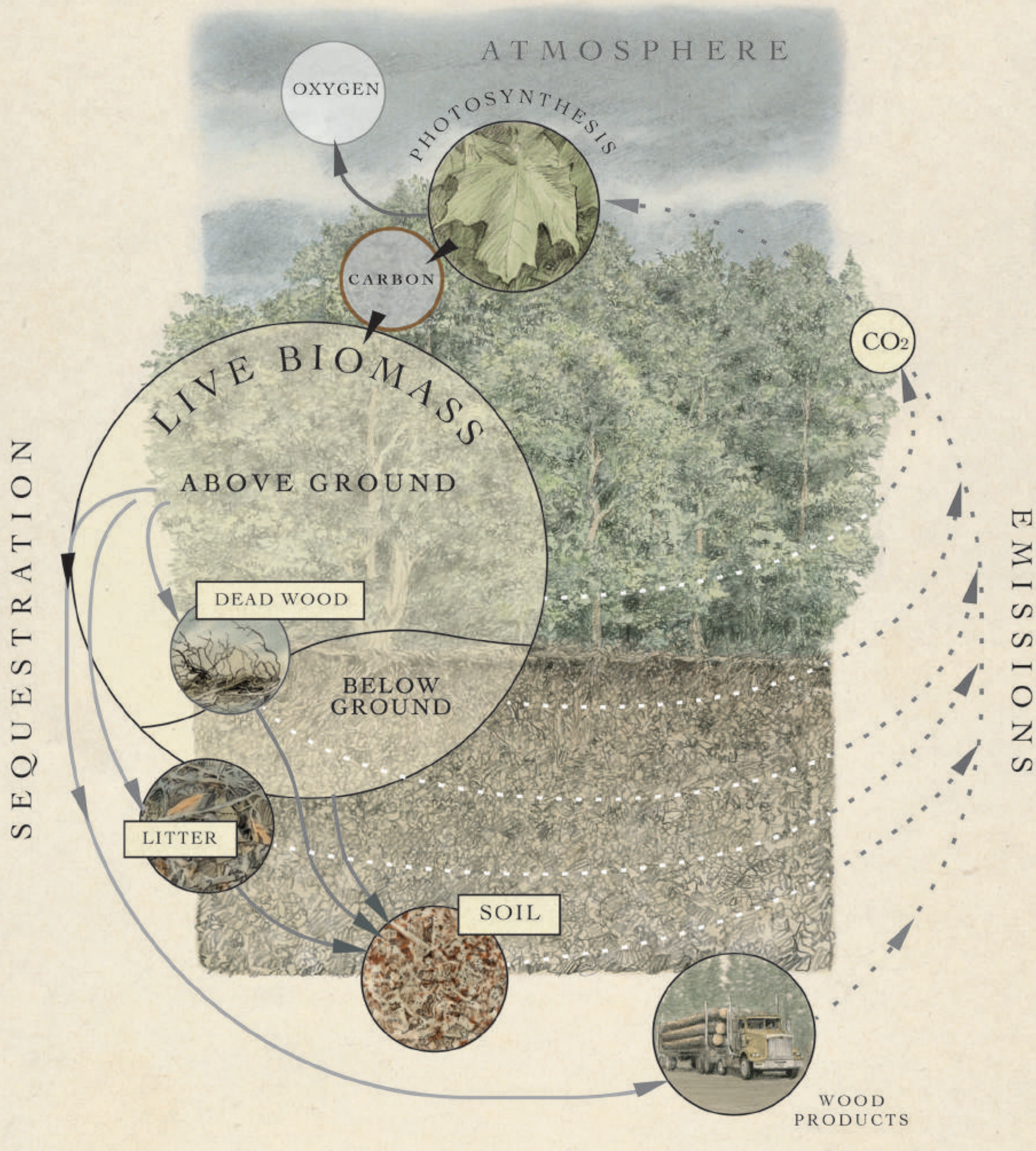
Drawing from these experiences and support from the *Securing Northeast Forest Carbon Program*, I wrote a four-part series for *Northern Woodlands* magazine. We've now compiled these articles into a standalone booklet, *A Guide to Forest Carbon in the Northeast*.

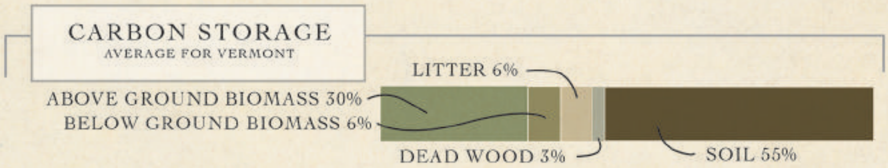
The deeper I delve in to this field, the more I realize its complexity. Beyond scientific advancements, economic dynamics play a pivotal role, shaping emerging carbon markets and management practices. As we navigate these complexities, it becomes increasingly apparent that our decisions ripple far beyond our immediate sphere, resonating globally within the broader context of climate change. Even in the Northeast, one of the most forested regions in the United States, we shouldn't take forests' service as carbon sinks for granted. There is a delicate balance between forests' potential to mitigate climate change and their vulnerability to its effects. Minimizing this vulnerability is one of several important considerations that we must weigh.

Yet, amid these challenges lies a profound opportunity to acknowledge the interconnectedness of our actions and the imperative of conserving and managing forests for sustained benefits. I hope that readers of this guide will be inspired to recognize forests not only as carbon sinks but also as invaluable ecosystems that provide myriad critical benefits to humanity and the planet. I invite you to join me in embracing this journey of understanding and appreciation for forests, recognizing them as vital allies in our collective endeavor to address the pressing challenges of climate change and environmental conservation.

Alexandra Kosiba, PhD
University of Vermont Extension

FOREST CARBON CYCLE





An Introduction to Forest Carbon

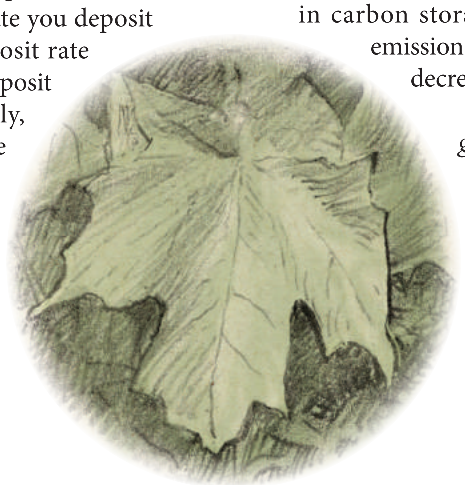
The first step to promoting carbon sequestration and storage in forests, is to understand how carbon moves through forest systems. This article explains key processes and terms.

What's the distinction between carbon sequestration and storage? And what are other key terms?

Carbon storage is the amount of carbon contained in an entity – such as a tree, an acre of forest, a piece of lumber, or a cubic yard of soil. One analogy that may be helpful is to think of carbon storage as the amount of money in your bank account. However, carbon is measured as mass (usually pounds or tons).

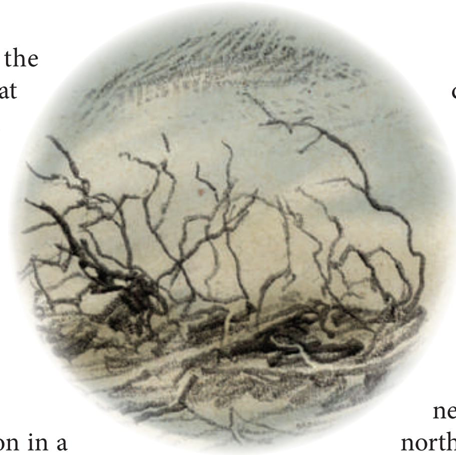
Carbon sequestration is the process of removing carbon dioxide (CO_2) from the air through photosynthesis and storing the carbon from those CO_2 molecules in wood, leaves, branches, bark, and soil. Although all green plants sequester carbon, trees are particularly good at it because of their perennial, woody structure and large size. In the bank account analogy, sequestration is the rate you deposit money into your account. A bank deposit rate may vary over time: some months you deposit more and other months less. Similarly, carbon sequestration varies over time and depends on numerous factors, such as the time of year, available moisture, weather patterns, and disturbance events. It is measured as the mass of carbon added over time (tons per year).

It may come as a surprise, but forests also emit CO_2 back out to the atmosphere – called *carbon emissions*. Emissions are like withdrawals from your bank account. There are three processes through which emissions occur in a forest: *cellular respiration* (the process of living cells using energy to meet their metabolic needs), combustion (fire), or *decomposition* (the breakdown of carbon-based matter – for example, wood or leaves – by fungi, bacteria, and other organisms). In low oxygen conditions, such as wet soils, the microbes that decompose plant materials produce a different carbon gas, methane (CH_4).



As forests both sequester and emit CO_2, the key question is whether sequestration is exceeding emissions or vice versa. If you deposit more money in your account than you withdraw over time, your account will grow, but if you withdraw more than you deposit, your account will shrink; the same is true for forest carbon. A forest is called a *carbon sink* when sequestration exceeds emissions, which results in an increase in carbon storage. A forest is a *carbon source* when emissions exceed sequestration, which results in a decrease in carbon storage.

Both CO_2 and CH_4 are *greenhouse gases* because they trap energy from the sun in Earth's atmosphere. Greenhouse gases act like a blanket around Earth that maintains temperatures to sustain life. However, the burning of fossil fuels and other human activities such as deforestation have effectively thickened this blanket by increasing the concentration of greenhouse gases in the atmosphere, causing the planet to warm at an unprecedented rate. In other words, we've altered the balance of Earth's carbon cycle by emitting carbon more quickly than it can be sequestered.

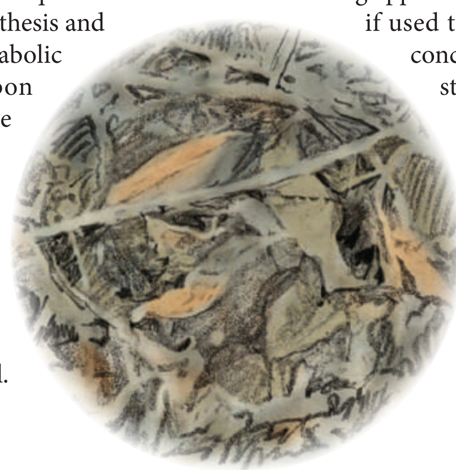


From the top branches of the canopy down into the soil, where does forest carbon accumulate?

When we talk about and measure carbon in a forest, it is helpful to break up the forest into *carbon pools*. Each one of these forest carbon pools has different carbon storage potential, rates of accumulation (sequestration) and loss (emissions), and is subject to unique factors that affect these processes. In addition, decisions we make about forest management and land use can affect whether pools are accumulating or losing carbon.

A pool loses carbon when carbon is transferred to another pool, or when CO_2 or CH_4 is emitted back to the atmosphere. As shown in the illustration, at every step of the forest carbon cycle, there are carbon losses (emissions). Within a forest, some pools might be carbon sinks while others are carbon sources, and this varies over time, including over seasons.

Living trees make up the *live biomass pool*. This pool is often divided into the aboveground portion (trunk, branches, and leaves) and the below ground portion (roots). Herbaceous plants, shrubs, seedlings, and animals that live in the forest also contain carbon, but these organisms are rarely included in carbon assessments because they make up a relatively small proportion of carbon in a forest compared to trees and it is difficult to measure the carbon they contain. The living trees that make up this pool sequester carbon from the atmosphere through photosynthesis and emit carbon from their day-to-day metabolic activities (cellular respiration). Carbon from live trees is the primary source of carbon for the other pools, which occurs when a tree or its leaves, roots, or branches die. Living trees also directly transfer carbon into the soil through root excretions, which feed microbes that live underground. The live biomass pool is typically the second largest carbon pool in the forest, after soil.



The *deadwood pool* includes standing dead trees (called "snags"), logs, and branches on the ground. This pool changes most drastically when there is a disturbance that causes live trees to lose branches or when a tree dies. Losses are driven by decomposition rates, which are affected by the climate, site conditions, and the local biological community.

The *litter pool* is composed of leaves, needles, and twigs that lie on top of the soil. In northeastern forests, this is usually the smallest of the forest carbon pools. The amount of carbon in the litter pool varies depending on the time of the year, the species composition of the forest, and decomposition rates.

When dead leaves, roots, and wood are decomposed by fungi, bacteria, and other organisms, some of the carbon is emitted as carbon gas (CO_2 or CH_4) and some is transferred to the *soil pool*, where it can remain for years, centuries, or even longer. The soil pool contains carbon stored both as organic carbon – a mixture of compounds from the decay of living matter and soil organisms – and as inorganic carbon (primarily as carbonates). In northeastern forests, the soil pool typically stores the most carbon but accrues carbon very slowly. Decomposition rates and disturbances to the soil drive changes in this pool. Additionally, soil erosion and leaching can cause carbon to be transferred out of the soil pool and into water bodies.

There is also another carbon pool that exists outside the forest: *harvested wood products*. Solid, durable wood products store carbon for as long as the product is used and may store carbon for longer if the wood is recycled or sent to a landfill where it slowly decays. Using wood for certain building applications can have additional climate benefits if used to replace high-energy products, such as concrete, steel, or plastics. Paper products also store carbon, although rarely for as long as carbon is stored in solid wood products. As for harvested wood that is used for energy, such as firewood, wood chips, or wood pellets, the carbon is released to the atmosphere when the wood is combusted. However, the use of wood energy can reduce the use of fossil fuels. When evaluating the carbon cycle implications of different wood products, it is important to consider the impacts of alternative materials, including how and where they are sourced and what happens to these products after they are used.

How much does carbon sequestration and storage potential depend on tree age and size?

Generally, but not always, younger stands (roughly 25 to 70 years old) sequester carbon at a higher rate than older stands, but older stands store more carbon. This is because trees in younger stands are vigorously growing taller and wider and expanding their canopies, such that their rates of photosynthesis are higher than in older stands. In contrast, older stands often have larger individual trees, a range of tree sizes, and more carbon that has accumulated in the deadwood and soil pools.

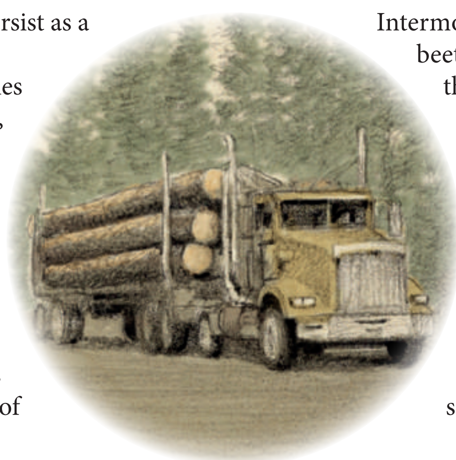
Although stands with higher tree densities (in forestry terms, called "stocking") have more stored carbon than less dense stands, higher stocking can result in lower individual tree growth and greater tree mortality because of competition for light, water, and nutrients. To maximize both storage and sequestration requires a diversity of tree ages and complexity in forest structure, which includes canopy gaps, trees of different sizes, standing dead trees, and downed logs. Diversity and complexity in a forest also provide critical ecological benefits, such as wildlife habitat, water and nutrient cycling, and erosion control, and improve the chances that the forest can adapt to changing conditions and persist as a forest in an uncertain future.

Forest carbon also varies by tree species and forest type. Faster growing species, such as aspen and birch, can have high rates of sequestration early in stand development, whereas species that attain greater sizes at maturity, such as red oak and white pine, have higher carbon storage potential. Conifer-dominated forests often have more carbon stored in the soil and litter pools because of the slow decomposition rate of their needles. Yet overall, when we examine data from monitoring plots around the region, we see that site conditions, disturbance histories, and past land use influence forest carbon much more than species composition.

How important a role do northeastern forests play in climate change mitigation, and is that changing over time?

The forests of New England and New York are currently a carbon sink, but it hasn't always been that way. More than a century and a half ago, these states experienced forest clearing for farmland and development ranging between 30 and 80 percent loss in statewide forest cover. This resulted in the region's forests being a carbon source. When much of the abandoned agricultural land began to regrow as forest, the land became a carbon sink; this persists today.

Using data collected in long-term monitoring plots by the U.S. Forest Service*, we can estimate the carbon sequestered and stored in the 50 million acres of forests across New England and New York. In 2019, these forests sequestered about 14 percent of the region's greenhouse gas emissions (52 million metric tons of CO_2). In total, these forests store the equivalent of 17 billion metric tons of CO_2. If all this carbon was emitted tomorrow it would equate to 54 years of the region's fossil fuel, industrial, and agricultural greenhouse gas emissions. Outside this region, most U.S. states have forests that are carbon sinks. The exception occurs in the Intermountain West and Southwest, where bark beetle outbreaks and catastrophic fires mean that forests have become carbon sources.



Although each of the northeastern states' forests is a carbon sink, the overall forest sequestration rate is declining in some of these states, meaning that each year they are absorbing a little less. The trend of declining sequestration seems to be related to natural forest dynamics that have followed agricultural abandonment. As forests age, stand-wide sequestration tends to decline due to lower

* *Domke, Grant M.; Walters, Brian F.; Nowak, David J.; Smith, James, E.; Nichols, Michael C.; Ogle, Stephen M.; Coulston, J.W.; Wirth, T.C. 2021. Greenhouse gas emissions and removals from forest land, woodlands, and urban trees in the United States, 1990–2019. Resource Update FS-RU-307. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 5 pages [plus 2 appendices]. https://doi.org/10.2737/FS-RU-307*

net-growth rates of individual trees coupled with natural mortality. And there is another factor that affects the strength of the region-wide carbon sink: the continual conversion and loss of forestland every year to other non-forest uses. Forest loss slowly chips away at the region's carbon sequestration potential.

How can we manage forests to mitigate climate change?

To help mitigate climate change, we need to keep CO_2 out of the atmosphere and to actively remove it – not just now, but for years to come. When it comes to mitigating climate change through forests, what affects the concentration of CO_2 in the atmosphere is the balance of sequestration to emissions across the forest carbon cycle. But forests and the carbon they store and sequester also face another threat: climate change. Changing climatic conditions are likely to bring large-scale disturbances, extreme weather events, drought, and tree mortality from insects and diseases that could result in losses of stored carbon and reduce future sequestration.

Considering the balance between storage and sequestration and the threats forests face supports management for increasing species diversity and structural complexity, which can help promote forest carbon, health, and long-term resilience. Because climate impacts and disturbances can affect certain species or age classes differently than others, diverse and complex forests are often better able to withstand and recover from extreme weather events, insect and disease outbreaks, and other stressors.

For these reasons, consider managing for "resilient carbon" rather than seeking to maximize storage or sequestration alone. Years of forest management have shown us that the best outcomes occur when we do *not* singularly focus on one goal to the detriment of another; the same is true for forest carbon. Managing for resilient carbon means making choices that maintain carbon by supporting critical ecological functions while also considering the long-term trajectory of the forest to sustain health, reduce vulnerabilities, and promote sequestration. Strategies for resilient carbon may include preserving old trees, designating specific areas as "no cut" reserves, and increasing the amount of deadwood for its critical role in nutrient and water cycling and wildlife habitat. Strategies may also include creating gaps to promote regeneration, thinning stands to limit the impacts of insects and diseases, controlling invasive plants, and promoting species diversity and structural complexity through thoughtful stand management.

Resilient carbon also means recognizing that the carbon cycle doesn't end at the forest's edge. This means considering the forest's position in the broader landscape – and our broader society – when making management decisions. For example, we should think strategically about how to sustainably harvest wood for wood products that store carbon, do not push our impacts elsewhere, and reduce our dependence on more carbon-intensive materials such as concrete, steel, fossil fuels, and plastics. We also want to ensure that we have forest diversity and complexity across the landscape for climate resilience and to act as steppingstones that allow for the migration of species under a changing climate. And last, we should seek to reduce the continual loss of forest cover that our region is experiencing.

Carbon is not the only critical ecosystem service that forests provide. Forests also cycle oxygen that we breathe and the water that we drink; they moderate temperature fluctuations, control soil erosion, and reduce flooding; and forests provide a local source of building materials and fuelwood, habitat for wildlife, and a place for recreation and cultural importance. When we think about the role forests can have to help mitigate climate change, we must consider their present role along with their future health and resilience.

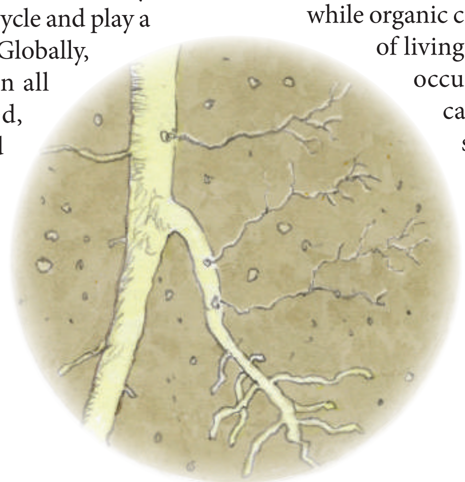
Understanding Forest Soil Carbon

When people think about forest carbon, they typically think of wood. Yet in the Northeast, soil is actually the greatest forest carbon pool. This article offers an overview of forest soil's role in carbon storage, and describes management techniques to protect soil as part of managing forests for climate change mitigation goals.

Why are forest soils important?

Walking through a forest, it's easy to overlook the soil. But forest soils provide a vital space for roots, nutrient cycling, and water storage, and are home to a biodiverse suite of organisms collectively known as the soil biota. Soil biota include microbes such as bacteria, fungi, protists (amoebae), and viruses, as well as larger soil fauna such as earthworms, snails, slugs, spiders, millipedes, nematodes, and mites. Soil biota provide vital functions in breaking down and decomposing organic matter. Without them, dead matter would accumulate and nutrients would be inaccessible.

Recently, soils have gained attention because they are a critical component of the global carbon cycle and play a major role in regulating Earth's climate. Globally, soils store four times more carbon than all aboveground plant biomass combined, making them the largest land-based carbon pool on Earth. Another notable feature of soils is that they can store carbon for a long time, in some cases over millennia. As discussed in the first article in this series, more than half of the carbon found in the forests of the Northeast is stored in the soil.

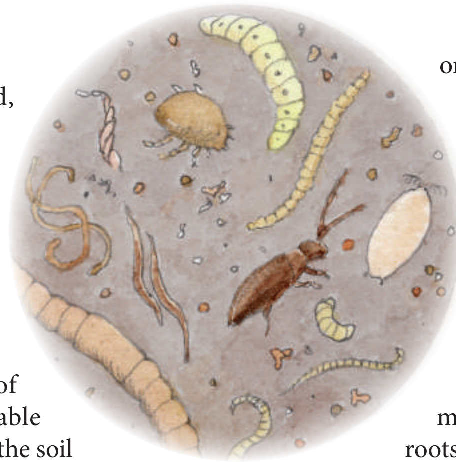


Given the vast size of the soil carbon pool, any changes to it can significantly impact atmospheric carbon dioxide (CO_2) concentrations. Therefore, understanding whether forest soils gain or lose carbon over time is critical to understanding Earth's future carbon balance, and to managing forests to mitigate climate change.

How does carbon get stored in soil?

Soil carbon originates from two sources: inorganic carbon and organic carbon. Inorganic carbon forms from the weathering of rocks or from soil minerals reacting with CO_2, while organic carbon arises from the remains and wastes of living organisms. Inorganic carbon in the soil occurs largely as carbonate minerals, such as calcite and dolomite. In arid regions with sparse vegetation, inorganic carbon is more abundant in the soil than organic carbon. But in our humid forests of the Northeast, carbonates are quickly dissolved by rain. Here, organic carbon is the primary type of soil carbon. Organic carbon arises from dead organic matter on the forest floor and from roots and microbes in the soil.

When leaves and bark are shed, twigs break, and organisms die, the soil microbes begin to break down the organic matter into smaller and smaller pieces that can then be consumed and excreted by soil fauna such as earthworms, millipedes, and snails. Evidence of this decomposition is easy to find beneath the leaf litter. What you're likely to see is a layer of dark soil, comprised of indistinguishable particles of plant and animal matter. As the soil biota continue to consume organic matter, carbon compounds are transported to deeper soil depths. When the soil biota die, they, too, contribute to the organic carbon pool.

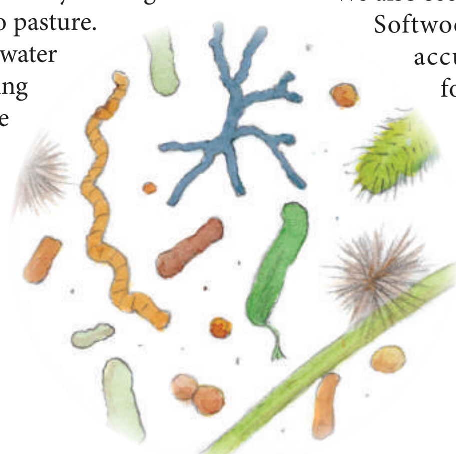


Tree roots and their associated mycorrhizal fungi add a significant amount of organic carbon directly to the soil. This happens through the frequent turnover and decomposition of small feeder roots as well as through exudations of carbon compounds by living roots and associated mycorrhizal fungi. These exudations produced by roots and mycorrhizal fungi, as well as by bacteria that live in the soil, play an important role in stabilizing the soil carbon pool. This sugary mucous facilitates clumping, or aggregation, of soil particles, which reduces carbon losses from erosion, leaching, and decomposition.

How is carbon lost from the soil?

Carbon can be lost through physical or chemical means. Physical loss occurs when water, wind, or other erosive forces carry soil, carbon, and other nutrients offsite. A historical example of this loss was the rapid erosion of topsoil from northeastern hill farms in the 19th century during a period of mass conversion of forests into pasture. The widespread removal of trees altered water patterns and reduced soil stability, resulting in losses of soil carbon from the landscape during wind and rain events.

Chemical loss of soil carbon results from combustion of organic matter during a forest fire or from the metabolic processes of the soil biota, which we call respiration. As soil organisms break down and consume organic matter, they respire carbon gas back into the atmosphere. Most respiration is in the form of CO_2, but when oxygen levels are low in the soil, which occurs when the soil is saturated with water, the soil organisms will emit methane (CH_4), a potent greenhouse gas. Living roots also release CO_2 into the soil during metabolic processes associated with maintenance and growth. Collectively, release of carbon gas through the metabolism of living microbes, fauna, and roots is called soil respiration. It's important to note that it is the living organisms in the soil that are respiring, not the soil itself.

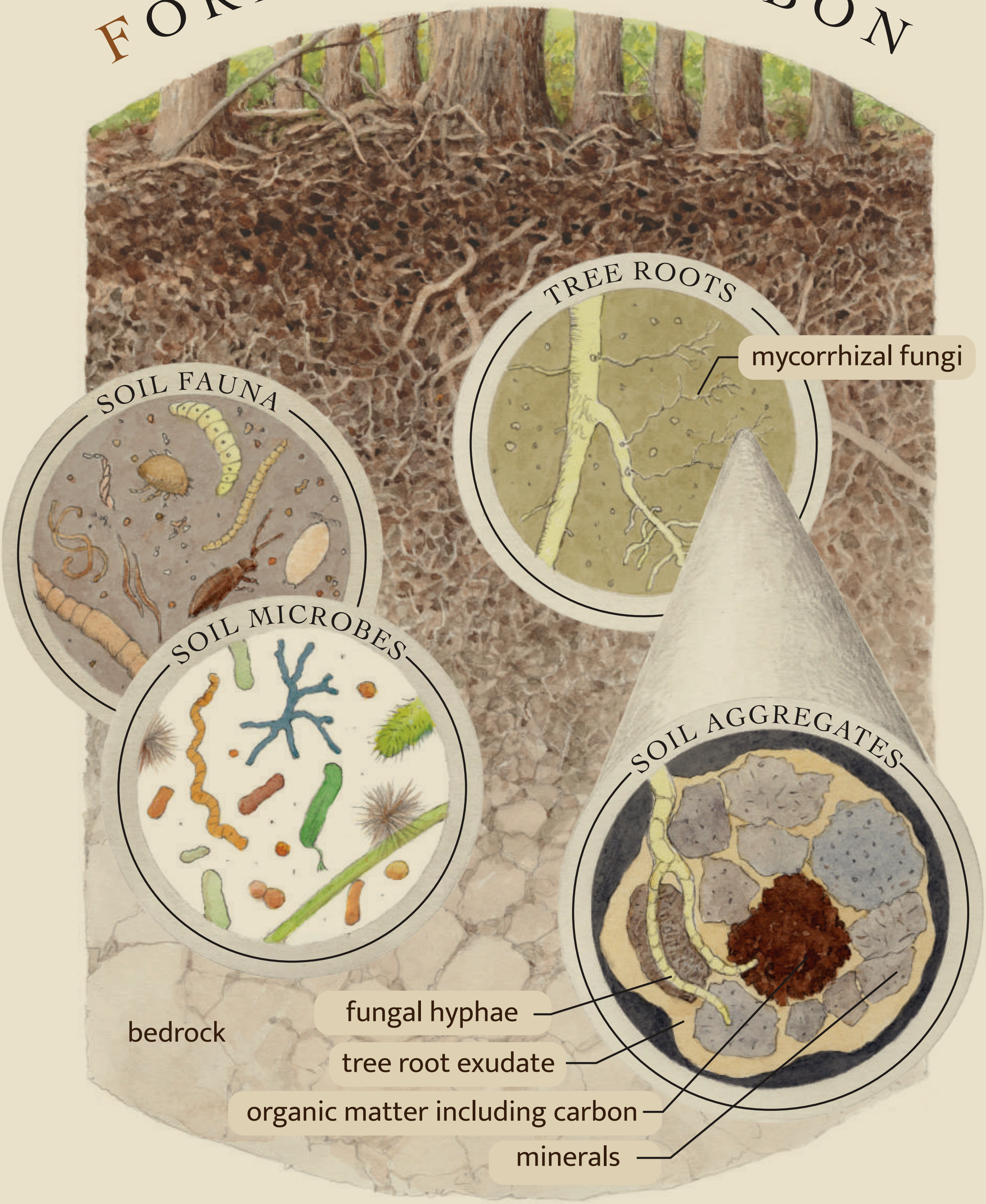


What factors affect how much carbon forest soils can store?

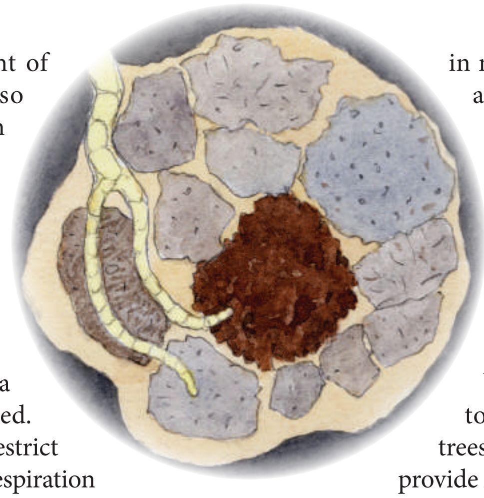
As with the other forest carbon pools, carbon in the soil is dynamic. On an ongoing basis, there are both carbon inputs and losses. Many factors impact the balance of these inputs and losses, including soil texture, site conditions, and vegetation. The most important factors in determining the stability and longevity of organic carbon in the soil depends on microbial processing and mineral associations. Organic carbon can exist as particles of plants and animals in different stages of decay, dissolved in water, or chemically bound to soil minerals. This last form of organic carbon is the most stable and can persist in the soil for centuries or even millennia. Some soil types, such as clay soils, can bind a large amount of carbon, whereas sandy soils cannot. Across all soil types, the deeper in the soil the carbon is stored, typically the longer it can remain.

We also see differences in soil carbon by forest type. Softwood (evergreen conifer) forests tend to accumulate more organic carbon in the forest floor and topsoil layer compared to hardwood (deciduous broadleaf) forests. This is because conifer needles have a waxy coating and high acidity that resists decomposition by soil microbes. In contrast, hardwood leaves decompose much more rapidly and as a result, carbon is transported deeper in the soil.

Forest Soil Carbon



Site conditions, such as the height of the water table and the climate, also affect soil carbon. Soils that have high water tables can store large amounts of carbon because the lack of oxygen slows decomposition. For this reason, peat bogs store the highest amounts of soil carbon of any terrestrial ecosystem. A bog's high water table results in sphagnum moss and other organic matter accumulating at a faster rate than they can be decomposed. Similarly, below freezing temperatures restrict decomposition. In the Northeast, soil respiration and decomposition increase in the spring when soils warm, and decrease in the fall when soils cool. Over time, the amount of carbon added to northeastern forest soil exceeds the amount lost through decomposition and respiration. By contrast, tropical climates tend to have lower amounts of organic soil carbon on the forest floor because decomposition and respiration occur year-round.



What are the impacts of timber harvests on soil carbon?

In the short term, a timber harvest often, but not always, reduces soil carbon. The magnitude of losses and recovery time depend on the harvesting intensity and physical impacts to the soil, along with the characteristics of the soil and the site. Clearcutting tends to result in greater losses of soil carbon than stand thinning. Partial harvests with areas of retention may have short-lived or undetectable declines in soil carbon. Carbon outcomes associated with timber harvests strongly depend on soil type: sandy soils exhibit greater reductions than clay soils.

As long as best management practices are followed, carbon losses post-harvest are usually larger in the forest floor and upper portion of the soil, and less detectable deeper in the soil profile. This is because deeper soil horizons are not disturbed, and carbon tends to be more stable if it is deeper in the soil. The reduction in soil carbon after a timber harvest primarily results from a temporary loss of organic matter inputs because of a reduction in fine root turnover, aboveground litter, and root exudates. Soil carbon stocks may also decline after a timber harvest due to higher rates of decomposition that are stimulated by the removal of the tree canopy, resulting in more sunlight reaching the forest floor and therefore warming the soil. Usually, the warmer soil conditions will increase the activity of the soil biota. Generally, the more trees that are removed, the larger the reduction in organic matter inputs post-harvest. Without a continued replenishment of organic matter to feed the soil community, there will be a gradual reduction in soil biota and carbon. Managing the stand to encourage the establishment of new trees, as well as leaving some trees on site, can provide inputs of organic matter that feed the soil biota and replenish carbon.

Aside from tree removal, soil carbon losses also occur if machinery or vehicles cause soil rutting and compaction, which can degrade the soil structure and cause erosion. Wet soils are more prone to rutting and compaction than dry or frozen soils. In addition, where soils are compacted, oxygen contained in the soil pores is pushed out. In low oxygen conditions, soil microbes produce methane instead of CO_2. Elevated emissions of methane are worrisome because methane has much greater warming potential in the atmosphere as compared to CO_2. Severe impacts to the soil can also reduce the soil's ability to sequester carbon in the future. For example, compacted or heavily disturbed soils may constrain future plant growth by restricting roots or limiting nutrient and water availability.

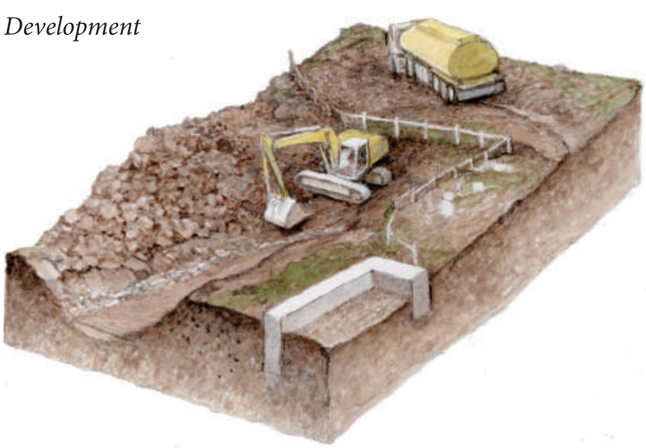
How will continued climate change affect soil carbon?

The impact of climate change on forest soil carbon is uncertain. Warming may accelerate decomposition and soil respiration rates, leading to significant losses of soil carbon as is occurring in the Arctic where permafrost is thawing. Heavy rainfall events caused by a warmer atmosphere could increase soil erosion. Higher water tables could also increase methane emissions if soils are saturated for longer periods of time. Climate change may also influence tree growth and health, which in turn could influence live root exudates, root turnover, and organic matter inputs. Scientists project that over time, the effects of climate change are likely to alter the distribution and composition of vegetation, which may result in changes in the amount of carbon stored in the soil. And we may see more incidents of wildfire that result in emissions of stored carbon. While the impact of climate change on soil carbon is complex and context-dependent, because forest soils store a lot of carbon, they should be protected.

Erosion

Compaction

Development



How can we manage soil carbon?

To prevent soil carbon losses, forest managers and landowners should seek to minimize disturbances caused by water runoff, equipment, vehicles, tilling, and excavation. Maintaining vegetation adjacent to wetlands, seeps, streams, vernal pools, and other water bodies can reduce soil erosion from water runoff. Water diversion structures on roads and trails, such as dips and water bars, help to minimize erosion and keep water on site by redirecting water into depressions where it can be slowly absorbed by the soil.

Strategies to reduce soil carbon losses also include laying out roads and trails to avoid steep slopes and to allow for their future reuse to concentrate impacts. Restricting equipment and vehicle use to times when the soils are frozen or dry, avoiding wet soils, and using structures such as bridges, corduroys, or branches spread across the traveled surface will reduce soil rutting and compaction. Because soil disturbance intensity is directly proportional to soil carbon reduction, disturbances should be limited to as small an area as possible.

However, in some cases, strategic soil disturbance may be beneficial. One example is soil scarification, which involves removing the leaf litter and exposing the mineral soil to promote regeneration of tree species that require these conditions to establish. Scarification will result in temporary soil carbon losses, but if it promotes successful tree regeneration that would not have occurred otherwise, this may be worthwhile. In a short time, the newly established trees should compensate for the prior carbon losses.

Beyond avoiding soil carbon loss, landowners and managers can help promote soil carbon through several strategies, all of which have additional ecological benefits. In a timber harvest, consider leaving some branches and treetops from harvested trees in the woods as a source of organic matter to sustain the soil biota. Dead logs on the forest floor retain water, prevent erosion, and provide a source of decaying organic matter and habitat for invertebrates and microbes that contribute to the soil carbon pool.

Forest management strategies that increase species diversity and forest structural complexity can support additional soil carbon storage. Forests with more species, particularly stands with both deciduous and conifer species, and those with greater variability in the vertical and horizontal structure, tend to contain more soil carbon. One tactic is to retain clumps of trees or individual trees scattered throughout the harvested area as a continued source of belowground carbon and to maintain mycorrhizal fungi and other soil biota that rely on living root systems. Management strategies that promote adaptation to climate change, such as encouraging tree species better adapted to a future climate, can allow for long-term carbon inputs.

Finally, keep in mind that the greatest and most enduring threat of soil carbon loss is the conversion of forestland to different land uses, especially when this conversion includes the excavation of soil for development. When physically disturbed by human activities that occur during land-use change, forest soils can become a significant source of both CO_2 and methane emissions. Keeping forests as forests is the best way to preserve soil carbon and the biotic community. Allowing once-forested areas to re-grow as forests, or planting new trees in yards, farms, or along streets, will increase carbon both above and below the ground.

A key point to remember is that soil carbon can be lost relatively quickly if disturbed, yet it takes a long time to rebuild. In addition to preventing carbon emissions, maintaining soil carbon storage has numerous benefits, including increased nutrient availability, water-holding capacity, biodiversity, and forest productivity.

Managing Forests for Carbon

Once a landowner has a basic understanding of how carbon moves through a forest, they need to integrate this knowledge with other considerations, including the current conditions in their forestland. This article offers guidance on different approaches that may promote carbon sequestration and storage, and explains how management decisions relate to the bigger goals of climate resilience, and meeting resource needs.

Considering the threat of climate change, many landowners and forest managers want to manage forests for the greatest carbon benefit. The question often boils down to: is it better for the climate to manage a forest actively or passively? An active approach involves using silviculture to intentionally alter the composition, structure, and/or growth of the forest and may include removal of trees for personal use or to sell. A passive approach is more hands-off and allows the forest to develop on its own. In a passively managed forest, wood is not harvested.

Passive management has served predominantly as a strategy to protect specific conditions, including sensitive soils, water resources, unique sites, uncommon species, or old-growth forests[1], or to create wilderness areas. There is growing interest in also using passive management for climate change mitigation. A new term for passive management that includes this carbon focused concern is "proforestation."

Because active management will reduce the amount of carbon stored in the forest for a period of time following management activities, a passive approach may seem like the best option to keep carbon dioxide out of the atmosphere. However, the decision is not simple. Both active and passive management have carbon benefits and costs, and both are needed to derive the full suite of services we require from forests.

As we seek to make forest management decisions that factor in carbon, it is important to recognize that climate change is a global atmospheric issue. In other words, the atmosphere registers the same warming effect if carbon dioxide is emitted locally or far away. This means that to have a measurable impact on mitigating climate change, we must carefully consider the impacts of our decisions beyond the forest's edge. We also need to take into account how climate change is stressing forests in new ways, and thereby potentially degrading forests' capacity to sequester and store carbon.

As landowners weigh these decisions, it is important to recognize that every landowner who chooses to keep their land forested is making a vital contribution to climate change mitigation. Differences between how much carbon could be sequestered or stored by an acre of forest under alternative management approaches are overshadowed by the loss of long-term carbon benefits when that acre is converted to non-forest[2].

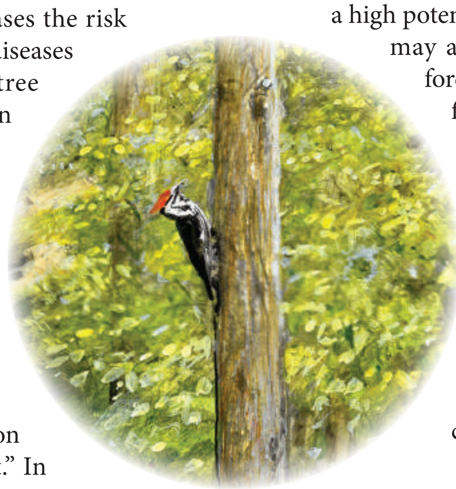
1 *Old-growth forests are forests that were never directly impacted by intensive human land use. See D'Amato, A and Catanzaro, P (2022), Restoring Old-Growth Characteristics to New England's and New York's Forests.*

2 *For more information, see Williams CA, Hasler N, Xi L (2021). "Avoided Deforestation: A Climate Mitigation Opportunity in New England and New York." Report for United States Climate Alliance Natural and Working Lands Research Program.*

Considering the carbon implications of our resource needs

To fully understand the outcomes of our management decisions on climate change mitigation, we need to ask: if we don't use regionally grown wood, what types of resources will we use instead and from where will we get them? How will these decisions affect the amount of carbon dioxide in the atmosphere? Along with keeping forests as forests, a critical strategy for managing forest carbon is to reduce our resource demands for wood and other products. This can involve changing our behavior to consume fewer resources, using wood more efficiently, and/or better utilizing waste products, for example, finding ways to use salvaged wood and wood waste from tree maintenance in towns and cities.

If we continue to use the same amount of wood but stop harvesting timber in our region and instead import wood from elsewhere, the carbon benefits here will be negated because carbon emissions will still occur where the wood is sourced. Plus, there likely will be greater total greenhouse gas emissions from more fossil fuel use due to the longer transportation distances the wood must travel. There also may be other carbon implications that occur when we outsource our wood demands. For example, when we source wood from elsewhere, including parts of the globe with limited environmental regulation, we are potentially funding less sustainable forestry practices, which could lead to environmental degradation in these other places that exacerbate carbon losses[3]. Another concern is that importing wood increases the risk of introducing novel forest insects and diseases to our region, which could increase tree mortality and result in additional carbon losses.



Instead of wood, could we rely on other materials? There are exceptions, but in most cases and for most uses, the alternatives to wood are more carbon-intensive. By using wood instead of other materials such as concrete, steel, fossil fuels, or plastics, we avoid the emissions associated with these materials' production and transportation – a carbon savings known as a "substitution effect." In most cases, these other materials are not as easy to reuse, repurpose, or recycle as are wood products.

Managing for resilient carbon

Not only is the impact of our resource needs complex, so are the consequences of a rapidly changing climate on forests and the carbon they sequester and store. Some tree species are facing elevated stress because of climate change, and as the frequency and intensity of disturbances increase, there is a higher risk of tree growth reductions and mortality. These stressors could reduce a forest's carbon sequestration rate or even change a forest from a carbon sink to a carbon source.

Therefore, ensuring the long-term resilience and persistence of forests' carbon benefits is crucial. To maintain carbon sequestration and storage into the future, a management approach should reflect the specific conditions and potential vulnerabilities of a forest. Active management should foster ecological characteristics that confer resilience, such as diversity, complexity, and redundancy; this is also referred to as "ecological silviculture.[4]" Importantly, there is no one-size-fits-all tactic; each forest is unique based on its historical land use and management, current characteristics and stressors, future anticipated stressors, larger landscape context, and other goals the landowner may have in addition to carbon.

From a carbon perspective, a passive approach may yield the best outcome for forests with a low risk of carbon loss and a high potential for carbon gain. Passive management may achieve the desired carbon benefits for forests that are diverse, complex, and already functioning well – in other words, forests that have not been significantly altered or degraded by past land use or forest health issues. Passive management for carbon should include monitoring to identify stressors or threats that could harm the health and condition of a forest. If stressors do develop, intervention may be the most effective way to promote the forest's long-term carbon benefits.

As noted above, a hands-off approach

3 There are additional social and economic consequences of outsourcing our resource demands.

4 For more information, see Palik B, D'Amato A, Franklin J, and Johnson KN. Ecological Silviculture (Waveland Press, 2021).

is often a good fit when it aligns with other objectives, such as protecting biodiversity, riparian areas, old-growth or old forests, uncommon species, and unique sites. For example, for a stand of northern white-cedar growing on wet soils, a passive approach may help achieve a landowner's goals of reducing carbon losses and protecting biodiversity. During active management, use of equipment can compact the sensitive soils and access roads can alter the hydrology. Plus, northern white-cedar forest swamps provide habitat for several rare or uncommon species, such as showy lady's slippers.

Active management may be more suitable for forests that could benefit from improvements in terms of diversity, structure, wildlife habitat, and ecosystem functioning to ensure long-term carbon sequestration and storage. Because of past land use decisions, heavy deer browse, and the introduction of invasive plants, insects, diseases, and earthworms, some forests in the region lack the suite of characteristics that confer resilience to climate change–related disturbance and stress. Ecologically informed active management can accelerate the development of resilient forest characteristics, such as the presence of large trees, a diversity of species, variation in tree sizes and ages, ample deadwood, and complex structure.

For instance, consider a stand of white pine trees that grew up on an old field and are roughly the same age. Thoughtful active management can help transition this group of pines to a multi-age, multi-species stand and in doing so, provide local wood products; help reduce vulnerability to destructive events such as windstorms, insect outbreaks, and drought; and deliver sustained carbon benefits. Without active management, this stand would likely develop complex structure and species diversity over time, but the transition could take decades to centuries, with carbon fluctuations along the way.

Another example of a common forest condition in the Northeast region is a forest stand dominated by American beech trees that are suffering from beech bark disease. In response to the disease, weakened and dying beech trees produce root sprouts in a dense thicket that shades out most other plants. Because these sprouts are clones of the parent tree and attached to the same root system, they will also succumb to the disease. As a result, the stand will go through a pattern of perpetual growth and decline without ever achieving full carbon potential. If carbon is a goal for this stand, shifting composition to other species may be more likely to achieve desired carbon benefits, create more diversity, and help reduce the stand's vulnerabilities to additional stressors.

Ecologically focused active management can also facilitate a forest's adaptation to climate change by promoting the establishment of climate-adapted species – species that scientists believe will be better suited to future conditions likely to occur at a given site. For example, in a warmer climate, oaks and hickories may be able to expand their range into new locations within the region; however, these species require gaps in the forest's canopy to provide adequate and ample sunlight to establish and thrive. Active management can create these growing spaces, which also support a wide range of forest-dwelling wildlife. For instance, many bird species rely on canopy gaps, dense understories, and a variety of plant species to find insects, fruits, and nesting sites, which may not be present in forests with uninterrupted canopies.

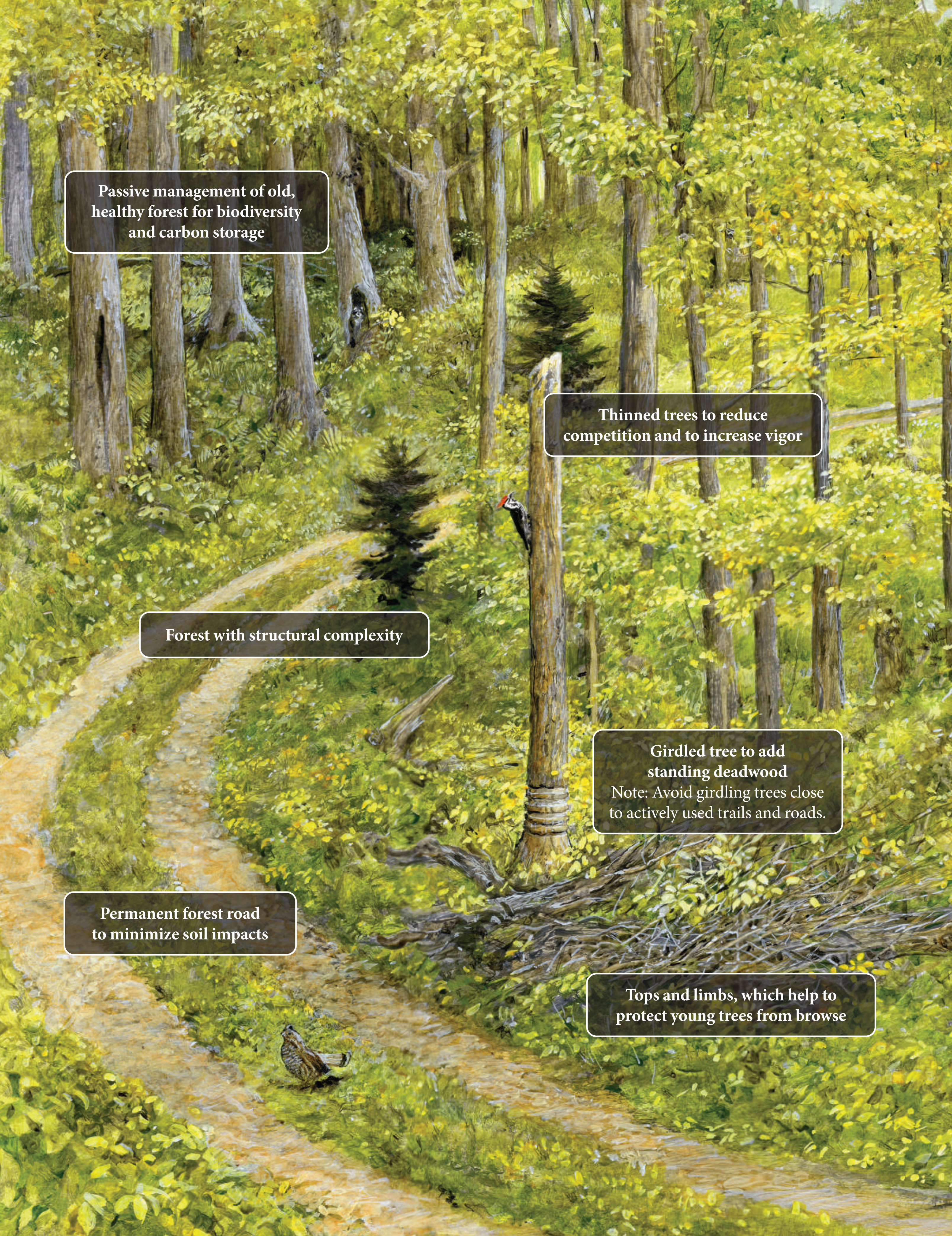
It is important to note that passive and active management approaches can be combined on a forest parcel to achieve multiple goals. Forest management strategies should be flexible and adaptable over time, considering the unique characteristics of each forest, objectives of landowners, and importance of mitigating climate change.

Strategies to manage forests for carbon

There are numerous ways to manage forests for carbon. The most critical strategies, which we can all play a role in regardless of whether we own land, are keeping forests as forests and reducing consumption. Within a forest, many of the strategies listed below can be combined and complement adjacent areas reserved for passive management. A diversified and ecologically informed management approach can promote forest resilience to disturbances and stressors, facilitating adaptation to climate change.

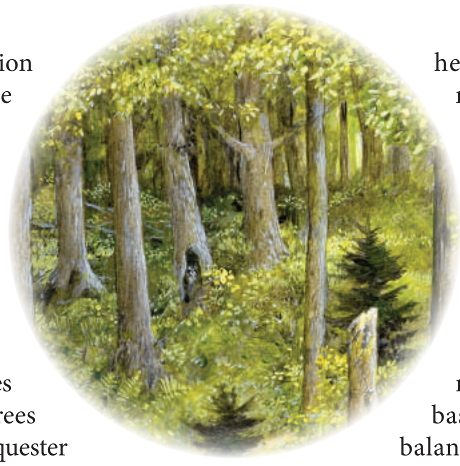
Designating reserves to protect certain features, species, or conditions will retain carbon on site. Reserves can range in size from a group of trees to a much larger area, depending on the landowner objectives and condition of the forest.

Reserving large trees as biological legacies protects the substantial amounts of carbon in these trees and contributes to forest complexity. Large trees are often the oldest trees in a stand and as such are a source of locally adapted seed for future generations. Large trees are also more likely than smaller trees to develop cavities that provide essential habitat for wildlife. As these trees die, their branches and trunks become part of the deadwood pool, where they will continue to provide many ecosystem benefits as they decompose. For landowners interested in the carbon and associated benefits of


Passive management of old, healthy forest for biodiversity and carbon storage
Thinned trees to reduce competition and to increase vigor
Forest with structural complexity
Girdled tree to add standing deadwood
Note: Avoid girdling trees close to actively used trails and roads.
Permanent forest road to minimize soil impacts
Tops and limbs, which help to protect young trees from browse


Biological legacy trees
Regenerated young forest for wildlife habitat and carbon sequestration
Removed invasive plants and planted a variety of tree species that are well adapted to climate change impacts at site

large trees, proper marking and protection of these trees should be included in the forest management plan.

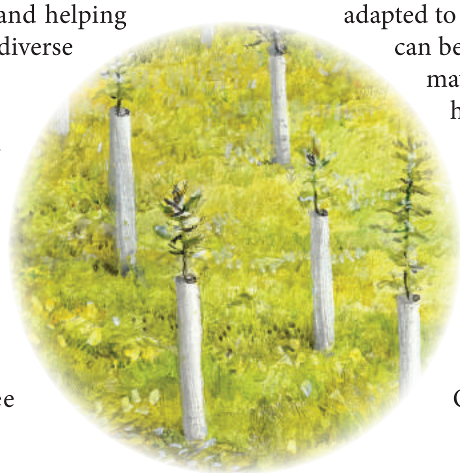


Enhancing the diversity of tree species is likely to improve carbon sequestration and storage over time. Different tree species occupy unique ecological niches, which can allow for more efficient resource use and carbon sequestration. For example, evergreen trees can photosynthesize when deciduous trees are leafless, while deciduous trees can sequester carbon at higher rates during summer. Species diversity also enhances forests' resilience to disturbances such as insect outbreaks, frost events, and windstorms, and can facilitate adaptation to climate change with the presence or establishment of future climate-adapted tree species. A diverse forest also supports a wider array of wildlife, contributing to ecosystem health.

Increasing both vertical and horizontal structural complexity of the forest has numerous benefits. A complex forest structure is characterized by variation in tree diameters, standing and downed deadwood, multiple canopy layers, and periodic canopy gaps. Such complexity enhances carbon storage and sequestration, improves resilience to disturbances and stressors, and provides habitat for wildlife. For example, some forest birds, such as the eastern wood-pewee and Canada warbler, require a complex forest that includes canopy gaps to forage for insects or to rear young. Old-growth forests often exhibit these characteristics, and ecological silviculture can create old-growth characteristics on an accelerated time scale, emulating natural disturbances and helping to develop multi-aged and structurally diverse forests.

Implementing thinning practices, including removal of unhealthy-looking trees, those prone to breakage, and those with small crowns, can improve the growth and health of remaining trees and enhance carbon sequestration in the long term. Close tree spacing leads to high competition for light and resources, negatively impacting tree health and growth, and increasing tree mortality. Thinning can also be used to promote species diversity, including those species expected to be better adapted to a future climate. Foresters use stocking charts based on forest type, tree spacing, and average tree size to manage stand density. For example, recommended stocking densities for hardwood forests typically range between 60 and 90 square feet of basal area[5] per acre. This range strikes a balance between stand-level carbon storage, individual tree sequestration, long-term vigor, and regeneration opportunities. However, thinning may not be suitable for especially dense stands, which could result in windthrow. Thinning treatments can benefit both younger and older forests, reducing competition, promoting diversity, alleviating drought pressure, and enhancing resilience to climate change. One effective practice known as crop tree release involves selectively removing neighboring trees that are growing near the desired (crop) trees, which also creates space for a new cohort of trees to establish.

Allowing natural regeneration or planting in areas with low tree density or no trees will increase carbon sequestration and storage. Formerly forested areas that are currently devoid of trees but not utilized for other purposes can be allowed to regrow naturally as forests, although these areas may require periodic interventions to prevent the spread of invasive plants. In cases where forests have poor natural regeneration, tree planting can be employed. Tree planting can also be a good strategy to increase the number of tree species that are well adapted to future climate conditions. Planting trees can be expensive, however, and local nurseries may not offer a wide array of tree species or have sufficient volumes to meet demands. Trees also may need to be protected from animal browse with cages or other deterrents.



Increasing the amount and distribution of deadwood, both standing and downed, transfers carbon from the live tree carbon pool to the deadwood pool. Over time, deadwood will decompose and

5 *Basal area is a way to describe the density of trees in a forest. It is measured by summing the cross-sectional area of each tree's trunk measured at breast height (4½ feet above ground).*

in doing so, emit carbon dioxide back to the atmosphere, but some carbon will help build the soil carbon pool. Additionally, creating deadwood can allow the remaining living trees to have more space to grow and sequester carbon. Deadwood also provides other important ecosystem benefits such as moisture retention, reduced soil erosion, nutrient cycling, and wildlife habitat. Larger logs are important as they take longer to decompose, thereby storing carbon for a longer duration, and they also provide greater value to wildlife.

To manage deadwood, leave dying trees undisturbed, and if possible, don't remove fallen trees. To create more deadwood, selectively cut trees and leave them on the ground. Another method is to kill some trees by girdling them, which involves cutting around the trunk of a tree without causing it to fall. Note that any standing dead or dying tree can be a hazard, so avoid girdling trees near roads, trails, and areas where active management is planned within the next five years. During a timber harvest, leave tops and limbs in the woods, without cutting them into smaller pieces or compacting them with equipment. These tops and limbs contribute to the deadwood carbon pool and protect young trees against deer browse.

Extending the length of time between harvests of commercially viable stands allows trees to grow larger and store more carbon. This approach can also yield higher-quality trees suitable for long-lived wood products, such as flooring, furniture, and building materials, which can store carbon for longer than other wood products, such as paper, cardboard, and firewood. Extending rotations can complement some of the other practices in this list to create structural and ecological attributes in younger stands that resemble those found in old-growth forests. For instance, pairing extended rotations with thinning can accelerate the growth of larger trees and foster a range of tree sizes. However, extending rotations carries the risk of losses from storms or other disturbances, so it may not be suitable for all forest conditions. Delaying a timber harvest may not yield the desired carbon benefits if a forest stand is dominated by unhealthy, low-vigor trees, impacted by forest health issues such as insects or diseases, or if it is severely under- or overstocked.

Ensuring successful regeneration is crucial to sustain the forest's long-term carbon benefits if age diversity in the stand is lacking. One effective method is to create light-filled growing areas for young trees by removing overstory trees. These canopy gaps can range in size from a small space created by removing a single tree to a larger area. Over time, gaps can be expanded to create a mosaic of tree ages and species. In some cases, removing the understory may also be necessary if it lacks tree species diversity or is in poor condition due to heavy deer browse. The size of the canopy gap should be based on the forest type, site characteristics, and desired species – as individual tree species have specific requirements for success. For instance, red oak and white pine do not thrive in shade and therefore need larger canopy gaps. Some tree species benefit from specific conditions on the forest floor; for example, decaying stumps and logs aid in the establishment of hemlock, red spruce, and yellow birch.

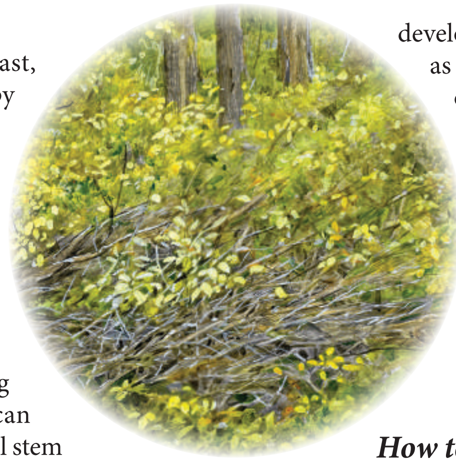
Keep in mind that high densities of invasive plants can outcompete tree seedlings, and deer and other herbivore browse can reduce the diversity and abundance of young trees. To address these issues, landowners may want to use strategies such as mechanical and/or herbicide-based invasives removal, promoting deer hunting, or leaving tree tops and limbs from harvested trees to physically protect regeneration. If there is a lot of deer browse pressure, another option is to create fewer, larger gaps that produce more seedlings than deer can consume.

Minimizing damage to trees and soils caused by equipment, vehicles, and foot traffic protects carbon benefits. Soils play a crucial role in supporting biodiversity, nutrient cycling, water retention, and carbon storage, as highlighted in the second article of this series. Therefore, it is important to take extra precautions to reduce soil disturbances when using equipment and vehicles in the woods. Adhering to best management practices (BMPs[6]) is essential in minimizing the impacts of timber harvesting on soil and water resources.

Traditionally, harvesting during winter when the ground is frozen has been the preferred approach to minimize soil impacts. However, due to climate change, the number of days with frozen ground conditions has decreased and become less consistent, necessitating alternatives to minimize impacts throughout the year. One effective strategy is to establish permanent forest access roads, concentrating impacts to specific areas. Timber mats, corduroy, or bridges can provide equipment access while minimizing compaction and damage to wet soils. Soil damage concerns may also influence the type of management activity. For example, stand-wide partial cutting treatments require equipment to traverse larger portions of the forest, which may lead to

6 BMPs are guidelines released by state agencies that provide recommendations for sustainable forest management. In Vermont, these guidelines are called Acceptable Management Practices (AMPs).

more extensive soil impacts. By contrast, cutting groups of trees to create canopy gaps can concentrate impacts within limited areas, thereby reducing the overall soil disturbance. Additionally, it is crucial to consider ways to minimize damage to the remaining trees from equipment. Because wounding can allow wood decay fungi to enter trees, damage to trees can negatively affect their health and growth. Careful planning and utilizing deadwood as shielding can protect standing trees from unintentional stem damage during harvesting operations.



Cultivating and harvesting timber that can be utilized in durable, long-lived products promotes long-term carbon storage. Focusing management activities on enhancing the quality and size of trees can result in a higher proportion of harvested timber that is appropriate for beams, boards, and other long-lasting products that store carbon for decades or even centuries. However, one challenge to this strategy is the limited availability of local mills and markets for specific species and sizes of logs. Even if harvested wood can't be milled into boards or beams, it may still provide carbon benefits by reducing imports of non-wood alternatives. One example is oriented strand board (OSB), which is a type of engineered wood that uses small wood pieces to make large sheets for flooring and sheathing. There are also new and developing ways to use wood for products such as insulation, which has traditionally relied on more carbon-intensive materials. And in the Northeast, many homes rely on wood heat during cold winter months instead of using fossil fuels. Depending on the forest's condition, harvesting wood can help achieve forest health and resiliency goals while providing financial support for forest management efforts.

How to manage forests is a complex decision

How to best manage a forest for carbon – including whether to employ active management strategies or to take a hands-off passive approach – requires us to think simultaneously about the specific characteristics and values of the forests in our care, and to consider how management choices interact with larger forces, such as natural resource markets and changing climate conditions. Recognizing that we rely on forests for many services means being considerate and intentional about forest conservation and stewardship, and ensuring the integrity of the larger forested landscape. Thoughtful planning can help us consider where to apply different types of management and importantly, how to keep forests, and all the many benefits they provide, healthy in an uncertain future.

RESOURCES FOR MORE INFORMATION:

Catanzaro, P and D'Amato, A (2019). "Forest Carbon: An Essential Natural Solution to Climate Change." University of Vermont and University of Massachusetts Extension.

Marx, L, Zimmerman, C, Ontl, T, and Janowiak, M (2021). "Healthy Forests for our Future: A management guide to increase carbon storage in Northeast forests." The Nature Conservancy and Northern Institute of Applied Climate Science.

Massachusetts DCR. "Caring for Your Woods: Managing for Forest Carbon" (2021).

Palik B, D'Amato A, Franklin J, and Johnson KN. Ecological Silviculture (Waveland Press, 2021).

D'Amato, A and Catanzaro, P (2022). "Restoring Old-Growth Characteristics to New England's and New York's Forests." University of Vermont and University of Massachusetts Extension.

Kosiba, AM (2022). "12 Steps for Climate Resilience: Managing Your Forest with Climate Change in Mind." Vermont Woodlands Association, Vermont Forests, Parks & Recreation, UVM Extension, and Vermont Tree Farm.

Audubon's Foresters for the Birds. Available in multiple states.

Payments for Forest Carbon

Few forestland owners are able to make decisions about their land, without taking into consideration costs. This article offers guidance on new opportunities for landowners to receive compensation for making climate-friendly management choices, both through carbon offsets and practice-based programs.

Many forest landowners are interested in managing their forests for carbon benefits, yet few are able to do so without considering the financial consequences. To address this need, there are emerging opportunities for landowners to be compensated for the carbon sequestered and stored by their forests. Options include selling a forest's carbon benefits in a carbon offset market, as well as with more traditional programs that pay landowners to implement specific carbon beneficial practices that are not based on selling offsets. Because carbon offset markets are novel, complex, and often confusing, most of this article is devoted to explaining how they work.

Carbon offset markets are also subject to ongoing debate. Most of this discussion centers around whether carbon offset markets are achieving their intended goal of climate change mitigation by reducing and stabilizing the levels of heat-trapping greenhouse gases in the atmosphere. Therefore, it's important to distinguish between the financial opportunity that can help landowners keep land forested and subsidize both conservation and forest stewardship efforts, and the less proven value of offsets as tools to directly reduce global emissions.

If none of the current options work for you right now or are not available where you live, keep in mind that new opportunities for being paid for the carbon your forest sequesters and stores are rapidly developing. Any landowner who commits to keeping their forest as forest, manages their forest sustainably, and harvests durable wood products that store carbon and help to reduce our dependency on more carbon-intensive materials is helping to mitigate climate change, regardless of whether they are getting paid directly to do so.

What are carbon offsets?

Carbon offsets, or carbon credits, are designed as a market-based approach to climate change mitigation. They are based on the idea that greenhouse gas emissions at one location can be balanced out, or offset, by carbon sequestration and storage in another location. In this framework, a carbon offset buyer (typically a company, although it could be an individual) who is responsible for greenhouse gas emissions pays someone else to keep that same amount of greenhouse gases out of the atmosphere. This includes actions that avoid emissions by keeping carbon stored, as well as actions that promote the sequestration of additional carbon from the atmosphere.

A single carbon offset is a certificate that represents the reduction or removal of one metric ton of CO_2, or the

equivalent amount of other greenhouse gases, for a set amount of time. The buyer can use this certificate as a "license" to produce one metric ton of emissions. By purchasing offsets, the buyer seeks to counteract their own emissions. If the number of offsets purchased is equal to the amount of emissions, the buyer can claim to have "net zero" emissions.

How are carbon offsets bought and sold?

Carbon offsets are transacted in *carbon offset markets*. There are two types of carbon markets: compliance (or regulatory) and voluntary. *Compliance carbon markets* are created by governments as part of a regulatory regime that requires certain greenhouse gas emitters, such as power plants and factories, to reduce their emissions over time. Emitters have the option of purchasing a percentage of required emissions reductions as offsets from certified projects. Over time, the percentage that is eligible to be offset decreases to force emitters to make enduring shifts away from fossil fuel usage. One example of a compliance carbon market is California's Cap-and-Trade program.

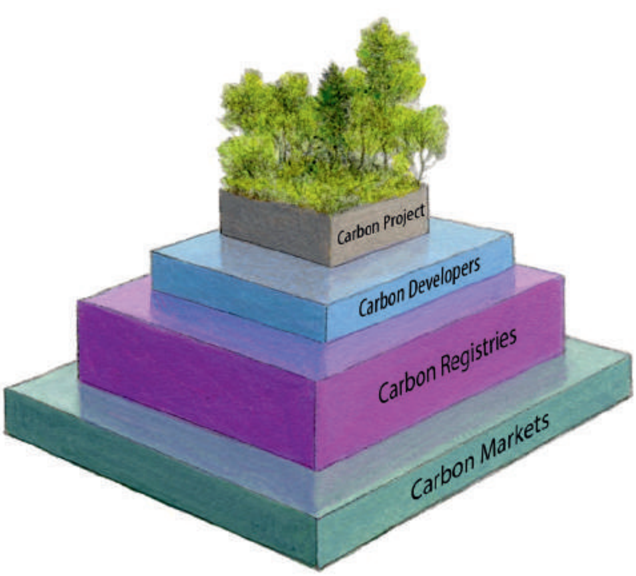
In contrast, the *voluntary carbon market* is unregulated. Anyone can purchase offsets in the voluntary market and because participation is not legally mandated, entities can choose what percentage of their emissions they offset, and there is no requirement for emitters to reduce emissions over time. In the Northeast, most forest landowners interested in selling forest carbon offsets will do so in the voluntary market. This is because California's compliance market restricts where offsets may be generated, and currently the Northeast does not have a compliance market that includes forest-based offsets.

How are carbon offsets generated?

Carbon offsets can be generated by reducing emissions or increasing sequestration from a variety of sources. For example, carbon offsets may be generated by a landowner through the growth of trees, by delaying a planned timber harvest, or by planting trees in an un-used field. Offsets can also be generated in other ways, for example, by reducing methane emissions from manure pits on a dairy farm. Each of these is an example of an individual *carbon offset project*.

Calculating and verifying the number of offsets generated by a project is complex, labor intensive, and costly. As such, a landowner can't typically do it on their own. Instead, a landowner contracts with a c*arbon offset developer*, which is a company that oversees the documentation, accounting, verification, marketing, and selling of carbon offsets generated from a carbon offset project. In doing so, the carbon offset developer bears the financial risk of the project.

Because of the complexity and cost of creating a carbon offset project, until recently, entry for forest landowners has been limited to large parcels (greater than 2,500 acres). But some carbon offset developers have created carbon offset programs that allow landowners with smaller parcels to enroll. Two examples available in the Northeast are the Family Forest Carbon Program (developed by American Forest Foundation and The Nature Conservancy) and the Conserve Program (developed by Forest Carbon Works). To reduce associated costs, these programs differ from traditional carbon offset projects in that enrolled parcels and their generated offsets are combined, or pooled.



Regardless of which developer you work with, landowners wishing to sell forest carbon offsets are required to manage their forests within specific guidelines for the length of the contract. Some developers disallow any tree harvesting, while others allow active management, but stipulate the amount of wood volume that's permissible to be harvested.

How are the number of carbon offsets quantified?

Because carbon offsets are purchased by another entity to compensate for emissions made elsewhere, it is important that offsets represent a real carbon benefit that can be measured, that this carbon benefit be additional to what would have occurred otherwise, and that the benefit last for a set amount of time. How to reliably quantify the carbon benefit of a forest and management activities therein is one of the greatest challenges of carbon offset methodologies.

A crucial element of a carbon offset project is establishing the *baseline*, which is the forest's carbon storage potential in the absence of its enrollment in a carbon offset market. The baseline can be estimated several ways depending on the specific protocol used by the carbon offset developer, and may be referred to as the business-as-usual scenario or common practice. For example, some developers estimate the baseline as the carbon storage potential of the forest if the landowner harvested the maximum amount allowable by law. Other developers estimate the baseline from the average carbon storage in nearby forest-monitoring plots. Because these forest plots are presumed to be managed differently than forests enrolled to sell carbon offsets, measurements of their stored carbon can serve as the baseline.

To generate offsets, the enrolled parcel must store more carbon over a certain time interval compared to the baseline – this is called *additionality*. Thus, the baseline is critical in determining the number of carbon offsets generated by the forest, and consequently, the quantity of emissions that can be compensated by the offset buyer.

The baseline is not the only determinant of an offset project's carbon benefit. To ensure that the carbon project provides a sustained benefit, many carbon offset developers require landowners to sign a long-term contract. The length of this contract varies by the developer's methodology and the type of market. In the voluntary market, the length of the contract may be 10, 20, or 40 years, while in compliance markets, the length often exceeds 100 years. In addition, periodic monitoring of the forest's carbon storage may be required. In most cases, the developer oversees this monitoring.

However, there are a couple of factors that can reduce the intended carbon benefit. Natural disturbances, such as hurricanes, fires, and insects, can cause tree mortality and reductions in carbon storage. To account for these losses, developers may require that enrolled parcels allocate a portion of generated offsets to a *buffer pool*. This buffer pool acts as a reserve of carbon offsets that the developer retains as insurance to compensate for unforeseen carbon losses.

Leakage is another issue that can result in a reduced carbon benefit of enrolled parcels. Leakage occurs when reductions in timber harvesting in enrolled parcels results in increases in harvesting elsewhere to meet market demands. As described in the third article in this series, the intended carbon benefit of the forest can be negated if the same amount of wood is harvested from somewhere else. Developers have specific protocols they use to determine the leakage deduction depending on the amount of harvest reductions incurred.

Taken together, the total number of offsets generated from a forest is determined by the additionality relative to the baseline, minus deductions for the buffer pool and to compensate for leakage. To provide a level of oversight for these quantifications, carbon offset developers often seek to have their protocols approved by organizations such as the American Carbon Registry or the Climate Action Reserve. While it is not obligatory to have this approval to sell offsets in the voluntary market, developers that have verified protocols usually have greater credibility and appeal to buyers.

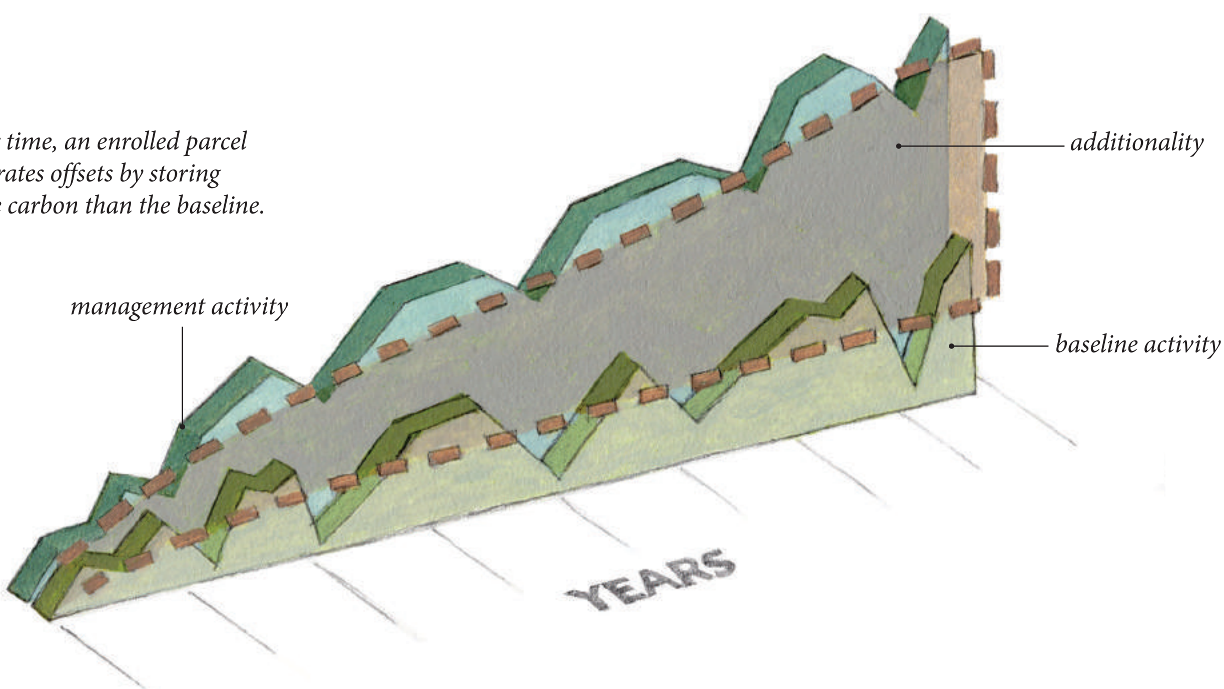
How much revenue can a landowner make selling forest carbon offsets?

The amount of compensation a landowner can receive from selling forest carbon offsets varies. Landowner revenue has ranged from $5 to $25 per acre per year for forest projects that have occurred in New England (and perhaps more; sale prices in the voluntary market are often not publicly disclosed).

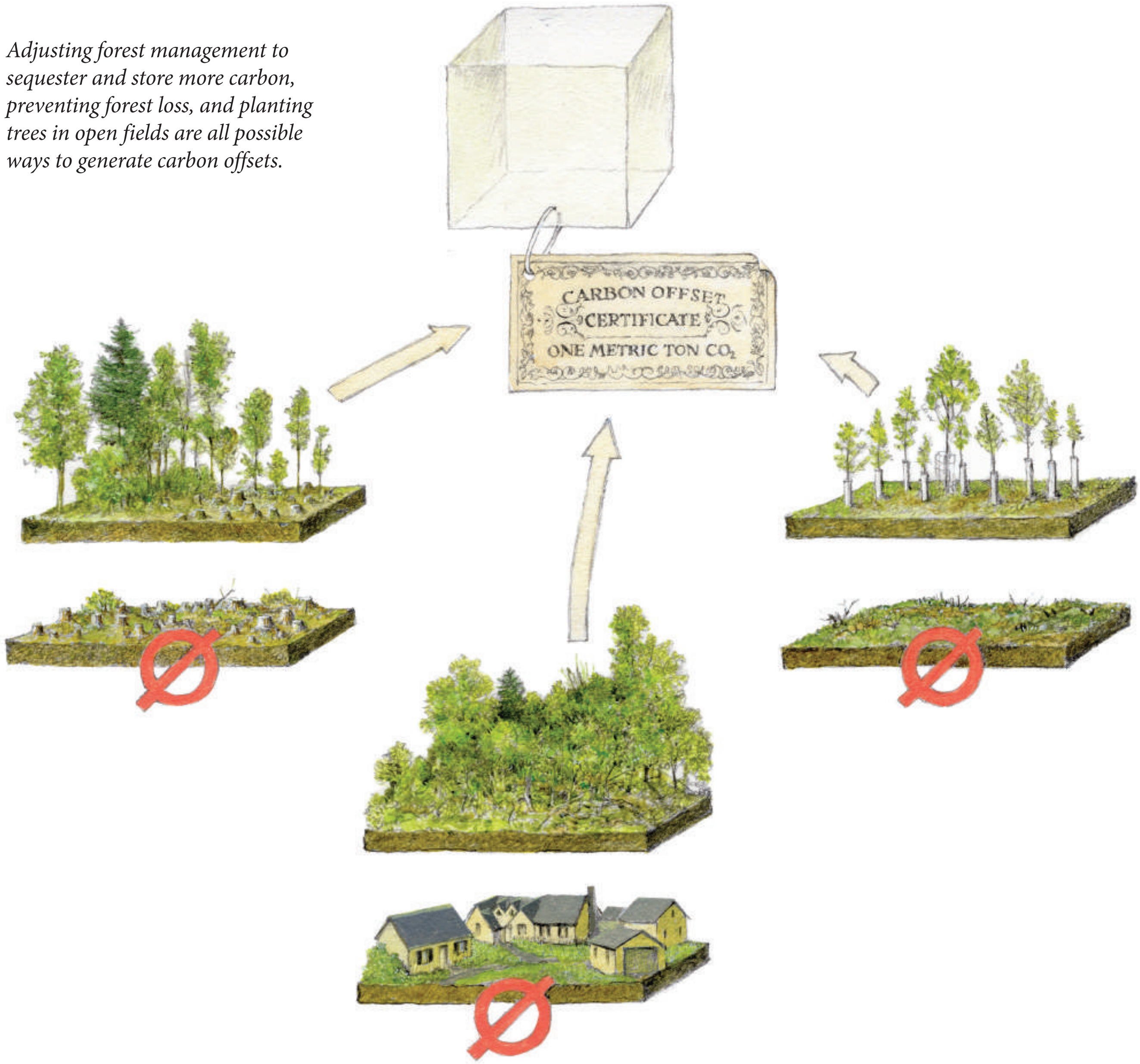
An important factor determining the revenue is the sale price of an offset. Compliance markets typically set the price of an offset, and periodically increase the price to incentivize transitions away from fossil fuels. In contrast, the sale price of an offset in the voluntary market varies considerably depending on demand, the reputation of the developer, and marketing. The developer allocates a portion of the revenue from selling these offsets to the landowner(s) and retains a portion, which typically ranges from 20 to 50 percent.

Because the total number of offsets generated from a forest depends on its size, larger parcels typically yield higher total revenue. Site and forest factors also affect the additionality, as certain forest types and locations may generate more revenue than others. Some of the newer programs for smaller parcels

Over time, an enrolled parcel generates offsets by storing more carbon than the baseline.



Adjusting forest management to sequester and store more carbon, preventing forest loss, and planting trees in open fields are all possible ways to generate carbon offsets.



combine multiple enrollees to ensure uniform per-acre payments.

Carbon offset developers also have different payment schedules. Payments may occur regularly over time, begin with an upfront payment and smaller payments at specified intervals, or only occur at the end of the contract. For some contracts, the landowner may incur financial penalties if the requirements are not fulfilled.

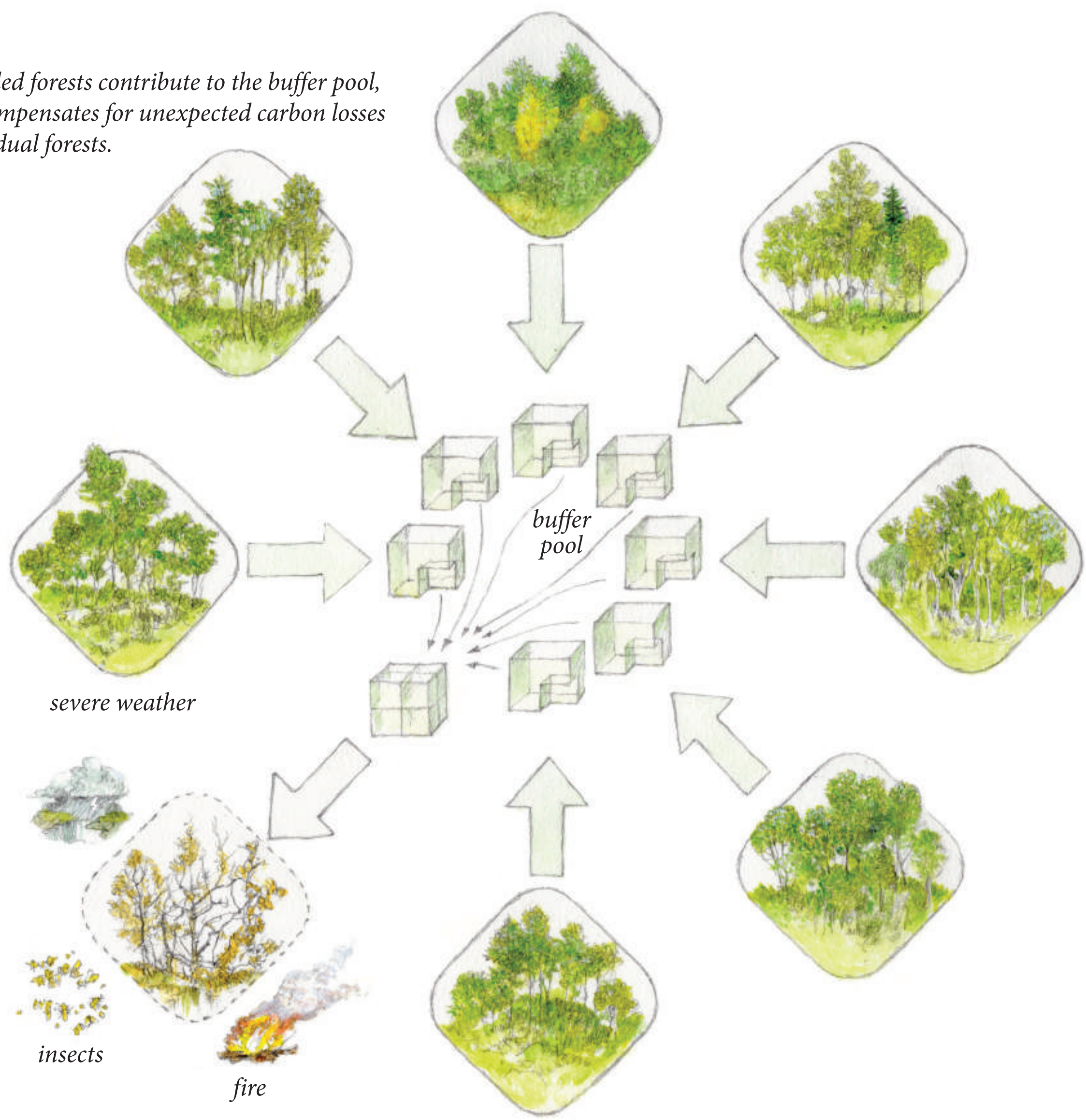
What are the benefits of selling forest carbon offsets? What are the concerns?

Because selling carbon offsets typically requires long-term commitments from landowners, enrollment can prevent deforestation and conversion of the forest into other land use types, which not only maintains the forest's carbon benefit but also the other important ecosystem services that the forest provides, such as wildlife habitat and flood prevention. Further, the revenue generated from selling carbon offsets can help landowners pay taxes and fund stewardship-related activities, including land conservation and restoration.

However, whether carbon offsets mitigate climate change by reducing net emissions is more difficult to determine and depends on several factors. The first issue is that verification of a forest's actual carbon benefit poses a significant challenge. Part of this challenge is due to the "counterfactual" nature of offsets, in other words, the necessity of speculating about what would have happened without the parcel being enrolled in a carbon offset market. There's no way to truly know how much carbon would have been emitted or not sequestered in that other reality, and thus, there's no perfect way to compute the additionality. Because offsets are used to cancel out emissions made elsewhere, an overestimation of carbon benefits can inadvertently increase emissions into the atmosphere.

There is also debate about whether the different ways offsets can be generated – by avoiding emissions (keeping carbon stored) and by increasing sequestration (absorbing more carbon) – provide the same climate change mitigation benefit. For instance, in an emissions avoidance project in which a landowner agrees to delay a timber harvest, the carbon benefit is assessed based on the counterfactual of an earlier harvest. That benefit is inherently more difficult to confirm as compared to a project that increases sequestration, such as tree planting. It may be impossible to prove that the

All enrolled forests contribute to the buffer pool, which compensates for unexpected carbon losses in individual forests.



landowner would in fact have conducted the early timber harvest, while the newly planted trees are clear evidence of a measurable change in management.

An emerging concern of carbon offset markets revolves around accurately addressing leakage. Again, and as described in the third article in this series, the benefit to the atmosphere of reducing wood harvests in one area may be negated if the same amount of wood is harvested from somewhere else, or if people use more carbon-costly materials as a substitution for wood. Worse, that "somewhere else" may have less rigorous environmental protections and require longer transportation distances leading to greater overall emissions. Quantifying and verifying leakage is a challenging task, but as global demand for wood continues to rise, it's probable that reductions in timber harvesting in certain areas will be countered by increased harvesting elsewhere.

There is also growing concern regarding the permanence of carbon stored within forests, given the threat of ongoing climate change. Natural disturbances – which are likely to become more frequent and severe as temperatures continue to rise – can cause forests to shift from carbon sinks to sources of carbon emissions. To date, some carbon offset projects in western states have not met their carbon targets because of catastrophic fire. While the buffer pool is intended to account for these natural disasters, an increase in disturbances may require the pool to be much larger.

A concern that is limited to the voluntary market is how to ensure that offset buyers make strides to reduce emissions over time and use offsets to cancel out only those emissions they cannot avoid right now. Otherwise, some worry that carbon offsets can give emitters a perpetual "license to pollute." To address this concern, some carbon offset developers require offset buyers to show a decarbonization plan that outlines a path to emissions reductions.

What are key considerations to make before enrolling in an offset program?

Before signing a contract to sell carbon offsets, it is critical to understand the terms of the contract and implications for your land. Important practical considerations are the length of the contract, stipulations about early termination, responsibilities for long-term monitoring costs, and contingencies if the parcel fails to meet the expected carbon benefits. Some contracts remain with the land if the parcel is sold, while for others the landowner may face penalties when they sell enrolled land. It is advisable to consult with a lawyer before agreeing to the contact terms, and landowners may also want to talk to an accountant because revenue from carbon sales is currently taxed as income[1].

Another important consideration to be aware of before enrolling is whether the parcel has any legal encumbrances that mandate or restrict certain activities. Changes in forest management may invalidate eligibility in other forest programs, such as state tax equity programs (often referred to as current use). Each state has different requirements to maintain eligibility, and there can be significant financial penalties if you are determined to be out of compliance. Carbon offset developers may not be well versed in state-specific requirements, so if in doubt, reach out to a service or county forester in your state. Third-party forest certifications, such as Sustainable Forestry Initiative (SFI), Forest Stewardship Council (FSC), and American Tree Farm System, are usually compatible with selling carbon offsets. Parcels with a conservation easement may or may not be allowed to enroll. Because easement contracts vary considerably, landowners will need to show the easement to the offset developer.

In terms of evaluating the positive impact of selling carbon offsets, you may want to ask if the protocol used by the developer is verified by a credible third-party organization, as described above, as this demonstrates that their methods have been evaluated and approved by other experts. You may also be interested in asking the developer which types of entities are able to purchase the offsets they sell, and whether the developer requires those entities to commit to emissions reductions over time.

What are good sources of information about carbon payment programs?

If you are interested in exploring whether selling carbon offsets is a good fit for you and your land, a recommended initial step is to take advantage of the growing number of resources and information geared for landowners by local forest landowner groups, state extension services, state and federal governments, and universities. For example, the *Securing Northeast Forest Carbon Program*[2] is a regional collaboration that provides information on forest carbon science and payment opportunities. It may also be helpful to consult with a professional forester who can assist you

1 Cushing, T. Tax Dimensions of Forest Carbon Contracts. University of Florida Extension Forest Business & Economics.
2 Visit northeastforestcarbon.org

in defining objectives for your land, identifying any legal restrictions, and evaluating the current state of your forest.

The next step is to reach out to different carbon offset developers [3], which will help you determine whether your land qualifies for enrollment and if proceeding is financially viable. Typically, this process is either free or involves a nominal fee, and it does not necessitate a commitment. It's important to note that developers may have eligibility criteria tied to factors such as parcel size, forest type, tree density, accessibility, and preexisting legal encumbrances that limit harvesting or land clearing. Consequently, not all forest parcels will be eligible for enrollment.

Are there other options for landowners to fund forest carbon practices?

Practice-based programs offer a separate option from selling carbon offsets. In these programs, landowners can receive payments for implementing specific actions that are likely to provide enhanced carbon benefits. Because practice-based programs do not sell offsets to generate revenue, many of the concerns about carbon offset markets do not apply. Instead, these programs are designed to compensate the landowner for the cost associated with implementing a management action. One important consideration is that if the land is already enrolled in a practice-based program specifically for carbon, the land will likely not be eligible to also sell carbon in an offset market because it would be difficult to demonstrate additionality.

Practice-based programs have been available to landowners for many decades, usually offered through federal and state governments. The most notable are the Environmental Quality Incentives Program (EQIP) and Conservation Stewardship Program (CSP) administered by the Natural Resources Conservation Service (NRCS). Under these programs, landowners can receive technical and financial assistance for a variety of forest stand improvement actions, from controlling invasive species to enhancing wildlife habitat.

Recently, the list of NRCS practices has been updated to include those intended to increase forest carbon storage[4]. Under this practice, landowners follow specified active management techniques designed to maintain or increase carbon storage over the 10-year contract period[5]. Currently, the annual per-acre payment for this practice is about the same amount a landowner might be paid to sell carbon in an offset market.

For landowners interested in practice-based programs, the next step is to reach out to a professional forester or to your state forestry office. You can inquire about the availability of state-funded initiatives or get in touch with your local Natural Resources Conservation Service (NRCS) office.

The future of forest carbon

The options available for landowners to be paid for the carbon benefits their forest provides will no doubt change over time. Carbon offset markets are under immense scrutiny, and our understanding of the science of forest carbon continues to advance. With recent federal legislation to fund climate-focused forest stewardship, practice-based incentives for landowners will continue to grow.

Although carbon offset markets still have considerable distance to go before they can prove their value as a means to keeping greenhouse gases out of the atmosphere, the revenue generated from selling offsets can help landowners fund activities related to maintaining the health and integrity of their forests by subsidizing stewardship-related activities. There's also little doubt that large carbon offset markets have the potential for unintended consequences, for example, by transferring timber harvesting activity away from the Northeast. As noted in the first article in this series, the carbon cycle does not end at the forest's edge.

Forests by themselves cannot solve the climate crisis. This crisis requires us to be thoughtful about the impacts of our resource needs, to consider how we can sustainably harvest local wood to meet our growing housing demands, and to reduce our dependence on more carbon-intensive materials. We also have the opportunity, through thoughtful forest management, to promote the long-term resilience of our forest ecosystems to climate change and other stressors. Above all, it's critical that we pursue ways to reduce overall emissions, recognizing that there is no way to grow our way out of this problem.

3 *For a list of current program developers, see northeastforestcarbon.org/forest-carbon-financial-markets*

4 *For more information on NRCS "climate-smart" practices, see https://www.nrcs.usda.gov/conservation-basics/natural-resource-concerns/climate/climate-smart-mitigation-activities. Refer to the subsection Forest Stand Improvement (code 666).*

5 *https://www.nrcs.usda.gov/sites/default/files/2022-11/E666H_July_2022.pdf*

GLOSSARY

Active forest management
The use of silvicultural practices to alter the composition, structure, and/or growth of the forest. Active management may serve one or a combination of purposes, for example, habitat restoration, *carbon sequestration*, and the production of timber.

Additionality
For a forest enrolled in a *carbon offset program*, the additional amount of carbon stored by a forest over a certain time interval as compared to the *baseline*. In other words, the additional carbon that the forest has stored due to enrollment-related management choices.

Baseline
A forest's potential for *carbon storage* in the absence of its enrollment in a *carbon offset program*. The baseline can be estimated several ways depending on the specific protocol used by the *carbon offset developer*, and may be referred to as the business-as-usual scenario or common practice. At Year 0, the baseline is the same as the newly enrolled forest's total stored carbon, but by the end of the *enrollment period*, it should be significantly below the enrolled forest's total stored carbon (see additionality).

Biological legacy trees
Large trees that a forest manager exempts from cutting, in order to protect the substantial amounts of carbon in these trees and to contribute to *complex forest structure*. Biological legacy trees are often the oldest trees in a stand and are a source of locally adapted seed for future generations. They are also more likely than smaller trees to develop cavities that provide essential habitat for wildlife.

Buffer pool
A reserve of *carbon offsets* that a *carbon offset developer* retains as insurance to compensate for unforeseen carbon losses. The carbon offset developer typically establishes the buffer pool by requiring landowners who enroll in a *carbon offset program* to allocate a portion of their parcels' generated offsets to the buffer pool.

Carbon credit
See *carbon offset*.

Carbon emissions
The release of carbon into the atmosphere via *greenhouse gases*. There are three processes through which emissions typically occur in a forest: cellular respiration, combustion (fire), and decomposition.

Carbon offset
Also known as a *carbon credit*, this is a certificate that represents the reduction or removal of one metric ton of CO_2, or the equivalent amount of other greenhouse gases, for a set amount of time.

Carbon offset developer
A company that oversees the documentation, accounting, verification, marketing, and selling of *carbon offsets* generated from a *carbon offset project*.

Carbon offset market
A market-based approach to climate change mitigation, based on the idea that *greenhouse gas* emissions at one location can be balanced out, or offset, by *carbon sequestration* and *storage* at another location. In this framework, a *carbon offset* buyer who is responsible for greenhouse gas emissions pays someone else to keep greenhouse gases out of the atmosphere. There are two kinds of carbon offset markets: *compliance* and *voluntary*.

Carbon offset program
Programs in which multiple forest landowners enroll parcels, and their generated offsets are combined, or pooled, under the management of a *carbon offset developer*. These programs enable owners of relatively small parcels to participate in *voluntary carbon offset markets*.

Carbon offset project
A specific (typically, site specific) project that is enrolled in a *carbon offset market*. In compliance with the terms of enrollment, the land manager implements plans to reduce or prevent emissions and/or to increase *sequestration* and *storage*.

Carbon pool
A component of a larger system that has the capacity to store, accumulate and emit carbon. In a forest, the carbon pools are *soil*, *live biomass* (*both above- and belowground*), *litter* and *deadwood*. Forest management and land use decisions affect whether pools accumulate or lose carbon. In managed forests, there is an additional pool that exists outside the forest in harvested wood products.

Carbon sequestration
The process of removing carbon dioxide (CO_2) from the air through photosynthesis and storing the carbon from those CO_2 molecules in wood, leaves, branches, bark, and soil. How much a forest sequesters varies over time and depends on numerous factors, such as the time of year, available moisture, weather patterns, and disturbance events. Sequestration is measured as the mass of carbon added over time (typically in metric tons per year).

Carbon sink
A forest or other system, in which overall *carbon sequestration* exceeds emissions, resulting in an increase in *carbon storage* over time.

Carbon source
A forest or other system, in which overall *carbon emissions* exceed *sequestration*, resulting in a decrease in *carbon storage* over time.

Carbon storage
The amount of carbon contained in site or system, such as a tree, an acre of forest, a piece of lumber, or a cubic yard of soil. It is measured as mass (usually pounds or tons).

Chemical loss of forest soil carbon
The loss of carbon that occurs through combustion of organic matter (for example, during a forest fire), or from the metabolic processes of the soil biota, i.e. cellular respiration.

Complex forest structure
Having a variety of tree diameters, standing and downed deadwood, multiple canopy layers, and periodic canopy gaps. Such complexity enhances *carbon storage* and *sequestration*, improves resilience to disturbances and stressors, and provides habitat for wildlife.

Compliance carbon market
A *carbon offset market* established by a government as part of a regulatory regime that requires certain *greenhouse gas* emitters, such as power plants and factories, to reduce their emissions over time.

Counterfactual
An approach to measuring the value of *carbon offsets*, by speculating on what would have happened without the parcel being enrolled in a *carbon offset program*.

Deadwood pool
The *forest carbon pool* that includes standing dead trees (snags), logs, and large branches on the ground.

Ecosystem services
The variety of benefits that forests provide, including *carbon storage* and *sequestration*, oxygen cycling, water purification, flood mitigation, temperature moderation, wildlife habitat, recreational opportunities and locally sourced building materials and fuelwood.

Enrollment period
For *carbon offset programs*, the term of years in which a parcel of forestland is enrolled in a program.

Greenhouse gases
Gases, including carbon dioxide (CO_2) and methane (CH_4), that trap energy from the sun in Earth's atmosphere. The burning of fossil fuels and other human activities have increased the concentration of greenhouse gases in the atmosphere, causing the planet to warm at an unprecedented rate.

Harvested wood products
Wood that people take out of the forest to meet natural resource demands. These include products that store carbon for decades or centuries, such as construction materials, and more ephemeral products, such as paper and firewood. When evaluating the carbon cycle implications of different wood products, it is important to consider the impacts of alternative materials, including how and where they are sourced and what happens to these products after they are used.

Inorganic soil carbon
The portion of carbon in the soil that forms from the weathering of rocks or from soil minerals reacting with a. It occurs largely as carbonate minerals, such as calcite and dolomite, which appear in sedimentary rocks such as limestone.

Leakage
The externality that occurs when a reduction in *carbon emissions* generating activities in one place prompts an increase in *carbon emissions* generating activities in another place. For *carbon offset programs*, leakage can result in a reduced carbon benefit of enrolled parcels or even a negative impact – for example, when reductions in timber harvesting in enrolled parcels results in increases in more carbon-costly harvesting elsewhere or longer transportation distances.

Litter pool
The *forest carbon pool* composed of leaves, needles, and twigs that lie on top of the soil. In most northeastern forests, this is the smallest of the forest carbon pools.

Live biomass pool
The *forest carbon pool* that includes living trees, both aboveground (trunk, branches, and leaves) and belowground (roots). Herbaceous plants, shrubs, tree seedlings, and forest wildlife are also part of this pool, although they are rarely included in carbon assessments because they make up a relatively small proportion of carbon as compared to trees, and the carbon they contain is difficult to measure. The live biomass pool is typically the second-largest carbon pool in a forest, after soil.

Net zero emissions
A state of equilibrium in which *greenhouse gas emissions* are balanced by *carbon sequestration* and *storage*. Companies and organizations that have net zero emissions goals may purchase *carbon offsets* as a means to "pay" for emissions causing activities.

Organic soil carbon
The portion of carbon in the soil that arises from dead organic matter that accumulates on the forest floor and from roots and microbes in the soil. Organic carbon concentrates in the dark layer of rich soil beneath the leaf litter, but over time, it is also transported to deeper soil depths.

Passive forest management
A generally hands-off approach, but intentional, to forest ownership, that allows the forest to develop on its own. In a passively managed forest, wood is not harvested. Passive management may include monitoring to identify stressors or threats that could harm the health and condition of the forest, and the possibility of intervention (active management) to address those threats.

Physical loss of forest soil carbon
The loss of carbon from the soil that occurs when water, wind, or other erosive forces carry carbon out of a forest.

Practice-based carbon programs
Programs (typically offered by federal or state entities) through which landowners can receive payments for implementing specific actions that are likely to provide enhanced carbon benefits. Practice-based programs do not sell *carbon offsets* to generate revenue. Instead, they compensate the landowner for the cost associated with implementing a management action.

Proforestation
A new term for *passive management* that includes a carbon focused concern. Proforestation may achieve the desired carbon benefits for forests that are diverse, complex, and already functioning well – in other words, forests that have not been significantly altered or degraded by past land use or forest health issues.

Protocol
For a *carbon offset developer,* the method by which it assesses the value of *carbon offsets*. In order to ensure credibility, many carbon offset developers seek third-party *verification*.

Regulatory carbon market
See compliance carbon market.

Reserves
Portions of a forest, ranging from a group of trees to much larger areas, that are for the most part passively managed in order to protect certain species, features or conditions, including forest carbon pools.

Resilient carbon management
In a forest, the continued maintenance of *forest carbon pools* so that the forest remains a *carbon sink*. Managing for resilient carbon means making choices that maintain carbon by supporting critical ecological functions while also considering the long-term trajectory of the forest to sustain health, reduce vulnerabilities, and promote *sequestration*.

Soil pool
Typically the largest and most stable *forest carbon pool* in northeastern forests, which contains carbon stored both as *organic soil carbon* and as *inorganic soil carbon*.

Substitution effect
The carbon savings generated by using a less carbon-intensive alternative instead of a more carbon-intensive one. For example, choosing to use wood instead of steel in a construction project, may avoid the greater emissions associated with steel's production and transportation, and therefore produce less total emissions.

Verification
The review and approval of a *carbon offset developer's protocol* for assessing *carbon offsets*, by a credible third-party organization.

Voluntary carbon market
A *carbon offset market* in which private entities, as opposed to a government, set the terms of participation and there is no statutory obligation to participate, or for the buyer to reduce emissions over time. Most northeastern landowners who produce *carbon offsets* participate in a voluntary carbon market.

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NEXT STEPS FOR LANDOWNERS

If you're looking to integrate carbon goals into your forest management plans, there are professionals in your area equipped to offer guidance and technical support. A recommended initial step is to connect with your local stewardship, county, or district forester employed by either the state government or university extension service. While their titles may vary, these foresters share a common role: assisting private landowners in navigating the complexities of forest stewardship and identifying relevant programs, resources, and technical aid.

Depending on your location and specific objectives, you may also decide to enlist the services of a private consulting forester for tasks such as conducting a thorough inventory of your woodland and drafting a comprehensive management plan.

As a forest landowner, the most impactful decision you can make to sustain carbon benefits is ensuring that your land retains its forested status. Each state offers information and programs tailored to assist landowners in this endeavor. Land trusts may be able to help you permanently protect your property. To find a land trust near you visit https://landtrustalliance.org/land-trusts.

If you're interested in cost-sharing initiatives, reach out to your local Natural Resources Conservation Service (NRCS) office to set up a consultation. To consider carbon offset programs, explore the *Securing Northeast Forest Carbon Program* website at www.northeastforestcarbon.org.

Here are some links that may be helpful:

Find a forester in your state:

CT Department of Energy & Environmental Protection Service Forestry
https://portal.ct.gov/DEEP/Forestry/Service-Forestry-in-CT

MA Department of Conservation & Recreation Forest Stewardship Program
www.mass.gov/info-details/forest-stewardship-program

ME Forest Service District Foresters
https://www.maine.gov/dacf/mfs/policy_management/district_foresters.html

University of New Hampshire Cooperative Extension County Forester Program
extension.unh.edu/countyforesters

NY Department of Environmental Conservation Forest Stewardship Program
https://dec.ny.gov/nature/forests-trees/private-forest-management#Forest_Stewardship_Program

RI Department of Environmental Management Forest Stewardship Program
https://dem.ri.gov/natural-resources-bureau/agriculture-and-forest-environment/forest-environment/forest-stewardship

VT Department of Forests, Parks and Recreation County Forester Program
https://fpr.vermont.gov/forest/list-vermont-county-foresters

Find information on conservation-based estate planning in your state:

Connecticut: https://portal.ct.gov/DEEP/Forestry/Legacy/Estate-Planning-Resources-and-the-Forest-Legacy-Program
Massachusetts: www.MassWoods.org/legacy
Maine: www.forest.umaine.edu/legacy
New Hampshire: www.extension.unh.edu/resource/estate-planning-nh-woodlot-owners
New York: www.nyfoa.org/resources/plans-contracts
Rhode Island: https://web.uri.edu/rhodeislandwoods/legacy/future-ownership
Vermont: www.vhcb.org/forestland

Find information on programs offered by the Natural Resources Conservation Service (NRCS):

Environmental Quality Incentives Program (EQIP)
www.nrcs.usda.gov/programs-initiatives/eqip-environmental-quality-incentives

Conservation Stewardship Program (CSP)
www.nrcs.usda.gov/programs-initiatives/csp-conservation-stewardship-program

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