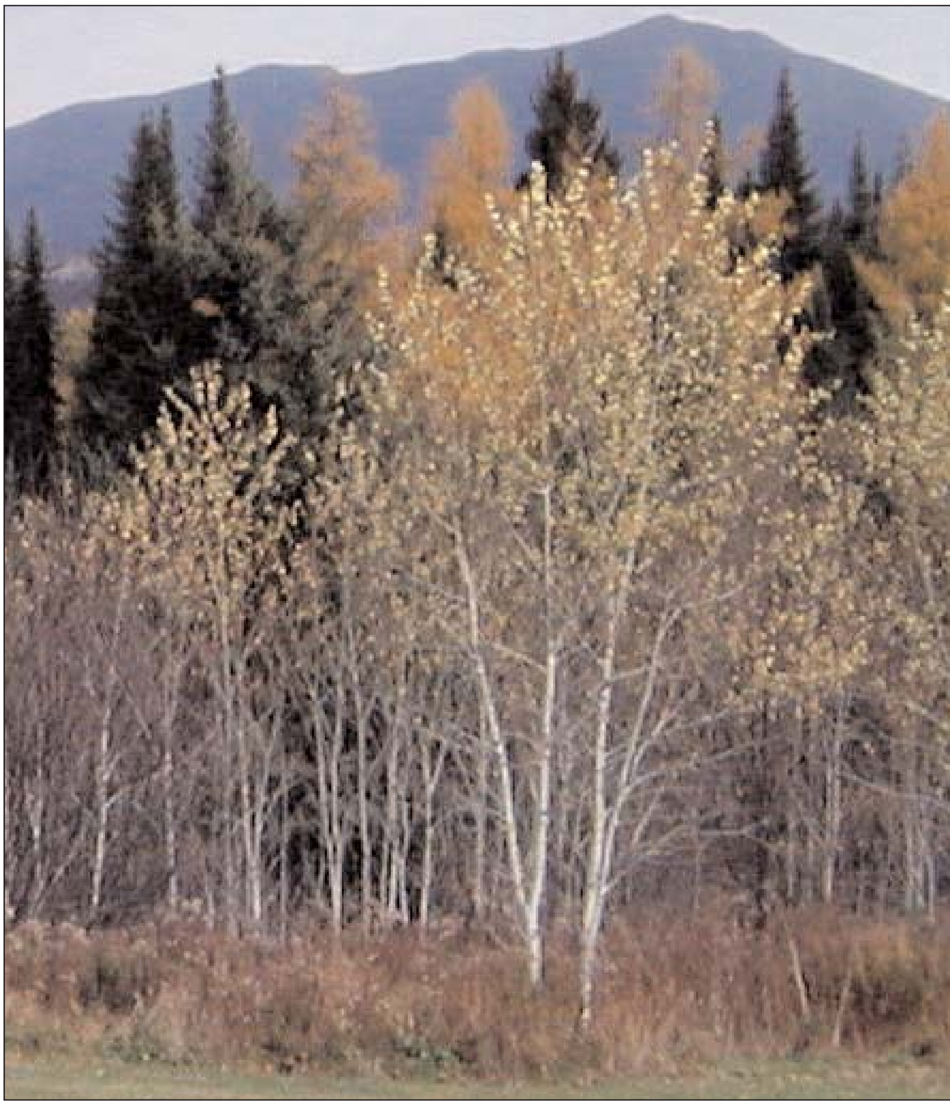
Climate Change, Carbon, and the Forests of the Northeast

by Robert T. Perschel, Alexander M. Evans and Marcia J. Summers



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The Forest Guild promotes ecologically, economically, and socially responsible forestry - "excellent forestry" - as a means of sustaining the integrity of forest ecosystems and the human communities dependent upon them. The Guild provides training, policy analysis, and research to foster excellence in stewardship, to support practicing foresters and allied professionals, and to engage a broader community in the challenges of forest conservation and management.

*forest***GUILD** PO Box 519 Santa Fe, NM 87504 505-983-8992 www.forestguild.org

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Executive Summary

Scientific data overwhelmingly indicates that the climate in the Northeast will change rapidly in this century because of human-caused emission of carbon dioxide (CO_2) and other gases. The Northeast is projected to get at least 2°F warmer in the summer and 4°F warmer in the winter by 2050. Although more rain and heavier storms are predicted, there may also be more frequent droughts because of the timing of precipitation. These changes to the climate will impact our forests. It is important to reduce greenhouse gas emissions through conservation, efficiency improvements, and the appropriate substitution of renewable energy for non-renewable sources. In addition, there are management practices that can be employed to build resistance, resiliency, and adaptation into forest systems. Many of those same practices can also help to mitigate climate change by increasing carbon sequestration.

Ten Northeast and Mid-Atlantic states have developed an initial plan, the Regional Greenhouse Gas Initiative (RGGI), to reduce their carbon impact. Afforestation, the planting of forests on non-forested land, is currently the only carbon offset recognized by RGGI. Forestry can and should play a larger role in RGGI's and other regional and state carbon reduction goals. Excellent forestry—forestry that is ecologically, economically, and socially responsible—offers a number of additional ways to sequester carbon. Northeastern forests sequester 12 to 20 percent of annual CO_2 emissions from the region, mostly in living plants and soil. This sequestration capacity figure includes all management regimes—practices that enhance carbon sequestration, are carbon neutral, or actually result in net carbon emissions. By expanding excellent forestry in northeastern forests, the percent of annual emissions that can be sequestered by forests can be substantially raised. Excellent forestry can help increase the amount of carbon sequestered in forests while also harvesting wood products and protecting ecological values. Forest reserves, in addition to their many other values, are also important for increasing carbon sequestration.

As forests are employed to help mitigate climate change, many foresters and other natural resource professionals recognize that there is a risk of other forest values being ignored. The Forest Guild presents the following recommendations for forest management and carbon sequestration to inform and shape climate change mitigation policies and practices so that they also ensure and promote stewardship of a full range of forest values. These recommendations are based on scientific research and field observations and are addressed in detail in the body of this report.

Policy Recommendations

1. Retain the Northeast's forestlands as forests. Conversion of forestland to any other uses releases stored carbon and damages the region's long-term ability to sequester carbon in forests and wood products. Forest conversion to other land uses has clear negative effects on forests that are compounded by landscape fragmentation. Forestland must be protected through working forest conservation easements and other tools including full fee purchase and robust zoning incentives and regulations.

2. Include standards for excellent forestry in the criteria for earning and trading carbon credits from forestlands. Forestry projects that meet those standards along with criteria for demonstrating additional carbon sequestration should be eligible for carbon credits within the Regional Greenhouse Gas Initiative (RGGI) and other regional and national initiatives and forestry protocols.

3. Maintain and increase carbon stocks and increase forest resilience, resistance, and adaptation by augmenting current programs to better regulate harvesting practices, enhance landowner education and incentives, and more widely require and promote the use of professional licensed or accredited foresters. These actions will also reduce the use of poor forest management practices that diminish forest carbon stock and damage the forest's potential to replenish lost carbon.

Forest Management Recommendations

Working Forests:

1. Available research indicates that some currently utilized practices of excellent forestry can increase carbon storage and help forests maintain their resiliency in the face of climate change. The following practices must be actively promoted and encouraged:

   a. Use forest management plans and the supervision of a professional forester to guide harvests.

   b. Extend rotations or entry periods to promote carbon storage and ecological values.

   c. Manage for structural complexity of forests (i.e., leaving snags, coarse woody material, and—in multi-aged stands—high levels of post harvest basal area).

   d. Retain trees as biological legacies after harvests.

   e. Use low-impact logging to protect soil and site productivity.

   f. Choose appropriate thinning regimes that concentrate growth on fewer, larger trees.

   g. Restore understocked stands to full stocking and productivity.

2. Avoid harvesting practices that degrade forest ecosystem health because of their negative impact on carbon storage. The most harmful practices are high grading, whole tree harvesting on nutrient-impaired sites, liquidation cutting, and relying on short-term rotations that produce short-lived products.

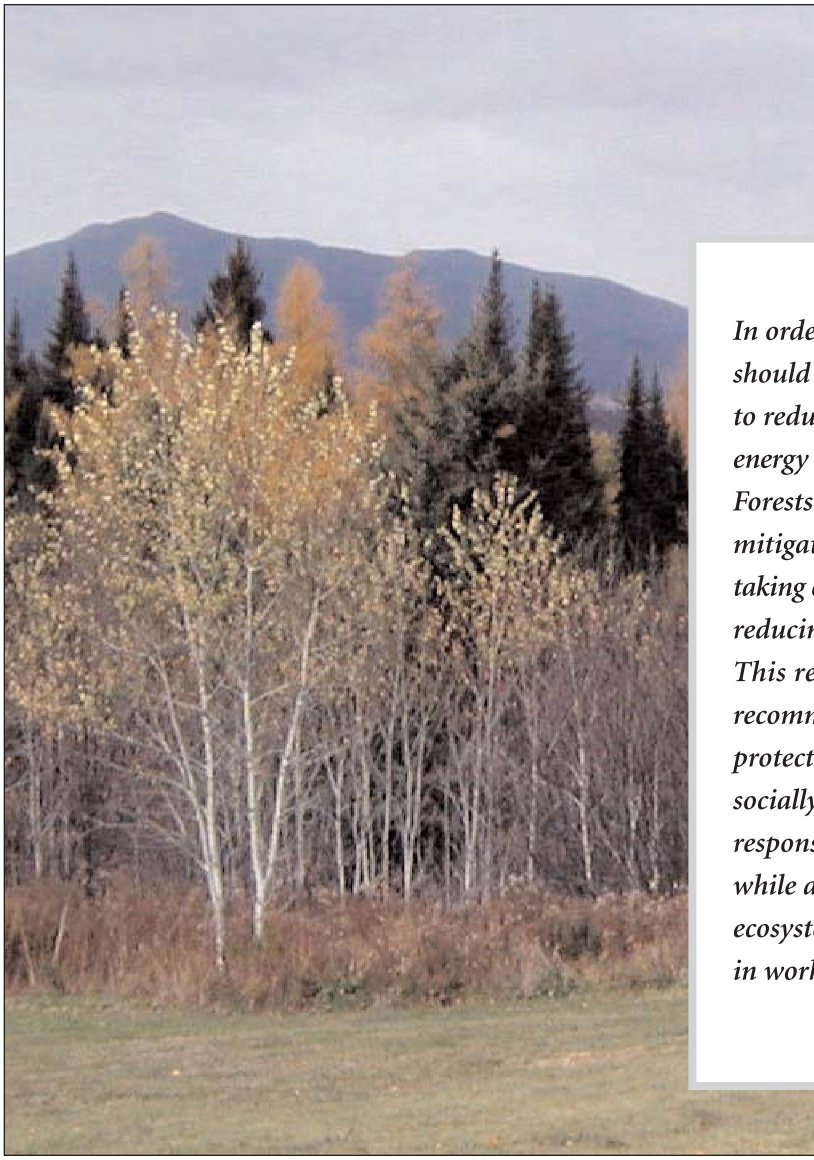
Forest Reserves:

1. Maintain forest reserves for carbon sequestration, genetic diversity, and habitat refuges in the face of climate change.

2. Include resilience to climate change and carbon sequestration in addition to the traditional benefits of protected areas in the evaluation of potential reserves.

3. Consider management to increase overall ecosystem function and accelerate accumulation of carbon for reserves in an unhealthy or undesirable condition.

1. Introduction



In order to mitigate climate change, society should immediately take significant steps to reduce greenhouse gas emissions through energy conservation and improved efficiency. Forests can also play an important role in mitigating climate change by naturally taking carbon out of the atmosphere, thereby reducing the impact of CO_2 emissions. This report's policy and management recommendations will promote forest protection and allow foresters to practice socially, economically, and ecologically responsible forestry–excellent forestry– while also increasing carbon storage and ecosystem resilience to climate change in working forests.

There is overwhelming scientific evidence that climate change is a rapidly growing global dilemma. Fossil fuel combustion, industrial processes, and unprecedented land use conversion have led to rising levels of carbon dioxide (CO_2) and other greenhouse gases (GHGs) in the atmosphere.[68] This in turn has created "the greenhouse effect," which if unabated will continue to warm the earth resulting in devastating ecological, social, and economic consequences. The 2007 Intergovernmental Panel on Climate Change (IPCC) report demonstrates unequivocally that ecological changes are already occurring and describes a range of future threats.[4]

Forests are a focus for action because they can play an important role in mitigating climate change by naturally taking carbon out of the atmosphere. Forest preservation maintains carbon storage and forest management that increases carbon sequestration can augment forests' natural carbon storage capacity in working forests. Wood products sequester carbon and wood fuel has less of a climate impact than fossil fuel. Policymakers at global, national, regional, and state levels have recognized forests' ability to remove carbon from the atmosphere, offset emissions, and mitigate humans' impact on climate. For example, the 1997 Kyoto Protocol, the first major international agreement on climate change, recognizes forests and some land management practices as crucial carbon sinks. In the U.S. for 2005, forests sequestered 687 million tons (698 Tg) CO_2, about 11 percent of the CO_2 emitted.[39]

Forest ecosystems are also profoundly affected by global environmental transformations. Alterations in temperature, rain patterns, disturbance regimes, and other natural conditions can make it difficult for some plants, animals, and ecosystems to survive. The negative impacts of climate change are magnified by fragmentation of natural areas and invasive species. However, effective management decisions can increase forests' resistance, resilience, and adaptation to climate change and even help restore ecosystem patterns and processes to increase the forests' ability to sequester carbon.

In the Northeast, climate change and forests are inextricably linked. Although the forests will be affected by altered precipitation and temperature patterns, they can also play a role in mitigating climate change. The Northeast's forests can sequester from 12 to 20 percent of current annual emissions from the region and therefore reduce the rate of climate change.[150] For that reason, the Regional Greenhouse Gas Initiative (RGGI), the multi-state Northeast/Mid-Atlantic regional policy effort to address carbon emissions and climate change, already identifies creation of new forests—afforestation—as a carbon benefit. However, RGGI and other regional and national climate protocols and initiatives should also acknowledge the vital role that existing forests can play in mitigating climate change by recognizing and rewarding excellent forestry that increases forest carbon stocks while also maintaining other forest values.

In light of the increased discussion and focus on policies and on-the-ground practices concerning climate change, carbon sequestration, and forests, we have written this report to present recommendations related to climate change policy and forest practices, along with the supporting scientific information, so that society can use forests to help mitigate climate change while also protecting a full range of forest values.

To facilitate reader access to specific topics, the body of the report is divided into chapters and is followed by a glossary of relevant terms and an extensive list of references.

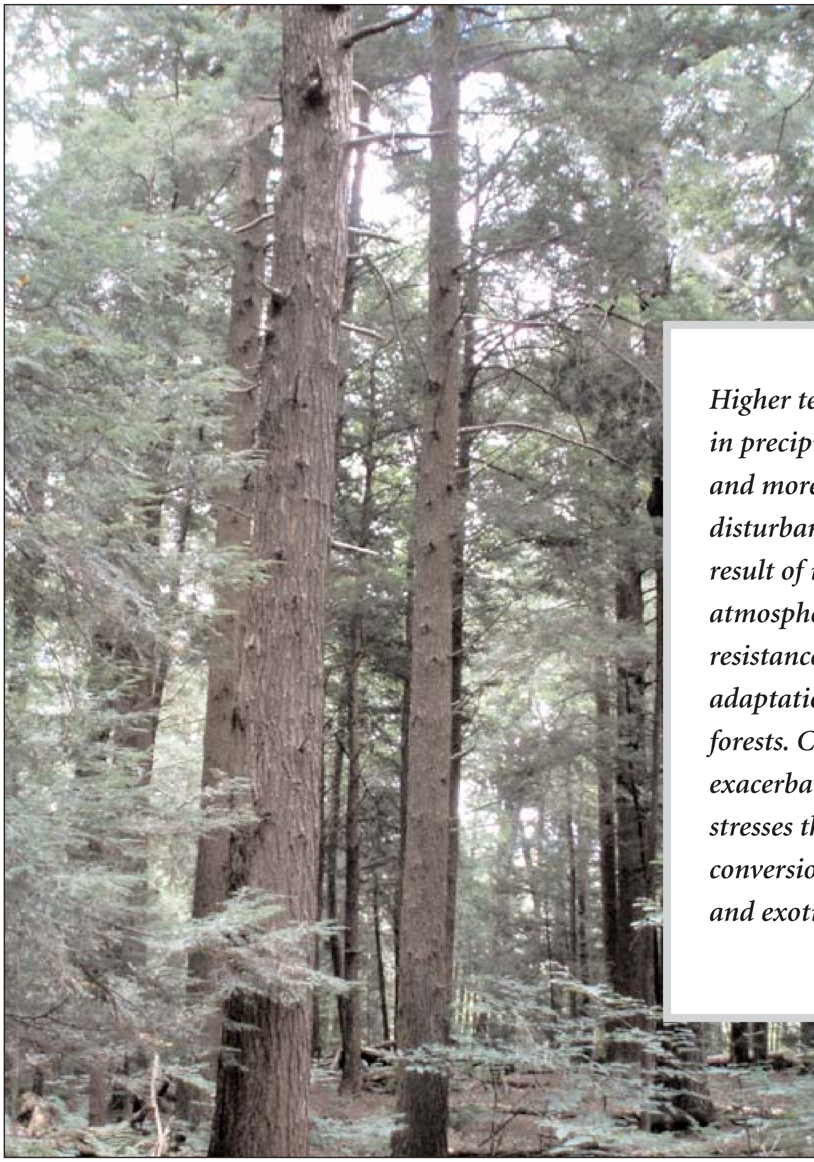
Chapter 2, Background: Climate Change and Carbon in the Northeast, reviews the science of climate change in the Northeast through a survey of historical trends and future projections including temperature changes, severity of weather patterns, and species migration of both plants and wildlife. The chapter assesses the relationship between greater atmospheric CO_2 concentrations and tree growth, increased risk of insect outbreaks, and wildfires. Chapter 2 also examines carbon stocks and emissions in the Northeast and presents a model of the carbon cycle in forests.

Chapter 3, Carbon Trading and Protocols for Forestry, summarizes the status of regional carbon registries, climate change initiatives, carbon markets, and sequestration protocols. It concentrates on the California Climate Action Registry and California Air Resources Board, Western Climate Initiative, Climate Registry, RGGI, and Chicago Climate Exchange, as well as forestry protocols for carbon sequestration. The chapter examines the relationships between voluntary registries, legislated CO_2 emissions levels, and commercial carbon trading.

Chapter 4, Managing Forests for Climate Change and Carbon, reviews the challenges involved in preserving and managing the forests of the Northeast to mitigate the effects of climate change and sequester carbon. Issues include shifting habitats, invasive species, and the importance of applying excellent forestry to improve forest resistance, resilience, and adaptation through mixed-species management and increased site productivity. The overarching need to preserve forestlands is also addressed in the context of efficiently protecting ecosystem values and sequestering carbon.

Chapter 5, Additional Areas for Research, touches on issues needing further study: including carbon storage in wood products, substitution of forest products for fossil fuel intensive products, effects of management on soil carbon, carbon emissions from forest harvesting and management operations, carbon-free forest ecosystem services, state regulations that support carbon sequestration and excellent forestry, and silvicultural systems and carbon capture.

2. Background: Climate Change and Carbon in the Northeast



Higher temperatures, changes in precipitation patterns, and more frequent and severe disturbances–all the projected result of increased levels of atmospheric CO_2 –will test the resistance, resiliency, and adaptation of the Northeast's forests. Climate change will exacerbate existing forest stresses that include land conversion to non-forest uses and exotic, invasive insects.

Climate Changes in the Northeast

Over the last century and particularly in the last few decades, the Northeast has become hotter and wetter. Global mean temperatures have increased since the start of the 20th century by 0.7 to 1.5°F.[26] More specifically, the Northeast has gotten warmer, particularly since 1970 at the rate of 0.45°F per decade.[67] Post 1970 warming should be put in the context of a global cooling period from 1946-1975, which was particularly noticeable in the eastern U.S.[26] Changes in the number of frost-free days in the Northeast are less clear, but the growing season has increased since 1980 by approximately one week nationally with greater increases in the western U.S. than in the eastern U.S.[33, 35, 88]

In addition to temperature changes, there have been other important changes in global weather patterns that have affected the Northeast as well as the U.S. more generally. For example, wintertime westerly winds over sub-polar latitudes have become stronger in recent decades.[26] In the Northeast, average annual precipitation has increased by 0.4 inches over the last century, even accounting for droughts in the 1930s and 1950s.[35, 67] In the Northeast, very heavy daily precipitation has also increased in the last century[35] and the decrease in the percent of precipitation the Northeast receives as snow has been most notable in northern and coastal areas.[76]

Predicting the changes in temperature for the next century is difficult. Depending on the assumptions and models used, estimates of global temperature increases (over the 1980-1999 average) run from 2.3 to 3.2°F by 2050 and 3.2 to 7.2°F by 2100.[107] Model estimates for the increase in average minimum temperature (over the 1961-1990 average) are 1.8° F by 2030 and 5.8 to 9°F by 2100, and increases in average maximum temperature are very similar.114 Using a high emissions scenario, summers in the Northeast will be 6 to 14° F warmer and winters will be 8 to 12° F warmer than historic averages by 2100 (Table 1). [52]

Table 1. Temperature Increase Estimates for the Northeastern U.S.[52]

Period	Season	High Emissions	Low Emissions
2050	Summer	4 to 8°F	2 to 5°F
	Winter	4 to 7°F	4 to 5°F
2100	Summer	6 to 14°F	3 to 7°F
	Winter	8 to 12°F	5 to 8°F

Total precipitation in the Northeast may increase in the range of 10 to 30 percent over the next century.[114, 52] Winter precipitation may increase 11 to 14 percent over the century with a greater proportion falling as rain rather than snow.[76, 67] Intense rain incidents are likely to increase as well with more rain falling during an event and longer rain events. However, even with more rain there may be more frequent droughts due to the timing of precipitation.[52, 67]

Climate change impacts on forests and wildlife can be difficult to predict because of the complexity of natural systems. However, a number of anticipated impacts are outlined below.

Range Shifts

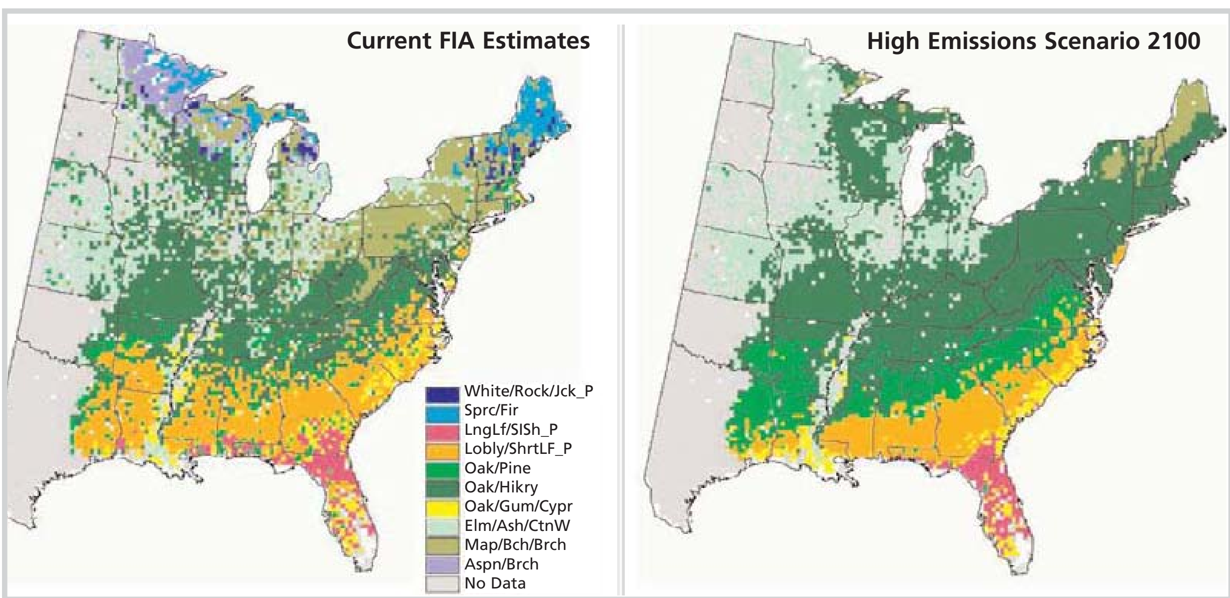
Globally, climate change has caused plant and animal ranges to shift towards the poles.[126] The concept of range shifts combines two ideas: suitable habitat and physical movement. To the extent that temperature dictates species range in the Northeast, those ranges will shift as the climate warms. Natural plant movement is essentially limited to seed dispersal. Recent models suggest species such as loblolly pine

(*Pinus taeda*) and southern red oak (*Quercus falcata*) might only move 6 to 12 miles (10 to 20 km) beyond their current range over the next century.[79] This rate of dispersal is comparable to estimates of post-glacial species range expansion.[23] For example, after the most recent glaciation 12,000 years ago, eastern hemlock (*Tsuga canadensis*) migrated to its current geographical distribution at a rate of about 12 to 16 miles (20 to 25 km) per 100 years.[32] Modern dispersal would tend to be slower than post-glacial rates because areas which had been recently freed from glaciers also would have been relatively free of competition and unfragmented.[122, 112]

While species migration rates are relatively slow, changes in habitat suitability are predicted to be much more rapid although they do not immediately dictate changes in tree distribution.[78] Long-lived native species can persist in locations that are no longer suitable and no longer permit regeneration,[51] which would slow changes in species composition due to climate change.[62] What is clear is that where there is a mismatch between current tree distribution and habitat suitability, forests will be under increased stress. Unfortunately, invasive species are at an advantage in moving to suitable habitats in new locations because they tend to be site generalists, mature quickly, and have successful dispersal strategies.[166, 100, 62]

Current species associations in the Northeast are relatively new and as ranges shift these associations will change.[163, 32] Generally, it is very difficult to include the complex interactions that determine species range in a model.[6] For example, initial estimates of the suitability of New Hampshire in 2100 for the Maple-Birch-Beech forest type were very low,[62] but more recent modeling rates it as relatively high (Figure 1).[129] The Northeast's forest types of the next century will be determined by temperature, precipitation, disturbance patterns, differential species dispersal, species competition, and land use.[62]

Figure 1. Predicted Habitat Suitability by Forest Type [119]



Increasing temperatures may push species habitats higher in elevation as well as farther north. Evidence for changes in tree line is still weak, perhaps because of seasonally different climate patterns, browsing, and abrasion.[155, 30] Mountain habitats are threatened by range shifts, loss of the coolest climatic zones on peaks, and genetic isolation of populations.[11]

Climate change impacts will vary by region, species, and even site. For example, increases in freeze/thaw events due to climate warming could cause dieback and decline in yellow birch (*Betula alleghaniensis*) in the Northeast.[14] Because of shifting habitat suitability and differential effects on species, current species associations are likely to change. However, species richness generally increases with temperature, so ultimately climate change is likely to increase species richness in the Northeast.[62] Some threatened and endangered species may benefit from warming temperatures while others suffer. A review of hotspots of endangered species suggests that while endangered reptiles and amphibians may benefit from climate changes, birds and mammals may suffer.[62] Endangered species may suffer disproportionately from future range restrictions because their habitats have already been drastically reduced by development and human land use.[100]

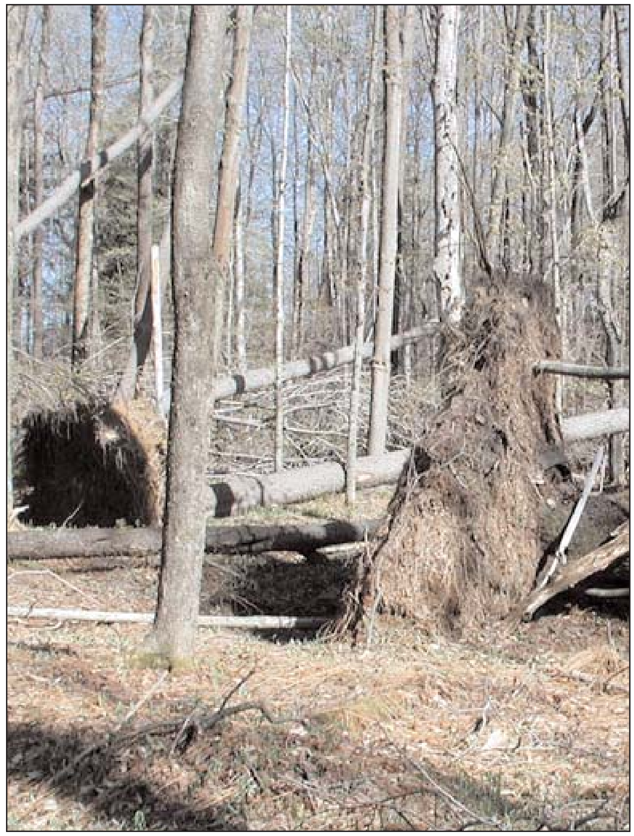
Tree Growth and Soils

The additional CO_2 in the atmosphere may increase tree growth in the Northeast, but the increases may be limited by availability of water and nutrients, particularly nitrogen.[1, 148] A plant's water use efficiency can increase with elevated levels of CO_2, which reduces the impact of water stress.[1, 116] Experiments during the last decade have shown an approximately 12 percent increase in net primary productivity due to elevated CO_2 levels.[116, 63] Such increases in the Northeast are supported by some modeling efforts.[100] However, increases in primary productivity from CO_2 fertilization and longer growing seasons must be weighed against potential increases in drought stress, nitrogen deficits, and potential increased tree death due to more frequent wind storms.[139] Because of drought conditions, some researchers predict a decrease in leaf area of about 25 percent for temperate forests in the Northeast.[159, 1] Changes in growth may be determined by how much the climate warms with large increases in temperature leading to growth reductions.[8] An integrated model of the effects of tropospheric ozone, nitrogen deposition, elevated CO_2, and land use change in the Northeast indicates that in combination the positive and negative effects of these changes had little net effect on forest growth.[119]

Soils are a key element in the climate change equation and perhaps the least understood. Soils in the Northeast store 38 percent of forest carbon.[39] Although models of soil organic matter decomposition predict increasing rates with increasing temperature, field measurements seem to contradict model results.[139] In addition to increases in CO_2, industrialization has increased the amount of nitrogen deposition. Nitrogen deposition from human activities may help forests that are nitrogen limited, but excess nitrogen deposition can lead to soil acidification and reduced nutrient availability to plants.[1] One recent study suggests that once stand disturbance effects are factored out, nitrogen deposition is the most important factor in forest carbon sequestration.[99] Similarly, although calcium depletion in Maine is not currently a problem, if climate change prompts an increase in growth and species change it may become a limiting factor in potential carbon sequestration.[75] Additionally, heavy storms and more intense runoff may increase erosion and degrade soils in the Northeast.[52]

Disturbance Regimes

The alteration of basic environmental conditions will cause changes in the disturbance regimes in the Northeast including hurricanes, windstorms, ice storms, droughts, and fires.[28] Over the near term climate-driven natural disturbances may be even more important than the direct effects of climate change in causing abrupt or rapid forest ecosystem responses.[82] Although current predictive capabilities are insufficient to model the processes that determine hurricane and windstorm frequencies, research does suggest that storms will become more frequent and more intense in the Northeast.[153] Increasing frequency of storms would favor species that can respond to growing space release by blowdown and snap-offs, such as eastern hemlock.[153]



Hurricanes also have a dramatic effect on carbon sequestration. A study from the Southeast suggested a single hurricane can blow over the equivalent of 10 percent of the carbon sequestered by all U.S. forests in a year.[106] An increase in hurricanes may result in a larger proportion of forest carbon residing in the dead woody material pool.[153] Ice storms may become less frequent in the Northeast as winters warm and more precipitation falls as rain.[28, 76] In addition, high CO_2 levels may result in reduced injury to trees during ice storms, at least in conifer species.[104]

Although the Northeast may get more rain because of climate change, there may be more frequent droughts because of the timing of precipitation. The combination of precipitation and temperature changes will lead to earlier peak runoff and may cause more frequent short- and medium-term droughts.[67] The frequency of fire in the future may change because of increasing temperature, more frequent droughts, and changes in species composition. Rising temperatures may be responsible for the increase in fires in the western U.S. and boreal forests.[47, 161] Species composition has been tied to fire frequency over the last 10,000 years.[24, 18]

Insect and Disease Dynamics

Climate changes may alter insect and pathogen patterns in forests with both positive and negative consequences. Temperature increases will shift insect ranges northward so new areas are affected, but at the same time some previously affected areas may no longer be suitable for some insects.[7] A larger concern is the potential for climate change to disrupt predator-prey relationships and permit outbreak conditions.[98] In fact, warmer, drier conditions have helped drive insect outbreaks in the Southwest and Alaska.[98] Similarly, climate changes will affect forest pathogen dynamics and may exacerbate some disease problems such as sudden oak death (*Phytophthora ramorum*).[154] Climate change and shifts in suitable habitat may also increase plant stress and reduce resistance to insects and diseases.
In addition to native insects, there is also a threat that global climate change will exacerbate exotic species problems.[142] For example, hemlock woolly adelgid may be able to expand its range farther north with warmer temperatures,[43] and rising CO_2 concentrations may benefit another destructive invasive species, cheat grass (*Bromus tectorum*).[22]

Carbon Stocks and Emissions in the Northeast

About 6.8 billion tons (6.9 Pg) of carbon are stored in the Northeast's forests. On average, each acre of northeastern forestland holds 75 t/ac (185 Mg/ha) of carbon of which 38 percent is alive aboveground carbon, 8 percent is alive belowground carbon, 6 percent is in dead wood, 10 percent is in litter, and 38 percent is in soil organic material (Figure 2).[38] In addition, carbon storage varies by forest type (Figure 3).[38]

Figure 2. Northeast Forest Carbon Stocks [38]

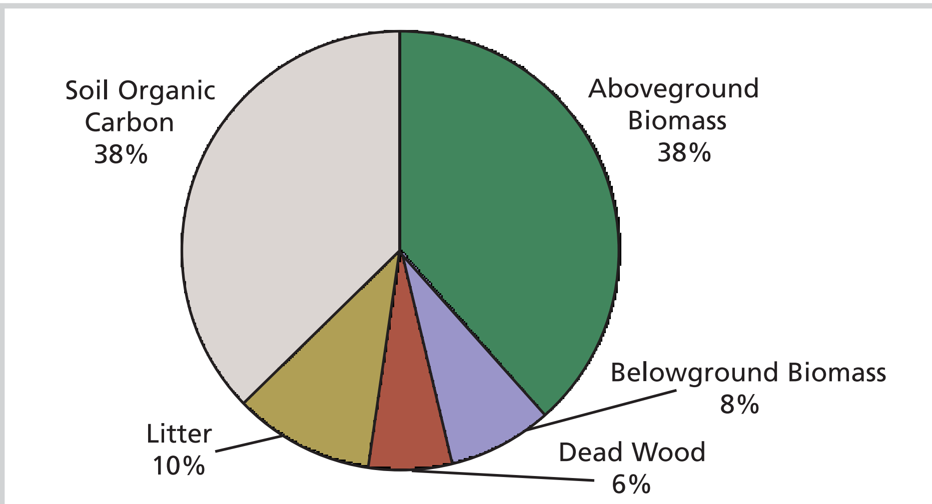
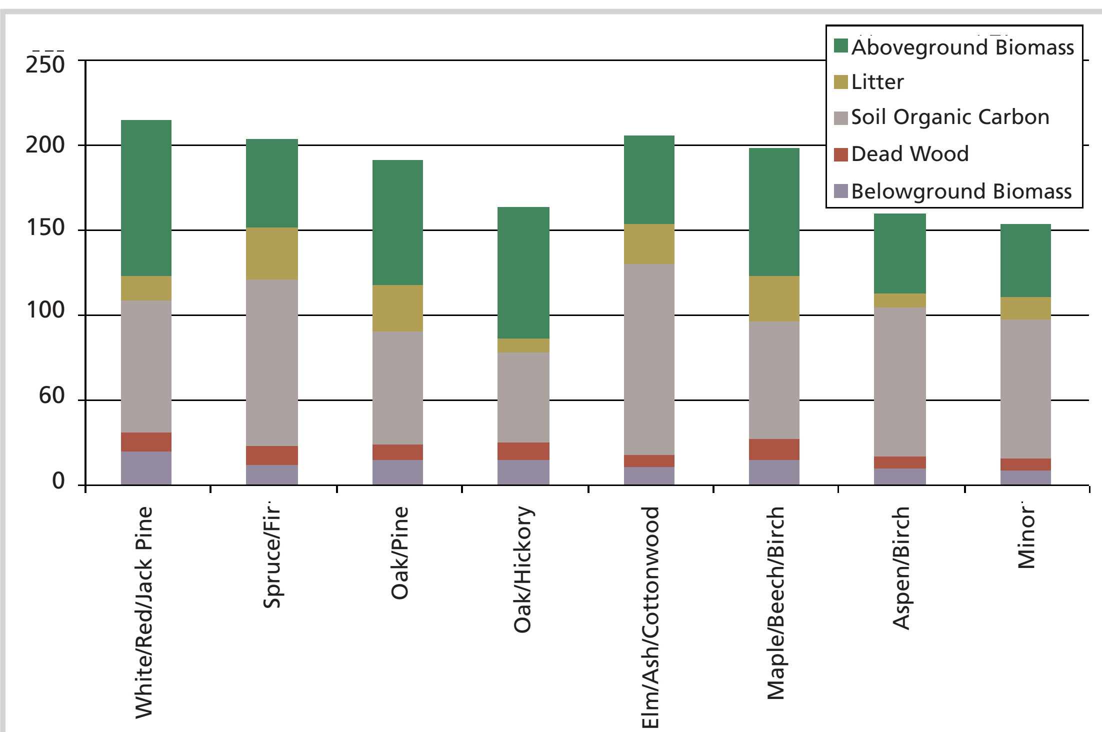


Figure 3. Forest Carbon Stocks by Forest Type [38]



The Northeast's forests can sequester from 12 to 20 percent of annual carbon emissions from the region and therefore reduce the rate of climate change.[150] The Northeast released 1,260 million tons (1,280 Tg) of CO_2 in 2003, a 7 percent increase from 1990 (Figure 4).[37] The electric power and transportation sectors make up the majority of emissions in the Northeast (Figure 5).*[39]

Figure 4. Northeast Emissions by Year [37]

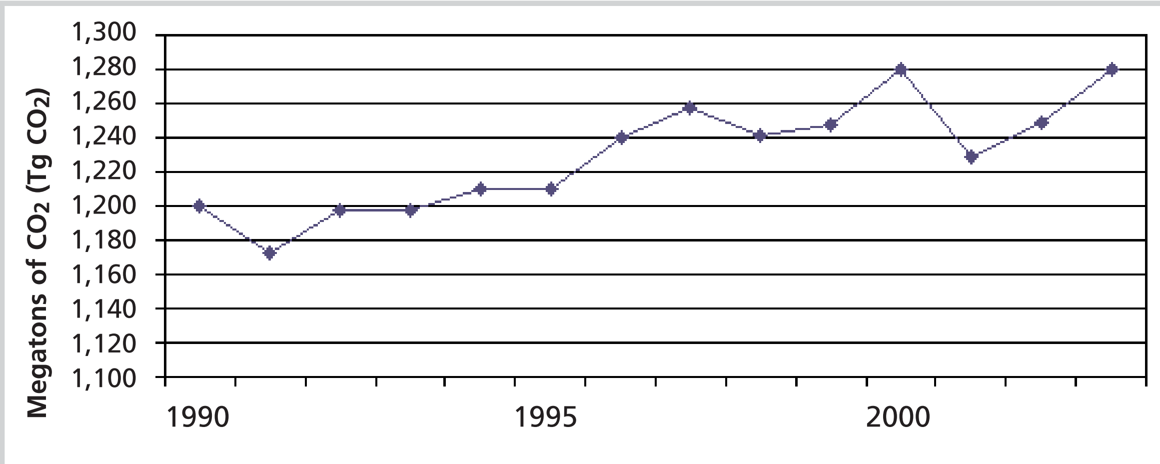
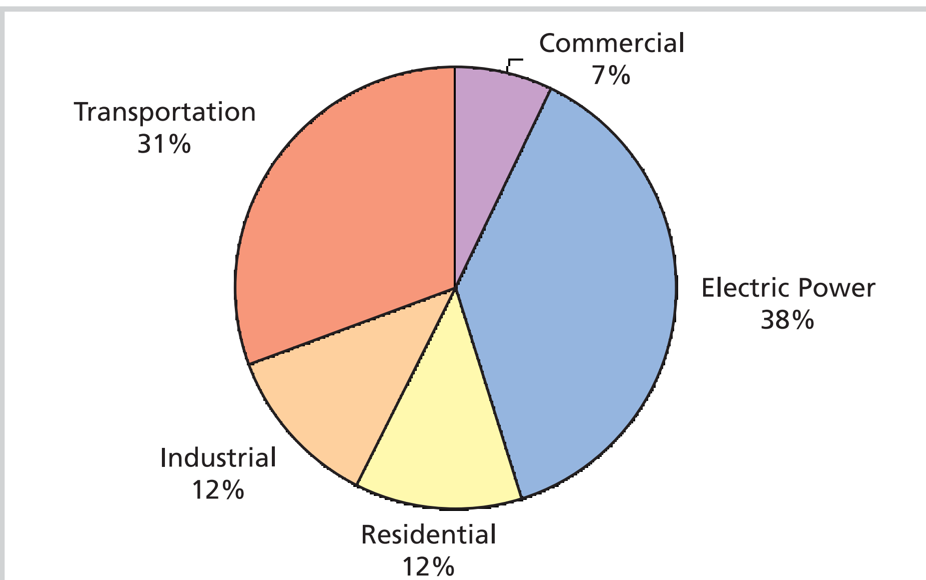


Figure 5. Northeast Emissions by Sector [39]



Increasing concentrations of CO_2 in the atmosphere are the main driver of climate change. Pre-industrial levels of atmospheric CO_2 were about 280 parts per million (ppm). It is 380 ppm today and increasing by roughly two ppm annually.[52] Increases in atmospheric CO_2 have direct, and sometimes dire, consequences for climate change. A series of reports in the last few years indicates that at CO_2

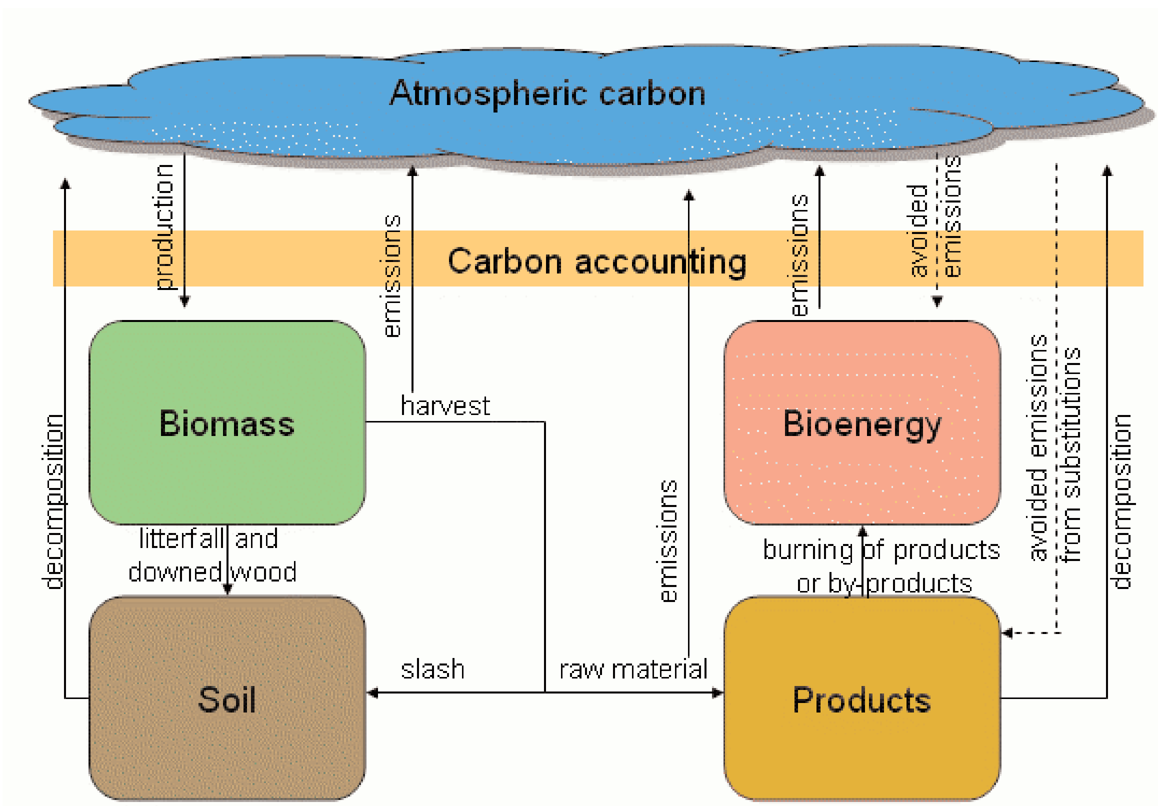
*Where the Northeast is: CT, DC, DE, MA, MD, ME, NH, NJ, NY, OH, PA, RI, VT, and WV for comparability with the Environmental Protection Agency's forest type carbon sequestration estimates.

levels above 450 ppm, the earth will face a sea level rise of giant proportions.[105] The most recent IPCC high emissions scenario predicts 940 ppm by 2100 while the low emissions scenario predicts 550 ppm by 2100.[107] In reaction to these consequences, it is critical that the forestry community help mitigate atmospheric carbon increases by identifying and implementing management practices that foster and improve forests' ability to sequester carbon.

Carbon Cycle Model

For foresters to effectively investigate management practices for carbon sequestration, it is important to use a complete and mutually agreed upon model of the forest carbon cycle. Complete models can help us consider all the relevant factors that determine the effect of forestry practices on atmospheric carbon. Analyses must also be clear about their timeframes, i.e. how long flows in and out of the forest are monitored. The timeframes used can determine the results of the analyses and the policies derived from them. This model should include all carbon pools and points of emission in the entire forestry process. How far down the product chain the model extends is yet to be determined, but for now it should at least consider the use of wood products that substitute for more carbon-intensive products.

Figure 6. Carbon Cycle Model [140]



One model to consider is the modified Carbon Flux Model (Figure 6).[140] This model is useful for several reasons:

1. It tracks the carbon that flows into the live vegetation of the forest from the atmosphere.
2. It integrates components essential to an overall analysis and includes forestry offsets that are left out of other models. For example, it accounts for the fossil fuel carbon emissions that are part of harvesting or wood production systems.
3. It considers the carbon that is offset by burning forest biomass or substituting for fossil fuel intensive products.
4. It accounts for the dramatic loss of carbon caused by conversion of land to non-forest uses. Although it does not highlight these losses as separate from normal forest management activities, the large flow of carbon out of the system during conversion and the minimal returns to the new, non-forested system are accommodated.

We have made three additions to the model in order to make it more comprehensive. We added two "emissions" lines pointing upward to indicate fossil fuel emissions into the atmosphere, one from the harvesting activities and the second from the creation of wood products. The third change is the dotted line, "avoided emissions from substitutions," from the atmosphere to the product box to indicate the potential offsets from substituting wood products for more carbon intensive materials.

3. Carbon Trading and Protocols for Forestry

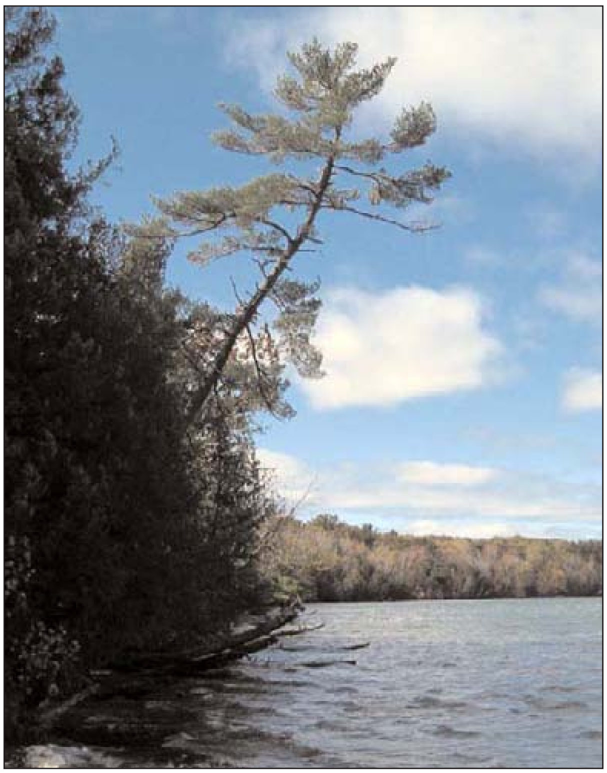
In the absence of a cohesive national policy, regions and states have created regulatory bodies to establish legislative and commercial frameworks for reducing greenhouse gas emissions. Registries are being set up that identify protocols and criteria to measure and qualify carbon sequestration projects for carbon offset trading opportunities. It is essential that standards for excellent forestry be part of the criteria for earning and trading carbon offset credits from forestlands so that carbon storage efforts support the other ecosystem benefits that forests provide.

Background

For more than 15 years the international community has worked to develop a global response to climate change. In 1992 the United Nations Framework Convention on Climate Change called the world community to action. In 1997 the Kyoto Protocol was established to provide international guidance and a framework for action to reduce global greenhouse gas (GHG) emissions. Although 175 parties have ratified the Kyoto Protocol, to date the U.S. has not.

In the U.S. the regulatory framework for carbon is in a state of flux. In the absence of a comprehensive national policy, state and regional carbon or GHG registries and cap and trade systems have been created. The registries facilitate reporting of projects that can sequester carbon or defer emissions, but do not in and of themselves create a market for the carbon offsets. Markets are created when individual states, national governments, or regional compacts cap emissions and require emitters to seek carbon sequestration or conservation projects to offset any emissions over the cap. Markets are also springing up around voluntary commitments to cap emissions. Under a cap and trade system, trading exchanges facilitate the sale and purchase of emissions rights. The following is a brief summary of some important carbon trading initiatives.

California Climate Action Registry/California Air Resources Board



In 2001, the state of California established the California Climate Action Registry (CCAR), a non-profit voluntary registry "to establish greenhouse emissions baselines against which any future GHG emission reduction requirements may be applied."[16] CCAR was mandated to thoroughly examine complex protocols and allow businesses and organizations that complied to bank sequestered carbon for potential regulatory markets.

In 2006, California passed two landmark laws to reduce emissions of CO_2 and other pollutants and established the first carbon cap and trade system in the U.S. Through the California Global Warming Solutions Act (AB 32), California became the first state to limit statewide global warming pollution.[16] AB 32 requires the state to develop market mechanisms and regulations that will reduce California's GHG emissions by 25 percent by 2020.[16] Similarly, the Greenhouse Gas Emissions Performance Standard Act (SB 1368) made California the first state to ensure that new electrical generating capacity meets minimum performance levels for global warming pollution. As a result of these and other pieces of legislation, a market for carbon credits was established and the first projects were completed in 2007.[16] California law SB 812 required CCAR to develop protocols that would encourage carbon sequestration by creating an incentive for landowners to implement forest conservation, conservation-based management, and reforestation projects.

The California protocols for projects and accounting procedures were groundbreaking and may serve as models for other states and regions. Key requirements as stated in the "California Climate Action Registry Forest Protocols Overview" include:

1. Forestland registered as part of a forestry project must be dedicated permanently to forest use through the use of a perpetual conservation easement.

2. All projects must promote and maintain native forests.

3. All forest management projects must utilize natural forest management practices so the attainment of climate benefits is not achieved at the expense of water quality, biodiversity, and species habitat.[16]

In addition, a Forest Certification Protocol was developed to provide guidance for approved third-party certifiers to enable them to conduct accurate, standardized assessments of GHG data to ensure credible emissions reductions.[16]

On October 25, 2007, the California Air Resources Board (CARB), the state agency mandated to administer AB 32 (which includes monitoring and regulating sources of GHG emissions), unanimously adopted the California Climate Action Registry Forest Sector Protocols. This landmark decision is the first by a government agency in the U.S. to establish protocols for voluntary carbon offsets in the forestry sector. [16]

The protocols provide specific methods and parameters for measuring carbon stores in three types of forest projects:

1. Reforestation – planting and restoration of native trees on land that was previously forested but has been out of forest (less than 10 percent tree cover) for at least 10 years.

2. Conservation-based Forest Management – using natural forest management practices to enhance carbon sequestration while engaged in commercial or non-commercial harvest and regeneration of native trees.

3. Conservation – preventing the conversion of native forests to non-forest use (based on concrete knowledge of site-specific threat or county-specific land conversion trends).[17, 124]

The CCAR Forest Protocols meet and set international standards for carbon accounting and reductions, an important factor in creating stability in the voluntary carbon offset market.[17, 124] The protocols also establish standards for additionality (measuring carbon storage against a consistent baseline of standard forest practices) and permanence through permanent conservation easements and third-party verification.[123]

Western Climate Initiative

The Western Climate Initiative established in February 2007 involves California, Washington, Oregon, New Mexico, Arizona, Utah, Manitoba, and British Columbia (as of October 2007) in a joint effort to set regional cap and trade systems for GHG emissions. In contrast to the federal government's current emphasis on voluntary emissions control, the group agreed to an aggregate reduction in GHG emissions of 15 percent below 2005 levels by 2020.[162] According to Christopher Busch, an economist with the Union of Concerned Scientists, the regional initiative would cap pollution at about 2 percent above 1990 levels.[15] The members will design the regional market-based cap and trade system by August 2008. As part of their effort each of the partners has joined the Climate Registry (see below) which is expected to be operational by 2008.[162]

Other State Efforts

In July 2007 the Georgia Forestry Commission (GFC) launched the Georgia Carbon Sequestration Registry "to provide forest landowners, municipalities, and public and private entities with an official mechanism for the development, documentation, and reporting of carbon sequestration projects undertaken in Georgia."[53] Administered by GFC and the Georgia Superior Clerks Cooperative Authority, this completely voluntary registry provides a record of carbon storage in registered forestland that may be used for many different purposes but does not incorporate sale of carbon offsets. [53]

Many states are currently in various stages of formulating climate change initiatives. According to the Pew Center on Global Climate Change, as of September 2007, 18 states have legislative and/or executive branch commissions on climate change.[128] On November 15, 2007, the governors of nine states in the Midwest and the Premier of Manitoba signed the Midwestern Regional Greenhouse Gas Accord and will set targets for GHG reductions and develop a cap and trade system during 2008.[109] In addition to promoting energy efficiency, renewable energy resources, and geological reservoirs for CO_2, the accord calls on the leadership of the forestry community to implement "terrestrial carbon sequestration programs and practices."[108]

Regional Greenhouse Gas Initiative (RGGI)

Ten Northeast and Mid-Atlantic states are working together through RGGI to develop a cap and trade system to reduce emissions from the electric power sector through caps, one mechanism of which is through the pricing and trading of allowances. The initiative currently includes Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont. The Eastern Canadian Provinces Secretariat and New Brunswick are observing the process. In the Memorandum of Understanding signed on December 20, 2005 the signers agreed to "stabilize carbon dioxide emissions at current levels from 2009 to the start of 2015 followed by a 10 percent reduction in emissions by 2019." [52 p. 107, 131]

RGGI will be operational in 2009 when the first allowances (including offsets) will be traded. In August 2006 the participating states issued a model rule for the RGGI program. The model rule includes protocols for the proposed program that would form the basis for each state to establish appropriate implementing regulations. Among other actions, the model rule establishes a set of standards for projects that would qualify as carbon offsets available for purchase by power companies that exceed their cap. At present, use of offsets is limited to 3.3 percent of a facility's cap.

The only forestry offset category in the model rule involves afforestation, the practice of planting trees on land that had not had forest for at least 10 years.[132] Because of land patterns, economics, and forest regeneration dynamics in the Northeast, there is little opportunity for afforestation. The Northeast is 67 percent forested compared to 49 percent in the Pacific Northwest and 33 percent nationally.[5] However, there is a process for developing additional offset standards. The participating states are charged in the Post Model Rule Action Plan to "evaluate new offset categories and types, prioritize those types, and develop new offset standards that are real, additional, verifiable, permanent, and enforceable."[131] In April 2007 the RGGI Staff Working Group asked the Maine Forest Service (MFS) to draft a proposal for additional offset categories specifically related to forest management. MFS is working with the Maine Department of Environmental Protection, the Manomet Center for Conservation, and Environment Northeast on this project, and anticipates involving additional stakeholders in the near future.

The Climate Registry

The Climate Registry is a national collaborative effort to develop and manage a common voluntary GHG emissions reporting system. As of November 2007 most U.S. states (including the District of Columbia), several Canadian provinces, one Mexican state, and three North American indigenous nations have signed on. The goals as stated by the Registry are to "develop and manage a common GHG emissions reporting system with high integrity that is capable of supporting multiple GHG emissions reporting and emissions reduction policies for its member states/tribes and reporting entities; and provide an accurate, complete, consistent, transparent, and verified set of GHG emissions data from reporting entities, supported by a robust accounting and (third-party) verification infrastructure." This third-party verified information is intended to be consistent across borders and emissions reduction programs. The Registry is expected to be operational on January 1, 2008.[133]

Chicago Climate Exchange

The Chicago Climate Exchange (CCX) is the world's first and North America's only rules-based GHG emissions trading system. It is a voluntary, legally binding integrated trading system that uses offset projects worldwide to reduce emissions. CCX emitting members make a voluntary, but legally binding commitment to meet annual GHG emission reduction targets. Those who reduce below the targets have surplus allowances to sell or bank and those who emit above the targets comply by purchasing CCX Carbon Financial Instrument contracts.[20] In June 2007 CCX announced that trading volume during the first half of 2007, almost 11.7 million tons (11.9 Tg) of CO_2, surpassed the total 2006 volume of 10.1 million tons (10.3 Tg). Thirteen percent of the 2006 total was forest sequestration credits.[20] Current forestry projects among the eligible offsets are afforestation, forest enrichment projects, conservation projects, and urban forestry projects that demonstrate a long-term commitment to maintain the carbon stocks.[20]

Over-the-Counter Markets

In the spirit of American business ingenuity, there is also a growing trade in "over-the-counter" transactions. All that is required is a willing buyer and a willing seller of carbon offsets from a project. If the two parties agree, a trade occurs. Hundreds of companies interested in demonstrating their environmental credentials have already purchased credits in this manner. Forestry projects involving tree planting have proven attractive in this market. Because this market is not regulated, there is some risk that projects purchased in this manner may look less acceptable when the other more regulated markets have established themselves.

Forestry Protocols

The goal of the RGGI offsets category, and that of similar programs, is to identify cost-effective projects that lead to significant real reductions in atmospheric carbon and then to set up carbon trading opportunities to help implement these projects. Establishing protocols for forestry carbon sequestration, aside from afforestation, is particularly complex because of the many challenges associated with accounting for carbon, and any changes attributable to different management strategies, in forested ecosystems. In addition, forested ecosystems are associated with a wide range of additional ecological and social benefits (e.g., wood products, clean water, recreation, biodiversity, and wildlife habitat). Generally, simpler GHG reduction projects, such as landfill methane capture, have little or no ancillary social benefits while more complex forestry carbon sequestration projects have many co-benefits.It is extremely important that those co-benefits to ecosystems and society are acknowledged and included in forestry protocols for carbon sequestration.

Protocols depend upon clearly defined and measurable criteria to provide a high degree of assurance that a project produces a carbon offset (i.e., actually sequesters more carbon than the business-as-usual baseline) and to provide guarantees to the voluntary and regulatory carbon markets of its permanence and value. The following list reviews the current criteria most often used for inclusion of forestry offsets:

> Additionality – A measure of carbon sequestered or precluded from release by a project that exceeds the baseline characterization. It is complex for forestry because carbon is potentially sequestered in a number of pools and emitted by a number of sources. The practice of measuring additional carbon sequestration above a prescribed baseline has made it extremely difficult to access credits in cap and trade systems to keep forestland intact. The CCAR Forest Protocols may help to mitigate this situation.
>
> Baseline Determination – A measurement of the original carbon condition of the forest area before the project was initiated. This determination would also have to include the predicted future management practices and expected outcomes if current management was continued. The expected future management could be set to state-level best management practices or regulations. There are tools and procedures, including direct sampling and modeling results, already in use and new ones are being developed for measuring carbon in forests. For example, there are protocols for measuring carbon in subplots and formulas for calculating carbon stock and changes in carbon stock.[165]
>
> Co-benefits – All additional environmental, cultural, health, and socioeconomic benefits that arise from forestry carbon sequestration projects in addition to the carbon sequestration benefit.Offering carbon credits for forestry yields a host of benefits not captured in other potential projects. These ecosystem benefits include forest products as well as many non-monetized benefits that flow from forestland and benefit society as a whole. Clean drinking water, storm run-off storage, wildlife habitats and wildlife, recreation settings, and forests' aesthetic value are essential co-benefits.

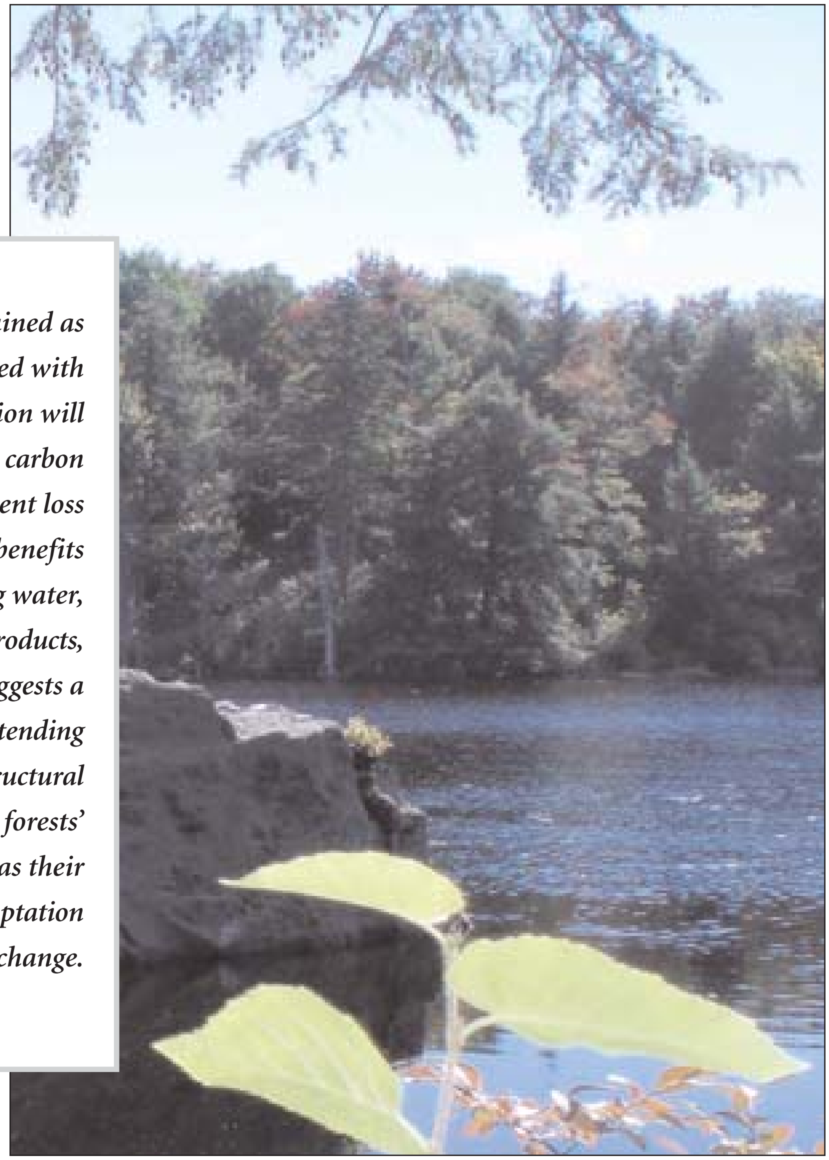
Leakage – The extent to which events occurring outside the project boundary tend to reduce a project's carbon sequestration benefit. If the carbon sequestered in one project creates a situation where more carbon is leaked in another activity there is no net benefit to the final goal. An example would be where a forest landowner sets aside for longer rotation a particular parcel of land, but then engages in liquidation harvesting on another parcel of equivalent size.

Monitoring – A method that quantitatively determines to what extent a forestry project is meeting its objectives over time. It needs to determine how well a forestry project is responding over a number of years and changing environmental conditions. Stocking surveys, now part of general forest inventory systems, can be used to monitor carbon in a cost-effective manner.

Permanence – Forestry offset projects must in perpetuity, rather than temporarily, sequester carbon.

Verification – A method (in most cases conducted by an objective third party) that validates and confirms the accuracy of the monitoring process and sequestration data. A certified standard of sustainability will be required for a forest project to qualify for offsets in both voluntary and regulated markets.

4. Managing Forests for Climate Change and Carbon



Forestlands must be maintained as forests. Land conversion coupled with increased land fragmentation will result in a reduced capacity for carbon sequestration and the permanent loss of vital associated forest co-benefits such as clean drinking water, biodiversity, recreation, wood products, and aesthetics. Research suggests a range of practices, including extending rotations and managing for structural complexity, that will increase forests' ability to store carbon as well as their resistance, resilience, and adaptation in the face of climate change.

Climate change presents forest managers with new and unique challenges that will make it more difficult to protect and enhance forest values such as aesthetics, recreation, biodiversity, game species, clean water, timber, and non-timber products. Past experience and research may no longer provide a guide for future growth and competition. For the first time foresters are faced with fundamental changes to environmental conditions occurring within one or two rotations. Forest management must be flexible given the uncertainty in predictions of temperature, precipitation, disturbance, and species interactions.[13]

One of the major tenets of excellent forestry is to continually guide forests to as healthy a condition as possible. Now, in the face of climate change, land managers can draw on this and many other basic principles of excellent forestry to provide the best guidance in an uncertain world. Silviculture, the art and science of growing and manipulating forests for a range of objectives, is one of the primary tools available to land managers.[147, 146] In fact, silvicultural prescriptions have aided with many other grave problems facing forests by restoring ecosystems,[3, 141] building resilience,[136] managing native insects,[164] dealing with invasive species,[158] recovering from disease,[121] and mitigating species decline.[144, 34] It will become increasingly important to apply and adapt these techniques to address the effects of climate change.

This chapter discusses management challenges related to climate change as well as management practices that can employ forests in increasing carbon sequestration while also protecting other forest values. Any harvest in an unmanaged forest reduces on-site carbon storage, although the total on-site and off-site storage may eventually increase depending on the fate of wood products. In managed forests that are not candidates for preservation—working forests—the research described in this chapter suggests a set of forest practices that can increase carbon storage.

Changing Habitat Suitability

Many suitable habitats will move north as the climate warms, leaving individual trees and whole forests outside of their optimal habitat. It may be preferable to focus on future desired forest functions rather than aiming for specific species mix.[21, 91] In other words, attempts to maintain the current species mix on a particular site for the next two hundred years may be futile. There are compelling reasons (discussed below) to maintain parks and reserves with minimal management, but in areas where foresters are actively managing forests, the focus should be on adapting to inevitablechanges.

In the short term, shifting habitats are likely to manifest themselves as declines in species at the edge of their current range. For example, balsam fir in western Massachusetts and southern Vermont and New Hampshire is at the southern extent of a range that currently extends well into Canada.[97] Managers working in the southern portions of a range should probably not plan for growth rates of those species to continue at past rates in the next century. More complex models are available to help managers plan which species may be under particular stress in a given location such as the U.S.D.A. Forest Service's Climate Change Tree Atlas.[129, 78] In fact, the Climate Change Tree Atlas suggests that while balsam fir may face changes in southern Vermont or New Hampshire, the major change may be the diminishing importance of balsam fir in central and northern Maine. It may behoove managers there to consider the potential to include red oak (*Quercus rubra*) in their long-term management plans since it is projected to increase in importance in the region.[129] Managers will need to balance activities that support current habitat communities with those that favor species more suitable to future environments. Current communities must be kept as healthy as possible to facilitate migration either northward or to higher elevations.[62] In order to aid the dispersal of animal species whose suitable habitat has moved north, it may be more important to increase the habitat quality, including food, cover, and other resources of the forest, at the landscape scale rather than to focus specifically on habitat connectivity.[9] Climate change and associated changes in forest functions may even provide a window of opportunity for forest restoration. For example, increased frequency of fire in the Northeast may aid efforts to re-establish American chestnut (*Castanea dentata*).[49, 103]

Forest Resistance, Resilience, and Adaptation

Managers can increase forest resistance, resilience, and adaptation by using natural disturbances as a guide, maintaining natural communities, protecting against exotic invaders, and preserving soil productivity. Resistance describes forests' ability to avoid alteration, such as excluding a non-native species from becoming established. Resilience is a forest's ability to regain normal function and development following a disturbance, for example regenerating after a fire. Adaptation to climate change may include focusing on local species that will fare better under warmer conditions or encouraging the migration of more southern species into new ranges.

Plants, animals, and ecosystem processes are more likely to survive in managed forests when human disturbances are similar to the patterns and processes of natural disturbances.[111] Since many disturbance regimes (drought, wind, fire, insects, etc.) overlap in any one location, managers should focus on the most relevant type of disturbance to model human manipulations.[13] For example, in Acadian forests a light, regular entry, strip harvesting methodology has been suggested to approximate natural gap disturbance and foster ecosystem resilience.[136]

Forest managers practicing excellent forestry have long used natural disturbance as a guide for management. For example, windstorms and the gaps they create can be models for the size and distribution of harvest gaps in a silvicultural prescription for regeneration.[50] Now, as climate change increases the frequency and severity of some disturbances, managers will be forced to react more often to natural disturbances. To some degree, disturbances can be planned for. For example, areas that are particularly susceptible to blowdown from wind storms can be mapped and vulnerable stands can be managed for species more resistant to windthrow.[42] Similarly, insect outbreaks tend to be species specific and stands can be managed to reduce the dominance of preferred species.[164] In some cases, the most appropriate reaction to disturbance is to allow nature to take its course.[29] However, in other cases societal concerns, e.g. carbon sequestration, may dictate some sort of response such as salvage or replanting. Active management should focus on areas most likely to be impacted by climate change.[146]

Climate change underscores the importance of mixed-species forestry. Because the effects of climate change are uncertain and each species will react differently, it will be wise to maintain species diversity.[95] Maintaining or restoring species diversity on a site can increase the likelihood that some species will flourish as the climate changes (i.e., spread the climate change risks across multiple species). Mixed-species stands may also be more resistant to indirect effects of climate change such as insect outbreaks and exotic invasives.[80, 158]

Climate change may foster the introduction of new invasives and exacerbate problems with non-native species already established. The best strategy with exotic species is to avoid their establishment through detection and eradication.[94] Intact, diverse forest ecosystems may be more resistant to spreading exotic invasions,[74, 101] although research is not conclusive on this point.[73, 54] Once established, the impact of exotic and native insects may be lessened by increasing individual tree vigor. Standard silvicultural approaches to increasing tree vigor such as crown thinnings have been shown to ease some insect infestations.[158] Conversion to different species composition may be necessary in certain severe infestations or particularly susceptible sites.[55] Biological or chemical control may be possible or warranted in some cases where unique ecosystems or trees can be protected without damaging other resources (e.g., hemlock woolly adelgid).[27]

Thinnings and other timber stand improvement activities that enhance individual tree vigor may help forests respond to climate change as well as insect outbreaks. Thinnings can be targeted to the most influential local disturbance, such as wind or drought, in order to encourage forest resistance.[13] Thinning concentrates more growth on fewer, larger trees with greater potential carbon storage benefits. Thinnings should be tied to the long-term landowner goals and plans for regeneration. Another approach, called "continuous cover forestry" in Europe, uses continuous forest canopies to ameliorate the microclimate beneath the canopy. This can lead to higher seedling survival and may affect the overall potential of the forest to store on-site carbon.[84]

Regeneration methods that maintain forest cover help protect forests from invading plant species[74] and maintain connectivity for species migration in response to climate change.[9] There may also be occasions where targeted plantings are able to match species to suitable habitat more rapidly[10] and enrichment planting can help restore or protect valued forest species.[103, 41] Whatever the regeneration method, climate change highlights the importance of preserving legacy trees. Retaining legacy trees or groups help protect plant and animal communities that are under stress because of climate change and under represented on the landscape.[136] Even after legacy trees die, they contribute coarse woody material to the ecosystem.[168]

Site productivity is a crucial element in forest resistance, resilience, and adaptation. Therefore, maintaining favorable soil structure, organic matter, and nutrient availability should always be a focus of silviculture, particularly in a changing climate. For this reason whole tree harvesting may be inadvisable because it may lead to nutrient depletion.[2] While the impact of management and harvesting practices on soils is site specific, the research supports some general guidelines. It is important to avoid soil compaction; so maintaining a permanent skid trail network may benefit forest health.[71] In the Northeast, timber harvests often are timed to occur when soils are frozen to minimize compaction. Harvesting timber on frozen soil may become more difficult because of warmer winters.[52] However, forest soils may freeze more often due to reduced snow coverage and reduced insulation caused by climate change.[57] Thus far, research suggests that harvest operations have no effect on soil carbon in the Northeast.[81, 70] However, on sensitive sites low-impact logging techniques, such as directional felling or careful trail layout, protect soil nutrient resources.[60]

Forest Preservation

The most beneficial aspect of managing forests in the face of climate change is the ability to keep forests intact and the greatest challenge to sequestering carbon in forests is their conversion to other land uses. Over the next 25 years, three million acres (1.2 million ha) of forestland in the Northeast may be lost to development.[36, 77] Most of the carbon stored in forests is released if the parcel is converted to a non-forest use. In the Northeast, this can amount to about 150 t/ac (370 Mg/ha) of CO_2.[77] In addition to damaging the capacity to store carbon in living biomass in northeastern forests, land conversion reduces the

opportunity to sequester carbon in wood products.[36] Moreover, forest fragmentation, caused by the conversion of forest to other land uses, makes forests more susceptible to alien species invasions,[145] and alters watersheds, nutrient cycles, species composition, forest structure, and species diversity.[51]

Forest conversion to other land uses has clear negative effects on forests that are magnified by fragmentation of landscapes. Even without management forests efficiently protect ecosystem values and sequester carbon. Natural reserves or parks are a crucial element in preserving biological diversity and other ecological values. The current forest reserve paradigm will be strained by climate change because as habitat moves, the reserve location may no longer offer habitats for the species and forest types that it was designed to protect.[61] Active management may be crucial in protecting unique habitats that have few options for expansion to new areas.[62]

Reserves and other unmanaged natural areas serve another important role as genetic reserves. Genetic diversity will help species adapt to climate change as new traits are called upon to match up with new habitat.[134, 125] More intensive silvicultural systems reduce the number of rare alleles (a measure of genetic variation) and hence the future genetic potential and ability to adapt.[66] While rare alleles may reduce current growth or form, they also represent traits that may be beneficial to species as the environment changes.

Although a considerable portion of the Northeast's forest landscape is not under active management, only five percent is designated as non-managed reserves.[5] In addition to habitat, biodiversity, recreation, and other values, these reserves are important for carbon storage. Forests store more carbon as they age due to high levels above and below ground.[64, 92, 12] Recent studies indicate forests can accumulate carbon for far longer periods than previously thought.[59] Although many protected areas are on public lands, there are additional opportunities to expand reserve lands that will mature and accumulate carbon for long periods, barring certain disturbances. Many of the region's forests are on a recovery trajectory toward greater concentrations of on-site carbon.[48] Protecting more of these mature forests while sequestering carbon would also protect key habitat conditions, ecosystem functions, and recreational experiences not found on the managed landscapes.

The forest reserve system in the Northeast is gradually expanding and some of the new reserves are on former industrial lands that had been heavily harvested. In some cases, low stocking levels are impeding their development into mature and older growth conditions. In these situations, it is possible to enhance the development of desired forest structure and stocking through selected management techniques.[138] This restoration forestry will help accelerate the accumulation of carbon.[83]

The Effect of Poor Harvesting Practices on Carbon Stocks

Understocked stands in the Northeast are typically the result of faulty management or the lack of professional forest management including haphazard harvesting practices such as high grading and simple overcutting, also known as liquidation cuts.[120] These understocked stands are not taking advantage of the site potential to sequester carbon or produce forest products and can be enhanced by specialized harvests and replanting. In the Northeast, there are 4.6 million acres (11.4 million ha) greater than 40 years of age in a poorly stocked or under-stocked condition.[145] Stands younger than this may have the potential to reach full stocking naturally, but for stands over age 40 some intervention is probably required. By harvesting the existing biomass and then replanting appropriate native trees, the total carbon stored per acre can be increased from 17 tons (17 Mg) to 37 tons (38 Mg) over a 300 year period.[145]

Thousands of private forests that have not been harvested or managed in decades are likely to receive some treatment in the future.[160, 86, 135] Forest surveys indicate that fewer than one-third of the private forest owners in the Northeast have a management plan for their land and fewer use the services of a professional forester when they harvest trees.[160] Unfortunately, one of the most commonly used harvesting practices on private forestlands—high grading or liquidation cuts—removes the largest and most valuable trees in one operation.[87, 85] These harvests destroy much of the future value for wood production, reduce growth rates, damage forest aesthetics, and increase vulnerability to disturbances.[117, 44, 46, 157] These ecologically-degrading poor harvest practices reduce the ability of the forest to accumulate and store carbon for many years.

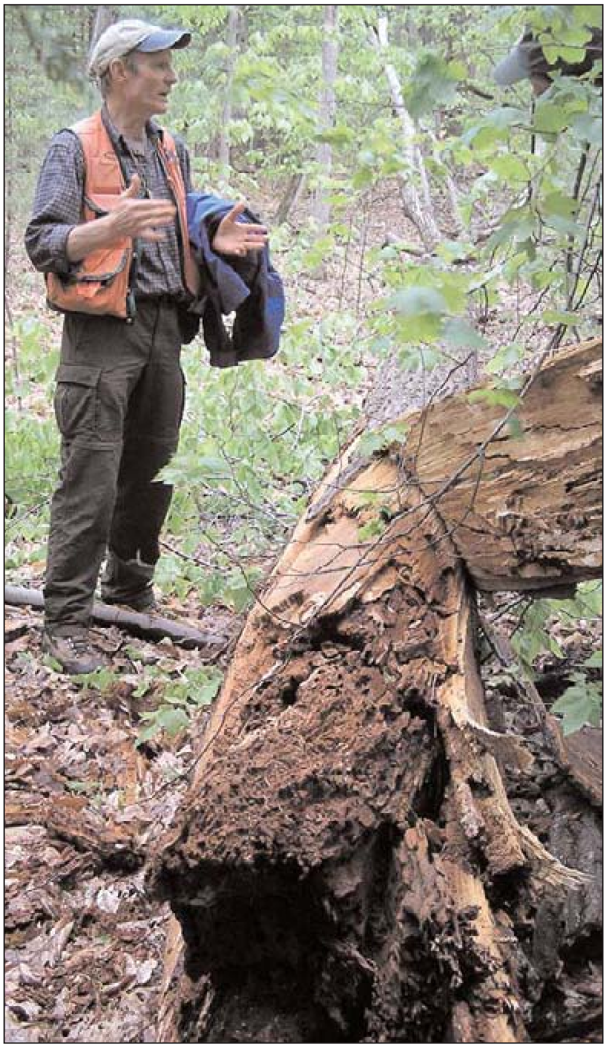
Excellent Forestry Management Practices to Increase Carbon Sequestration in Working Forests

In addition to improving forest resistance, resilience, and adaptation to climate change, forest management can increase carbon sequestration in working forests. Stavins and Richards list nine forestry practices that can be used to sequester carbon:[149]

1. Afforestation of agricultural land.
2. Reforestation of harvested or burned forestland.
3. Modification of forest management practices to emphasize carbon storage.
4. Adoption of low-impact harvesting methods to decrease carbon release.
5. Lengthening forest rotation and entry cycles.
6. Preservation of forestland from conversion.
7. Adoption of agro-forestry practices.
8. Establishment of short-rotation woody biomass plantations.
9. Urban forestry practices.

This report considers practices #2 through #6 because they are related to natural forests and natural stand dynamics and because there is significant potential for their use in northeastern forests to sequester more carbon. Due to the relatively small amount of agricultural land and the high cost per acre, it is not expected that afforestation (practice #1), a practice already included in the RGGI offsets, will have a major impact on carbon in this region. Practice #9, urban forestry practices, may offer significant potential but is not covered in this report. Adoption of agro-forestry practices and establishment of short-rotation woody biomass plantations may also offer carbon sequestration potential (practices #7 and #8), but they do not promote the ecosystem co-benefits that excellent forestry offers.

There are a range of forest management practices that can increase carbon sequestration while also



protecting other forest values such as wildlife habitat, recreation, aesthetics, or biodiversity. Site conditions, species mix, disturbance regimes, and landowner objectives all help define excellent forestry on a particular site. The North East State Foresters Association states that "management strategies that encourage larger trees, employ harvest methods that reduce waste and damage to residual trees, and minimize soil disturbance during harvest all improve carbon sequestration activities."[115]

Extending rotations or entry cycles and increasing the length of time trees grow before harvest can capture more carbon on site.[137] A potentially large amount of carbon could be sequestered in a relatively short time period by increasing the rotation ages of softwood stands beyond financially optimal ages. Studies looking at increasing rotation ages 5, 10, and 15 years indicate 1.2 t/ac/yr (3 Mg/ha/yr) CO_2 can be sequestered by increasing the rotation age of softwoods in the Northeast.[145] However, in some forests shorter rotations can increase the carbon held in soils because of litter production and harvest residues.[96]

Another option to increase carbon storage is to increase the structural complexity of forests. Structural complexity and carbon storage can be increased by preserving reserve trees, snags, and coarse woody material.[65, 83] Leaving reserve trees, unharvested trees, or groups of trees adds to the current structural complexity of a stand and provides a source of coarse woody material into the future.[83, 136] Leaving some trees after the final harvest can add another 8 t/ac (20 Mg/ha) to the carbon stored on site.[82] Selective thinning to promote larger trees, elevate down wood material, and large snag densities may yield forest products on a continual basis while increasing carbon by as much as 22.3 t/ac to 32.1 t/ac (55.9 to 80.7 Mg/ha).[82] Uneven-aged management is often used to promote a structurally complex forest and may sequester more carbon. For example, in oak-hickory and oak-pine communities in the Ozarks, uneven-aged management stores 16 t/ac (40 Mg/ha) more carbon than clearcut even-age management.[93]

Reducing damage to the residual stand can help preserve forest productivity and permit use of wood in products that store carbon for longer periods.[12] Low-impact logging has been shown to improve carbon storage and protect biodiversity in tropical forests.[130, 31] The type of trees cut, operator skill, and logging machinery used can reduce residual stand damage, minimize waste, and maximize harvest yields in northeastern forests.[118, 25, 45, 113] Improvements in harvesting methods are a relatively simple way to improve carbon sequestration and forest health.

Thinnings, particularly crown thinnings, have the potential to increase carbon sequestration while enhancing forest structure and function. Removing less vigorous trees can increase forest productivity and concentrate growth in fewer trees.[156] Crown or crop tree thinnings can have a future carbon benefit because of the increased efficiency of harvesting fewer, larger trees. Also products made from larger diameter trees tend to have slower decay rates.[72, 40] Widespread use of pre-commercial thinning could substantially increase annual harvests by 30 percent over the next 30-50 years in Maine.[145]

Other Forest Management and Carbon Sequestration Considerations

The working forest portion of our forested landscape has successfully provided society with a host of ecosystem benefits including an array of wood products. The goals of carbon sequestration and production of wood products can be compatible even as the importance of carbon sequestration increases. Estimates from Canada suggest that as much as two to seven times the carbon offset benefits of emissions reductions planned in the Canadian climate action plan could be generated by forest management practices.[19] Some management activities, such as replanting to reduce the delay in carbon accumulation after disturbance, can increase landscape-level carbon storage.[89] Contrary to some long-held beliefs, research suggests that litter decomposition and carbon storage in soils are largely unaffected (change of less than 10 percent) by timber harvests.[151, 167] Forest management to sequester carbon must be balanced with other values. For example, plantations may be able to sequester carbon, but they can threaten diversity, watershed health, and forest resilience in the face of climate change.[62]

The fate of wood products removed from the forest and the carbon emitted in the transportation and manufacture of wood products has a major impact on the carbon accounting for forest management. For example, forest products, harvesting, and processing residues that are burned will quickly re-release carbon into the atmosphere. Paper and shipping materials, including pallets, are the most rapidly decaying products (possessing a short span of carbon sequestration after harvest). Solid wood and wood composite products—particularly those used in home construction—store carbon for the longest periods.[72, 127] Wood used in home construction has a half life of 70-100 years while wooden pallets have a half life of six years.[143] Solid wood products decay and release carbon at a rate of about one percent per year while paper decays at a rate of about 10 percent per year.[72] For wood products that end up in landfills, decay may be incomplete. On average only three percent of the carbon in solid wood products and 38 percent of office paper are projected to ever be released from landfills.[56] Although wood products store carbon, it is a fraction of the original amount stored in trees. Some use the losses of carbon from tree to product to argue for greater use of forest reserves for the sequestration of carbon.[77]

Two major forestry carbon accounting issues also need to be addressed. The first is the potential benefit of substituting wood for more carbon-intensive building materials. Some researchers have shown that there are significant carbon benefits to using wood as a construction material in place of concrete or steel.[58, 40] The second issue is whether replacing fossil fuels with forest biomass for energy helps reduce carbon in the atmosphere. Forest biomass is a carbon neutral source of energy to the extent that the carbon released from burning is recaptured by the next generation of trees through sustainable forestry operations. In comparison, burning fossil fuels represents release of carbon from essentially permanent geologic storage and adds to the carbon already in the atmosphere over the long term. A full accounting of forest biomass for energy should take into account the carbon released in growing the forest, harvesting the trees, and transporting the fuel and should be compared to a similar full accounting for fossil fuels. Forest biomass can come directly from the forest or from residues from paper and saw mills that use their own waste products for heating and energy without having to use fossil fuels.[56] Burning wood is generally less efficient than burning fossil fuels,[19] and those efficiencies need to be accounted for as well.

Most forestry operations use fossil fuels to power harvesting equipment. Fuel consumption depends on terrain, openness of the stand, and operator skill. In general, fossil fuel use in forestry is negligible when compared with other industrial processes.[19] However, intensive silvicultural systems that involve site preparation and fertilizer use require larger fossil fuel inputs.[102] By using natural regeneration methods and low-impact logging techniques, forestry-related fossil fuel use can be minimized.

5. Additional Areas for Research

Our ability to meet the challenges of climate change and plan for the future requires more research into topics including the following: accounting for carbon storage in wood products, substitution of forest products for fossil fuel products, effects of increased management on soil carbon, ecological effects of biomass harvesting for energy, CO_2 emissions from forest management, carbon-free forest ecosystems services, state regulations that support carbon sequestration and excellent forestry, and the comparative carbon capture of different silvicultural systems.

The Reliability and Accounting of Carbon Storage in Wood Products

In working forests some carbon is stored on site, some is released in harvesting and processing activities, and a significant portion is converted to wood products. The amount of carbon that is legitimately kept out of the atmosphere in these removed wood products is an additional variable to be examined in the carbon forestry equation. In order to accurately assess the potential for storing carbon in wood products and landfills, we need much better life cycle analyses to document the amount of carbon stored in these products and the length of time it is stored.

Substitution of Forest Products for Fossil Fuel Intensive Products

It may be possible to keep additional carbon out of the atmosphere by substituting wood products for products now manufactured and transported with fossil fuels, e.g., replacing a steel beam with a wood beam. However, serious questions about this subject need to be addressed. For instance, will carbon credits for this replacement actually prompt an additional use of wood products and a reduction in use of the substitutes? Does it provide additionality or would it happen without the forestry carbon credit? How much fossil fuel is used to produce a substitute wood product, such as a beam and how long will the wood beam last compared to a steel beam? Would an effective cap and trade system also need to include the building/construction industry to account for substitution? Here, too, more accurate data from detailed life cycle analyses will be required.

Effects of Increased Management on Soil Carbon

Any time a forest is entered for harvests there is the potential to disturb soil conditions and affect carbon stores. Soils and belowground biomass are the largest pool of carbon in northeastern forests and also the most difficult to measure. Forestry carbon sequestration projects must account for and demonstrate that soil carbon is not being lost while carbon in aboveground stocks and forest products are increased. Chapter 4 noted research that indicates neutral and negative impacts of soils from management depending on site and harvest conditions.

Effects of Biomass Removal for Energy on Forest Health and Productivity

The rising demand for forest biomass as an energy source and carbon offset may put an additional strain on our forests. The effect of biomass harvesting on forest health and productivity needs to be better understood. New guidelines for woody biomass removal at the state level, such as those developed in Minnesota,[110] may help ensure ecologically and socially responsible harvesting. The use of woody biomass for energy calls for its own detailed analysis, which is beyond the scope of this report.

Carbon Emissions Due to Fossil Fuel Use in Harvesting and Management Operation

Studies summarized in Chapter 4 indicate that fossil fuel use in forestry harvesting operations in the Northeast may be negligible. Regardless of its magnitude, additional study of fossil fuel use associated with specific management approaches, logging equipment, and techniques could lead to further carbon emission reductions.

Sustainability and the Carbon-Free Ecosystem Services Provided by Forests

To date there has been minimal recognition of the vast array of ecosystem services that forests provide that would have to be substituted by fossil fuel intensive systems if they did not exist. The destruction or mismanagement of any forested acre not only sacrifices the onsite carbon and the potential to store carbon offsite in products, it also requires that clean and free ecosystem services provided by the forest be replaced by fossil fuel intensive alternatives. The low-cost filtering of drinking water is an example. How much energy and carbon pollution would New York City have to expend to purify its water if the upstate New York forest preserves were not in place? Other ecosystem services examples are flood control and recreation venues.

Supporting Carbon Sequestration and Excellent Forestry through State Regulations

While less than one-third of private forestland has a forest management plan, an even smaller fraction is benefiting from excellent forestry practices that maximize carbon sequestration. This situation could be improved if state regulations that have served as obstacles to excellent forestry were modified. State laws typically require only minimal practices to protect water quality and achieve adequate regeneration, or only set a baseline to prevent the worst practices while doing little to encourage excellent forestry. Some states do not license foresters or adequately support licensed foresters as essential to important management decisions. State forestry regulations must be strengthened and enforced to support excellent management practices that maximize forests' ability to sequester carbon.

Analysis of Silvicultural Systems and their Carbon Capture

As discussed in Chapter 4, specific forest management techniques that sequester additional carbon include capture of mortality, development of structural complexity, retention of trees, and implementation of low-impact logging. The uneven-aged, selection management system seems to offer the greatest potential for carbon capture for some northeastern forest types because it integrates those four carbon sequestration techniques:

- Capture of mortality – Uneven-aged selection harvest systems focus on thinnings that remove trees dying from natural causes.
- Development of structural complexity – Uneven-aged forests contain more vertical complexity and species complexity than even-aged systems and afford a more hands-on approach to encouraging larger trees, elevated down material, and large snags.
- Retention of trees – Uneven-aged systems provide for a continuous forest cover with no single complete harvest point where all mature trees are removed as in even-aged systems. Trees are retained and carbon is kept on site.
- Implementation of low-impact logging – Greater attention by forest managers is required in the planning and execution of uneven-aged systems and results in less logging damage.

In fact, uneven-aged management has been shown to store more carbon than clearcut even-aged management in the Ozarks.[93] However, additional research is needed that compares management systems in the forest types of the Northeast.

6. Conclusion and Recommendations

Conclusion

Scientific data overwhelmingly indicates that the climate in the Northeast will change rapidly in this century because of human-caused emission of CO_2 and other GHGs. While climate change will impact forests, there are management practices that can build in resistance, resiliency, and adaptation to lessen those impacts. In addition, those same forests and management practices can help to mitigate problems brought on by climate change through increasing carbon storage in forests.

How can northeastern forests contribute to the mitigation of regional climate change effects in the face of increasing climate change threats to those same forests? Forestry can and should play a larger role in carbon reduction goals in the Northeast and throughout the U.S. Excellent forestry—forestry that is ecologically, economically, and socially responsible—can help increase the amount of carbon sequestered in forests while at the same time providing many co-benefits. Forest reserves are also important for increasing carbon sequestration.

We are at a critical juncture where policymakers, scientists, and forestry and other natural resource professionals can collaboratively develop and adopt forestry protocols and carbon sequestration policies that will mitigate the adverse effects of climate change while protecting forests and their full range of co-benefits including forest and watershed health, biodiversity, recreation, wood products, and aesthetic values. If we choose to not adopt policies for carbon sequestration that require excellent forestry, and instead adopt policies that are less rigorous, then we may be institutionalizing a system that promotes forest carbon management at the expense of many other values, resulting in degraded forested ecosystems.

The Forest Guild presents the following recommendations for forest management and carbon sequestration to inform and shape policies and practices that will be adopted to mitigate climate change while also protecting a full range of forest values.

Policy Recommendations

1. Retain the Northeast's forestlands as forests. Conversion of forestland to any other uses releases stored carbon and damages the region's long-term ability to sequester carbon in forests and wood products. Forest conversion to other land uses has clear negative effects on forests that are compounded by landscape fragmentation. Forestland must be protected through working forest conservation easements and other tools including full fee purchase and robust zoning incentives and regulations.

2. Include standards for excellent forestry in the criteria for earning and trading carbon credits from forestlands. Forestry projects that meet those standards along with criteria for demonstrating additional carbon sequestration should be eligible for carbon credits within the Regional Greenhouse Gas Initiative (RGGI) and other regional and national initiatives and forestry protocols.

3. Maintain and increase carbon stocks and increase forest resilience, resistance, and adaptation by augmenting current programs to better regulate harvesting practices, enhance landowner education and incentives, and more widely require and promote the use of professional licensed or accredited

foresters. These actions will also reduce the use of poor forest management practices that diminish forest carbon stock and damage the forest's potential to replenish lost carbon.

Forest Management Recommendations

Working Forests:

1. Available research indicates that some currently utilized practices of excellent forestry can increase carbon storage and help forests maintain their resiliency in the face of climate change. The following practices must be actively promoted and encouraged:

    a. Use forest management plans and the supervision of a professional forester to guide harvests.

    b. Extend rotations or entry periods to promote carbon storage and ecological values.

    c. Manage for structural complexity of forests (i.e., leaving snags, coarse woody material, and—in multi-aged stands—high levels of post harvest basal area).

    d. Retain trees as biological legacies after harvests.

    e. Use low-impact logging to protect soil and site productivity.

    f. Choose appropriate thinning regimes that concentrate growth on fewer, larger trees.

    g. Restore understocked stands to full stocking and productivity.

2. Avoid harvesting practices that degrade forest ecosystem health because of their negative impact on carbon storage. The most harmful practices are high grading, whole tree harvesting on nutrient-impaired sites, liquidation cutting, and relying on short-term rotations that produce short-lived products.

Forest Reserves:

1. Maintain forest reserves for carbon sequestration, genetic diversity, and habitat refuges in the face of climate change.

2. Include resilience to climate change and carbon sequestration in addition to the traditional benefits of protected areas in the evaluation of potential future reserves.

3. Consider management to increase overall ecosystem function and accelerate accumulation of carbon for reserves in an unhealthy or undesirable condition.

Glossary of Terms

Adaptation – The processes whereby species change to better survive under given environmental conditions.[69]

Additionality – A measure of carbon sequestered or precluded from release by a project that exceeds the baseline characterization.[152]

Afforestation – The establishment of a forest or stand in an area where the preceding vegetation or land use was not forest.[69]

Allele – An alternative form of a gene (at a given locus) differing in DNA sequence.[69]

Basal area – The cross-sectional area of a tree measured at breast height (4.5 ft or 1.37 m). Stand basal area is a measure that integrates the number and the size of trees and indicates density.[69]

Baseline determination – A measurement of the original carbon condition of the forest area before a project was initiated.152

Biomass – Harvesting the wood product obtained (usually) from in-woods chipping of all or some portion of trees including limbs, tops, and unmerchantable stems, usually for energy productions. Or the living or dead weight of organic matter in a tree, stand, or forest.[69]

Business as usual – The scenario for future patterns or energy consumption and greenhouse gas emissions which assumes that there will be no major changes in attitudes and priorities.[152]

Capture of mortality – Thinnings that remove trees dying from natural causes.

Carbon sequestration – The uptake and storage of carbon.[152]

Carbon sink – Natural reservoirs or processes that take in and store more carbon than they release.[152]

Coarse woody material (or debris) – Any pieces of dead woody material (e.g., tree trunks, limbs, and large root masses) on the ground in forest stands or streams.[69]

Co-benefits – All additional environmental, cultural, health, and socioeconomic benefits that arise from forestry carbon sequestration projects in addition to the carbon sequestration benefit.[152]

Deforestation – The removal of a forest stand where the land is converted to a non-forest use.[69]

Disturbance – any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment.

Disturbance regime or pattern – The type, frequency, and intensity of forest disturbance. Disturbance regimes can determine the composition and structure of tree and other forest communities.[69]

Duff – The partially decomposed organic material of the forest floor beneath the litter of freshly fallen twigs, needles, and leaves.[69]

Ecological niche – A localized environment that favors the survival of some particular population.[69]

Ecological forestry – The set of practices that emphasizes the maintenance or enhancement of the full suite of ecological values, while allowing for human use. See http://www.forestguild.org/ecological_forestry.html.

Even-aged stand – A stand of trees composed of a single age class.[69]

Excellent forestry – Forest management practices that are ecologically, economically, and socially responsible.

Forest fragmentation – The process by which a landscape is broken into small islands of forest within a mosaic of other forms of land use or ownership.[69]

Forest management plan – A document that lays out goals and directs harvests, thinnings, and other treatments on a specific area.

Greenhouse gas (GHG) – A gas that contributes to the warming effect exerted by the atmosphere upon the earth because the atmosphere radiant energy from the earth and re-emits infrared radiation or heat. 69 The Kyoto Protocol includes six GHGs produced by human activities: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride.[152]

High grading – The removal of the most commercially valuable trees, often leaving a residual stand composed of trees of poor condition.[69]

Leakage – The extent to which events occurring outside the project boundary tend to reduce a project's carbon sequestration benefit.[152]

Legacy trees – Large trees, snags, and down logs left after harvesting to provide refugia and to structurally enrich the new stand.[69]

Liquidation cuts – High grading, often followed by land conversion or sale.

Litter – The surface layer of the forest floor that is not in an advanced stage of decomposition, usually consisting of freshly fallen leaves, needles, twigs, stems, bark, and fruits.[69]

Monitoring – A method that quantitatively determines to what extent a forestry project is meeting its objectives over time.[152]

Nitrogen deposition – Accumulation of nitrogen from the atmosphere.

Offsets – The results of a specific project of action implemented to avoid, sequester, or displace greenhouse gas emissions.[152]

Permanence – A criteria of carbon offset eligibility that requires permanent avoidance, sequestration, or displacement of emissions.[152]

Prescription – A planned series of treatments designed to change current stand structure to one that meets management goals, and normally considers ecological, economic and societal restraints.[69]

Range shift – A change in the area or region over which an organism occurs.

Resilience – The capacity of a species or ecosystem to maintain or regain normal function and development following disturbance.[69]

Resistance – The ability of a species or ecosystem to avoid alteration of its present state by a disturbance.[69]

Silviculture – The science and practice of controlling the establishment, composition, and growth of the vegetation of forests stands. It includes the control or production of stand structures such as snags and down logs in addition to live vegetation.[90]

Stand – A contiguous group of trees sufficiently uniform in age-class distribution, composition, and structure, and growing on a site of sufficiently uniform quality to be a distinguishable unit. [69]

Structural complexity – A forest with a vertically differentiated canopy, high densities of snags and coarse woody material, and variable horizontal density, including small canopy gaps.[83]

Sustainability – A path which balances economic, social, and environmental considerations. A process and an aspiration, not a single, immutable end-point or static condition. Goals as well as the process for sustainable forestry change in response to changes in what society values and how science and technology inform management and conservation.[90]

Thinning – Reducing the stand density of trees primarily to improve growth, enhance forest health, or recover potential mortality (trees dying from natural causes).[69]

Uneven-aged stand – A stand with trees of three or more distinct age classes, either intimately mixed or in small groups (see stand).[69]

Verification – A method (in most cases conducted by an objective third party) that validates and confirms the accuracy of the monitoring process and sequestration data.[152]

Working forest – A forest that provides goods, such as timber, and employment.

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