Forest Carbon
in the United States:
Opportunities & Options for Private Lands

LAURIE A. WAYBURN, JERRY F. FRANKLIN, JOHN C. GORDON,
CLARK S. BINKLEY, DAVID J. MLADENOFF, NORMAN L. CHRISTENSEN, JR.

Forest Carbon
in the United States:
Opportunities & Options for Private Lands

LAURIE A. WAYBURN
JERRY F. FRANKLIN
JOHN C. GORDON
CLARK S. BINKLEY
DAVID J. MLADENOFF
NORMAN L. CHRISTENSEN, JR.

Cover photo by Larry Ulrich

Contents

Regional Implications

Figures and Tables

Acknowledgments

This project has been made possible by the generous financial support of the Catherine T. and John D. MacArthur Foundation, as well as the Wallace Global Fund. Particular thanks to Melissa Dann for her continuing support, and to Dan Martin for his early and thoughtful enthusiasm for our work.

Dr. Mark Harmon of Oregon State University provided essential advice and review of the report. Dr. Peter Frumhoff of the Union of Concerned Scientists also reviewed the report. Constance Best of the Pacific Forest Trust provided invaluable testing of various assumptions. Jennifer O'Donnell of the Pacific Forest Trust was instrumental in editing and production. Jay Chamberlin of the Pacific Forest Trust provided key support in the early stages of this project.

Introduction

There is no doubt that forests affect the national—and global—carbon budgets. Forest loss, gain, or changes in management lead to significant gains and losses in carbon stocks and atmospheric levels of carbon dioxide. While there is agreement that forests are important to carbon balances, there has been much discussion, indeed controversy, over the potential role of forest management and conservation in reducing net US emissions of carbon dioxide. Concerns have ranged from fears that the US will offset all of its emissions through forestry and forest conservation, to fears that a credit system, called for by some industry groups, might lead to very short-term and highly uncertain "gains" crediting "business-as-usual." Further, characterizations of the accuracy and certainty of accounting for changes in carbon stocks gained or lost from forestry and forest conservation have often been misleading.

This report is intended to describe the range of potential forest conservation and management activities on private forests that can lead to net increases in carbon stocks. It identifies and illustrates causes of forest carbon loss, outlines the principles and mechanisms for forest accounting on a practical level, and proposes potential options for reversing existing trends toward forest loss through market mechanisms to create changes to business-as-usual. It further explores how market systems can prevent forestland loss and increase forest age, benefiting many biodiversity interests. The focus of this report is on private forests, as they make up the majority of US forests and are the ones most at risk from loss and conversion; however, many of the principles concerning forest management apply equally to public forests.

Executive Summary

The United States has a highly significant opportunity to reduce its net emissions of carbon dioxide (CO_2) through actions on private forests in three areas:

- Reducing forest loss
- Increasing reforestation of former forests
- Increasing forest age

Actions in these three areas could permanently increase US carbon stocks by millions of tons annually at a cost per ton equivalent to the lower end of the range of mitigation costs.

Forest Extent and Carbon Retention

Forests occupy one-third of the US land mass (747 million acres), with private ownership on almost two-thirds of that area (424 million acres). Private forests are the most productive—and threatened—forests in the country. Their state of carbon accumulation or release has a major impact on the US carbon balance. When forests accumulate and hold carbon (sequestration), they contribute to lowering emissions overall, acting as carbon “sinks” or reservoirs. When forests are disturbed through harvest or conversion to other land uses, they release carbon, adding to emissions overall. From the net atmospheric carbon balance, a molecule of CO_2 removed from the atmosphere is equivalent to not releasing a molecule of CO_2 to the atmosphere. Whether these forests accumulate and hold carbon, release carbon, or are lost entirely as carbon sinks will be a major determinant in how quickly and cost effectively the US can meet its goals to reduce carbon emissions.

Currently, the US counts on forests to help reduce its net total emissions; for example, forests sequestered 310 million metric tons of carbon (MMT CE) in 1999. However, this amount was less than the prior year and continued a decline in stores from the past five years. When forests store less carbon, they are releasing more. The two major causes of decline in stores of forest carbon are forest conversion and loss and the increase of harvest versus the amount of growth on private forest lands.

Forest cover in the US has declined by one-third to one-half its extent since European settlement. While there has been considerable re-growth of US forests since the early to mid-1900s, especially in the Northeast and Southeast, the US is nevertheless currently losing forests at an increasing rate, with lost acreage in the five years from 1992 to 1997 estimated to be twice as great as in the 10 preceding years, 1982-1992. Further, land in forest use is projected to continue to decline as competition for land for development continues to increase. As forests are lost, particularly older forests, so too are carbon reservoirs, as older forests accumulate and store more carbon than younger ones.

In addition to forests lost to development, increases in timber harvests outstripped the amount of tree growth on private forests in the 1980s and 1990s, extending a trend from the 1960s. As a result, the US is beginning to lose more carbon in private forests than it is accumulating, especially in faster growing softwoods and the most productive forest regions of the country, the Pacific Northwest and Southeast. Overall, the US lost 11.5 million acres of existing forest between 1982 and 1997, and the average age of forests on private lands declined in this period as well. The results include diminished forest habitat and watershed values as well as decreased carbon stocks. Since 1990, the US has stored less forest carbon each year. That trend is projected to continue to 2020 through the loss and unsustainable harvest of private forests.

Increasing Carbon Stores

While the total amount of forest carbon storage is declining, especially on private lands, it is not irreversible. The US has the opportunity to increase net forest carbon stores on private forests significantly by addressing the causes of these trends and encouraging landowners to alter prevailing business-as-usual practices through changes in management actions consistent with increasing carbon stores. These actions include preventing forest loss by conserving current forestland, reforesting former forest areas, and increasing average forest ages. With such actions, forest carbon stores could increase in the US by hundreds of millions of tons during the next several decades and play a significant role in diminishing net US emissions of CO_2.

These changes in management depend on the development of a new market for forest carbon sequestration services. Value added to standing timber in the form of carbon credits, if sufficiently valued, could encourage private forest owners to make the management decisions that would reduce CO_2 emissions and increase carbon stores. To be an effective economic incentive, the price of carbon needs to be at least \$20/ton C (\$5.45/ton CO_2). This enables carbon to provide some incremental value to landowners, resulting in either retention of land for forest or retention of trees during harvest. At prices of \$100/ton C (\$27.25/ton CO_2) and greater, the value of carbon alone begins to pay landowners to hold land and increase forest age, competing directly with returns from development and short rotation timber harvest. However, carbon values are likely to have the most significant impact when used to pay for partial interests: keeping the land in timber production, but changing forest management and paying part of the cost to keep land from conversion. In most cases of high development or very high timber values, carbon values must be at least \$150/ton C (\$40.87/ton CO_2) to be competitive.

To create this marketplace, the US needs to establish some essential infrastructure. This includes:

- Formally identifying carbon rights
- Developing a standardized carbon accounting system that includes both credits and debits and adjusts appropriately for risk
- Establishing a credible registry at the federal and state levels

Accounting for forest carbon should follow the same principles, such as additionality (crediting above business-as-usual), permanence, and accuracy levels, established for other carbon emissions sectors, such as energy and transportation. Standard accounting rules for a forest carbon market must:

- Include both debits and credits
- Discount appropriately for risk
- Discount for less-than-permanent stores
- Require accuracy to the same level as for other emissions sectors

Increasing net and permanent forest carbon sequestration while decreasing forest carbon emissions is clearly a meaningful piece of the set of actions that the US needs to pursue to reduce global warming. With a transparent and credible accounting system, a robust market for long-term and verifiable US forest carbon credits would yield a significant new revenue base for private forest landowners and lower the cost of permanent emissions reductions for carbon producers. It would also lead to substantial benefits for biodiversity, watershed values, open space protection, and long-term, sustainable domestic timber supplies. A carbon market would promote restoration of forest timber inventories, and therefore carbon, on private forests in the US, leading to more sustainable forest economies overall.

Overview

The Role of Forests in the Carbon Budget of the United States

Rising atmospheric levels of carbon dioxide (CO_2) are agreed to be a source of significant concern as a cause of global warming (IPCC 1995). CO_2 is the target of most efforts to reduce greenhouse gases; though it does not have the greatest global warming potential of the greenhouse gases, it is emitted in the greatest quantity. Thus, reducing net emissions of CO_2 to the atmosphere is the goal of both national and international efforts to mitigate or avoid global warming. Achieving net reductions of CO_2 can be done both by reducing direct emissions and by increasing the amount of CO_2 removed from the atmosphere through photosynthesis and stored in plant biomass for the long term (sequestration). A ton of carbon dioxide removed permanently from the atmosphere through sequestration is equivalent to preventing a ton of carbon dioxide emissions.

The forest sector is the second-largest *source* of CO_2 emissions globally; it is also the most expandable long-term *sink* for CO_2 (Dixon et al. 1994). Forest-based carbon emissions are largely due to forest loss, such as through conversion to agriculture or development, and to harvest. While forests can recover from harvest losses, conversion of forest land to other uses eliminates current stocks and future stores permanently. With unsustainable management, such as when harvest exceeds growth and forests are degraded, forest carbon stocks never fully recover.

As part of the implementation of the 1992 United Nations Framework Convention on Climate Change, more than 160 nations agreed

LARRY ULRICH

Older forests, especially those never harvested or cleared for agriculture, hold great stocks of carbon. Conserving them helps balance the US carbon budget. These older forests also have irreplaceable biodiverisity, habitat and watershed values.

GARY BRAASCH

Deforestation from increasing development in forests across the United States causes the loss of existing carbon stocks, as well as any potential future stocks. Preliminary data from the most recent NRCS National Resources Inventory shows that the US lost forests to development at twice the rate in the period 1992-1997 as it had in the prior ten years.

that the risks of global warming warranted concerted international action. In response, they developed the Kyoto Protocol in December 1997. This document provides international guidance and a framework for actions to reduce global warming. As of September 2000, 84 countries had signed the Protocol. The second article of the Protocol acknowledges the importance of forest ecosystems both as sources of CO_2 emissions and as a critical means to reduce CO_2 emissions through maintaining and increasing sequestration:

> Article 2
> 1. Each Party...shall:
> (a) Implement and/or further elaborate policies and measures in accordance with its national circumstances, such as:
> ... (ii) Protection and enhancement of sinks and reservoirs of greenhouse gases not controlled by the Montreal Protocol...; promotion of sustainable forest management practices, afforestation and reforestation. (UNFCCC 1997)

While discussions continue as to how individual nations will choose to proceed with implementing the Protocol and what degree of effort should be placed on any single means of emissions reduction, there is strong agreement, especially in the United States, that forests have a role to play (IPCC 2000; US Department of State 2000).

The 747 million acres of forestlands in the United States are some of the most productive in the world for biomass (Barbour and Billings 1998). The 424 million acres of forest in private ownership are the most productive forests in the US, producing the greatest amount of timber-and having the capacity to store the greatest amount of carbon-in the country. Paradoxically, these private forests are increasingly at risk of conversion and degradation (USDA 2000; Best and Wayburn 2000). Nationwide, harvest of private forests has been increasing relative to growth for the past four decades. Loss and degradation of these forests means greater forest carbon emissions, along with the loss and diminution of any future potential to increase critical carbon stocks.

On average, the US lost 1.275 million acres of forest each year during the last 15 years (USDA 1999). In 1998, the National Research Council projected that the US will lose another 20 million forested acres by 2020. The Southeast and Northwest, the nation's most productive forestland areas, lead the country in forest loss. Although millions of acres of pasture and crop land, primarily in the Southeast, were planted to trees since 1985, these areas will take many years to begin to accumulate significant amounts of carbon and decades more to replace the forest carbon that has been lost (USDA 2000).

With these conditions, the US faces both a challenge and an opportunity to manage its forest carbon stocks for the future. It can either enable a continuation of business-as-usual, with concomitant declines in carbon stocks, or encourage a broad portfolio of forest conservation and management activities to enhance forest carbon sequestration, increasing long-term forest carbon stocks.

Accounting Principles
Myths & Realities

Forest carbon accounting differs from other, non-land-based sectors, as forests both sequester and emit carbon. Whereas a ton not emitted, for example, through conservation, is simply not emitted, a ton sequestered, for example, in an afforestation project, can later be re-released on harvest. The goal in the forestry sector, therefore, goes beyond achieving “carbon neutral,” a state of zero emissions, which other emissions sectors may target. The forest sector can achieve a target of “carbon negative.” Achieving carbon negative results in forest carbon stores that last millennia—and even longer. Forest carbon accounting thus must include both accumulation in, and release from, forests—that is, both credits and debits accounting—and it needs to include both annual and long-term accounting over a period of at least 100 years—the time frame recommended by the Kyoto Protocol.

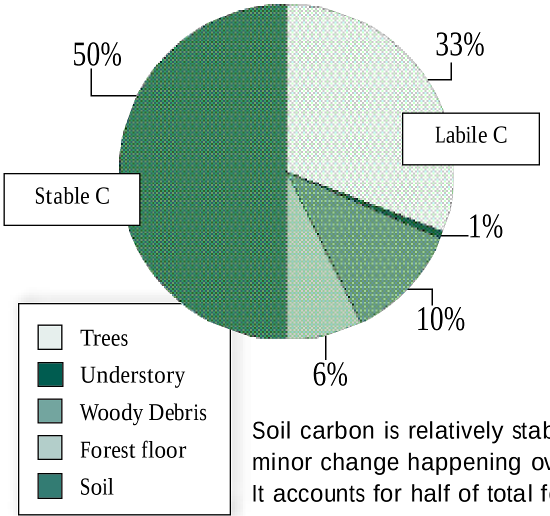
As with other emissions sectors accuracy in accounting for forest carbon varies depending on scale: global, national, and project or site-based. The larger the area considered, the greater the uncertainties. Global-level accounting for forest carbon change or flux is the most uncertain. National-level accounting is significantly more accurate. Project-level accounting accuracy is in the same range as for other emissions sectors in the US. Project-level accounting for sequestration and release of forest carbon can be achieved with 90% to 95% accuracy (Brown 1995). The following sections identify how accurate project-level accounting up to landscape scales can be accomplished.

What to Count and How to Count It

Forests store carbon in virtually all their components: soils, litter (forest floor), and understory, as well as trees (Figure 1) (Turner et al. 1995 a and b). Forest carbon is both organic (from biomass) and inorganic (mineral carbon—carbonates). Organic carbon material varies widely in its stability, from being easily released to the atmosphere (labile carbon) to not easily released (stable carbon). Forest-soil carbon is a large, stable pool, accounting for some 50% of total forest carbon and changing very slowly over hundreds of years (Kimmins 1997). For time frames of 100 years and less, forest accounting

Figure 1

CARBON POOLS BY SECTOR



Soil carbon is relatively stable with minor change happening over time. It accounts for half of total forest carbon. Only 10% of labile carbon is in soil organic matter.

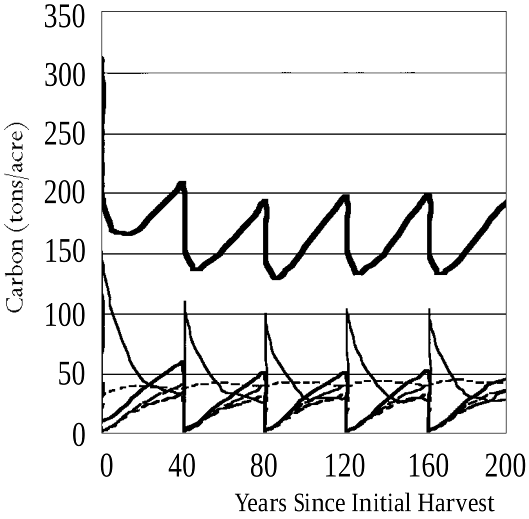
Source: Turner et al. 1995 a.

can ignore this pool and focus on changes to more labile forest carbon components.

The vast majority of forest carbon accumulation is from photosynthesis by trees, with understory vegetation accounting for less than 5% (Kimmins 1997). Accumulation of carbon through tree growth and the release of carbon from timber harvest, including from decay of dead material or from burning in post harvest site management, therefore, constitute the primary accounting focal points. (Figure 2) Harvest causes a decrease of forest carbon, as forest carbon is transferred from the site to the forest products "pool" and is released from decaying stumps and slash (branches, tops and leaf litter), from soil, and from burning the site in preparation for re-forestation. When trees are harvested, increased exposure of soils increases the release of carbon from litter and soil (Harmon et al. 1990). For example, in the period 1972-1991, post-harvest-related carbon release from decay of slash, litter, and soil in Washington and Oregon alone is estimated at 11.8 million tons/year (Cohen et al. 1996).

Figure 2

FOREST CARBON FLUX AFTER HARVEST



This figure illustrates the "fate" of carbon in a Douglas fir forest managed on 40-year rotations. After harvest, dead material decays and releases carbon to the atmosphere for approximately 40 years. Thus while new carbon is absorbed in trees (bole, root, branches) carbon emissions outweigh accumulations until after 20 years.

Source: Harmon et al. 1996c.

Standing live trees account for 64% of forest labile carbon, with roughly half of that carbon in the bole (main tree trunk) and the remainder in roots, bark, branches, and leaves or needles (Turner et al. 1995 a and b). Tree-bole volume is measured in standard accepted methodologies, with standard extrapolations for volumes of root, branch and other carbon (Birdsey 1996). The efficiency of the harvesting and milling determines how much of the harvested bole[1] ends up in forest products. Estimates vary, but roughly between 20% and 33% of labile forest carbon ends up in forest products (Birdsey 1996; Skog and Nicholson 1998; Harmon et al. 1996a). Up to 40% of this carbon is stored over the long term in such products as saw timber and furniture, lasting for 20 to more than 100 years. The remainder is stored for the short term in such products as paper, lasting five years or less. However, the decay rates for these products are unpredictable at best, as paper, for example, may be landfilled and remain undisturbed for decades or it may be burned and released immediately. Given these variations, forest products may be best treated as a whole, rather than divided into short- and long-term stores. When taken as a whole, the average estimate of the decay rate for all forest products combined is 2%/year (Figure 3) (Harmon et al. 1996a).

Taking the high end of this range, if a harvest affects 100 units of carbon, on average 35 units of carbon remain on site and 65 units leave with the harvest. After manufacturing, however, 32.5 units of that carbon remain in a forest product,

---

[1] During harvest, parts of the bole are left behind such as the stump, top, and imperfect sections. The harvested bole is the bole minus these sections.

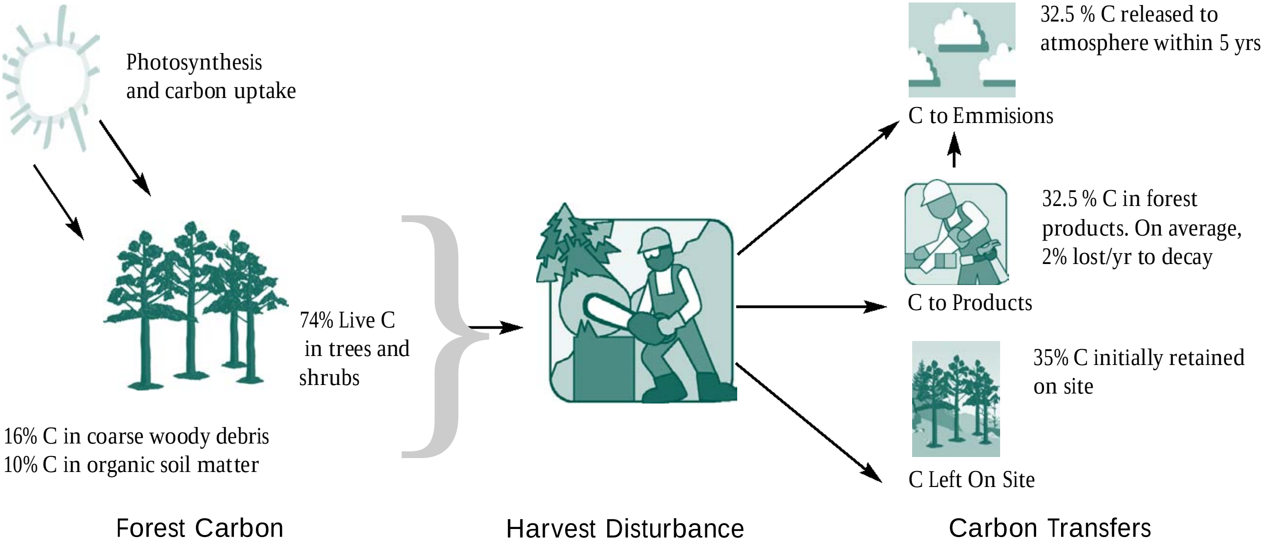
where it decays slowly over time. The other half becomes volatile or is burned in processing. (In fact, some of the material is burned for fuel or as part of chemical processing and may offset other fuel sources, though this is arguable.) Of the 35 units of carbon that remained in the forest, more than 30 are lost in subsequent site-preparation fires and increased decay over time. Roughly 5% of the original 100 carbon units remain in the forest over time (Harmon et al. 1996 a). Thus, nearly two-thirds of forest carbon in a harvest is released as emissions over time.

Changes in forest carbon stocks from forest growth, harvest, and decay can therefore be accounted for through the inventory of trees with the application of standard algorithms to include root, branch litter, and decay pools (Birdsey 1996). On commercial forestlands in the US, tree inventory is typically done with 90-95% accuracy. Documentation and data on the dominant forest types and tree species in the US are well developed and widely available. Multi-billion-dollar industries rely on the accuracy of these inventories and the US government has invested substantial sums in updating and maintaining those data. Unlike many other forest regions worldwide, data and infrastructure to accurately track and verify forest carbon flux by project site and, increasingly, at the national scale, exist in the US.

As noted, the mechanics of forest carbon accounting are relatively straightforward, once the basic data of tree growth and decay are collected. However, natural disturbances, such as pests, wildfires, storms, or disease, can alter forests outside of human intentions, making some carbon outcomes unpredictable. Further, the short-term and sometimes unpredictable nature of human decision-making that can serve to increase carbon removal, such as altering the

Figure 3

LABILE FOREST CARBON: GROWTH, HARVEST, DECAY

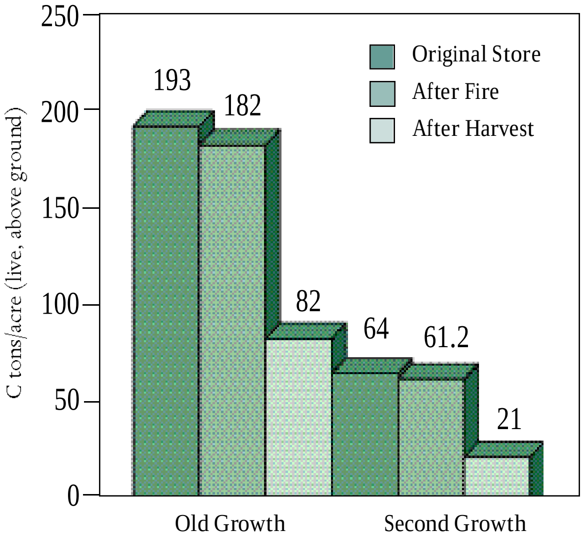


When forests are disturbed by harvest, 32.5% of the carbon is released to the atmosphere within 5 years. This increases to 62.5% over time as the majority of the 35% of carbon initially retained on site (in stumps, roots, and coarse woody debris) is released through decay. 32.5% of carbon is transferred to the forest products pool, where 2% of this carbon is released per year through decay.

Sources: Harmon et al. 1996 c; Turner et al.1995 a and b.

Figure 4

EFFECTS OF HARVEST AND FIRE ON FOREST CARBON



Though impacts of fire are notable in many respects, their impact on forest carbon is significantly less than that of harvest.

Source: Harmon et al. 1996 c; Harmon, Personal Communication 2000.

land use on a parcel that had been slated to remain in forest or accelerating harvest, creates the need for some risk discounting in forest carbon accounting. Such factors mandate that a set of standard accounting principles, a “Generally Accepted Accounting Practices” (GAAP) for forest carbon, be developed to enable a same-scale comparison of the durability and quality of carbon tonnage stored both within the forest sector and across other emissions sectors.

Such a GAAP should be constructed around three fundamental precepts:

- Accounting includes both accumulation and decay over time
- Accounting uncertainty is within the same range as for other emissions sectors
- Accounting is adjusted for risk against short-term release, re-release, or unanticipated release over time to ensure net gains and comparability with other sectors

Accounting for Accumulation and Release

When analyzing forest carbon sequestration, two critical points must be kept in mind:

1. Forests release significant amounts of CO_2 when they are disturbed,
2. Forests continue to emit carbon from decay well after the initial disturbance

Disturbances include the activities involved in harvesting, pest and disease outbreaks, and wildfires. Each of these disturbances causes both initial and long-term carbon release, with amounts relative to the type of disturbance; however, the impact of harvest far outweighs those of any natural disaster (Figure 4).

These carbon releases are derived both from volatilization and decay of dead vegetation/biomass carbon and from decomposition and decay of soil carbon. Harvest disturbance causes both initial and long-term carbon releases. Initially site-preparation fires release slash, some woody debris, fine litter and some organic soil carbon; root and coarse woody debris, and other soil organic carbon decay for up to several decades. Over time, harvest effects the release of over 60% of the labile carbon.

Pest and disease outbreaks slow growth, and therefore carbon accumulation. If mortality results, they can also lead to increased decay. Wildfires increase carbon release as well as decay over time, but leave substantial standing live and dead biomass carbon in the forest. On average, forest fires release roughly 10-20% of the carbon that harvest does in an old-growth stand and 5-10% of that in a second-growth stand.

Accounting must therefore include accumulations in new biomass; transfers to forest products, litter, and organic soil pools; and release or emission to the atmosphere over time.

Risk-Adjusted Forest Carbon Accounting

Risk to the accuracy or certainty of forest accounting-outside of that in the inventory-occurs in two main areas:

- Natural risks of fires, pests, etc.
- Human risk of plans and actions changing over time

These risks can be accounted for or discounted to ensure comparability with other sectors.

In addition, there are other factors that affect all sectors: establishing baselines; "leakage," or the risk of simply shifting carbon emissions from one area to another; the risks of re-release or increased emissions at later dates; or factors unpredicted at the time a project is started. As these uncertainties affect all emissions sectors, standardized means must be developed to deal with them uniformly. As with accuracy at the inventory level, forest accounting can and should be held to similar uncertainty levels, or discounted to those levels, as described below.

Natural Risks

Natural risks include natural disasters: fires, catastrophic storms, pests, and disease. The natural risks involved all release carbon, either directly or through reduced growth. As such, they have historically been tracked by the timber industry to account for risks to their timber inventory, which is effectively a surrogate for a carbon inventory.

Historically, this risk of loss to inventory is less than 1% over time, but this does not translate to a loss of 1% per year of timber inventory. Some investors may adjust projected forest earnings downwards by some fraction of this 1% factor over time. As forest earnings are based on growth and harvest, this risk factor can reasonably be translated to carbon credits and debits. Within a market system where estimated carbon credits and debits become the basis for trading in emissions, one can revise projections of carbon accumulations over time downward by some fraction of 1%. Perhaps more reasonably and accurately, one would require annual accounting to verify actual stores and require diversified pools of "insurance carbon" to ensure actual carbon gains are achieved. Maintaining such a guaranteed pool of carbon might be done in a fashion similar to what the Federal Deposit Insurance Corporation (FDIC) requires of banks, with forestland owners depositing some measure of "carbon credits" with the government as insurance.

Human Risk

Another risk in forest sector accounting is human: people shortening the time to harvest after a project has occurred, re-releasing carbon accumulated and credited by a project for which credits were traded. This risk can be dealt with through discounting non-permanent projects credit as well as by permanently entering forests into a trading system. Such a trading system will require the development of a national or potentially state-based carbon registry. The registry would ensure the quality and standardization of these credits, as well as ensuring that there is no double counting of credits.

Forest species can be very long-lived. Many tree species live hundreds and even thousands of years, making forests the longest-term and most expandable of terrestrial carbon reservoirs. Yet these ecological time frames are largely incompatible with human economic and political time frames, which typically range from weeks to several years. The Kyoto Protocol identifies the average 100-year cycling time of carbon as the desired time frame in which to operate. Thus, forest carbon projects need to have a longer time frame than other sectors to account for the potential of re-release of carbon from forest harvest or conversion over time. Discounting projects from a hundred-year or permanent duration can be combined with annual credit and debit accounting. This would effectively encourage longer-term projects with more durable carbon gains, as full annual credit would be given to projects that store carbon for 100 or more years, with proportional credits, or discounted credits, given to shorter-term stores.

Creating Carbon Stores: Myths and Realities

There are several pervasive myths about how forests should be managed to create the "best" carbon stores. These illustrate the importance of a standardized forest carbon accounting system as, depending on how the accounting is done, different management systems will be put into place. Major myths include:

- Younger trees (preferably plantations) are better than older forests as carbon stores because young trees grow faster, whereas older forests are decadent.
- The US has lost and gained roughly the same number of acres of "forestland" over the last few decades and so is not losing forest carbon.
- Harvest does not have a negative effect on forest carbon because most of the carbon is transferred to products, creating a net increase in overall forest carbon.

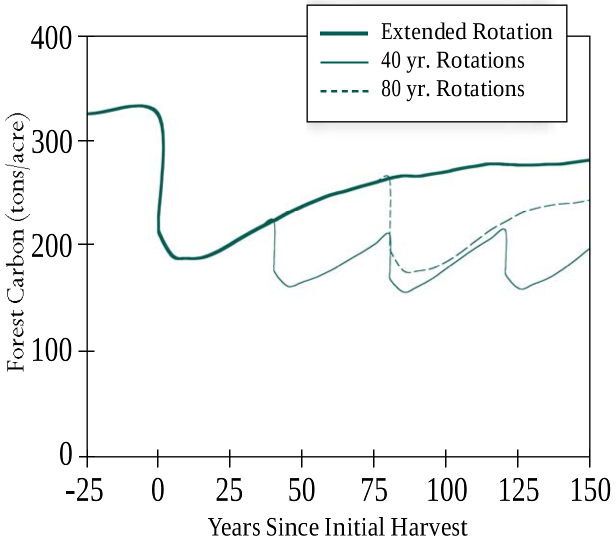
Forest age: Are younger or older forests better?

The argument that younger forests' rapid growth increases carbon stores most quickly posits that the best way to increase forest carbon is to increase tree planting and the extent of young plantations. This argument neglects the fact that existing older forests typically have a greater impact on total forest carbon than young forests of the same acreage.

While a high rate of sequestration is important, the total amount of carbon sequestered (absorbed and stored) is equally, if not more, important in terms of annual carbon budgets. Thus, an acre of Douglas-fir forest at sixty years contains roughly 125-150 tons of carbon and accumulates carbon at 2.2 tons/year, while the same acre at only 10 years may contain roughly 50 tons of carbon and accumulate carbon at roughly 1.4 tons per year. An old-growth forest of more than 500 years may contain more than 1,000 tons of carbon/acre, and accumulate at about a quarter-ton/year. All three forests are valuable to maintain. Replacing the 60-year-old forest or the old-growth forest with a ten-year-old one, however, would not result in a net gain of carbon despite the more rapid growth of the young trees; in fact, it would produce a significant net loss. Whether the practice is harvesting older hardwood forests in the Southeast for chip and replacing them with pine plantations, or harvesting older conifer forests in the Northwest and replacing them with short-rotation plantations, a net negative carbon balance is created that takes many decades, or more, to rectify.

Figure 5

FOREST CARBON DURING TIMBER HARVESTS



To replenish carbon stock fully after harvest, the forest must grow to the same age as it was at harvest. Repeated harvest diminishes overall stocks, as demonstrated by these 40-year rotations on Douglas fir.

Source: Harmon et al. 1996 c.

Forest extent: Are we losing forest carbon?

The amount of land in forests significantly influences total forest carbon stocks, but, as noted, the age of forests on that land is the more determinant factor in carbon storage. A common myth is that US forest carbon stores have remained constant because forest extent has remained relatively constant over the past several decades: while some forests are lost to conversion, particularly in the Northwest and Southeast, other areas of abandoned or marginal cropland, primarily in the Southeast, are planted as replacement forest. This "constancy" equates older forests lost to conversion with forests added from re-forestation and afforestation.

However, these young plantation forests have negligible carbon stocks initially. Although they grow at a fast rate after establishment, they sequester only small amounts of carbon compared to the carbon lost when standing forests are converted to urban or agricultural land. It will take many decades for the new forests to accumulate substantial stores of carbon. As a result, the net carbon balance in the country is negative even though "forest area" remains relatively constant.

Many of the marginal crop lands being converted to young plantations were originally forestlands. They are considered marginal because, depending on the profitability of a tree crop or an agricultural crop, they swing back and forth from forest to agricultural land use. Thus, one strategy to increase net carbon in this arena is to encourage the long-term retention of these lands as forestlands, making them long-term or permanent carbon sinks. A recent study by the University of Michigan demonstrated that forests store roughly 220% more carbon than the amount of carbon released from the same land in annual crops (Long 2000).

Forest products: Are we increasing net carbon?

Harvest results in the transfer of a portion of forest carbon to the forest products pool, as well as other pools and the atmosphere (Figure 3). Because several hundred years are required to replenish the carbon lost in the harvest of an old-growth forest and decades are needed to replenish carbon in younger forests (Figure 5), net carbon gain from wood product carbon storage does not occur unless on-site forest carbon is allowed to fully recover. Moreover, repeated short rotations cause net declines in forest productivity, requiring greater time periods to achieve equivalent carbon stocks. One 90-year rotation stores more carbon than three 30-year rotations, both in the forest and in forest products (Kershaw et al. 1993), due to the on-site decay of forest carbon after harvest, which can continue for more than three decades. Wood products carbon can, therefore add to total carbon stocks, but only if the on-site forest carbon lost to increased decay is fully replenished.

Increasing Forest Carbon

A strategy to increase the amount of carbon in managed landscapes is to substantially increase the average age of the forest stand. This can be done by lengthening the time between regeneration harvests (the rotation period) or by retaining older trees through successive harvests (variable retention). One way of implementing such a strategy would be to delay harvest until stands achieve what is called "culmination of mean annual increment (m.a.i.)"-the point at which the average yearly growth increment reaches its maximum. Mean annual growth increases prior to culmination and gradually declines thereafter.

Allowing forest stands to grow until they reach culmination of m.a.i. would greatly increase the carbon stores in managed forest landscapes as well as provide for greater wood production. Currently most private forests are harvested well before culmination of m.a.i. using rotations driven by economic models based on discounted present net worth. By utilizing rotations based on culmination of m.a.i., the carbon stores in managed forests could be more than doubled in productive forest regions such as the Pacific Northwest and Southeast.

Creating a Carbon Right

A key assumption behind the creation of a carbon market is that there is an actual commodity called a carbon credit and that everyone knows what it is. However, this is not entirely clear. For example, in the section on accounting, we discuss the difference between a long-term or permanent ton of carbon and a short-term one. Accounting rules can level the playing field and create a system to equate tons of differing qualities. However, there is another, quite fundamental element to creating carbon credits, which is that one must have the legal basis for that credit. One needs to have a carbon right in order to derive credits from that right. That right would be the means by which one can create credits, as a right is the “inherent privilege or interest which is recognized and protected by the power of law”(Gilbert Law Dictionary, 1994). Defining that right is essential, as forest carbon is embodied in real and personal property: trees, forest products, and soils.

Developing a carbon right presents a number of challenges and issues to consider. First there is the question of whether the right is a real or personal property right. Standing trees may be considered as either real or personal property, depending on the state in which the property is located. However, once cut, trees become personal property, as they have left the “real property” status when they are removed from the land. Soil, and by implication soil carbon, would likely be considered real property. The treatment of carbon as either real or personal property has significant tax implications. If carbon credits are to be treated as a commodity, then likely they would be best classified as personal property. This would potentially create access to additional tax benefits for growing a carbon crop.

Other issues that arise include:

- At what point does a carbon right become created? One might assume that this is when it becomes measurable and has a certain durability. For example, understory vegetation in forests includes grasses and annual plants that will fix carbon but release it in short order as they die and decay. Thus one might restrict carbon credits in forests to trees and

Another strategy that achieves the same end is to have greater retention within stands at harvest, leaving 15-35% of merchantable inventory on site until the next harvest, then retaining 15-35% of inventory until the following harvest, ad infinitum. This effectively increases the average stand age and leaves carbon on site over time. It also has the advantage in many cases of increasing growth in the remaining stand, thereby accelerating accumulation of volume of timber as well as carbon. Finally this approach also results in retaining essential habitat through successive harvests. One particularly useful component of variable retention is to retain permanent buffer strips in sensitive habitats.

Examining these myths about forests and carbon illustrates the need for a portfolio approach to managing forests to increase net carbon stores. This approach includes three main elements:

1. Maintaining existing carbon stores, especially where they have high ecological significance
2. Increasing average stocks of carbon per acre through increased retention and/or managing to culmination of mean annual increment
3. Reforesting/afforesting and maintaining more land in appropriate ecological/agricultural conditions for future increases in sequestration

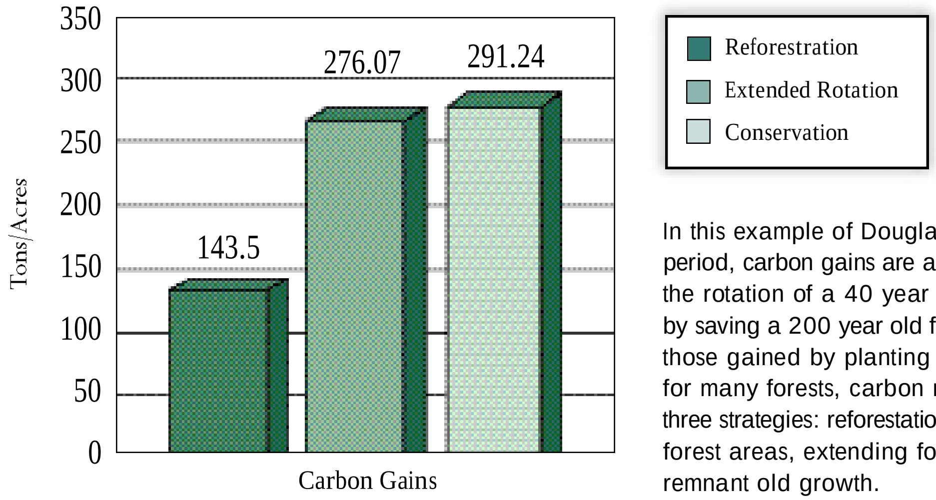
Each of these strategies operates at different time frames, as illustrated in Figure 6, with synergistic effect. This figure demonstrates the value of growing and retaining older forests as recently verified by Dr. Ernst-Detlef Schulze in the journal Science. (Schulze 2000).

organic soil carbon, or simply trees.

- Who takes credit for the carbon in wood products? When the products leave the forest, the entity that "created" the credit, i.e. the landowner, no longer controls the fate of that wood product. Thus, can they ensure the carbon still exists and has not been released? It might be initially incorporated in a building that then is burned in a fire, or it could last for many, many years. If the credit, and right, leave with the product, who is responsible for accounting for its decay over time? One also needs to ensure that there is not double or triple sale of carbon credits in products: one as the tree is grown, another for the product itself, or another for the product as it changes hands yet again. One might argue that it was simpler not to count forest products carbon, though in an ideal construct one would account for their benefits over time.
- If a carbon right is real property, this could create constitutional issues, as it leads to the potential for new "takings" claims. The desirability of creating this potential is dubious. An examination of these questions suggests that a carbon market will require the development of an insurance system to provide for stability and guarantees. As suggested earlier in this report, one might consider a role for the federal or state government in this regard in creating something similar to the Federal Deposit Insurance Corporation for banking carbon.
- In selling carbon credits, one retains the carbon right, but the value of that right is then diminished by the amount of the value of the credit, and this must be reflected as an encumbrance on the title to the property from which the carbon credits were sold. Further, in Tort law, when a credit is sold apart from the right itself, it would be a personal property interest that the buyer acquires. The owner of the underlying right then has a new duty not to interfere with the credit. For example, if a landowner sold carbon credits associated with creating an older forest, the other rights of the new owner that are associated with the carbon may be affected, such as the right to harvest or otherwise manage the forest.

Figure 6

RELATIVE CARBON GAINS FROM REFORESTATION, FOREST MANAGEMENT, AND CONSERVATION



In this example of Douglas fir, over a 50 year period, carbon gains are almost doubled by extending the rotation of a 40 year old stand to 90 years, or by saving a 200 year old forest from conversion,over those gained by planting a new stand. However, for many forests, carbon management will entail all three strategies: reforestation of harvested or former forest areas, extending forest age, and saving remnant old growth.

Ecological Implications

INFLUENCE OF CARBON SEQUESTRATION ON BIODIVERSITY AND ECOSYSTEM FUNCTION

Implicit in the discussion of the need for carbon sequestration is that there are continuing negative consequences for not maintaining and even increasing carbon stores. Namely, if more CO_2 continues to be added to the atmosphere, there will be a continuing risk of further, direct global effects on the biosphere, the ecosystems within it, and human welfare. One aspect of the consequences of forest management practices to increase carbon retention are the effects on forest biodiversity. These can be direct, physical and physiological effects on organisms, or more complex, indirect effects that operate through ecosystem and biosphere feedbacks. These indirect pathways can then further influence carbon dynamics negatively or positively (Myers 1992).

Most studies of direct effects of forest practices on carbon emissions and biodiversity have been done in the tropics. Here both areal loss of tropical forests and degradation of remaining areas through burning and other impacts have resulted in widespread species extinction (Myers 1989, FAO 1993) and deterioration in ecosystem health (Groom and Shumaker 1993).

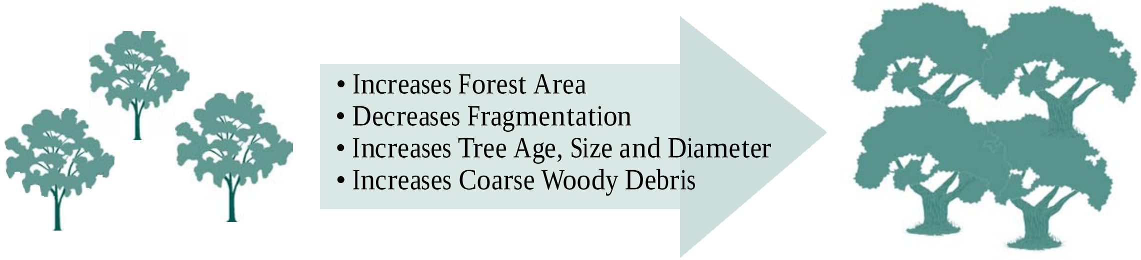
In temperate regions, forest management that affects carbon dynamics can also have strong effects on ecosystem health and biodiversity. Management strategies that restore total forest area and increase mean forest stand age and tree sizes in order to increase carbon stores have parallel beneficial effects on biodiversity and forest ecosystem functioning. The question of whether greater species diversity per se in a particular community enhances ecosystem functioning directly has not been answered unequivocally and is the subject of a great deal of current research. However, at a larger landscape or regional scale, maintaining the full range of biodiversity helps to assure that the system has the variety and abundance of components needed for long-term persistence and productivity in the face of an uncertain future environment. Ultimately, if long-term stability is enhanced on a landscape, all of these direct and indirect effects can also enhance reductions in carbon emissions, contributing to further climatic stability and more sustainable, long-term forest productivity (Figure 7).

Increasing forest area improves biodiversity and also benefits the pattern of forests on the landscape. Restoring forest area increases the total amount of habitat for organisms. Increasing forest area can also reduce landscape fragmentation, thus affecting biodiversity directly by enhancing the habitat quality of the forest (Franklin and Forman 1987, Saunders et al. 1991). Also, larger forests provide connectivity with reserve areas, which can enhance the overall functional value of the landscape for large, broad-ranging species that typically have home ranges larger than most feasible reserves (Grumbine 1990, Mladenoff et al. 1997). These strategies can be particularly important on private forests that occur amidst public forest lands, as they improve habitat connectivity.

At the stand scale, managing for greater car-

Figure 7

MANAGING FORESTS FOR GREATER CARBON STOCKS



Forest NOT Managed for Carbon Result In:

- Decreased Biodiversiity
- Decreased Ecosystem Health, diversity and Resilience
- Decreased Carbon Stability
- Increased Carbon Emissions

Forests Managed for Carbon Result In:

- Increased Biodiversity
- Increased Ecosystem Health, Diversity and Resilience
- Increased Carbon Stability
- Decreased Carbon Emissions

bon sequestration would result in forests of greater mean age overall, thus a more diverse distribution of stand ages and greater structural diversity. Such stands would contain more complex, multiple canopy layers, trees of larger stature, and more coarse woody debris on the forest floor. There would also be opportunities for longer successional sequences and therefore a better balance of regional tree species diversity. By helping maintain a more diverse distribution of habitat, such stand-level changes would also benefit biodiversity at a variety of habitat and microhabitat scales. Maintaining a range of communities and forest age classes across landscapes, and their spatial relationships, can be another way that long-term diversity and productivity persist. Natural, diverse landscapes often have repeating juxtapositions of different habitats. (Mladenoff et al. 1993)

The relationships of adjacent communities can be important for forest regeneration as well as for animal species with multiple habitat needs. The health of ecosystem services is also enhanced by such changes, such as movement and retention of water, reduction of erosion potential, and retention and availability of nutrients. The landscape and stand-level changes would also reduce forest edge contrast and micrometeorological effects that influence the understory forest environment, affecting animals, micro-organisms, and tree regeneration (Chen et al. 1992, Wilcove et al. 1986).

These direct benefits to biodiversity and ecosystem function may feed into longer-term and indirect effects. For example, forests that are more complex and diverse in age and habitat structure have greater capacity to buffer against changing climate and may afford better protection against changing disturbance regimes, such as wind, fire, insects, and disease. More rapid climate change itself will be a growing background “disturbance,” since it may occur faster than species can adapt to changing conditions or migrate. Enhanced forest area and reduced fragmentation can best allow species movement under such conditions (Peters and Lovejoy 1992).

Similarly, diverse, healthy, functioning forests are likely to be best able to respond to continued forest harvesting under such potential environmental changes, as they are more resilient. The net result can be enhanced biodiversity and ecosystem services, more stable climate, and more sustainable forest productivity on our landscapes in the long term.

Recent Trends in U.S. Private Forest Carbon

Of the nine forest service regions identified by the US Forest Service (USFS), four are most important in terms of potential gains and losses in US forest carbon stores: the Northeast, Southeast, Midwest /Lake states and Pacific Northwest regions. The forests in these regions contain the majority of private forest lands, are the most productive, most intensively managed, and most threatened by conversion (Best and Wayburn 2000). Thus, their carbon fate is a major determinant in national forest carbon flux. Of these four regions, the Southeast and Pacific Northwest have the greatest forest productivity and ability to increase carbon stores. These two regions are particularly important in tracking overall carbon flux.

Three factors are significant in tracking forest carbon:

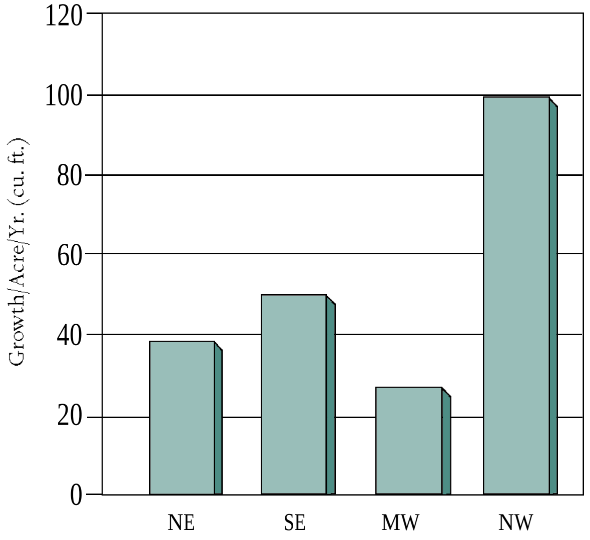
- The amount of area in forest (forestland extent)
- Average forest age
- The balance of harvest to growth

Forestland Extent and Forest Carbon Reservoirs

Forests are the most significant, expandable long-term future carbon reservoirs or sinks in the US. While the Northeast and Midwest/Lake states regions have gained some 1.5 million acres of forestland, the Pacific Northwest and Southeast combined have lost 3.2 million acres, mainly to development. The USFS projects that this pressure for development will increase, affecting the afforestation of croplands as well and leading to an accelerated decline in forest extent (Alig 2000). *Decreasing forestland losses would substantially decrease US forest-based carbon emissions and increase net stores.*

Figure 8

REGIONAL COMPARISON OF FOREST PRODUCTIVITY



Northeast=Maine, New Hampshire, New York, and Vermont
Southeast=Florida, Georgia, N. Carolina, S. Carolina, and Virginia
Midwest=Michigan, Minnesota, and Wisconsin
Northwest=Oregon and Washington

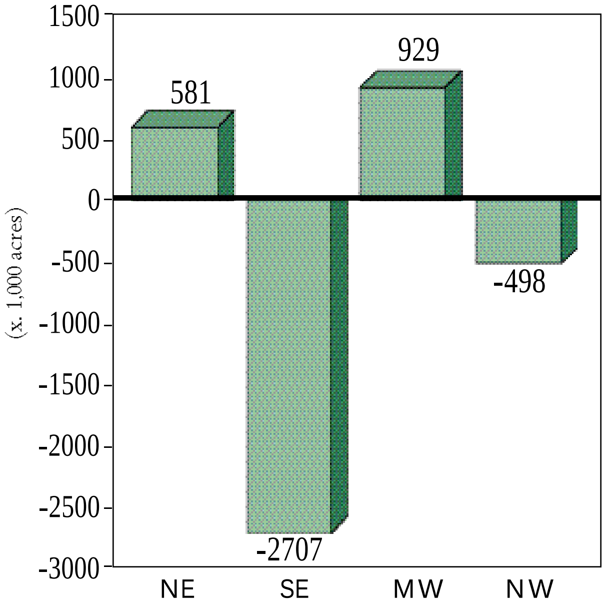
The two most productive forest regions of the United States are in the Northwest and Southeast. These have the greatest capacity to increase forest carbon stores in the short term and maintain them. These two regions are experiencing a net loss of forest land (see Figure 9). Maintaining stocks in the Northeast and Midwest where forests have regrown over the past decades is equally important.

Source: Powell et al. 1992.

Figure 9

TRENDS IN PRIVATE FORESTLAND GAIN AND LOSS

(1982-1997)



Northeast=Maine, New Hampshire, New York, and Vermont
Southeast=Florida, Georgia, N. Carolina, S. Carolina, and Virginia
Midwest=Michigan, Minnesota, and Wisconsin
Northwest=Oregon and Washington

Between 1982 and 1997, the Southeast and Northwest experienced losses of forestland while the Northeast and Midwest experienced slight gains. The net loss of forestland between 1982 and 1997 is 1,695,000 acres.

Source: USDA 1997.

At an average carbon stock of 35 tons per acre, the 1982-1997 loss of 1.7 million acres of existing forests in Oregon, Washington, Georgia, Florida, Virginia and the Carolinas alone meant the release of at least 60 million metric tons of carbon, as well as the loss of additional potential stores from the forests' diminished capacity to store carbon.

The US Forest Service is projecting the loss of another 20 million acres of timberland by 2050. Conserving these lands would prevent release of 700 million tons of carbon and 19 billion tons of carbon dioxide, not to mention the loss of future stores. Increasing forest age could result in a doubling of carbon stocks in the major forest areas over the next 25 to 50 years.

There has been a significant focus on reforesting, but in many states this has not been successful. Oregon, a highly productive forest state, estimates that some 775,000 acres of former forest remain in unforested condition (Cathcart 2000).

Reforestation and afforestation have substantial long-term potential, especially in the Southeast and in Midwest agricultural areas. The Conservation Reserve Program has demonstrated the appeal and effectiveness of tree planting in Midwest areas for net carbon and other ecological gains.

Combining these efforts of conservation, stewardship, and reforestation could clearly increase net long-term US carbon stocks by hundreds of millions of tons by 2050.

Forest Age and Carbon Stores

The longer a forest is allowed to grow prior to harvest or the greater the average age of a standing forest, the greater the carbon stores, as older forests accumulate and store more carbon than younger forests. There is a declining average age of forests on private lands, continuing a long-term trend since settlement, when virgin forests began to be harvested. This is especially the case on private lands, exacerbated by the need to generate economic returns on shorter and shorter cycles. For example, in the Pacific Northwest, the average age of harvest of commercial species has declined from 80 to 40 years during just 20 years (Haynes 1995). As illustrated in Figure 10, this trend is projected to lead to a decrease of more than 100 million metric tons of carbon stores between 1990 and 2010, based on the loss of older age classes and gain in younger age classes of forest.

There is a significant opportunity to reverse this trend in carbon stocks by extending rotations, retaining trees through one or more harvests, and rebuilding older age classes of forest on the landscape.

The estimates of forest age recorded in traditional growth-and-yield tables for commercial forests can be a useful surrogate for estimating carbon volume. The Forestry Inventory Analysis, or FIA, also gathers data on the growing stock volume. This, in turn, is translatable to standing carbon. Table 1 illustrates changes in standing volume of carbon in the main forest regions; it highlights overall declines in carbon in the Southeast, Northwest, and Lake States and increases in the Northeast.

Sustainability of Management, Harvest and Growth

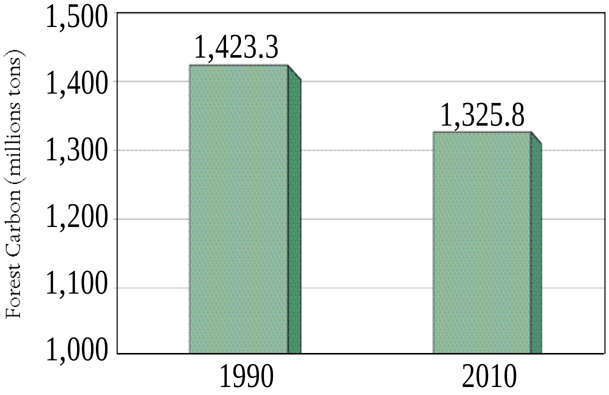
When more biomass is accumulated through the growth of forests than removed in harvest, a net gain of carbon occurs. When more harvest occurs than growth, a net decrease occurs. Overall, private forests in the US are experiencing an increase of harvest compared to growth, despite continuing reforestation of the Northeast since the early 1900s and an increase in growth in the Southeast, especially in hardwoods. This trend is expected to continue, as illustrated in Tables 1 and 2. Hardwood harvest is projected to accelerate while harvest of softwoods declines as softwood inventories are depleted (Haynes 1995). In the four major forest regions primarily considered here, there is a net excess of harvest over growth in three regions, with greater growth than harvest only in the Northeast. *The US has an opportunity to alter these business-as-usual trends, decrease harvest over the next decades, and rebuild carbon and timber inventories.*

PFT FILE PHOTO

Clearcutting is common silviculture in many forest regions. Typically, harvested sites are then burned to remove slash and competing brush. Often the soils are then cultivated prior to planting, releasing more carbon. With increasingly short rotations, this silviculture results in substantially reduced carbon stocks which do not recover by the next harvest.

Figure 10

TRENDS IN FOREST CARBON STORES: THE NORTHWEST WEST REGION



From 1990 to 2010, the Northwest West Region (Western Oregon and Washington) is expected to lose more than 97.4 million tons of carbon under business-as-usual management.

Source: Haynes et al., 1995.

Table 1 illustrating growth versus harvest by region in 1996, shows that removal of forest carbon exceeds growth of forest carbon by a net 7.5 million tons, not including loss of carbon from decay or transfer to the products pool. As indicated above, roughly 60% of labile forest carbon is released over time due to increased decay. With these factors included, more than 50 million tons of carbon were released to the atmosphere in that year alone. *By allowing growth to exceed harvest, this trend could be substantially altered.*

Table 1

GROWTH VERSUS HARVEST BY REGION (TONS C) 1996

Northeast

	Growth	Harvest	Tons Gained
Softwood	3,661,251	4,525,926	
Hardwood	17,588,434	14,428,906	
Total	21,249,685	18,954,832	2,294,853

Southeast

	Growth	Harvest	Tons Lost
Softwood	21,707,230	26,102,454	
Hardwood	16,976,851	18,597,599	
Total	38,684,081	44,700,053	-6,015,972

Midwest

	Growth	Harvest	Tons Lost
Softwood	1,872,349	1,563,066	
Hardwood	13,430,444	14,750,751	
Total	15,302,793	16,313,817	-1,011,024

Northwest

	Growth	Harvest	Tons Lost
Softwood	6,416,371	9,650,127	
Hardwood	1,080,244	647,054	
Total	7,496,615	10,297,181	-2,800,566

Northeast=Maine, New Hampshire, New York, and Vermont
Southeast=Florida, Georgia, N. Carolina, S. Carolina, and Virginia
Midwest=Michigan, Minnesota, and Wisconsin
Northwest=Oregon and Washington

In 1996, more carbon was released into the atmosphere through harvest than was accumulated.

Harvest data sources: FIA Website data (http://srsfia.usfs.msstate.edu/rpa/tpo/) and 1997 RPA data Growth data sources: Powell et al, 1992 (GTR-RM-234) and Draft 1997 RPA

Table 2

NATIONAL TRENDS IN GROWTH AND HARVEST ON PRIVATE FORESTS

a. Total Private Owners: Softwoods

	Annual Growth	Annual Harvest	Growth/ Harvest
	(billions cubic feet)		(ratio)
1953	5.3	6.3	0.84
1963	6.6	5.3	1.25
1977	8.8	7.1	1.24
1987	8.3	8.4	0.99
1992	8	8.6	0.93
1997	8.2	9.2	0.89
2010	10.5	8.8	1.19
2020	11	9.9	1.11

b. Total Private Owners: Hardwoods

	Annual Growth	Annual Harvest	Growth/ Harvest
	(billions cubic feet)		(ratio)
1953	5.3	3.8	1.37
1963	6	4.1	1.47
1977	7.9	3.9	2.03
1987	7.9	4.7	1.68
1992	8.3	4.8	1.72
1997	8.5	5.8	1.45
2010	8.1	7.7	1.06
2020	7.8	8.1	0.96

c. Total Private Owners: Hardwoods and Softwoods

	Annual Growth	Annual Harvest	Growth/ Harvest
	(billions cubic feet)		(ratio)
1953	10.6	10.1	1.05
1963	12.6	9.4	1.34
1977	16.7	11	1.52
1987	16.2	13.1	1.23
1992	16.3	13.4	1.22
1997	16.7	15	1.11
2010	18.6	16.5	1.13
2020	18.8	18	1.04

The U.S. overall has been increasing its harvest, as compared to growth of timber on private lands, since 1977. This is projected to continue. Where softwoods have been harvested in excess of growth for over 15 years, hardwoods harvest is now increasing. This leads to creating and maintaining younger forests, and lower carbon stocks nationwide.

Source: USDA 2000.

Regional Implications

CARBON SEQUESTRATION OPPORTUNITIES ON PRIVATE LANDS IN THE PACIFIC NORTHWEST

Ecological Setting

The temperate rain forests of the Pacific Northwest-western Washington and Oregon and northwestern California-have the ability to accumulate immense stocks of carbon; in fact, old-growth forests in this region[1] have the greatest carbon accumulations of any ecosystem on Earth. These record capacities for carbon accumulation relate to several important variables, including the following:

- Long-lived conifers capable of continued growth
- Large amounts of decay-resistant litter
- Environmental conditions favoring high tree productivity
- Infrequent natural disturbances

Forests in western Washington, Oregon, and California are composed primarily of very long-lived conifers, such as Douglas fir *(Pseudotsuga menziesii)*, Hemlock *(Tsuga heterophylla)*, Western Cedar *(Thuja plicata)*, and Coast Redwood *(Sequoia sempervirens)*. Many of these species continue to grow in diameter and volume throughout their lives and, most unusually, even in height for two centuries or more. These tree species typically represent the largest and longest-lived representatives of their genera (Franklin and Dyrness 1973). Many of these tree species also produce large amounts of decay-resistant litter, including large boles, when they die. As a consequence, the primeval forests contain large amounts of dead as well as live organic matter.

Many of these Pacific Northwest forest sites are highly productive because of environmental conditions favorable to the evergreen trees. Much of the annual photosynthetic production actually occurs outside of the summer growing season, during the spring, fall and even the relatively warm, wet winter months. As a result, positive net carbon balances-meaning significant uptake of carbon from the atmosphere-are characteristic of these forests. Continued net carbon sequestration appears to persist to much older ages (e.g., 500-year-old stands) than originally believed; maximum organic matter accumulations may not occur in these forests until stand ages of 800 years or more.

Major wildfires and windstorms are the most usual natural disturbances, but they appear to occur at long intervals, allowing forests long periods for recovery. For example, fire-return intervals for major natural fires average 400 to 500 years in western Washington and 100 to 150 years in central western Oregon. Furthermore, while such disturbances kill many trees, they do not consume or remove much of the organic matter, so most of the carbon stocks are subject to very slow release by decay processes. Consequently, natural disturbances, unlike clear-cut harvests that claim to mimic such disturbance, almost never draw carbon stocks to the low levels encountered following forest harvest.

---

[1] The record is held by the Sequoia sempervirens, a temperate rainforest species in northern California.

History

An estimated 65% of the forests of the Pacific Northwest were dominantly old-growth and mature forests at the time of European settlement. By 1800, these forests probably averaged about 300 years of age.

The most productive forest lands are found at lower elevations in western Washington and Oregon and northwestern California. Most of them were acquired by private individuals and corporations in the late 19th and early 20th centuries through a variety of processes, including government land grants to subsidize railroad and road construction, homesteading, purchase, and fraud. The federal government reserved significant forest lands as Forest Reserves that become the National Forests; however, these were the less productive mountainous lands.

Major logging of the virgin forests began late in the 19th century and was largely completed on private timberlands by 1975. Logging of federal timberlands began somewhat later and peaked between 1970 and 1990. It is estimated that logging of virgin forests in the Pacific Northwest between 1890 and 1990 released 1.6-1.9 billion tons of carbon to the atmosphere, even though the majority of the logged areas were reforested (Harmon et al. 1990). To provide a global perspective, harvesting in Pacific Northwest forests, which constitute about 0.25% of the global forests, has contributed nearly 1.5% of the total global carbon flux to the atmosphere that is ascribed to recent land use changes.

The second and, in many cases, the third cycle of forest harvest is underway on private forest lands within the Pacific Northwest. Carbon levels in these stands are far below the levels that were found in natural forest stands, even of the same age, and are only a fraction of what the stands can actually sequester. These low carbon levels are a consequence of the following actions:

DAVID SWANLUND, COURTESY OF SAVE-THE-REDWOODS LEAGUE

Old growth forests of the Pacific coast, such as these coastal redwoods, hold massive amounts of carbon, exceeding 1,000 tons/acre. Replacing these carbon stocks with young forests would require thousands of years of regrowth.

- replacement of large old trees with much smaller young trees
- elimination of dead organic matter
- shortened cutting cycles

Cutting cycles (rotation age) on private forest lands are typically very short (35 to 60 years) because they are based on economic criteria calculated on present net value rather than biological criteria, such as culmination of mean annual increment (m.a.i.). Consequently, private forests are cut long before annual volume growth—and carbon accumulation—culminates. Non-living organic material has also been drastically reduced in private Pacific Northwest forests. This is due to several factors, including the accelerated decay of organic materials on logged sites resulting from increased temperatures and fragmentation, active removal or burning of residues, and elimination of replacement sources of debris. As noted in this report, such collateral

Table 3

AREA AND TIMBER VOLUMES FOR PRIVATE TIMBERLAND IN WESTERN OREGON AND WASHINGTON (1952 AND 1992)

Survey Year (year)	Area (thousands of acres)	Volume (millions of cubic feet)
1952	21,979	55,802
1962	21,132	51,857
1977	19,742	46,051
1987	18,267	47,572
1992	17,561	49,055

carbon losses from logged and intensively managed sites are rarely considered in carbon balance work.

Recent Trends

Trends in private forestland area and timber volumes have not been positive during recent decades. Table 3 indicates results from 1952 to 1992.

The private timberland[2] base declined at the rate of about 0.5%/year between 1952 and 1992. This trend is particularly critical in western Washington and Oregon and results from rapid increases in population and urbanization, especially along the I-5 corridor. Based on recent rates of conversion, another 1.8 million acres (nearly 16%) of private forest lands in western Oregon and Washington are projected to be lost to conversion in the next 50 years. The conversion of forest lands to other uses is a response to a variety of pressures: economic—the opportunity for large monetary returns; social—the antagonism of neighbors toward forest harvesting, especially by clearcutting; and, potentially, regulatory—the increasingly restrictive regulatory environment associated with wildlife and fisheries issues.

Harvest pressures on private forest lands have also increased and are evident in declines of standing stocks and average stand age. While some older data show an upturn in timber volume, they do not reflect major changes in the region from greatly reduced harvests on federal lands and increased regulatory pressures. Reductions of more than 80% in federal timber harvest levels in the 1990s (after an unprecedented increase in harvests in the 1980s) produced dramatic increases in stumpage values, providing major incentives for harvest on private lands. The effect of this situation, as reflected in more recent statistics (see USDA 2000 and Tables 1 and 2 of this report), has been accelerated harvest of timber on all private forestland ownerships, reducing the average timber volume and carbon stock levels on these lands. Data from western Oregon show significant reductions in average per-acre growing stock volume and live carbon tonnage in the decade ending in 1995.

Reductions in per-acre carbon stocks on private lands is probably much greater than suggested by inventory statistics, which consider only live carbon, as discussed earlier in this report. Levels of non-living organic matter have also been reduced by intense harvesting and site preparation practices that have increased removals and accelerated decomposition of organic residues.

Potential for Increasing Carbon Storage

The potential for increased carbon storage in Pacific Northwest forests is immense. These forests have a huge capacity for carbon storage, which they have not begun to reach.

The regional capacity of forests to sequester additional carbon can be illustrated by a simple example. These forests could easily recover half or more of the carbon released during the 20th century (Harmon et al. 1990) by modifying forest practices throughout the region. If the regional forest were managed so as to recover half of the reduced carbon (76 tons/acre) on about half of the forest land base (12,350,000 acres) the total additional carbon sequestered would be 9.4 million tons. Biologically, this could easily be accomplished in three to five decades. Federal forest management

---

[2] Timberland is a classification of highly productive forestland.

policies are already contributing significantly to this goal with the extensive series of forest reserves established in the Northwest Forest Plan. Tens of thousands of acres of cutover federal forest land are being managed for restoration of late-successional forest conditions and, coincidentally, much higher levels of carbon stocks (Tuchmann et al. 1996).

Maintaining and increasing carbon stocks in Pacific Northwest forests, as nationwide, can utilize a variety of measures, including:

- Maintaining the existing forest land base
- Adding land to the forest land base
- Retaining more carbon at harvest
- Lengthening rotation periods

Keeping and Adding to the Private Forest Land Base

Private forest landowners will need financial incentives to retain existing forest land base as well as add to that base through reforestation and afforestation. Creation of an active carbon market could be a major financial opportunity for landowners interested in retaining and managing their forest lands, as discussed earlier in this report.

As noted earlier, we are currently losing about 0.5 % of the private forest land base each year. This level of forest land loss is potentially adding about 2.2 million tons of carbon per year to the atmosphere, assuming that each acre lost currently stores about 100 tons of labile carbon per acre. This significant leakage might be reduced dramatically through a carbon market.

Retention Harvesting

Retention of additional carbon at time of regeneration harvest is a practice that significantly increases average stand carbon levels. Variable retention harvesting techniques are being substituted for traditional clearcutting practices on public and private forestlands throughout the region. Under variable retention harvesting, significant structural elements, such as large live trees, snags, and logs, are left behind to become a part of the next stand (Franklin et al. 1996).

Calculations of carbon contributions from structural retention are straightforward. They can be approximated by simply multiplying the level of structural retention that is being specified, such as retention of 15% of the basal area of live trees, by the carbon content of those particular structures. Under current private land management practices of clearcutting in a 35-40 year rotation, with 10% retention (current minimal practices on Weyerhaeuser Company's BC Coastal Division, for example) the additional carbon maintained on site would be about 9 tons/acre on an average site (Wayburn and Richards 1999).

Retention harvest practices have numerous additional ecological benefits beyond additional carbon sequestration. These include "lifeboating" a broad array of organisms on cutover areas and structurally enriching the subsequent forest stands.

Lengthening Rotations

Significant lengthening of rotations could be a very effective change in practice on private lands to increase sequestration of carbon in Pacific Northwest forests. The potential effects of longer rotations on carbon stocks can be easily illustrated using data provided by Birdsey (1996). These data show per-acre tree carbon stocks in an age sequence of fully stocked stands of Douglas fir forests grown following clearcutting of high-site lands.

We assume a traditional current rotation age of 35 years; stands at that age would have 140,000 lbs/acre (70 tons/acre) of tree carbon. Increasing rotation age to 60 and 70 years, respectively, produces the following increases in carbon:

Rotation Age	Tree C Stocks	Increase in C Stocks
60 years	333,000 lbs/acre	97t/acre (217 Mt/ha)
70 years	389,000 lbs/acre	125 t/acre (280 Mt/ha)

Assuming that these increased rotation ages are achieved on only 50% of the private land base of 5.8 million acres of western Washington and

Oregon, the additional sequestered carbon in Pacific Northwest forests would be 1.4 billion tons and 1.8 billion tons with increased rotations of 25 and 35 years, respectively. These values are very close to the levels of carbon released to the atmosphere by forest harvest in the Pacific Northwest during the entire 20th century and could be achieved within 40 to 60 years after adoption of the new rotation periods.

Lengthened rotations, as variable retention, would address many other important ecological and social goals as well as additional carbon sequestration. Wood yields from forested landscapes would actually be increased; a smaller percentage of the landscape would be harvested annually; and significant improvements in the hydrologic and geomorphic behavior of watersheds, as well as in the health and productivity of aquatic ecosystems, would almost certainly occur, in addition to benefits for habitat and biodiversity. Finally, as in the Southeast, the aesthetics of the private forest landscape would improve.

The Pacific Northwest forests have the potential to provide a very large carbon sink, thus helping to reduce US emissions overall. With an incentive program derived from carbon credits, private forest landowners could alter management techniques in ways that would not only sequester significantly more carbon, but would improve the health of the ecosystem overall.

CARBON IN THE GREAT NORTH WOODS: TRENDS AND IMPLICATIONS

The “Great North Woods” states of Maine, New Hampshire, Vermont and New York are among the most heavily forested states nationally. They contain about 43 million acres of forestland, with about 4 million acres each in Vermont and New Hampshire, and about 16.5 million and 17.5 million acres in New York and Maine, respectively. Maine and New Hampshire are experiencing a small loss of total forestland; Vermont and New York are experiencing an even smaller net gain in forestland. The average private forested acre in Vermont, New Hampshire, Maine, and New York contains between 20 and 30 tons of live carbon (see Table 4).

The average age of stands across the region is between 50 and 80 years; in Maine, the average is 62. Most of the region, outside the spruce-fir forest, is covered by mixed hardwood and conifer forests of relatively recent origin. Consistent with the region’s relatively early settlement by European-derived people, conversion of its forests to agriculture, grazing, and logging for fuel and forest products greatly reduced forest area through the 17th, 18th and 19th centuries. Reforestation after these lows is still proceeding, as the forestland increases in New York and Vermont illustrate.

These mixed-species forests are also mixed-age forests, although most forested acres are dominated by trees arising over a fairly short time, in forest terms. Vast areas are dominated by trees that began to grow after the abandonment of plowing and grazing in the first half of the 1900s, and the average age of the dominant trees in these areas is therefore from 50 to 90 years. Many abandoned, formerly plowed fields in the region support relatively pure stands of Eastern white pine. Because of their purity and relatively even spacing, these are often mistaken for plantations, or, if the trees seem large enough, for “virgin” forests. In terms of carbon storage, these white pine stands accumulate larger amounts of carbon per acre than do mixed species stands; thus, though there are fewer total acres of white pine, their carbon contributions are significant.

These are “young” forests, as the “virgin” stands encountered at European settlement were in the 150- to 250-year range. The predominantly glacial soils of the region are considered poor in agricultural terms, but they are clearly capable of supporting dense stands of healthy trees. Left undisturbed, these forests will continue to grow and develop for many years and continue to sequester more carbon in the structure of the trees and in and on the soil.

Economic and social forces in the Northeast have created these new forests. If trends that dominated the region for the last 50 years continue, forestland area will grow or remain roughly constant, and tree volume and carbon content will continue to increase with average age for at least another 50 to 100 years.

There are three forces that could intervene in the projected increase in volume of carbon: land use conversion, harvest, and natural risks of fire, disease and insects. The determination of whether these forces will exert large or small influences is critical to projecting the future of this carbon reservoir.

Land Use

The decrease in relative profitability of agriculture was the major reason for the reforestation of this region. It is highly unlikely that a new wave of land clearing for agriculture will occur in the Northeast. The greatest land use threat to this carbon reservoir today is conversion to small residential and commercial properties through forest “parcelization” and “fragmentation.” As long as conversion to residential and commercial real estate remains a more profitable use of forestland, it will occur at a faster or slower pace, depending on the region’s and nation’s economy. Conversion to building lots does not in itself decrease carbon storage or forest growth per unit of forest area immediately. However, some complete clearing occurs for roads and buildings even with the creation of sequestered forest dwellings on relatively large lots. A typical scenario for a forested property, perhaps all or a portion of a farm a century or two (or even three) old might be:

Table 4

TRENDS IN NEW ENGLAND CARBON STOCKS (1952-1992)

a. Growing Stock Volume of Private Timberland (x1,000,000 cu ft.)

	ME	NH	NY	VT
1992	23,47	6,833	19,243	6,095
1987	21,617	6,339	18,189	5,230
1977	22,183	5,900	12,167	4,547
1962	18,376	4,043	10,689	3,347
1952	15,275	3,129	9,662	3,145

Source; Forest Resources of the United States, 1992 (GTR-RM-234)

b. Live Forest Carbon per Acre (tons)

	ME	NH	NY	VT
1992	20.88	26.45	21.96	24.85
1987	18.96	24.73	20.88	22.44
1977	19.43	21.77	14.05	18.19
1962	16.05	14.48	14.24	13.76
1952	13.57	11.23	14.57	14.20

Source: Birdsey (1992) and Forest resources of the United States, 1992 (GTR-RM-234)

c. Live Forest Carbon (million tons)

	ME	NH	NY	VT
1992	343.66	107.05	324.01	98.38
1987	316.29	99.30	304.55	84.47
1977	317.11	89.51	202.61	72.92
1962	266.07	61.41	178.27	53.41
1952	222.97	46.44	161.12	50.41

Source: Turner et al (1993) and Powell et al (1992) (GTR-RM-234)

1. A timber sale that removes all or nearly all merchantable pulpwood and sawtimber
2. Subdivision into lots consistent with a zoning minimum (sometimes 5 to 6 acres, but often smaller)
3. The sale of lots and construction of houses and roads over a 5- to 10-year period
4. Further development (lawns, pastures, ponds, etc.) of the subdivided property over another decade

Each transition results in a loss of stored carbon and in a loss of carbon storage capacity. Even the subdivision itself (step 2) results in a loss of

New Hampshire: Threats to Forest Carbon

New Hampshire may best illustrate the need for concern about the future of the Northeastern forest carbon reservoir and sequestration capacity. Of the four states included in the “Northeast” here, New Hampshire experienced the most dramatic reforestation as agriculture declined. Its young forests spread over its magnificent hills and mountains support a stunning new array of wildlife, tourists, retirees, and economic activities. It is a splendid example of a place where letting trees grow, growing trees on purpose, and benefiting from them in many ways are easy to explain and apparent to most. Most of its forests are privately owned, though the White Mountain National Forest occupies more than 10 percent of the state. Its forests, with an average age of 58 years and about 33 tons of carbon contained in live trees per acre, form an excellent carbon reservoir and sequestration system. Its predominantly young forests are just coming into their maximum sequestration years and can be managed for a wide variety of purposes because of their varied species composition, age and size of trees, and extent. Most of the state has an excellent road system that facilitates tourism, forest protection, and forest product extraction.

Given this picture, one would think that in New Hampshire, if anywhere, "natural" forests could be left to themselves to sequester carbon and provide other benefits. A series of reports, most prominently from the Society for the Protection of New Hampshire Forests (SPNHF), make it clear that complacency on this point is out of place. Consider the following excerpt:

> Loss, parcelization and fragmentation of the forest land base have been identified as problems for forest industry and many other users of the New Hampshire forest. For the first time in many decades, the forest cover in New Hampshire has declined. This has implications for wildlife habitat, surface water quality, drinking water quality, recreation, tourism, and forest management. Forestland was being converted to development at a rate of about 13,000 acres per year between 1982 and 1992 [13,000 acres equals about 430,000 tons of carbon in trees alone]. Between 1983 and 1994, 44% of the white pine removals and 53% of red oak removals in New Hampshire occurred on land being converted from forestry to another use.
>
> In a study of forest cover fragmentation in southeastern New Hampshire and northeastern Massachusetts, 49% of the New Hampshire towns were found to have experienced a moderate to major increase in forest cover fragmentation between 1973 and 1988. Also of concern is forest parcelization-the division of forested ownerships into smaller and smaller parcels with lower volumes. Lower volumes affect the profitability of the harvest" and lower the carbon reservoir. (SPNHF, 2000)

Although forest conversion is probably the greatest threat to the New Hampshire forest carbon system, others loom. The effects of acid rain on forests was first seriously researched and reported at the Hubbard Brook Experimental Forest in New Hampshire. It is likely that air pollution now substantially reduces New Hampshire's forest carbon sequestration capacity, although specific estimates have not been made. As parcelization and fragmentation accelerate, so will unwise "pre-conversion" timber harvests that draw down the carbon reservoir and reduce sequestration capacity. As air pollution and high grading harvests reduce forest health and photosynthetic capacity, the likelihood of catastrophic forest losses to insects and disease increases.

Conversion alone is predicted to reduce forestland in New Hampshire by 372,462 acres between 1997 and 2020. Using today's numbers, that results in the loss of more than 12 million tons of carbon storage in this relatively small state. Because converted forests can't grow, the long-term loss will be much larger.

Society may or may not take action to maintain the health and extent of New Hampshire's forests. But it seems clear that unless action is taken, a substantial forest carbon reservoir will be lost or degraded.

capacity in that it makes management and protection of the forest harder and more expensive per unit area. Clearly, land use conversion of this kind is a threat to carbon storage in the forests of the Northeast and will continue to be until there is an incentive for forest owners to keep their forests growing in relatively large blocks. As illustrated by New Hampshire, the threat of forest conversion is real and increasing.

Harvest Types and Pressures

World wood use is rising, and the Northeast has millions of acres of valuable timber. As prices for timber rise, harvest rates are likely to increase. If the harvesting is done in ecologically sound ways, the forests of the Northeast can become both secure carbon reservoirs and enhanced creators of aesthetic and economic value. If much of the harvesting is done poorly, both the carbon reservoir and carbon storage mechanism are threatened.


PFT FILE PHOTO

Reforestation after harvest is essential to restore carbon stocks. Reforestation of former forests, such as in the old fields of the Southeast and Northwest, will build significant new carbon reservoirs.

Fewer than one-third of the private forest owners in the Northeast have a management plan for their land. Fewer still use the services of a professional forester when they harvest trees. These habits have profound implications for the future of carbon storage in the region. The most common kind of harvest remains the removal of the largest and most valuable trees in one operation. This minimizes cost per unit of wood volume removed and may maximize return at a single harvest time. It is also often destructive of the future value of the forest for wood production and may reduce the overall value of the property, even when the receipts from the harvest are included in the calculation of value.

For the mixed forests of the region, this sort of harvest has a potentially disastrous effect on carbon storage. Usually the remaining trees are not capable of rapid response to the new growing space afforded them by the harvest, but are numerous enough to slow or prevent natural regeneration of new trees of the species that will most quickly restore carbon storage capacity. Thus, this sort of harvest can diminish the carbon storage capacity of the forest for many years.

This need not be the result. Mixed forests of this kind can be managed to enhance carbon storage and timber value simultaneously, through the use of individual tree, group selection, and patch cutting (small clearcuts). By concentrating growth on the larger, more vigorous trees, and by removing less vigorous trees that nevertheless occupy space in the forest, both carbon storage and value are increased. Forest owners will practice this sort of management to the degree that it is available and attractive financially and otherwise. Societal transfer payments to owners to compensate them for the carbon their forests store, for example, would be a powerful, positive incentive to conservative management.

Fire, Air Pollution, Disease and Insects

The forests of the Northeast have been called “the asbestos forests,” meaning that they are hard to burn. Fire season tends to be in spring and fall, before and after green leaves are present on the annually deciduous trees in the forest. Winter’s snow fireproofs the understory and most places do not have enough conifers with evergreen leaves to carry a “crown” fire that burns through the whole forest’s vertical profile. Similarly, in summer, the green leaves, turgid with water, carry fire poorly. So catastrophic fires that release major amounts of stored carbon are not expected.

However, the extensive, in places almost unbroken, forests of the Northeast are artifacts of the 20th century, giving us less than a hundred years of experience with such forests. At the same time, human occupancy and use of these forests have increased dramatically. People start most forest fires in this region. Mix in the warming and drying that may occur as part of global climate change and the probability of catastrophic fire in the Northeast could quickly exceed the current perception.

Acid deposition, commonly called “acid rain,” is still a serious threat to Northeastern forests. Soils acidified by acid rain may develop levels of iron and aluminum that can decrease forest health. The increased availability of nitrogen by acid rain and some other forms of air pollution can increase susceptibility to insect and disease damage. Acid rain and other forms of air pollution thus can decrease carbon storage by Northeastern forests, and may now be doing so on a fairly grand scale.

Pests can also slow tree growth and, if serious enough, cause mortality. The 20th century had three catastrophic insect outbreaks in Northeast forests: the spruce budworm, the gypsy moth, and the wooly adelgid, two of them exotic, which caused losses in forest health and thus carbon storage capacity. Diseases such as shoestring root rot (native) and chestnut blight and Dutch elm disease (exotic) have also caused major problems. As human numbers, travel, and transport increase, so does the rate of introduction of new organisms, some of them harmful. Because of proximity to large human populations and centers of international commerce, Northeast forests are probably particularly vulnerable to new and old insects and pathogens. There are only two defenses that ultimately matter: knowledge and the intrinsic health of forests. We seem to spend little time or money on either, currently, perhaps particularly in the Northeast.

The Larger Picture

Some argue that we should replace relatively slow-growing forests such as those of the Northeast with “fast-growing plantations.” This would be extremely short-sighted. Not only would significant amounts of carbon be lost in the process, but it would also take more than a hundred years, at the current rate of incremental establishment, for plantations of, say, fast-growing tropical trees to replace the carbon reservoir and storage capacity of the Northeastern forests. A parallel and sensible course of action, and one that will prove socially viable, is to work harder to mitigate the threats to the Northeastern forest outlined above.

SOUTHEASTERN FORESTS AND THEIR CARBON FUTURES

The so-called “Southern Pinery” of the Southeastern United States is one of the most important timber-producing landscapes in the world and one of the country’s most important carbon reservoirs. In the century preceding the Civil War (1750-1850s), this region was extensively deforested for agriculture. In the century that followed, much of this land was abandoned from agricultural use and reforested naturally. Abandoned old-fields went through succession into pine and then hardwood forests. This region-wide reforestation produced a major “carbon sink,” as growing forests absorbed carbon dioxide to produce biomass and replenished soil carbon stores depleted by historic abusive farming practices. Despite its significant potential to increase future carbon stores, the Southeastern forests contain some of the most threatened carbon stores in the country. These threats could be ameliorated or reversed in the context of a workable market for carbon storage.

Total carbon storage on this landscape depends on the balance between the carbon taken up in growing forests and depletion of carbon stores when those forests are harvested. The trajectory of carbon uptake by a forest during its life is complex, but suffice it to say that older forests store more carbon than younger forests. Today, the carbon balance of this region is largely regulated by two forces: harvest and conversion. Harvest cutting practices on lands managed to produce wood fiber cause loss of substantial carbon; these practices are likely to increase, particularly on hardwood forests. The permanent conversion of forested land to other uses, particularly urban development, causes not only carbon releases, or emissions, but also the loss of future carbon sequestration.

Cutting cycles in Southeastern forests are highly variable, depending on site productivity and particular management goals. Overall, however, economics and technology have resulted in ever-shorter rotations. Where pines are grown for paper pulp, rotations may be as short as 12 years; for saw timber, rotations may be as short as 20 to 30 years. Carbon markets could provide new and specific economic incentives to lengthen these rotations, which would result in older forests and greater carbon storage on average over this region.

Permanent deforestation from urban conversion is increasingly important in the Southeastern carbon budget. Beginning in the late 1970s, a century of regional reforestation began to reverse. For example, in the last two decades, North Carolina has witnessed a 3% reduction in forested land, largely due to urban development. Much of this acreage might have remained in forest if the economic incentives of a voluntary forest carbon market program were in place to provide increased economic value to land with intact forests and a market-based mechanism to help manage urban sprawl.

Public and large industrial ownership accounts for less than 10% of forested land in the Southeast. Since most ownerships are small (<200 acres) and managed for a variety of goals, a voluntary market and incentive-based program makes a great deal of sense in this region. Such a program should set clear operational standards for management that will encourage practices that increase carbon stores in the region. The result will be not only the very real and tangible favorable impacts on our atmospheric carbon budget, but also the retention of forests that support a more diverse biota and aesthetically beautiful landscapes.

Economic Implications

THE IMPACT OF CARBON CREDITS ON FOREST MANAGEMENT DECISIONS AND FORESTLAND VALUES

Introduction

Forest growth is one of the few technologies available for actually taking carbon dioxide out of the atmosphere; forest loss and harvest are some of the largest sources of emissions to the atmosphere. These facts are recognized in Articles 2, 3.3 and 3.4 of the Kyoto protocol.

However, in the absence of economic incentives, forest landowners are unlikely to take the actions needed to unleash the power of forest management to achieve the socially desirable end of greater carbon stores. How would the availability of carbon credits-a payment for the carbon-fixing and storing services of forests-induce both profit-maximizing forest landowners and those for whom timber revenue is not the driving force of their management and ownership to increase the amount of carbon held in forests? As we have seen earlier in this report, increase in carbon stocks occurs in two main ways:

- increasing the average age and stocking of trees per acre
- maintaining and increasing the amount of land in forests

The first can be done in three ways: 1) by lengthening the period of time before the trees are cut (the rotation age), and leaving trees between harvests, thereby increasing the average standing volume of trees throughout all management periods; 2) by preventing conversion, and 3) by reforesting/afforesting former forests and marginal croplands. Furthermore, though not additional stores, forest products do serve to maintain carbon stocks. Forest biomass used for energy that offsets fossil-fuel consumption is another, though less easily accounted for, way that forests can help reduce the accumulation of carbon dioxide in the atmosphere.

Overview of Carbon Flows in a Production Forest from an Economic Perspective

To understand the economic impacts of carbon credits on forestland owners, let us consider the case where trees are planted on ‘bare ground’- reforestation of current agricultural or pastoral land (as is found through much of the Southeast) where the above-ground stock of carbon is low. Depending on the nature of the soil, the initial site preparation might release some carbon from the below-ground inventory (which may be large in grasslands). As the trees grow, carbon is fixed into plant tissues and the amount of carbon in the planted area increases. The rate and amount of increase (in tons/acre/yr) is initially small, as the trees are small and have few leaves or needles. The rate accelerates as the trees grow older, though the annual amount fixed remains small for a number of years. After culmination of mean annual increment, the rate and net annual amount of carbon fixed slows.

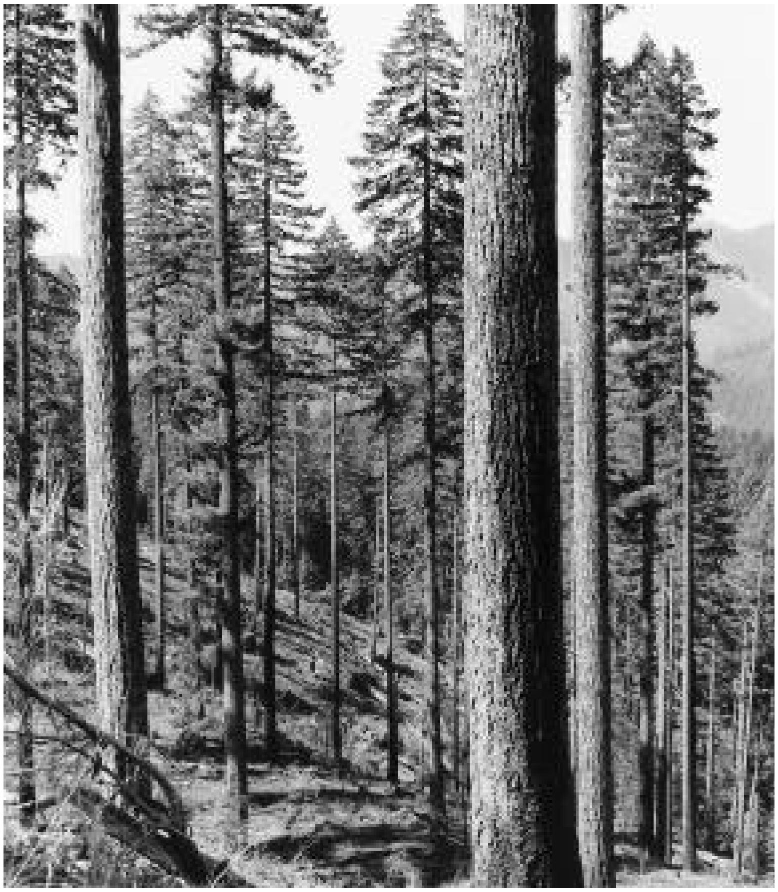
At the time of harvest, carbon is released in several ways. First, even in the most efficient harvesting systems of the most uniform wood, some of the stem of the tree will be left in the woods to decompose, that is, to release its carbon, along with that of tops, limbs, roots, leaves and needles of the tree as well. Second, some of the carbon is removed from the site to be transformed into products (see Accounting Principles, earlier in this report). In some cases, some of the tree will be used for energy, potentially offsetting fossil-fuel consumption. For example, in most modern chemical pulp mills the lignin residue from pulp manufacture is burned for energy.

The amount of carbon in each of these flows depends a great deal on the specific kind of forest in question. Harvest of highly regulated and managed plantations tend to be more "efficient," removing and processing more of the trees; "natural forest management" with older "defective" trees may leave more material on site after harvest.

General Economic Impacts on Forest Landowners if Carbon Services are Valuable

If carbon in the atmosphere is causing damage via global warming, then the services that trees provide in removing it from the atmosphere should be socially valuable. Forest owners should be credited for this carbon fixation and storage service, and those credits would surely affect their management of the land and indeed the amount of land they would keep in forests. However, to be consistent and fair, if and when owners cut their trees, they should pay a tax on the amount of carbon released. The payment for carbon services will increase the value of the land and make it more desirable to keep the trees growing longer or keep more trees overall. The tax on the carbon released will offset some of the increased land value, but will further induce landowners to keep trees growing. With this simple logic we can examine the impact of carbon credits on forest management decisions and the price of forest land.

First, a note about steady-state carbon reserves. Steady state reserves can be created when a landowner permanently increases the net amount of carbon on forest land. This is done by increasing the average amount of standing volume in the forest, for example, by moving a forest with 5000 board feet per acre to one with an average of 25,000 board feet to the acre, or by reforesting an old field and maintaining a continuous tree crop. In the first instance, a landowner would allow the forest to increase in age and volume and in future harvest, always leave some standing inventory (perhaps 25%), as with variable retention. In these cases, retention might be along sensitive areas such as streams as well as throughout the forest, providing habitat and structure.


COURTESY OF JERRY FRANKLIN

Variable retention silviculture is perhaps the most effective strategy for maintaining higher carbon stocks than would otherwise occur, while also allowing harvest of timber. Such an approach enables economic production on private forests and greater carbon gains, while also resulting in greatly improved habitat values.

In the second case, the owner would plant, each year, an area of land until the final harvest age of the first plantations is reached. For example, if the planned rotation is 20 years they might plant one acre each year for 20 years and then start harvesting one acre a year and replanting each year. Taking into account that frequent rotations diminish the productivity of the site and that decay (carbon release) continues to occur after harvest, future rotations would need to be extended several years out. However, with planning, such a scheme could permanently fix an amount of carbon equal to the standing inventory just before the first harvest. In each case, the forest owner can take full credit for this inventory without having to pay the "tax" discussed above. If, of course, the owner ever converts the forest to houselots, for example, the carbon tax would come due. This sort of scheme does not change the analysis or the results presented below, it just changes the perspective-one of the values of maintaining the steady-state carbon reserve is avoiding the tax associated with cutting it all down.

An Analytical Model for Evaluating the Impact of Carbon Credits

The economics of including carbon in forest management are well understood. A recent peer-reviewed paper by van Kooten, Binkley and Delcourt (1995) in the *American Journal of Agricultural Economics* provides all the mathematical details, and they will not be repeated here. Instead we provide a description of how the model works and the impact of including carbon credits and taxes in forest management.

In this economic model, we focus solely on the rotation length decision. We assume all forestry is even age and clear-cutting is used. We ignore important features of the problem such as the increasing value of trees as they grow older for timber products. We simply compare the situation when carbon credits are not available with one where they are. Analytically we make this comparison by assuming that the "price" of carbon is zero and compare this outcome with the situation where carbon is increasingly valuable.

A wealth-maximizing landowner will choose the rotation age to maximize the present value of all future harvests, including the carbon value. Mathematically, this problem can be written:

$$\underset{T}{\text{Max}}\ PV(T) = (PV_{\text{carbon}} + PV_{\text{timber}})/\ (1 - e^{-rT})$$

Where: PV(T)= present value associated with a rotation of T years
r = discount rate

The present value of the timber is

$$PV_{\text{timber}} = -C + P^{*}V(t)\ e^{-rT}$$

Where: C = the present value of all silvicultural costs for one rotation (planting, fertilization, etc.)
P = price of timber
V(t) = volume of timber at age t

The present value of the carbon is a bit more complicated. We assume that the amount of carbon fixed by the forest each year is proportional to the forest growth. While this is not precisely correct, it captures enough of the realism of the problem to be useful. We also assume that when the trees are cut, a fraction of the timber goes into long-term storage and the remainder is simply released back to the atmosphere. We call the fraction that goes into long-term storage the "pickling factor." It should be noted that this analysis assumes the only permanent stores are created in forest products, which is not the case, as forests in and of themselves can be permanent stores. However, one can easily extrapolate the results of this analysis to include the retention of trees as part of the pickling factor, as described below. With these assumptions, the present value of the carbon fixed in one rotation is

$$PVcarbon = \int_{O}^{T} P_C a V'(t)\, e^{-rt}\, dt - P_C a (1-ß) V(T) e^{-rT}$$

where P_C = price of a carbon credit
a = amount of carbon fixed per m^3 of timber
$V'(t)$ = the growth rate of the forest
$ß$ = the fraction of the final harvest that goes into long-term storage

The first term of the equation above accounts for the carbon fixed during the rotation. This is, in essence, a series of annual payments received by the landowner for letting the trees grow. The second term reflects the carbon cost of cutting the trees. Just as the landowner received a credit for adding to carbon stores while the trees were growing, they need to pay a tax for releasing carbon when they cut their trees.

The model includes some factors that are well known to foresters—the volume and growth-rate of trees, the price of timber, the discount rate and even the amount of carbon in each cubic meter of wood. But some of the numbers needed to solve this problem—such as the price of carbon and the amount of the harvest that will go into long-term storage—are not know with precision. Hence we present results with a range of these values.

Results for Pacific Northwest and South

To illustrate the importance of carbon credits for forest landowners, we examine two cases, one of growing loblolly pine in the South, and a second of growing Douglas-fir in the Pacific Northwest. Both species are commercially important and both forest types harbor important environmental values, especially in older forests. In each case, the timber and carbon yield tables are taken from standard sources. We determine the rotation age and forestland value with a variety of prices of timber, prices of carbon, carbon pickling factors, and discount rates. It is useful to break the results up into three parts. First, we discuss the impact of carbon credits on the optimal rotation age, and therefore on the economics of holding older forests. Second, we treat the impact of carbon credits on land markets, and therefore on the area of land that is apt to be held in forests. Finally, we comment on the impact of the pickling factor, whether long-term stores are in the forest or in products.

Availability of carbon credits may help landowners preserve older forests

Tables 5 and 6 show the optimal rotation age for the two forest types under a range of assumptions about carbon and timber values.

In the South today, timber sells for between \$50 and \$260 per thousand board feet (mbf) (the lower value for pulpwood and the higher for saw timber). Timberland markets appear to be valuing timber cash flows at about a 7-8% real discount rate. At the higher end of this range of timber values, carbon credits will not have much impact on the rotation age until the value of carbon gets fairly high (e.g. \$100-150/ton carbon, \$27.25- 40.87/ton carbon dioxide). However, for plantations grown primarily for fiber or pulpwood, even modest values of carbon will substantially increase the optimal rotation age. In the tables, the * indicates that it is optimal never to cut the trees since the carbon so far outweighs the value of the timber.

The situation is somewhat different for the Pacific Northwest, where the Douglas-fir forest type naturally carries a longer rotation. Again, as a point of comparison, Douglas-fir currently sells for about \$250-400/mbf, and timberland markets suggest that a discount rate of 8-10% is appropriate to use in this region. At carbon prices in the \$100+ range, there is a major impact on rotation ages. As timber prices continue to fall in the Pacific Northwest, the impact of carbon credits will increase. However, at modest carbon prices, the availability of carbon markets will not have a major impact on landowners' harvest decisions.

Note that these results apply regardless of the initial condition of the forest. If a landowner currently holds a forest that is above these optimal rotation ages, then it is profitable for them to log it now. If carbon credits are available, it may be economic not to log it, or to log less of it, by switching to variable retention.

To see this, take the case of medium-site Douglas fir. Assume an 8% discount rate, that timber is worth $200/mbf and that the pickling factor is 0.38. In the absence of carbon credits, Table 6 shows that the optimal rotation age is 35 years. Therefore, a landowner with timber of this age would want to log it immediately. Suppose that a carbon credit program were implemented and that carbon were selling for $90/ton. Then the optimal rotation age would be 49 years. The owner would then want to hold their trees for at least another 14 years before cutting them. Further, when the pickling rate includes carbon on site, the carbon values provide an effective incentive for variable retention, i.e. leaving up to 25% of the trees on site until the next harvest.

The availability of the carbon revenues, combined with the carbon tax on logging, provides a material incentive for landowners to grow their trees to older ages before cutting them. If a landowner is holding trees for longer rotations than indicated in the base case here in order, for example, to enjoy the environmental amenities associated with older forests, then the availability of carbon credits reduces the opportunity cost of this forest management. Further, if the landowner used variable retention to ensure permanent increased stocks of carbon in the forest (including forest carbon in the pickling factor), then the average age of the forest would be further significantly increased.

Carbon credits will keep more land in forest

Tables 7-10 show the incremental land value associated with various levels of carbon values and pickling rates. As a point of reference, the current value for Southern pine timberland is about $1000/acre, and for Douglas fir timberland in the Pacific Northwest is about $2200/acre (based on timberland values reported to the National Council of Real Estate Investment Fiduciaries-NCREIF). According to our analysis, at current timber prices and an 8% discount rate, the value of medium-site southern pine land would be about 15% lower than that of high-site land. The value of medium-site Douglas fir land would be about 40% lower than the value of high-site land. Again, first consider the South and then the Pacific Northwest.

In the South, even modest levels of carbon values increase land values by a material amount. At high levels of carbon prices, the land is worth more for carbon production than for timber production. On a percentage basis, the impact of carbon credits on medium-site land is greater than it is on high-site land as long as carbon values are small. As carbon values rise, the impact increases on higher-site lands.

In the Pacific Northwest, the impact of carbon credits on land values is even larger than it is in the South. Again, at modest carbon values the impact is modest, but can be quite material at high carbon values. As land carbon values include the timber carbon, the variable retention strategy and reforestation strategy again are highlighted as economically desirable.

What are the likely impacts of carbon credits on forest land use? In locations where the alternative use of the forest land is commercial or residential development, it will probably take very high carbon values to have a meaningful impact on land use conversion-development values are just too high relative to forestland values. However, in locations where the alternative is a rural use, then carbon credits may have a significant impact on land use. For example, the choice between row crops and timber plantation in the South or old fields and reforestation in the Pacific Northwest might easily be weighed in favor of trees if even a modest valuing of carbon occurred. In addition, even at more modest levels, carbon values can contribute significant new funds to help maintain forestlands in the face of conversion, nationwide.

Maximizing the impact of carbon credits depends on effective utilization of harvested timber for energy or long-lived products. The pickling rate has an impact on the outcome of the analysis. This factor represents the amount of the carbon not released at the time of timber harvest : i.e. that remains in the forest, or that goes into long-term storage. Elsewhere in this report it is argued that the pickling rate for products is between 20% and 32.5%. This factor depends on the nature of the forest being logged and the utilization of the wood. It is apt to be higher in plantations than in natural forests, for example, since the objective of plantation management is to increase the "economic yield" of the timber. It is apt to be higher in situations where a larger fraction of the timber harvested is utilized for solid-wood products. It is very unlikely that the fraction would ever reach 1.0 for forest products alone, since some carbon will inevitably be released from the forest as a result of decay of organic matter in the litter and soil. However, through increased efficiency of forest products use and increased retention of permanent stores in the forest, this rate could well be approached. For example, if a landowner shifted silviculture to variable retention of 25% of their inventory, the pickling factor for products would increase by that amount, having a substantial impact on total forest carbon values over time.

The pickling rate will also depend on the rules adopted to account for carbon in forests. Some have argued that none of the carbon fixed in forest products should be credited to forests because of uncertainty over its fate and tracking its decay over time. Others argue that not accounting for such carbon storage understates the value of forests in helping solve the problem of carbon dioxide accumulation in the atmosphere. Indeed, if one were to adopt a full accounting, one might give additional carbon credits to wood used in construction and industrial production where it can be shown that it displaced the use of high embodied-energy products such as concrete, bricks, steel and aluminum.

Regardless of these arguments, it is clear from this analysis that the accounting rules around forest products utilization will affect how carbon credits influence forest management and land use. While not "new carbon" per se, products represent a significant transfer from carbon in the forest to carbon in another long term store. Accounting for the carbon stored in products tends to reduce the impact of carbon credits on lengthening the optimal rotation (though this analysis does not include the well-documented additional value of larger dimension saw-timber that older forests provide). On the other hand, even with this notable exception, it also tends to increase the impact of carbon credits on land values. Hence, if the accounting rules accept the role of forest products in storing carbon, this will tend to keep a great deal more land in forest use and other economic forces may tend to encourage longer rotations on their own. Further, when one includes permanently retained carbon in the forest as part of the pickling factor, i.e. trees on site become a "product," it will tend to support significantly more variable retention. This result suggests that variable retention may be a better strategy for increasing net carbon stocks per acre in the forest than increasing rotations per se.

The Opportunity Cost of Holding Trees to Older Ages

Table 11 provides an analysis of the annual revenue from holding a timber stand another year and the annual opportunity cost. The case modeled is high-site Douglas fir, with a timber price of \$363/mbf, a carbon price of \$9/ton, a discount rate of 8% and a pickling rate of .325. Except for the timber volume and growth data, all figures are in \$/acre. This is the standard optimal rotation analysis used in forest management. The problem is to weight the annual revenue from holding the stand another year against its annual opportunity cost. In this case, the annual revenue comes from the growth of the trees (col. 4) plus the value of the carbon fixed (col. 5). The cost of holding the stand is the foregone interest income associated with cutting the stand and getting one-year's interest on the proceeds. In our case, the value of cutting the stand equals the value of the standing timber (col. 8) plus the bare-land value (col. 9) less the payment of the carbon tax for all the carbon that is released (col. 10).

The final column shows the net value of holding the stand. In this case, the net value goes from positive to negative at age 35, so that is the economically optimal rotation-the landowner starts losing money by holding the stand any longer at this point. Comparing the cost of holding the land for another year versus paying a carbon tax after harvest illustrates the impact of a carbon value. In this instance, it extends the rotation age to 45 or 50, after which the value of the timber sold clearly outweighs the cost of the carbon tax, not counting the influence of higher prices for larger dimension wood. However, when it includes timber retained in the forest through variable retention harvest as part of the pickling factor, the additional carbon value would likely offset the cost of holding 20-25% of inventory on site as permanent stores.

Table 5

OPTIMAL ROTATION FOR MEDIUM-SITE LOBLOLLY PINE IN THE SOUTH

Discount rate		4%				8%				12%			
Timber price [$/mbf]		0	155	259	363	0	155	259	363	0	155	259	363
Economic Rotation w/o Carbon		18				15				13			
Pickling rate	0												
C price [$/ton]	5	*	18	18	18	*	15	15	15	*	13	13	13
	10	*	19	18	18	*	15	15	15	*	14	13	13
	20	*	19	19	18	*	16	15	15	*	14	14	14
	40	*	21	19	19	*	17	16	15	*	15	15	14
	100	*	27	22	21	*	28	19	17	*	29	17	15
	150	*	61	25	23	*	137	25	20	*	136	24	18
Pickling rate	0.38												
C price [$/ton]	5	*	18	18	18	*	15	15	15	*	13	13	13
	10	*	19	18	18	*	15	15	15	*	14	13	13
	20	*	19	19	18	*	15	15	15	*	14	14	14
	40	*	20	19	19	*	17	16	15	*	15	14	14
	100	*	24	21	20	*	22	18	17	*	20	16	15
	150	*	27	23	22	*	28	21	19	*	28	19	16
Pickling rate	1												
C price [$/ton]	5	30	18	18	18	34	15	15	15	41	13	13	13
	10	30	18	18	18	34	15	15	15	41	14	13	13
	20	30	19	19	18	34	15	15	15	41	14	14	13
	40	30	20	19	19	34	16	16	15	41	15	14	14
	100	30	22	21	20	34	19	17	16	41	16	15	15
	150	30	23	21	21	34	20	18	17	41	18	16	15

* indicates that it is optimal never to cut

Table 6

OPTIMAL ROTATION FOR MEDIUM-SITE DOUGLAS FIR IN THE PACIFIC NORTHWEST

Discount rate		4%				8%				12%			
Timber price [$/mbf]		0	259	363	518	0	259	363	518	0	259	363	518
Economic Rotation w/o Carbon		43				32				26			
Pickling rate	0												
C price [$/ton]	5	*	44	44	44	*	35	35	35	*	28	28	27
	10	*	44	44	44	*	35	35	35	*	28	28	28
	20	*	45	44	44	*	36	36	35	*	29	28	28
	40	*	47	46	45	*	38	37	36	*	31	30	29
	100	*	57	52	49	*	47	42	39	*	39	34	32
	150	*	74	59	53	*	63	48	43	*	60	41	34
Pickling rate	0.38												
C price [$/ton]	5	*	44	44	44	*	35	35	35	*	28	28	27
	10	*	44	44	44	*	35	35	35	*	28	28	28
	20	*	45	44	44	*	36	36	35	*	29	28	28
	40	*	47	46	45	*	38	37	36	*	30	29	29
	100	*	54	51	48	*	44	41	39	*	36	33	31
	150	*	62	55	51	*	51	44	42	*	44	37	34
Pickling rate	1												
C price [$/ton]	5	*	44	44	44	*	35	35	35	*	28	28	27
	10	*	44	44	44	*	35	35	35	*	28	28	28
	20	*	44	44	44	*	36	35	35	*	29	28	28
	40	*	46	45	44	*	37	37	36	*	30	29	29
	100	*	51	49	47	*	42	40	38	*	34	32	31
	150	*	54	52	49	*	44	42	40	*	36	34	32

*indicates that it is optimal never to cut

Table 7

INCREMENTAL LAND VALUE FOR HIGH-SITE LOBOLLY PINE IN THE US SOUTH

(% increase over no-carbon case)

Discount rate		4%			8%			12%		
Timber price [$/mbf]		155	259	363	155	259	363	155	259	363
Pickling rate	0									
C price [$/ton]	5	1.50%	0.90%	0.60%	2.30%	1.40%	1.00%	3.00%	1.80%	1.30%
	10	3.00%	1.80%	1.30%	4.60%	2.80%	2.00%	6.10%	3.60%	2.60%
	20	6.00%	3.60%	2.50%	9.80%	5.60%	4.00%	12.70%	7.30%	5.20%
	40	12.70%	7.30%	5.10%	21.20%	11.90%	8.30%	27.80%	15.50%	10.70%
	100	38.10%	20.10%	13.70%	70.90%	34.70%	23.00%	98.30%	46.30%	30.30%
	150	71.90%	33.10%	21.80%	145.30%	60.30%	37.80%	193.80%	82.80%	50.80%
Pickling rate	0.38									
C price [$/ton]	5	3.20%	1.90%	1.30%	4.00%	2.40%	1.70%	4.70%	2.80%	2.00%
	10	6.40%	3.80%	2.70%	8.00%	4.80%	3.40%	9.50%	5.70%	4.10%
	20	12.70%	7.60%	5.40%	16.50%	9.70%	6.90%	19.40%	11.30%	8.10%
	40	26.00%	15.40%	10.90%	34.30%	20.00%	14.10%	40.80%	23.60%	16.50%
	100	68.90%	39.80%	28.00%	95.80%	53.40%	36.90%	117.70%	64.20%	44.00%
	150	107.90%	61.40%	42.80%	156.80%	84.70%	57.80%	197.70%	103.50%	69.60%
Pickling rate	1									
C price [$/ton]	5	6.00%	3.60%	2.60%	6.80%	4.10%	2.90%	7.50%	4.50%	3.20%
	10	12.00%	7.20%	5.10%	13.70%	8.20%	5.90%	15.10%	9.10%	6.50%
	20	24.00%	14.40%	10.30%	27.80%	16.40%	11.70%	30.60%	18.10%	12.90%
	40	48.40%	28.90%	20.60%	56.40%	33.40%	23.70%	62.60%	36.90%	26.00%
	100	123.10%	73.10%	51.90%	146.20%	85.80%	60.60%	164.60%	95.70%	67.30%
	150	186.20%	110.50%	78.40%	223.60%	130.90%	92.20%	253.60%	147.00%	102.90%

Table 8

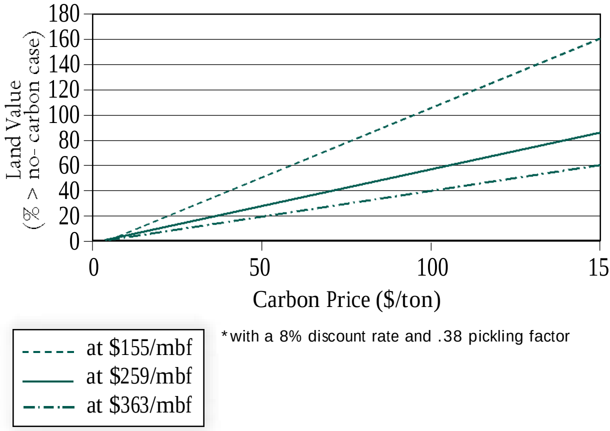
INCREMENTAL LAND VALUE FOR MEDIUM-SITE LOBOLLY PINE IN THE US SOUTH

(% increase over no-carbon case)

Discount rate		4%			8%			12%		
Timber price [$/mbf]		155	259	363	155	259	363	155	259	363
Pickling rate	0									
C price [$/ton]	5	1.50%	0.90%	0.60%	2.30%	1.40%	1.00%	2.90%	1.80%	1.30%
	10	2.90%	1.80%	1.30%	4.80%	2.80%	1.90%	6.10%	3.50%	2.50%
	20	6.10%	3.60%	2.50%	10.00%	5.90%	4.10%	12.90%	7.40%	5.10%
	40	12.90%	7.40%	5.20%	21.70%	12.20%	8.50%	28.40%	15.70%	10.90%
	100	39.30%	20.60%	14.00%	73.10%	35.60%	23.50%	100.70%	47.30%	30.90%
	150	74.90%	34.10%	22.40%	149.40%	62.10%	38.90%	197.90%	84.90%	51.90%
Pickling rate	0.38									
C price [$/ton]	5	3.20%	1.90%	1.40%	4.00%	2.40%	1.70%	4.60%	2.80%	2.00%
	10	6.30%	3.80%	2.70%	8.20%	4.80%	3.40%	9.40%	5.60%	4.00%
	20	12.90%	7.60%	5.40%	16.70%	9.90%	7.00%	19.60%	11.50%	8.00%
	40	26.30%	15.50%	11.00%	34.90%	20.30%	14.30%	41.20%	23.70%	16.70%
	100	69.80%	40.30%	28.30%	97.50%	54.30%	37.60%	119.70%	65.20%	44.50%
	150	109.70%	62.20%	43.40%	160.10%	86.20%	58.60%	201.40%	105.10%	70.50%
Pickling rate	1									
C price [$/ton]	5	6.00%	3.60%	2.60%	6.80%	4.10%	2.90%	7.50%	4.50%	3.20%
	10	12.00%	7.20%	5.10%	13.90%	8.20%	5.80%	15.00%	9.00%	6.40%
	20	24.10%	14.40%	10.20%	28.00%	16.70%	11.80%	30.80%	18.20%	12.80%
	40	48.70%	29.00%	20.70%	57.00%	33.60%	23.90%	63.10%	37.10%	26.30%
	100	123.90%	73.50%	52.20%	147.60%	86.70%	61.10%	166.10%	96.60%	67.90%
	150	187.60%	111.20%	78.90%	226.00%	132.30%	93.10%	256.30%	148.50%	103.90%

Figure 11

INCREMENTAL LAND VALUE FOR MEDIUM-SITE LOBOLLY PINE IN THE SOUTH*



*with a 8% discount rate and .38 pickling factor

Table 9

INCREMENTAL LAND VALUE FOR HIGH-SITE DOUGLAS FIR IN THE PACIFIC NORTHWEST

(% increase over no-carbon case)

Discount rate		4%			8%			12%		
Timber price [$/mbf]		259	363	518	259	363	518	259	363	518
Pickling rate	0									
C price [$/ton]	5	1.70%	1.20%	0.90%	2.40%	1.70%	1.20%	2.90%	2.10%	1.40%
	10	3.40%	2.40%	1.70%	4.90%	3.50%	2.40%	5.80%	4.10%	2.90%
	20	7.00%	5.00%	3.40%	10.00%	7.00%	4.90%	12.00%	8.40%	5.80%
	40	14.70%	10.20%	7.00%	21.30%	14.70%	10.00%	25.70%	17.60%	12.00%
	100	43.40%	28.60%	18.90%	65.00%	42.10%	27.50%	79.50%	51.20%	33.20%
	150	76.10%	47.50%	30.30%	116.60%	71.40%	44.80%	142.90%	87.40%	54.40%
Pickling rate	0.38									
C price [$/ton]	5	2.60%	1.90%	1.30%	3.30%	2.30%	1.60%	3.80%	2.70%	1.90%
	10	5.20%	3.70%	2.60%	6.70%	4.70%	3.30%	7.60%	5.40%	3.80%
	20	10.60%	7.50%	5.20%	13.60%	9.60%	6.70%	15.60%	11.00%	7.60%
	40	21.90%	15.40%	10.60%	28.40%	19.80%	13.60%	32.60%	22.70%	15.60%
	100	59.70%	40.90%	27.80%	79.80%	54.00%	36.20%	93.30%	62.70%	41.80%
	150	95.90%	64.60%	43.20%	131.10%	86.70%	57.10%	154.60%	101.40%	66.30%
Pickling rate	1									
C price [$/ton]	5	4.10%	2.90%	2.10%	4.80%	3.40%	2.40%	5.30%	3.80%	2.70%
	10	8.30%	5.90%	4.10%	9.70%	6.90%	4.80%	10.60%	7.60%	5.30%
	20	16.70%	11.90%	8.30%	19.60%	13.90%	9.70%	21.60%	15.30%	10.60%
	40	33.90%	24.00%	16.70%	40.20%	28.30%	19.60%	44.50%	31.20%	21.60%
	100	88.00%	61.80%	42.60%	106.60%	74.20%	50.90%	119.00%	82.50%	56.30%
	150	135.30%	94.60%	65.00%	165.80%	114.90%	78.20%	186.30%	128.40%	87.00%

Table 10

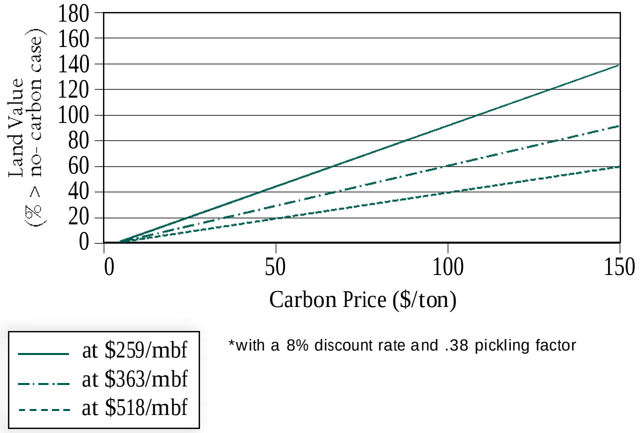
INCREMENTAL LAND VALUE FOR MEDIUM-SITE DOUGLAS FIR IN THE PACIFIC NORTHWEST

(% increase over no-carbon case)

Discount rate		4%			8%			12%		
Timber price [$/mbf]		259	363	518	259	363	518	259	363	518
Pickling rate	0									
C price [$/ton]	5	1.80%	1.30%	0.90%	2.50%	1.80%	1.20%	2.70%	1.90%	1.30%
	10	3.60%	2.60%	1.80%	5.10%	3.60%	2.50%	5.50%	3.90%	2.70%
	20	7.40%	5.30%	3.60%	10.50%	7.40%	5.10%	11.40%	7.90%	5.50%
	40	15.70%	10.90%	7.40%	22.40%	15.40%	10.50%	24.60%	16.70%	11.40%
	100	46.40%	30.50%	20.10%	68.70%	44.40%	28.90%	79.50%	50.00%	32.00%
	150	81.90%	50.90%	32.40%	123.40%	75.50%	47.20%	148.50%	87.90%	53.40%
Pickling rate	0.38									
C price [$/ton]	5	2.70%	1.90%	1.40%	3.40%	2.40%	1.70%	3.60%	2.50%	1.70%
	10	5.40%	3.90%	2.70%	6.90%	4.90%	3.40%	7.30%	5.20%	3.60%
	20	11.10%	7.80%	5.40%	14.10%	9.90%	6.90%	15.00%	10.50%	7.30%
	40	22.80%	16.00%	11.10%	29.50%	20.60%	14.10%	31.50%	21.80%	15.00%
	100	62.50%	42.80%	29.00%	83.20%	56.20%	37.60%	92.40%	61.30%	40.50%
	150	100.90%	67.70%	45.20%	137.10%	90.40%	59.40%	156.40%	100.80%	64.90%
Pickling rate	1									
C price [$/ton]	5	4.20%	3.00%	2.10%	4.90%	3.50%	2.40%	5.10%	3.60%	2.50%
	10	8.50%	6.00%	4.20%	9.90%	7.10%	4.90%	10.30%	7.30%	5.10%
	20	17.10%	12.20%	8.50%	20.20%	14.20%	9.90%	20.90%	14.80%	10.30%
	40	34.80%	24.60%	17.10%	41.30%	29.10%	20.20%	43.30%	30.40%	20.90%
	100	90.60%	63.60%	43.80%	109.80%	76.40%	52.20%	117.30%	80.90%	54.90%
	150	139.60%	97.50%	66.90%	171.10%	118.30%	80.50%	185.10%	126.60%	85.30%

Figure 12

INCREMENTAL LAND VALUE FOR MEDIUM-SITE DOUGLAS FIR IN THE PACIFIC NORTHWEST*



*with a 8% discount rate and .38 pickling factor

Table 11

OPPORTUNITY COST ANALYSIS OF A HIGH-SITE DOUGLAS FIR STAND

1	2	3	4	5	6	7	8	9	10	11
Age	Volume	Growth	Value of Timber Growth	Value of Carbon Fixed	Total Annual Value	Total Annual Cost	Value of Stand Timber	Value of Land	Carbon Tax	Net Value of Holding Stand
t (year)	v(t) (mbf/acre)	v'(t) (mbf/acre/yr)	Pt*V' ($/acre)	Pc*a*V' ($/acre)	TOTAL ($/acre)	TOTAL ($/acre)	Pt*V(t) ($/acre)	PI ($/acre)	Pc*a*(1-B)*(V(t) ($/acre)	Net Value ($/acre)
5	0	0	0	0	0	31	0	389	0	-31
10	0	0	9	0	9	32	7	389	0	-22
15	13	6	76	3	79	43	156	389	5	36
20	56	15	195	7	202	90	765	389	13	111
25	146	23	313	11	324	185	1984	389	66	139
30	275	29	404	14	418	321	3745	389	124	97
35	434	33	463	16	479	487	5896	389	196	-8
40	609	38	496	17	513	672	8286	389	275	-159
45	794	38	509	17	526	866	10797	389	358	-340
50	982	38	508	17	526	1063	13344	389	443	-538
55	1167	38	499	17	516	1259	15868	389	526	-743
60	1348	35	484	17	500	1449	18333	389	608	-949
65	1524	33	465	16	481	1633	20716	389	687	-1152
70	1692	33	445	15	461	1810	23003	389	763	-1350
75	1853	31	425	15	439	1979	25189	389	836	-1540
80	2007	29	404	14	418	2140	27271	389	905	-1723
85	2153	29	384	13	397	2294	29250	389	970	-1884
90	2291	27	364	13	377	2439	31130	389	1033	-2062
95	2422	25	346	12	358	2577	32914	389	1092	-2219
100	2547	25	328	11	339	2708	34607	389	1148	-2369

Without carbon values, optimal economic rotation is at 35 years. With carbon, it is extended to 50 to hold the entire stand. After 50, carbon values, combined with price appreciation of larger dimension timber, likely both extend rotations to some degree and pay for significant variable retention.

Conclusions

As the US examines the suite of actions that it can take to reduce its net carbon emissions, increasing forest carbon sequestration and decreasing forest carbon emissions clearly warrant a place in the "carbon portfolio." The US business-as-usual trends for carbon on private forests demonstrate increasing forest emissions and increasing threats to future carbon sequestration. Private forests make up the majority of forests nationwide, are the most productive, the most managed, and the most threatened. They have the largest impact, therefore, on US forest carbon stocks overall. The US can make demonstrable changes to business-as-usual trends to increase its net carbon stocks.

Increases in net carbon stocks are based on increasing the average carbon stocks on private forests. Such stocks are increased with older forests and more land in forest. These stocks are decreased with harvest (even when forest products are calculated as a store) and conversion. To increase average carbon stocks, three areas of action should be pursued:

- Preventing further forestland losses through increasing conservation of private forestlands
- Increasing reforestation of former forest areas
- Increasing the average stock of carbon per acre in the forest through increasing average forest ages and variable retention harvesting over clearcutting

For such actions to occur, a forest carbon market must be developed that is based on standard accounting rules. These rules must:

- Include both debits and credits
- Discount appropriately for risk
- Discount for less-than-permanent stores
- Require accuracy to the same level as for other emissions sectors

The science of tracking forest carbon changes on site is well developed in the US. Forest carbon accounting at the project level at the same level of certainty as other sectors is clearly feasible.

Forest carbon values provide a significant potential income for forestland owners. Depending on the price of carbon and competing values of timber or development, carbon values certainly provide an incentive for landowners to keep land in forest, reforest former forest lands or marginal croplands, and change forest management through increasing retention from harvest or extending rotations. Each of these actions provides carbon benefits over different periods of time. Preventing forestland conversion yields great carbon benefits immediately; increasing forest age and tree retention provides the greatest short and mid-term benefits, and reforestation/afforestation provides benefits over longer periods of time. Until carbon values are quite high, landowners are unlikely to manage for carbon only as compared to harvesting or developing their land when timber and land values are also high. However, carbon is clearly effective as an incentive for landowners to change forest management to increase forest age through retention or longer rotations, and, in cases of low or medium land value for development, preserve forest and reforest. In cases of high development value, carbon values may provide a significant portion of funding for an overall conservation approach.

The ecological benefits of increasing forest carbon stocks in these manners are many. They include increasing forest biodiversity, resilience, and watershed values. High carbon forests are generally more resistant to fire, disease, and pests. They release less sediment as they are less disturbed, yielding benefits for water quality as well as fish and other aquatic life. Older native forests that have more carbon provide essential habitat for many wildlife species, habitat that is increasingly rare on private lands. Greater area in native forest also reduces fragmentation, for a net biodiversity benefit.

References

Alig, Ralph J. 2000. Draft 2000 RPA assessment: Summary of findings from area change analyses and projections. Corvallis, Oregon.

Barbour, Michael G. and William Dwight Billings. 1998. North American terrestrial vegetation. New York: Cambridge University Press.

Best, Constance and Laurie Wayburn. 2000. America's Private Forests: Status and Stewardship. Island Press (in print).

Binkley, Clark S. 1981. Timber supply from private nonindustrial forests: A microeconomics analysis of landowner behavior. School of Forestry and Environmental Studies Bull. No. 92. New Haven: Yale University, School of Forestry and Environmental Studies.

Birdsey, R.A. 1996. Carbon storage for major forest types and regions in the conterminous United States. Chapter 1 in Forests and Global Change, Volume 2: Forest Management Opportunities for Mitigating Carbon Emissions. N. Sampson and D. Hain (eds.). Washington, D.C.: American Forests.

Brown, S., J. Sathaye, M. Cannell, and P.E. Kauppi. 1995. Management of forests for mitigation of greenhouse gas emissions. In Climate Change 1995: Impacts, adaptions, and mitigations of climate change: Scientific Analyses, ed. R.T. Watson et al. Geneva: IPCC. Contribution of Working Group II to the Second Assessment Report of the IPCC.

Cathcart, James F. 2000. Carbon sequestration: A working example in Oregon. Journal of Forestry 98 (9): 32-37.

Chen, J., J. F. Franklin, and T. A. Spies. 1992. Vegetation responses to edge environments in old-growth Douglas fir forests. Ecological Applications 2: 387-396.

Cohen, W.B., et al. 1996. Two decades of carbon flux from forests of the Pacific Northwest. Bioscience 46 (11): 836-844.

Dixon, R.K., et al. 1994. Carbon pools and flux of global forest ecosystems. Science 263: 185-190.

FAO. 1993. Tropical forest resource assessment. Rome: Food and Agricultural Organization of the United Nations.

Franklin, J.F. and C.T. Dyrness. 1973. Natural vegetation of Washington and Oregon. USDA Forest Service General Technical Report PNW-8: 417.

Franklin, J.F., and R. T. T. Forman. 1987. Creating landscape patterns by forest cutting: Ecological consequences and principles. Landscape Ecology 1: 5-18.

Franklin, J.F. and D.R. Berg, D.A. Thornburgh, and J.C. Tappeiner. 1996. Alternative silvicultural approaches to timber harvesting: variable retention harvest systems. Pages 111-139 in: Kohm, K.A. and J.F. Franklin (eds), Creating a forestry for the 21st century. Island Press.

Gilbert Law Dictionary. 1994. Orlando, FL: Harcourt Brace Legal and Professional Publications, Inc.

Groom, M. J. and N. Shumaker. 1993. Evaluating landscape change: Patterns of worldwide deforestation and local fragmentation. Pp. 24-44 in P. Karieva, J.G. Kingsolver, and R. B. Huey, eds. Biotic Interactions and Global Change. Sinauer Associates.

Grumbine, R. E. 1990. Viable populations, reserve size, and federal lands management: a critique. Conservation Biology 4: 127-134.

Harmon, M.E., W.E. Ferrell, and J.F. Franklin. 1990. Effects of carbon storage of conversion of old-growth forests to young forests. Science 247:699-702.

Harmon, M.E., S. L. Garman, and W. K. Ferrell. 1996a. Modeling historical patterns of tree utilization in the Pacific Northwest: Carbon sequestration implications. Ecological Applications 6: 641-652.

Harmon, M.E., J.M. Harmon, W.K. Ferrell, and D. Brooks. 1996b. Modeling carbon stores in Oregon and Washington forest products: 1900-1992. Climatic Change 33:521-550.

Harmon, M.E., B. Marks, N.R. Hejeebu. 1996c. A users guide to STANDCARB version 1.0: a model to simulate the carbon stores in forest stands. Department of Forest Science, Oregon State University, Corvallis, Oregon.

Haynes, Richard W. et al. 1995. The 1993 RPA timber assessment update. General Technical Report RM-259. Fort Collins, Colorado: U.S. Department of Agriculture, Forest Service. Rocky Mountain Forest and Range Experiment Station.

Intergovernmental Panel on Climate Change (IPCC). 1995. Intergovernmental Panel on Climate Change second assessment on climate change 1995. Cambridge University Press, UK. http://www.ipcc.ch/pub/reports.htm

Intergovernmental Panel on Climate Change (IPCC). 2000. Land use, land use change and forestry. Special report of the Intergovernmental Panel on Climate Change. Watson, Robert T. et al (eds.). Cambridge University Press, UK. http://www.ipcc.ch/

Kershaw, Jr., J. A. et al. 1993. Effect of harvest of old-growth Douglas fir stands and subsequent management of carbon dioxide levels in the atmosphere. Journal of Sustainable Forestry 1 (1): 61-77.

Kimmons, J.P. 1997. A foundation for forest management. Forest Ecology. Second edition. Prentice Hall.

Long, Mark. 2000. "Study shows impact of gases in farming," The Wall Street Journal. September 15, 2000. B9.

Mladenoff, D. J., M. A. White, J. Pastor, and T. R. Crow. 1993. Comparing spatial pattern in unaltered old-growth and disturbed forest landscapes. Ecological Applications 3: 294-306.

Mladenoff, D. J., R. G. Haight, A. P. Wydeven, and T. A. Sickley. 1997. Consequences of species recovery in altered ecosystems: A spatial landscape projection of wolf population recovery in the northern Great Lakes region. Bioscience 47: 21-31.

Myers, N. 1989. Deforestation rates in tropical countries and their climatic implications. Washington, D.C.: Friends of the Earth.

Myers, N. 1992. Synergisms: Joint effects of climate change and other forms of habitat destruction. Pp. 344-354 in P. Karieva, J.G. Kingsolver, and R. B. Huey, eds. Biotic Interactions and Global Change. Sinauer Associates.

Peters, R. L., and T. E. Lovejoy. 1992. Global warming and biological diversity. Yale University Press.

Powell, Douglas S., et al. 1992. Forest resources of the United States 1993. General Technical Report RM-234 (Revised 1994). Fort Collins, Colorado: U.S. Department of Agriculture, Forest Service. Rocky Mountain Forest and Range Experiment Station.

Schulze, Ernst-Detlef, Chritian Wirth, and Martin Heimann. 2000. Managing Forests After Kyoto. Science Sept 22 2000: 2058-2059.

Saunders, D. A., R. J. Hobbs, and C. R. Margules. 1991. Biological consequences of ecosystem fragmentation: a review. Conservation Biology 5: 18-32.

Skog, Kenneth and G.A. Nicholson. 1998. Carbon cycling through wood products: The role of wood and paper products in carbon sequestration. Forest Products Journal 48 (7/8): 75-83

SPNHF, Critical forest land base project: An analysis of the role of New Hampshire's forest land base in supporting a sustainable forestry economy. Concept paper, SPNHF, Concord, NH, March 6, 2000.

Sundquist, D, and M. Stevens. 1999. New Hampshire's Changing Landscape. Population Growth, Land Use Conversion, and Resource Fragmentation in the Granite State. SPNHF and The New Hampshire Chapter of the Nature Conservancy, Concord, NH.

Tuchmann, E.T., K.P. Connaughton, L.E. Freedman, C.B. Moriwaki. 1996. The Northwest Forest Plan. A report to the President and Congress. Portland, OR: USDA Office of Forestry and Economic Assistance.

Turner, D.P. et al. 1995a. A carbon budget for forests of the conterminous United States. Ecological Applications 5(2): 421.

Turner, D.P. et al. 1995b. Carbon sequestration by forests of the United States: current status and projections to the year 2040. Tellus 47B: 232.

United Nations Framework Convention on Climate Change (UNFCCC). 1997. Kyoto Protocol to the United Nations Framework Convention on Climate Change. http://www.unfcc.de/resources/docs/convkp/kpeng.html

U.S. Department of Agriculture, Forest Service. 2000. Draft resource planning assessment database. http://www.srsfia.usfs.msstate.edu/wo/wofia.htm

U.S. Department of Agriculture, Natural Resources Conservation Service, 1999. National Resources Inventory 1997. Entire report obtained Friday, December 3, 1999. http://wwwnhq.nrcs.usda.gov/NRI

U.S. Department of State, Bureau of Oceans and Scientific Affairs. 1997. Second US National Communication.

U.S. Department of State, Bureau of Oceans and International Environmental and Scientific Affairs. 2000. United States submission to Land-Use, Land-Use Change and Forestry. http://www.state.gov/www/global/global_issues/climate/fs_000801_unfccc1_subm.html

Van Kooten, G.C., C.S. Binkley and G. Delcourt. 1995. Effect of carbon taxes and subsidies on optimal forest rotation ages and supply of carbon services. American Journal of Agricultural Economics. 77:365-374.

Wayburn, Laurie A., and William Richards. 1999. Changes in on-site carbon stores resulting from the transitions in silviculture on forests managed by MacMillan Bloedel. A Report for the World Resources Institute. Boonville, CA: The Pacific Forest Trust.

Wilcove, D. S., C. H. McLelllan and A. P. Dobson. 1986. Habitat fragmentation in the temperate zone. Pp. 237-256 in M. E. Soule, ed. Conservation Biology. Sinauer Associates.

About the Authors and Contributors

Laurie A. Wayburn is the co-founder and President of the Pacific Forest Trust. Ms. Wayburn has more than 20 years' experience in conservation-based sustainable development, nationally and internationally. She has served on the boards of numerous entities to further forest conservation and stewardship, including the Seventh American Forest Congress, The University of California Center for Forestry, The Oregon Board of Forestry Incentives Group, and the Society of American Forestry Certification Task Force. She has also served on the boards of the US Man and Biosphere Committee for Biosphere Reserves and The Compton Foundation. Ms. Wayburn is a frequent writer and speaker on the topic of private forest conservation and most recently co-authored "America's Private Forests: Status and Stewardship," to be published by Island Press in Spring 2001.

Jerry F. Franklin is Professor of Ecosystem Analysis in the College of Forest Resources at the University of Washington, He was a scientist with the Pacific Northwest Research Station for 35 years, Director of the Long Term Ecological Research program for 12 years, and a Program Officer for the National Science Foundation. His research emphasis has been on structure and function of natural (especially old-growth) temperate forests and application of forest ecosystem principles in forest management.

John C. Gordon is Pinchot Professor at the Yale School of Forestry and Environmental Studies. He served as Dean of the School for ten years and was co-chair of the Seventh American Forest Congress. He is a principal of the Interforest LLC, a forestry consulting form, and Chairman and CEO of Candlewood Timber Group, a sustainable forestry venture in Argentina. His long-term research interests are carbon and nitrogen fixation by trees and forest policy.

Clark S. Binkley, Ph.D., Chief Investment Officer, leads the Hancock Timber Resource Group's research, client account management, and business development efforts. Immediately prior to joining HTRG, Clark was Dean of the Faculty of Forestry at the University of British Columbia. He has served on the boards of directors of several publicly traded forest products companies and private timberland ventures and has consulted to numerous forest products companies, governmental agencies and private conservation groups. He has written more than 100 books and articles on forest economics, and is known worldwide for his research on timberland investments. From 1978-90, he was a member of the faculty at Yale University in the School of Forestry and the School of Management, and in 1990 was named the Frederick K. Weyerhaeuser Professor of Forest Resource Management.

David J. Mladenoff is Professor of Forest Ecosystems and Landscape Ecology in the Department of Forest Ecology and Management at the University of Wisconsin-Madison. His research focuses on the interactions of natural and human-induced effects on sustainable forests. Publications include a recent book published by Cambridge University Press. His work has been recognized by the Pound Research Award of UW-Madison and participation on several state and national panels dealing with forest management and policy issues. He is currently editor in chief of the journal Landscape Ecology.

Norman L. Christensen, Jr. is Professor of Ecology and Dean of the Nicholas School of the Environment at Duke University. Christensen's research interests are broadly defined as the effects of disturbance on the structure and function of ecosystems. His professional accomplishments are numerous at the national, state, and regional level, where he has served collaboratively in many capacities for government, corporate, and non-profit organizations. Appointed by President Clinton in January 1997, Christensen serves as a member of the U.S. Nuclear Waste Technical Review Board.

Project Contributors:

William S. Richards is a forest ecologist with The Pacific Forest Trust with twelve years' experience in field application of wildlife biology. Mr. Richards has an emphasis in threatened and endangered species issues in the forests of the Pacific Northwest. He has a Master of Science degree in landscape ecology from Western Washington University, and a Bachelor of Science in zoology from the University of British Columbia.

Dr. G. Cornelis van Kooten is Professor of Natural Resource Economics at the Universities of Nevada, Reno, and Wageningen in the Netherlands. He is also co-director of the Forest Economics and Policy Analysis (FEPA) Research Unit located at the University of British Columbia. His recent books include The Economics of Nature (Blackwell, 2000) and Conserving Nature's Diversity (Ashgate, 2000). Professor van Kooten has published more than 100 articles in various academic journals and books.

Michelle Passero is PFT's Manager of Policy Initiatives—Forest Forever Fund, a program to promote the role of forest conservation and sustainable management in mitigating global warming in evolving domestic and international policy. Ms. Passero is a candidate for a Master of Laws degree in Sustainable International Development at the University of Washington, has a J. D. from the University of San Francisco, and a B.A. in Political Science and Sociology from the University of Vermont. She was previously a contract attorney in environmental law focussing on land-use regulations and the management of natural resources.

Emina Krcmar is a senior research associate with the Forest Economics and Policy Analysis (FEPA) Research Unit and Centre for Conservation Biology at the University of British Columbia. Her research focuses on the methods for multi-objective conflict resolution and decision-making under uncertainty, and their applications to sustainable forest management. Ms. Krcmar has taught courses in quantitative decision making, statistics and mathematical economics at the University of British Columbia and the University of Belgrade.

THE PACIFIC FOREST TRUST

The Pacific Forest Trust was founded in 1993 by concerned landowners, foresters, conservationists, and some of the nation's most experienced land protection experts to enhance, restore, and preserve the private, productive forests of the Pacific Northwest. With offices in California and Washington, PFT is a specialized land trust for working forestlands; an information, education and research center for stewardship forestry; and a policy institute promoting incentives for long-term forest stewardship.

A collaborative, problem-solving organization, PFT works with landowners, forest managers, public agencies, local communities, and others to sustain private forestlands for the wealth of goods and services they provide.

The Pacific Forest Trust believes that maintaining long-term, ecologically based productivity is the key to forest preservation. Private forests will be preserved only if they remain productive; they can produce only if they are preserved.