Terrestrial Carbon Sequestration in the Northeast: Quantities and Costs

Part 4. Opportunities for Improving Carbon Storage and Management on Forest Lands

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4 OPPORTUNITIES FOR IMPROVING CARBON STORAGE AND MANAGEMENT ON FOREST LANDS

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4.1 EXECUTIVE SUMMARY

This chapter examines the potential to increase carbon sequestration in forests of the northeastern states through alternative management activities. The activities investigated include extending rotation ages of softwood forests beyond their economically optimal rotation age, harvesting and re-stocking currently under-stocked, but mature, forests, conserving forests in riparian zones, and additional thinning. The first three of the analyses are conducted across the region, while the final analysis (the potential for increasing thinning to enhance carbon sequestration) is done as a case study.

The results indicate that up to 23.9 million t CO_2e of present value carbon may be sequestered in the region for $10/t CO_2e, and up to 28.6 million t CO_2e present value carbon may be sequestered for $20/t CO_2e. Around 56% of the sequestration available at these prices is due to extending rotation ages beyond optimal ages in softwood forests, with most of the remaining carbon achieved by harvesting and re-stocking of under-stocked, mature stands. Setting aside riparian zones along streams appears to have little carbon benefit in the region.

Potentially large quantities of carbon are available in relatively short time periods from these actions. For instance, up to 1.4 million t CO_2e could be sequestered within the next 10 years on around 195 thousand acres of land by harvesting and re-stocking forests. Similar amounts of carbon would be available in 10 years through extending the rotation age of softwood stands on only about 116 thousand acres. The riparian analysis indicates that it would take around 162 thousand acres for this much carbon in 10 years.

With all of these analyses, it is important to distinguish between short-run and permanent sequestration. All of the actions investigated in this study can provide short-term carbon gains, but because the baseline and the scenarios include forest rotations, the actual sequestration in any particular future year can be positive or negative. Simply summing sequestration over a particular number of years provides estimates of positive or negative sequestration depending on the number of years considered. The relatively large quantities of near term carbon, particularly in the analysis of extending rotation ages, tends to drive down the overall cost estimates when considered in present value terms (i.e., present value carbon and present value tons).

Regionally, the largest potential for extending rotation ages was found in the northern and eastern counties of Maine. In general, Maine appears to have the greatest potential with extending rotation ages. Moving further west, the potential declines. Similarly, Maine appears to have the greatest potential with options to re-stock poorly stocked stands, although there are no discernible spatial trends when mapped. There do appear to be fairly large areas with little potential at less than $10/t CO_2e.
CO_2e
A number of sensitivities were investigated in the analysis. When extending rotation ages, the inclusion of credits for biomass energy produced from milling residues reduces the potential carbon sequestered and raises the costs of carbon sequestration relative to the case where no credits are provided for biomass energy produced. Similar effects are inferred for the harvesting and re-stocking of under-stocked stands. Reducing the discount rate of the analysis increases the costs for extending rotation ages. All of the studies assume that timber prices remain constant, although widespread extending of rotation ages or widespread harvesting of under-stocked stands in initial periods would both be expected to alter prices in the near-term and raise costs.

4.2 INTRODUCTION

This chapter examines carbon (C) sequestration potential through management of forests in the northeast states of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont. Over the past century, the area of forests in these states has expanded dramatically on old, abandoned agricultural lands (Smith et al., 2006a). With this expansion in forests, carbon stocks have increased. In recent years, the area of forests in these states has stabilized at around 72.9 million acres and net growth of biomass in forests have slowed to around 0.5% per year (Smith et al., 2006a). It is useful to consider whether alternative management practices in these forests can increase the accumulation of carbon in forests, and thereby help reduce the potential impacts of climate change.

An earlier analysis of forest trends in the region (Sohngen, 2006, and summarized in Appendix 1 to this chapter) suggests the following about forests of the northeastern US:

(1) The area of forestland in northeastern states has remained relatively constant over the past several decades at around 72.9 million acres. The largest areas of forestland are located in the largest states, Maine, New York, and Pennsylvania. These states contain around 73% of the total forestland in the region. Total growing stock volume is around 2.9 billion m^3. Only around 65% of growing stock volume is located in the states of Maine, New York, and Pennsylvania.

(2) Most of the growing stock volume in the region is hardwood (71%). Maine has the largest proportion of total growing stock volume in softwoods, around 56%, followed by New Hampshire and Vermont.

(3) Net growth rates are approximately 0.5% per year for all species. Net growth in hardwoods is about 0.5% per year, and in softwoods it is about 0.4%. Net growth rates are slowest in Maine, New Hampshire, New York, and Pennsylvania and fastest in New Jersey, Massachusetts, and Maryland.

(4) The dominant hardwood types are Maple-Beech-Birch, and Oak-Hickory, accounting for about 69% of total forestland area and 51% of total growing stock volume. Softwood forest area is dominated by Spruce-Fir forests (10%), followed by White-Red-Jack pine (8%).

(5) Removals for industrial wood purposes are approximately 31.5 million m^3 per year. Most of the removals are in hardwoods (63%), although Maine does extract slightly more softwood volume than hardwood volume. The largest removals occur in Maine, followed by Pennsylvania, New York, and New Hampshire.

(6) Total carbon is increasing by approximately 8.9 million tons C per year. Increases in carbon are largest in smaller states like Maryland and Massachusetts, and smallest in states with relatively larger total volumes.

As a result of analyzing these trends, four options emerged as potentially providing the best opportunities to increase sequestration in existing forests at the least cost (see Sohngen, 2006). These options are

(1) Extending the rotation age in softwood forests

(2) Improving stocking conditions in poorly stocked stands

(3) Enhancing riparian zones along streams

(4) Thinning.

This chapter examines each of these options in more detail, including information on the methods and data used to estimate the costs and quantities of carbon sequestration.

4.2.1 A Note on Discounting

The question of whether to discount carbon flows when conducting analysis of carbon sequestration in forests has been confused in the academic and popular literature, as well as in discussions about carbon sequestration on the landscape. This brief discussion attempts to clarify this debate in the context of this report.

Consider an example of an energy plant that faces a cap on their carbon emissions. This cap will require them to reduce their annual emissions by X_t tons each year. X_t is not the same each year because the company is expected to grow, and the caps are expected to change over time. They can either reduce their emissions within their plant, or they can purchase offsets from a carbon market. To reduce emission from their plant, they could install a new technology to capture the additional carbon, and store it underground. They have capital costs of installing this technology and annual operating costs. As with other capital expenditures, the company would amortize the costs of the capital and depreciation over the life of the technology. This complex calculation would result in an annual equivalent cost of owning the capital, and to that they would add the annual operating costs to estimate the total annual equivalent cost of owning and operating the capital. The calculation would result in an annual dollar value of holding and operating the technology (C^p) that accounts for all costs, including interest rates. The technology provides a stream of annual carbon captured and stored into the future. Assume this stream is equivalent to the X_t tons each year that they need to reduce. C^p is already an annual equivalent amount that accounts for interest rates, depreciation, and operating costs, as discussed above. X_t is a path of carbon. How would the company determine whether to buy offsets from a carbon market, currently priced at $P^c{}_t$, or install the technology?

The company would need to compare expected costs of purchasing the path of X_t at prices P_t with the costs of installing the technology in their plant. Specifically, this would be:

(1) $$\sum_0^T C_t^p (1+r)^{-t} < \sum_0^T P_t^c X_t (1+r)^{-t}$$

If the discounted annual costs of installing and operating the technology inside their plant (which will provide X_t) are less than the annual costs of purchasing carbon credits from the market then they will install the technology. The plant could also impute a "break-even" price. This price is the constant price of carbon that would make them indifferent to installing the technology versus purchasing the carbon credits on the market:

(2) $$\frac{\sum_0^T C_t^p (1+r)^{-t}}{\sum_0^T X_t (1+r)^{-t}} = \overline{P}_t^c$$

Equation (1), which is derived from the companies benefit cost analysis of the technology versus the carbon market, tells us: **If the discounted costs of installing the technology divided by the discounted carbon provided by the technology is less than the assumed constant price of carbon, then the company would invest in the technology**. Equation (2) is a simplification of the more complex problem in (1). It assumes carbon prices are constant forever in order to assess a simple trade-off that companies can make. If companies have more complex visions about future carbon prices (i.e. suppose they assume the carbon prices rise with stricter caps), they will need to implement equation (1) and just compare the benefits and costs.

Now suppose that you are a supplier of carbon credits, and you are considering whether to supply those to the same market as above. Similarly to the energy plant, doing the carbon project entails initial costs, depreciation, and annual operating costs. As with the energy plant, the forest carbon producer can determine an annual equivalent cost by amortizing all of these costs over the life of the project. This annual equivalent cost is C^f. Similarly to the energy plant, the forestry project leads to a path of carbon gains over the life of the project. These are assumed to be S_t. The supplier would develop the project if the following condition is met:

$$(3) \quad \sum_{0}^{T} C_t^f (1+r)^{-t} < \sum_{0}^{T} P_t^c S_t (1+r)^{-t}$$

Equation (3) tells us that the supplier would invest the annual equivalent amount of C^f each year only if this investment is less than the present value of the annual carbon sequestration that can be sold on the market at a price of P^c_t. We can make a similar simplification as above for the supplier. Specifically, suppose the supplier believes that carbon prices will be constant over time. They can re-arrange equation (3) to determine:

$$(4) \quad \frac{\sum_{0}^{T} C_t^f (1+r)^{-t}}{\sum_{0}^{T} S_t (1+r)^{-t}} = \overline{P}^c$$

Equation (4), which is derived from the suppliers benefit-cost analysis of the decision to develop a carbon project in forests, tells us: **If the discounted costs of developing the forestry project divided by the discounted carbon provided by the forestry project is less than the assumed constant price of carbon, then the supplier would develop the project**. Equation (4) is a simplification of the more complex problem in (3). It assumes carbon prices are constant forever in order to assess a simple trade-off that the supplier can make. If the supplier has a more complex vision about future carbon prices (i.e. suppose they assume the carbon prices rise with stricter caps on energy emitters), they will need to implement equation (4) and just compare the benefits and costs.

Thus, one can see from equations (2) and (4), that the decisions facing energy companies and the decisions facing carbon offset suppliers are similar. Under the simple assumption that carbon prices are constant, one would invest in carbon sequestration in forests if the present value of costs divided by the present value of carbon is less than the constant price. *It is also clear from equation (2) that companies should be discounting carbon if they are trying to derive a break-even price for the carbon.* Discounting carbon is not unique to forestry.

In the context of most efforts to estimate carbon supply functions for forestry projects, a dilemma arises. Analysts can fairly easily estimate the present value of costs in the numerator of equation (4). This is just the stream of assumed costs across a project, with the appropriate discounting associated with it. They can also fairly easily estimate the present value of carbon in the denominator of equation (4) similarly. However, discounting carbon, a physical quantity, is not something that is typically done in economics or finance, so inevitably the debate arises: "should we discount the carbon." The answer is yes. If carbon is not discounted, then one is not conducting the benefit cost analysis in equation (3). Failing to conduct this analysis could lead to investments that do not perform as expected.

The rationale for discounting carbon flows thus arises from the notion that companies need to compare the present value of costs and benefits from energy projects with the present value of costs and benefits form forestry offset projects (i.e., they need to combine equations 2 and 4) A means for conducting this comparison is to assume that carbon prices are constant and calculate the ratio of discounted costs to discounted carbon as in equation (4) for specific projects This is the imputed cost of carbon sequestration. In the literature, many studies have referred to it as the marginal cost of carbon sequestration, although it is a true marginal cost only under some conditions.

However, equation (4) actually only provides a measure for arraying different projects. Projects with a lower calculated ratio of discounted costs to discounted prices would be preferred. They are the lowest cost projects because they provide the most carbon in initial periods for the least cost. Anything in the project that accelerates carbon (but holds costs constant), lowers the ratio of discounted costs to discounted carbon. Anything that pushes costs to the future (but holds carbon constant), also lowers the ratio of discounted costs to discounted carbon. These both are desirable properties and thus influence the evaluation of projects when using equation (4).

One of the confusions that arises in the literature occurs when policy makers want to know the undiscounted tons of carbon available in a particular time period or cumulatively by a particular time period. Summing up tons over a particular time-frame is a perfectly legitimate from an economic standpoint. For example, energy companies will often analyze the annual amount of electricity they expect to sell in future years when planning their investments in energy producing plants. However, when assessing whether making new investments is wise, they will assess the time path of fixed and variable operating costs, as well as the price of future energy and compare the present value of costs to the present value of prices times energy produced, as in equation (1) above. They will systematically vary the price to determine a break-even price that just sets benefits and costs equal. This is equivalent to what is done in equation (2). They then need to compare that price to their projection of prices.

Simply adding up kilowatt hours of energy, or tons of carbon, in different time periods is useful. When conducting economic analysis to consider whether the investments will pay off, however, one must pay careful attention to discounting. The interest rate used in equations (1) and (2) above is the rate of return on capital investments. If, under the prices the company projects for the future, and the assumed rate of return on capital investments, the project has present value costs greater than present value benefits, they would not make the investment. The company should consider different investments that can yield present value benefits greater than present value costs. The rate of return on capital defines the value of investing in other assets, where those assets return present value benefits greater than or equal to present value costs.

Similarly for forestry projects, if the present value benefits are less than the present value costs, then the company should consider different investments that have greater annual benefits. By failing to conduct present value analysis with forestry carbon sequestration projects, the results of the analysis will be biased towards potentially under-performing forestry projects.

Forestry projects, however, clearly are different from reductions in energy emissions. Investments in emissions reductions technology in the energy sector provide a flow of reductions in carbon emissions. Likewise, investments in forestry carbon sequestration projects, such as afforestation for forest restoration provide a flow of emissions reductions. But it is widely recognized that the forestry projects, especially those related to changes in forest management practices, may result in sequestration in some years and emissions in other years. Consequently, project assessments that simply account for carbon sequestration in some years, but ignore carbon emissions in other years will be incorrectly valued. This is a particular issue of the analyses conducted in this section, which focus on management changes and not simply reforestation or afforestation of agricultural land.

The issue raised in the preceding paragraph – permanence – is different from the question of discounting carbon. As argued previously, when analyzing the economics of investing in forestry sequestration projects, calculating the present value of carbon benefits and comparing it to the present value of costs is imperative. It is clear, though, that with discounting, additional periods of analysis will have smaller effects on the overall evaluation of benefits and costs. Thus, when evaluating the benefits and costs, it may only be necessary to evaluate the first 50 or 100 years to obtain an accurate analysis of costs and benefits.

This analysis relies on equations (3) and (4) to assess the benefits and costs of carbon sequestration in forests. Equation (4) shows the calculation of the price of carbon that would be necessary over the period of analysis for the project's present value of benefits to just equal the present value of costs. This is the measure of cost per ton used in this analysis.

To calculate total carbon sequestered with the projects investigated in this analysis, discounted carbon over the project period is used, as follows:

(5) Cseq = $\sum_{0}^{T} S_t (1+r)^{-t}$.

Discounted carbon is preferred as the measure of carbon sequestered from an economic perspective (Richards and Stokes, 2004). Discounted carbon is the amount of present value carbon today that is sequestered by the project. This number can be compared to tons of emissions reductions required today in other sectors.

In addition to discounted carbon, the total undiscounted carbon sequestered over 10, 20, and 40 year contract periods is also presented to provide policy makers with information on the total (undiscounted) carbon available over a given time period. Undiscounted carbon is calculated as

(6) CseqU = $\sum_{1}^{X} S_t$ where X = 10, 20, or 40 years

Policy makers (and companies) must be careful assuming that undiscounted sums of carbon in this chapter will be available in perpetuity (i.e., "permanence"), because the results below clearly show periods of carbon sequestration and periods of carbon emissions with all of the projects. Ignoring future periods when emissions occur may bias the results towards certain types of projects. If the companies buying the credits are liable for the future emissions, then simply calculating a short period of cumulative carbon and ignoring the possible future emissions will be incorrect (insofar as they may fail to account for the need to find permanent offsets somewhere else once these projects end). This issue applies both to discounted and undiscounted carbon when calculated over a short time period; however, because discounting reduces the effect of potential emissions from future time periods, the error in evaluating projects with discounting will be smaller than the error when evaluating projects without discounting. Thus, discounting carbon is preferred for all forestry carbon projects to reduce the errors that can be caused by ignoring future periods.

The analysis above has assumed that carbon prices remain constant. If carbon prices are rising, however, the calculations above change. Specifically, equation (3) becomes

$$(7) \quad \sum_{0}^{T} C_t^f (1+r)^{-t} < \sum_{0}^{T} P_0^c (1+g)^t S_t (1+r)^{-t}$$

In equation (7) P^c_0 is the initial carbon price, and g is the rate of growth of carbon prices over time, assumed here to be constant over the period T. Equation (7) can be re-arranged to be written as:

$$(8) \quad \sum_{0}^{X} C_t (1+r)^{-t} < P_0^c \sum_{0}^{X} S_t \left(\frac{(1+g)}{(1+r)} \right)^t$$

Equation (8) can then be written as:

$$(9) \quad \frac{\sum_{0}^{X} C_t (1+r)^{-t}}{\sum_{0}^{X} S_t \left(\frac{(1+g)}{(1+r)} \right)^t} < P_0^c$$

According to equation (9) if carbon prices are expected to rise, then project developers would develop the same project at a lower initial price compared to the case where carbon prices are constant (i.e., g=0). If carbon prices are expected to rise to higher levels, this creates more incentive to engage in carbon sequestration projects by lower the net discount rate on carbon. However, one must be careful when evaluating the trade-offs when prices are rising. At the margin, rapidly growing prices also create incentives to wait to sequester carbon.

Suppose an individual has $500 to invest in a carbon sequestration project. Suppose under constant prices, they find it optimal to invest immediately by equation (4) at a carbon price greater than $36/t C. If carbon prices instead rise at 2% per year, the **initial** price at which they could invest and still make money would fall to $19/t C. This ignores an additional important option they have of not investing right away in the carbon project at all and instead investing their $500 in a different project which returns 5% (the interest rate defines returns in other investments). If carbon prices were $19, they would be better off waiting several years to invest, collecting their interest payments on the $500 and investing in the carbon project when prices are higher. Thus, equation (9), which is used when carbon prices are assumed to be rising, can be used to array projects from lowest to highest cost. But it does not define the best option, among all in the economy, available for investing $500.

4.3 Extending The Rotation Age in Softwood forests

In this section, the costs extending the rotation age in northern softwood forests, particularly pine and spruce-fir forests in Maine, New Hampshire, Vermont, and New York are examined. These states only are considered because most industrial management of forests in the Northeast occurs there. Furthermore, softwoods are typically managed with even-age rotations. On the other hand, hardwoods are often managed unevenly aged with selective harvesting (as opposed to clear cuts) or other types of harvests and, as such, the carbon accounting for increased aging is not readily amenable for analysis. The analysis for softwoods accounts for potential changes in the age class at harvest on 9.3 million acres of white-red-jack pine and spruce-fir forests in the four states.

4.3.1 Methodology

Previous estimates of carbon sequestration costs through aging timberland have been developed for several southern and western states (Sohngen, 2003, 2004a, 2004b). The methods used to estimate the costs of carbon sequestration through aging in this chapter most closely follow those developed for aging timber in California (Sohngen, 2004b).

Several important **assumptions** underlie the analysis of extending rotation ages:

1. prices for all products and carbon are assumed to be constant over time;
2. for financial analysis, the value of carbon sequestration is discounted;
3. potential carbon storage for the purposes of determining the tons sequestered, additional tons gained over time, are also discounted. This is separate from the question of estimating the tons sequestered by specific time periods, and in several places below, undiscounted carbon estimates are provided.

To estimate the marginal cost of carbon sequestration in forests through extending the rotation age, the optimal rotation period with and without terms for the valuation of carbon storage is calculated. Optimal rotation periods for a range of carbon prices, and the additional (permanent) carbon stored for the alternative rotation periods are calculated. The carbon prices that achieve 5, 10, or 15 year aging periods are thus the marginal costs of sequestering carbon, assuming that carbon and timber prices are constant.

To calculate optimal rotation periods under alternative carbon and timber prices, the following function is maximized:

(10) Stand Value = W(a) =

$$\frac{(P_S\phi_S + P_P\phi_P)V(a)e^{-ra} + P_C\alpha V(a)e^{-ra} + r(P_C - C_m)\int_0^a \beta(n)V(n)e^{-rn}dn - C}{(1-e^{-ra})}$$

Where:

PS = price of sawtimber products (stumpage, \$/ft3)
Pp = price of pulpwood products is (stumpage, \$/ft3)
P_C = price of sequestering a ton of carbon forever.
V(a) = biomass yield, or growing stock volume (ft3 per hectare)
Φ_S = proportion of biomass used for sawtimber
Φ_P = proportion of biomass used for pulpwood
α = factor for converting harvested biomass into "permanently" stored carbon.
β(t) = factor for converting biomass yield into carbon.
C = harvesting costs
C_m = monitoring costs
r = interest rate
a = rotation period.

The first part of Eq. 10 represents the value of harvesting the stand and selling products in markets, (PSφS + PPφP)*V(a)e-ra. The second part of Eq. 10 is the value of storing carbon permanently in markets [PCαV(a)e-ra]. The term α is calculated as the present value of initial storage in market products less the present value of decomposition or replacement rate of products:

$$(11) \quad \alpha = \gamma\phi_S(0) - \int_0^\infty \delta_S \gamma\phi_S(n)e^{-rn}dn + \gamma\phi_P(0) - \int_0^\infty \delta_P \gamma\phi_P(n)e^{-rn}dn$$

The term γ accounts for wood density and converts wood biomass into carbon. The term α therefore accounts for the proportion of the harvested volume that is carbon as well as the proportion stored permanently in marketed products. Permanent storage is valued at the market price for carbon sequestration, PC. The term $[\, r(P_C - C_m)\int_0^a \beta(n)V(n)e^{-rn}dn\,]$ accounts for the value of carbon sequestered on the stump. Carbon on the stump is rented annually at the rate of rP_C. Because the volume of carbon on the stump grows over time, the annual value of rental payments for carbon sequestration will increase over time. Consequently, within each rotation, the present value of rental payments must be calculated with the integral in Eq. 10. The term β(n) converts timber volume into carbon. As noted in Smith et al. (2003b), carbon per unit of timber volume changes over time, so the carbon conversion factor for timber on the stump is a function of time.

For the analysis, Eq. 10 is solved numerically for each timber type and pricing region over a set of constant carbon prices (ranging from \$0 - \$270 per t CO_2e). This allows the optimal rotation age to be determined, given timber prices and carbon prices. The carbon price, as shown in Eq. 10, represents the marginal cost of carbon storage in forests. For each carbon price (or marginal cost), the optimal additional aging period is calculated.

The additional carbon stored when forests are aged is calculated separately for each aging period. For this analysis, several different time periods are used to estimate carbon gains, 10, 20, and 40 years to simulate specific contracts periods. A 300 year period is also used to assess permanent carbon gains. To estimate the tons sequestered in each of these cases, carbon stocks are calculated across the entire 300 year period for the baseline, and for each increment in rotation ages. The carbon benefit calculated for aging timber under a permanent contract is estimated as the net present value of the annual change in the difference in carbon stocks (both in products and stored on the stump) during this period. The annual difference in carbon stocks is given as:

$$(12a) \quad CSD_t = CS_t^{ER} - CS_t^{B}$$

where CS_t^{ER} is the carbon stock in each time period under the extended rotation, and CS^B is the carbon stock in each time period under the baseline. Stands are assumed initially to be at the optimal rotation period (the baseline rotation period, “B”). In the baseline, stands are assumed to be continuously harvested at the economically optimal rotation age. In the extended rotations with carbon prices, stands are also assumed to be harvested continuously at optimal rotations, but the optimal rotations will be longer due to carbon prices.

To estimate carbon gains, the change in stock differences from period-to-period is calculated as S_t:

(12b) $$S_t = CSD_t - CSD_{t-1}$$

The change in stock differences registers the net gain (or loss) of carbon in each period. The cumulative effect of net gains (or losses) in the future is the cumulative effect of the adjustment in the rotation age. In this study, present value techniques are used to discount the annual carbon flows measured by S_t. The net present value of the cumulative effect of the change in rotation is calculated as:

(12c) $$NPV(Carbon) = \sum_{0}^{300} S_t (1+r)^{-t}$$

If discounting is ignored, then r = 0. In cases where discounting is ignored, the analysis will result in no clear positive or negative effect, no matter what time period is used. This occurs because the two different rotations lead to different carbon stocks, but in any particular year, the cumulative difference may be positive or negative, depending on the length of the original rotation and the extension. Without discounting one must carefully choose the length of time for the analysis.

4.3.2 Data, carbon sequestration estimates, and sensitivities

Table 4-1 presents information on the stumpage values and the sources of data for stumpage values. Stumpage prices are delivered log prices minus the costs of logging and hauling wood, thus for the aging analysis it is not necessary to have estimates of logging and hauling costs. Stumpage price estimates contain a range of sale types, and consequently harvesting and hauling costs associated with them.

Table 4-1. Timber price and cost data used for analysis

	2005 Stumpage Price Range ($/m^3)			
	Sawtimber	Pulp	Biomass	Source
CT	$5.20 - $27.85	$0.38 - $0.76	$2.04 - $2.04	http://forest.fnr.umass.edu/snestumpage.htm
DE	$6.79 - $48.9	$1.85 - $1.85	$4.54 - $4.54	http://www.naturalresources.umd.edu/Stumpage_Prices.cfm
ME	$12.22 - $53.14	$3.27 - $17.93	$0.52 - $5.1	http://www.maineforestservice.org
MD	$6.79 - $48.9	$1.85 - $1.85	$4.54 - $4.54	http://www.naturalresources.umd.edu/Stumpage_Prices.cfm
MA	$5.20 - $27.85	$0.38 - $0.76	$2.04 - $2.04	http://forest.fnr.umass.edu/snestumpage.htm
NH	$14.43 - $35.65	$2.59 - $5.73	$1.11 - $1.67	www.nh.gov/revenue
NJ	$19.36 - $37.35	$3.9 - $4.55	$3.82 - $3.82	N/A - Used averages of neighboring states
NY	$8.91 - $50.79	$1.19 - $5.55	$3.4 - $5.94	http://www.dec.state.ny.us/website/dlf/privland/utilization/stumpage.html
PA	$4.97 - $48.71	$2.17 - $11.37	$4.54 - $4.54	http://www.sfr.cas.psu.edu/tmr/
RI	$5.20 - $27.85	$0.38 - $0.76	$2.04 - $2.04	http://forest.fnr.umass.edu/snestumpage.htm
VT	$12.72 - $54.84	$2.55 - $5.09	$0.8 - $2.41	http://stumpage.uvm.edu/stumpage.php

Annual costs of developing management plans for forests were included in the analysis, amounting to $0.81/acre/yr (Hersey and Kittredge, 2005). Many of the states in the Northeast require management plans in order to qualify forestland for reduced taxation land assessments, thus these costs were assumed for all forests. We also utilize the Winrock Sampling Calculator (to determine that carbon measuring and monitoring costs are on average $0.60/t of present value CO_2e (http://www.winrock.org/ecosystems/tools.asp?BU=9086). It is assumed that landowners use natural regeneration processes and thus we do not include regeneration costs in the aging analysis. The discount rate used throughout this analysis is 6%.

All states in the Northeast tax the value of land. They do not tax the value of the forests themselves. Although each taxing authority (county, village, city, etc.) has a different millage rate, they apply the same millage rate to forestland as they apply to other types of land uses. Typically, however, states offer a tax abatement for forest uses by lowering the valuation of forestland. Some states value forestland according to its current value as forestland. Other states apply fixed land values for all forestland. In addition to taxing land, some of the states in the Northeast impose a yield tax, which is applied on a percentage basis to the value of the stumpage harvested.

A summary of land and other timber taxes for states in the Northeast is found in Table 4-2. Information for this table is derived from several sources. General information on what types of taxes are applied was obtained from the National Timber Tax website (http://www.timbertax.org/statetaxes/statetaxes.asp). State taxing authorities in each of the states provided information on the specifics of taxation for those states. In particular they provided information on state policy associated with the valuation of land (i.e., deciding what value to give timberland). Finally, the National Association of Homebuilders provided information on applicable average millage rates ($ per $1000 of land value) to use in each county in the region (see http://www.nahb.org).

Table 4-2. Summary of types of taxes applied in each state.

	Land Tax	Yield Tax
CT	Y	Y (7%)
DE	Y	N
ME	Y	N
MD	Y	N
MA	Y	Y (8%)
NH	Y	Y (10%)
NJ	Y	N
NY	Y	Y (6%)
PA	Y	N
RI	Y	N
VT	Y	N

Yields were estimated for eight forest types and four site classes for the twelve states the region. Aggregate data on the growing stock volume per hectare (m^3 per hectare) for each forest type, site class, stocking class, and age class was used to determine parameters for yield functions with the following functional form:

(13) Yield (m^3/ha) = a - b/age.

Note that the yield functions were originally estimated in terms of m^3 per hectare, and the parameters for the yield functions are presented in those units. The appropriate factors to convert m^3 per hectare to m^3 per acre is to first estimate yield in terms of m^3 per hectare and then convert it to m^3 per acre by dividing by 2.47 (acres per hectare). The terms "a" and "b" are estimated parameters (Table 4-3). The functions provide information on the potential growing stock volume per hectare of forest land. Analysis was conducted to determine if yields varied by state or region, however, no discernible differences were detected in the analysis. The primary difference in yields was site class as identified by USDA Forest Inventory and Analysis.

Table 4-3. Yield function parameters.

		WRJ Pine[1]	SF[1]	OP[1]	OH[1]	OCG[1]	EAC[1]	MBB[1]	AB[1]
Yield Functions - Fully stocked									
S3 = 120-164 ft^3/ac/yr	a	6.44	5.90	5.87	6.44	6.45	5.70	5.75	5.76
	b	55.54	51.22	41.00	72.82	109.11	30.00	43.20	45.63
S4 = 85-119 ft^3/ac/yr	a	6.20	5.61	5.87	6.02	6.45	5.61	5.65	6.11
	b	51.41	45.48	41.00	55.56	109.11	27.22	48.16	77.00
S5 = 50-84 ft^3/ac/yr	a	5.71	5.33	5.49	5.60	6.45	5.39	5.61	5.85
	b	34.02	42.79	30.52	40.69	109.11	31.12	44.77	71.08
S6 = 20-49 ft^3/ac/yr	a	5.94	5.31	5.71	5.13	6.45	5.60	5.36	5.30
	b	61.30	45.86	57.86	32.60	109.11	85.40	40.90	53.17
Yield Functions - Poorly Stocked									
S3 = 120-164 ft^3/ac/yr	a	4.95	4.54	4.52	4.95	3.77	4.38	4.73	4.43
	b	27.00	22.28	17.00	45.00	33.73	15.00	40.30	47.56
S4 = 85-119 ft^3/ac/yr	a	4.80	4.29	4.52	4.01	3.77	4.31	4.29	4.70
	b	27.95	22.64	17.00	20.22	33.73	15.00	19.26	47.56
S5 = 50-84 ft^3/ac/yr	a	4.46	4.36	4.80	4.35	3.77	4.55	4.24	4.03
	b	13.89	24.14	38.16	51.66	33.73	66.01	17.35	38.98
S6 = 20-49 ft^3/ac/yr	a	4.13	3.95	4.80	4.35	3.77	3.67	4.32	4.65
	b	32.59	20.07	57.59	51.66	33.73	12.80	24.26	56.15

[1] WRJ Pine = White, Red, and Jack Pine; SF = Spruce and Fir; OP = Oak-Pine; OH = OakHickory; OCG = Oak-Gum-Cypress; EAC= Elm-Ash-Cottonwood; MBB = Maple-Beech-Birch; AB = Aspen and Birch.

Two sets of growth and yield functions for growing stock volume were estimated based on USDA Forest Inventory and Analysis data -- the yield of poorly stocked stands and the yield of fully stocked stands. For the aging analysis, the yield functions noted as "fully stocked" in Table 4-13 are used. These are based only on lands considered to be fully stocked in the region. For the stocking analysis of section 4.3, it was necessary to also estimate yield functions for poorly stocked stands. These are also shown here in Table 4-3, but they are not used until section 4.3.

To determine carbon content, estimates from Table 5 in Smith et al. (2003b) were applied. These estimates provide information on the above-ground biomass density, based on growing stock volume. Some poorly stocked sites were observed to have no growing stock, and were given the initial value from Smith et al. (2003) equation (i.e., assuming 0 growing stock volume).

Several additional parameters influence the carbon analysis. First, one must allocate the carbon upon harvest to different uses. The results in Winjum et al. (1998) are used to calculate the proportion of wood in different uses (Table 4-4). The total merchantable proportion of the aboveground carbon in softwoods was assumed to be 77%, while the merchantable portion in hardwoods was assumed to be 50%. The merchantable proportion used in wood products was assumed to be 80%, and 20% was assumed to be mill residues. This means that for fully stocked softwood stands that are harvested, 61% will be used in wood products, and 15% will be residues in the mill. The component for solid wood products was assumed to be 80%, and the component for pulp was 20%. Second, one must assume decomposition and turnover rates. We used the results of Winjum et al (1998) for turnover rates in wood products. For slash, a decomposition rate of 10% per year was assumed.

Table 4-4. Disposition of growing stock upon harvest and turnover or decomposition rates for wood products and slash.

	Fully Stocked		Turnover/ Decomposition
	Softwood	Hardwood	%/yr
Sawtimber	0.49	0.32	0.5
Pulpwood	0.12	0.08	0.1
Biomass	0.00	0.00	0.0
Mill Residues	0.15	0.10	0.0
Slash Left	0.23	0.50	10.0
Fuelwood	0.00	0.00	0.0

The effect of several sources of uncertainty in these parameters on total carbon storage is shown for a high site (site class 3) spruce-fir stand in Maine under four scenarios in Fig 4-1. Scenario 1 provides credits for biomass energy produced from milling residues and assumes 10% decomposition of slash; scenario 2 provides credits for biomass energy from milling residues but assumes immediate decomposition of slash; scenario 3 does not provide credits for biomass energy and assumes 10% decomposition of slash; and scenario 4 does not provide credit for biomass energy and assumes immediate decomposition of slash. These scenarios capture several major uncertainties about potential carbon credits associated with forestry - whether biomass energy production from milling residues will be credited, and the decomposition rate on slash.

The scenarios that provide credits for biomass energy suggest more overall carbon in the baseline and the lengthened rotation scenario because the offsets from energy production are "permanent." Thus, for the analysis, if energy production from milling residues is considered, then these permanent reductions in atmospheric carbon are registered in all periods forward from the time they occur. Slash decomposition rates also influence the path of potential carbon in the baseline and in the lengthened rotation scenarios, however the differences caused by different assumptions about decomposition rates are not as obvious.

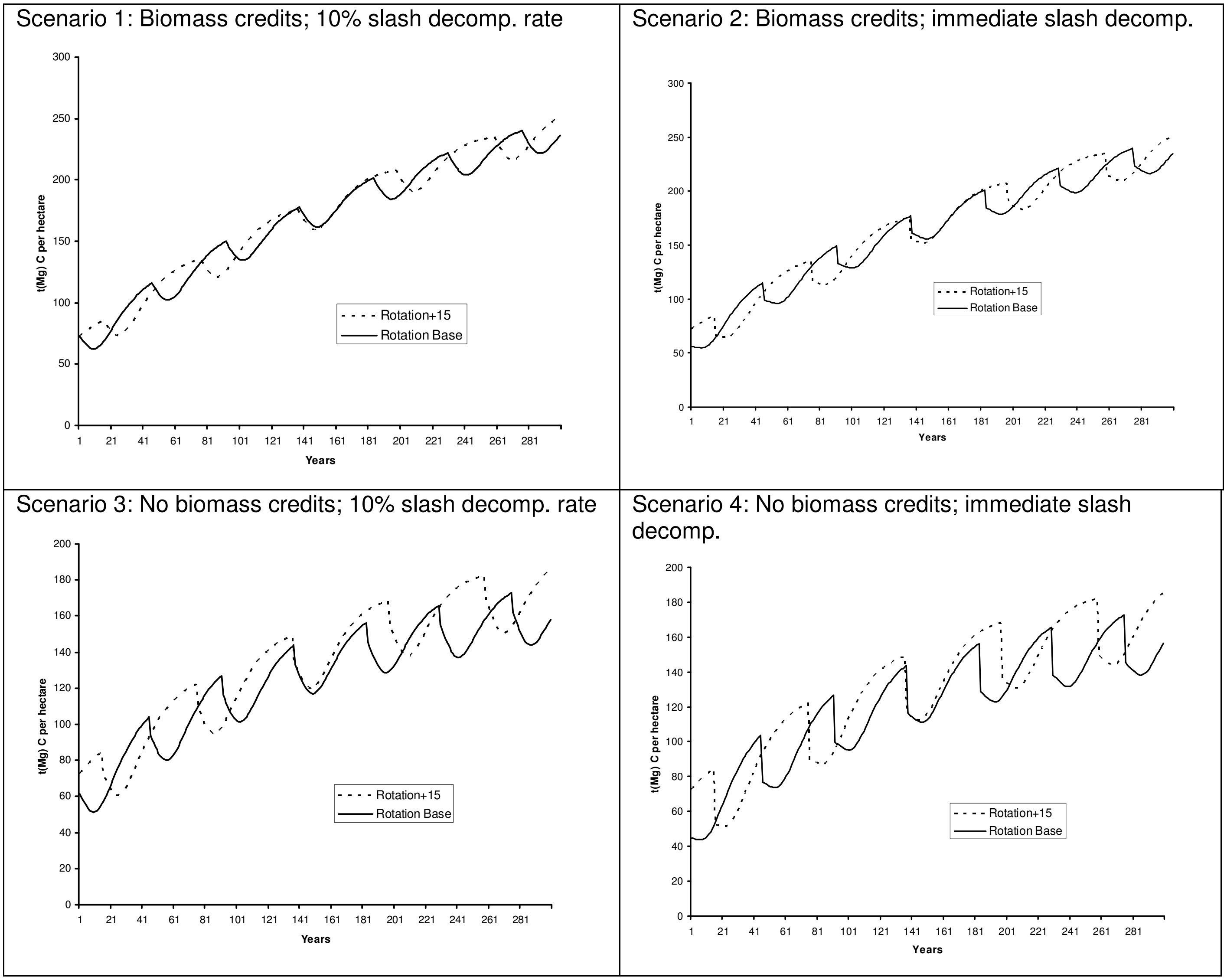

Figure 4-1. Comparison of total carbon storage on the landscape and in forest products over a 300 year period for a high site spruce-fir stands in Maine.

Carbon gains are calculated by comparing the differences in stocks under two rotations, and then calculating the annual change in this difference (see Eqns. 12a -12c). This credits the lengthened rotation for maintaining the stock initially and avoiding an emission initially, and it credits net future storage of timber products. It also debits the lengthened rotation for delaying the faster earlier growing period, and for emitting some carbon at harvest time. The stream of incremental carbon gains or losses are discounted to determine the net present value of the gain in carbon associated with aging a forest additional years.

The present value of carbon gains for softwood forests in the Northeast as calculated by equations 12a - c are shown in Table 4-5 across the four different assumptions about the role of biomass credits from energy produced by milling residues and decomposition of slash left on site after harvesting. The largest potential credits occur when biomass energy credits are not considered and when slash is assumed to decompose immediately. This assumption is consistent with earlier analyses conducted in the southeastern and western U.S (Sohngen 2003, 2004a, 2004b). When biomass credits are considered and decomposition rates for slash are set to 10%, then potential credits from lengthening rotations are lower.

In general, the results in Table 4-5a indicate that lower rates of decomposition reduce the potential carbon credits. One of the benefits of lengthening rotations is that holding timber beyond the original rotation ages avoids emissions that might occur from decomposition of slash. If this decomposition is assumed to be slow, then these benefits occur further in the future, and are discounted. Accounting for the credits from biomass energy production from milling residuals, however, has the opposite effect in that biomass energy reduces the potential carbon credit. Credits from biomass energy production from residues would occur in the baseline as well as the extended rotation case. Thus, by extending the rotation, one puts off some of these benefits for several additional years, and consequently, the benefits are estimated to be smaller.

One can also consider the undiscounted carbon obtained over the permanent "300" year period. Table 4-5b shows the undiscounted results for this period. As one can see from the table, carbon sequestration may be positive or negative, depending on the species and the rotation extension. Without discounting, the carbon gains depend on the relative difference in the age of the forests at time period 300. In terms of figure 4-1, this is just the difference between the two lines at year 300 (the far right "end" of the figures).

Table 4-5. Carbon gain over 300 years associated with increasing the rotation age in softwood forests (r = 6%). Biomass credits assumed to result from energy produced from milling residues only.

a. Net Present Value of Carbon

Rotation Age Increase	WRJ3	WRJ4	WRJ5	WRJ6	SF3	SF4	SF5	SF6
				t C/ha				
Biomass credits + 10% slash decomposition								
5 yr.	3.9	3.5	3.7	3.6	3.0	2.4	2.1	1.9
10 yr.	5.9	5.2	5.7	5.8	4.2	3.3	3.0	2.8
15 yr.	7.3	6.3	7.1	7.3	5.0	3.8	3.5	3.3
Biomass credits + 100% slash decomposition								
5 yr.	5.7	5.1	5.0	4.8	4.4	3.7	3.3	3.0
10 yr.	9.2	8.1	8.2	7.9	6.7	5.5	5.0	4.6
15 yr.	11.7	10.2	10.4	10.2	8.4	6.9	6.3	5.9
No Biomass credit + 100% slash decomposition								
5 yr.	9.0	8.0	7.4	6.8	6.9	5.9	5.3	4.8
10 yr.	15.0	13.3	12.5	11.6	11.2	9.5	8.7	8.0
15 yr.	19.6	17.3	16.4	15.2	14.4	12.3	11.3	10.4
No Biomass credit + 10% slash decomposition								
5 yr.	7.2	6.3	6.1	5.6	5.5	4.7	4.2	3.8
10 yr.	11.8	10.4	10.1	9.5	8.7	7.3	6.7	6.1
15 yr.	15.2	13.3	13.1	12.4	11.0	9.2	8.5	7.8

b. Undiscounted carbon gain

Rotation Age Increase	WRJ3	WRJ4	WRJ5	WRJ6	SF3	SF4	SF5	SF6
				t C/ha				
Biomass credits + 10% slash decomposition								
5 yr.	-15.5	14.1	-11.3	-10.7	27.5	20.3	22.9	19.4
10 yr.	4.4	24.1	6.6	7.0	-0.2	-4.1	8.8	19.9
15 yr.	-23.2	5.8	-14.8	-13.5	15.1	8.8	13.6	12.3
Biomass credits + 100% slash decomposition								

Rotation Age Increase	WRJ3	WRJ4	WRJ5	WRJ6	SF3	SF4	SF5	SF6
				t C/ha				
5 yr.	3.9	23.2	3.7	-13.9	28.6	20.7	24.6	22.4
10 yr.	26.6	34.5	23.7	7.0	-5.5	-6.9	1.7	9.3
15 yr.	-2.8	15.2	1.0	-15.4	16.2	9.3	15.3	15.4
No Biomass credit + 100% slash decomposition								
5 yr.	12.9	31.0	9.9	-18.8	35.0	26.4	30.1	27.4
10 yr.	47.2	52.6	38.4	9.1	-3.0	-4.7	4.0	11.4
15 yr.	14.3	30.0	12.4	-16.4	28.6	20.1	25.7	24.8
No Biomass credit + 10% slash decomposition								
5 yr.	-6.6	21.9	-5.1	-15.6	33.9	25.9	28.4	24.4
10 yr.	25.0	42.1	21.3	9.1	2.3	-1.9	11.1	22.0
15 yr.	-6.2	20.5	-3.3	-14.6	27.5	19.6	23.9	21.7

Table 4-6 shows the effects of different rotation extensions on carbon gains, under the assumption that biomass credits accrue for mill waste and slash decomposes at 10%, for different contract periods (10, 20, and 40 years). All estimates in Table 4-6 are discounted at 6%. Table 4-7 then shows the same results with no discounting. Even with discounting, the carbon change in the shorter contract periods depend heavily on the difference in carbon in the final period. The 10 year contract appears to have the greatest potential carbon simply because the carbon in the extended rotation scenarios is larger than the baseline during the first 10 years for all of the contracts. The 20 year contracts have less carbon, not surprisingly, because the baseline would have more carbon in some cases by the end of the 20th year of the contract.

It is not possible to say strictly which of these contract periods or rotation extensions is "best." It is not likely that the carbon trading rules will be written that would allow landowners to simply extend their rotations one time and then revert to the normal rotation. Although, as shown in Table 4-7, 10 year contracts have positive carbon, there is liability attached to this carbon, from the perspective of the atmosphere, if the landowner does not maintain the rotation extension. Simply calculating the carbon in the first 10 years and ignoring this future carbon liability is neither financially nor environmentally sound.

Carbon estimated with the 300 year permanent methods, with discounting, provide an economically and financially sound measure of the benefits of the rotation extension. They imply that the landowners who engage in these practices will have to develop management plans and corresponding easements on their property that require specific management regimes. Long-term conservation easements are common, and thus could be applied to the forestlands where rotation extensions are considered.

Table 4-6. Net present value of carbon gain associated with increasing the rotation age in softwood forests, assessment over different contract periods (r=6.0%). Biomass credits assumed to result from energy produced from milling residues only. Slash decomposition assumed to be 10%.

Rotation Age Increase	WRJ3	WRJ4	WRJ5	WRJ6	SF3	SF4	SF5	SF6
				t C/ha				
Permanent contract (300 years)								
5 yr.	3.9	3.5	3.7	3.6	3.0	2.4	2.1	1.9
10 yr.	5.9	5.2	5.7	5.8	4.2	3.3	3.0	2.8
15 yr.	7.3	6.3	7.1	7.3	5.0	3.8	3.5	3.3
10 Year Contract								
5 yr.	10.1	8.8	8.3	7.6	7.5	6.2	5.6	5.1

10 yr.	18.2	16.0	14.8	13.4	13.6	11.4	10.4	9.5
15 yr.	18.2	16.0	14.8	13.4	13.6	11.4	10.4	9.5
20 Year Contract								
5 yr.	3.3	2.7	3.4	3.7	2.0	1.4	1.3	1.3
10 yr.	7.1	5.7	6.9	7.3	4.2	2.8	2.7	2.7
15 yr.	12.3	10.3	11.3	11.4	8.0	5.8	5.5	5.3
40 Year Contract								
5 yr.	3.2	2.8	3.1	3.1	2.4	1.9	1.7	1.5
10 yr.	4.7	4.0	4.7	4.9	3.2	2.4	2.2	2.1
15 yr.	5.5	4.8	5.7	6.2	3.5	2.6	2.5	2.4

Table 4-7. Undiscounted carbon gain associated with increasing the rotation age in softwood forests, assessment over different contract periods (r=0.0%). Biomass credits assumed to result from energy produced from milling residues only. Slash decomposition assumed to be 10%

Rotation Age Increase	WRJ3	WRJ4	WRJ5	WRJ6	SF3	SF4	SF5	SF6
				t C/ha				
Permanent contract (300 years)								
5 yr.	-15.5	14.1	-11.3	-10.7	27.5	20.3	22.9	19.4
10 yr.	4.4	24.1	6.6	7.0	-0.2	-4.1	8.8	19.9
15 yr.	-23.2	5.8	-14.8	-13.5	15.1	8.8	13.6	12.3
10 Year Contract								
5 yr.	12.3	10.6	10.1	9.2	9.1	7.4	6.6	6.0
10 yr.	25.5	22.4	20.7	18.7	19.1	16.2	14.5	13.1
15 yr.	25.5	22.4	20.7	18.7	19.1	16.2	14.5	13.1
20 Year Contract								
5 yr.	-3.4	-3.3	-1.2	0.2	-3.4	-3.2	-3.0	-2.5
10 yr.	-1.9	-2.8	1.2	3.6	-3.8	-4.5	-4.1	-3.3
15 yr.	8.7	6.2	10.1	12.0	3.7	1.4	1.3	1.7
40 Year Contract								
5 yr.	-1.4	-0.7	-1.1	-1.3	0.3	6.3	0.2	-0.1
10 yr.	-8.1	-6.3	-6.0	-5.4	-4.5	3.0	-3.4	-3.3
15 yr.	-16.7	-13.6	-12.0	-10.1	-11.0	-2.2	-8.3	-7.7

4.3.3 Results

There are approximately 9.8 million acres white-red-jack pine and spruce-fir types in Maine, New Hampshire, New York, and Vermont, encompassing 88% of the total of these types for the entire Northeast (Table 4-8). Consequently, the analysis accounts for most of the softwood forests that could potentially be shifted to older age classes in the entire Northeast.

Only forests that are nearing the optimal age of harvesting are considered in the analysis. Analysis of optimal rotations suggests that they occur between 40 and 60 years, so that only forests in these age classes are included in the aggregated analysis. This further limits the analysis to around 2.2 million acres, with most of the forests occurring on private lands (Table 4-8).

Table 4-8. Forestland areas in white-red-jack pine, spruce-fir, and all other types in the Northeast and the four states under consideration for the aging analysis.

		WRJ	SF	Other	Total
		1000 acres			
Northeast					
	Private	3,966	5,423	47,578	56,967
	Public	561	539	9,347	10,448
	Total	4,527	5,962	56,926	67,415
ME, NH, NY, VT					
	Private	3,040	5,362	29,578	37,980
	Public	371	510	3,227	4,108
	Total	3,411	5,872	32,805	42,088
ME, NH, NY, VT => Age = 40 - 60					
	Private	970	982	10,144	12,096
	Public	129	128	945	1,203
	Total	1,099	1,111	11,089	13,299

Four analyses are conducted, as follows:

- Permanent sequestration – discounted carbon.
- 10 year contracts –undiscounted carbon
- 20 year contracts –undiscounted carbon
- 40 year contracts –undiscounted carbon

For the permanent sequestration contracts, the efficient carbon price for the rotation extension is estimated assuming permanent sequestration. The analysis is conducted by calculating the optimal initial rotation age for each site class for the relevant prices and taxes in each county. Then, the optimal rotation ages are calculated across a set of carbon prices ranging from \$1.67/t CO_2e to \$270/t CO_2e. The carbon gains and prices are then recorded for forest types, site class, and county. These estimated marginal costs are then used with data on the area of land in the 40 - 60 year age classes and forest types to assess the potential marginal cost and carbon sequestration for 5, 10, and 15 year increases in the rotation age. All financial estimates and carbon sequestration estimates are discounted at 6%. The carbon accounting follows scenario 1 in Fig. 4-1.

For the shorter contracts, the same concept is used for estimating the cost of the rotation extension, but the undiscounted carbon over the 10, 20, or 40 year periods are shown instead. The price of the carbon is the same for the shorter contract periods, but the present value of the costs of the projects is smaller than the permanent projects because only some of the carbon in the project is considered. This is discussed below.

Table 4-9. Summary of C sequestration opportunities softwoods for 5, 10, and 15 year extensions in rotation ages in Maine, New Hampshire, New York, and Vermont. The analysis if for Permanent Storage (discounted carbon) on private land only.

	Total Tons	Total Cost	Cost per ton
5 Year Extension	1000 tons C	Million \$	Avg. \$/tCO_2e
White-Red Jack Pine Site Class 3	95.5	\$3.4	\$9.69
White-Red Jack Pine Site Class 4	431.6	\$13.2	\$8.32
White-Red Jack Pine Site Class 5	732.2	\$13.1	\$4.86
White-Red Jack Pine Site Class 6	511.9	\$10.6	\$5.64
Spruce-Fir Site Class 3	48.5	\$1.0	\$5.45
Spruce-Fir Site Class 4	305.8	\$6.7	\$5.93
Spruce-Fir Site Class 5	576.4	\$9.2	\$4.35

	Total Tons	Total Cost	Cost per ton
Spruce-Fir Site Class 6	520.7	$19.6	$10.25
Total	3,222.6	$76.7	$6.48
10 Year Extension			
White-Red Jack Pine Site Class 3	140.1	$23.7	$46.11
White-Red Jack Pine Site Class 4	629.8	$74.4	$32.20
White-Red Jack Pine Site Class 5	1,098.0	$58.9	$14.61
White-Red Jack Pine Site Class 6	795.1	$53.3	$18.26
Spruce-Fir Site Class 3	72.9	$3.4	$12.76
Spruce-Fir Site Class 4	442.6	$22.2	$13.64
Spruce-Fir Site Class 5	864.6	$29.1	$9.17
Spruce-Fir Site Class 6	760.0	$135.2	$48.48
Total	4,803.0	$400.1	$22.70
15 Year Extension			
White-Red Jack Pine Site Class 3	168.5	$45.3	$73.31
White-Red Jack Pine Site Class 4	757.8	$197.9	$71.18
White-Red Jack Pine Site Class 5	1,338.7	$130.8	$26.62
White-Red Jack Pine Site Class 6	987.6	$107.1	$29.54
Spruce-Fir Site Class 3	88.8	$9.7	$29.80
Spruce-Fir Site Class 4	522.0	$62.5	$32.65
Spruce-Fir Site Class 5	1,031.3	$68.9	$18.21
Spruce-Fir Site Class 6	901.4	$221.9	$67.08
Total	5,796.0	$844.2	$39.69

The results of the analysis indicate that there are potentially substantial opportunities for increasing carbon sequestration through aging in NE softwood forests. For 5 year rotation extensions, around 2.9 million t C (discounted) could be sequestered for up to $6/t CO_2e (Table 4-9). The lowest cost opportunities appear to be site class 5 for both white-red-jack pine and spruce-fir forests. This amounts to about 3.8 t C/ha. Costs rise, as expected for the 10 year and 15 year rotation extensions, however, 10 year rotation extensions for spruce-fir site class 5 forests could still be accomplished for less than $10/t CO_2e. For the 10 and 15 year rotation extensions, average carbon sequestration per hectare is 5.6 and 6.8 t C/ha, respectively.

A marginal cost function for the full set of potential opportunities with softwoods in the four states is shown in Fig. 4-2 for discounted carbon. The results indicate that about 1.5 million t C (5.5 million t CO_2e) could be sequestered for less than $5/t CO_2e, and that 3.6 million t C (13.2 million t CO_2e) could be sequestered for less than $10/t CO_2e. Beyond that, costs rise fairly substantially and quickly. Most of these lower cost opportunities exist with 5 year rotation extensions: For projects with marginal costs <$5/t CO_2e, 98% of the carbon would arise with 5 year extensions; and for projects with marginal costs <$10/t CO_2e, 83% of the carbon would arise with 5 year extensions.

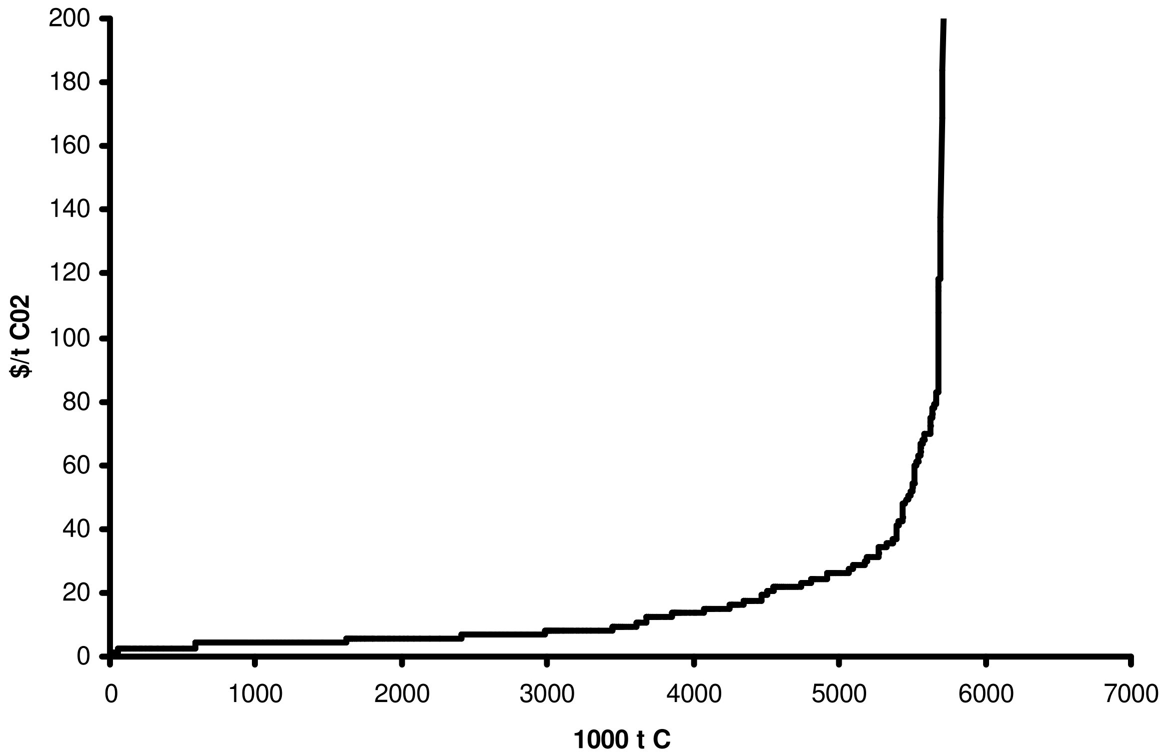

Figure 4-2. Marginal costs of carbon sequestration through aging softwood forests in Maine, New Hampshire, New York, and Vermont. Permanent contract (discounted carbon over 300 years; r=6%).

To get a sense for the spatial distribution of these potential activities, the average costs for 5 year rotation extensions are shown in Fig 4-3. As with the stocking results plotted above, there are a number of counties in the four states examined where there are apparently no opportunities to increase carbon through aging softwoods. This occurs because these counties either have no pine or spruce-fir stands, or they have no stands in the requisite 40 - 60 year old age classes. Total carbon (permanent carbon discounted over 300 years) that can be sequestered in each county for <$10/t CO_2e is plotted by county in Fig. 4-4. The largest potential appears to occur in Maine, but of course, this partly results from the relatively large counties in that state.

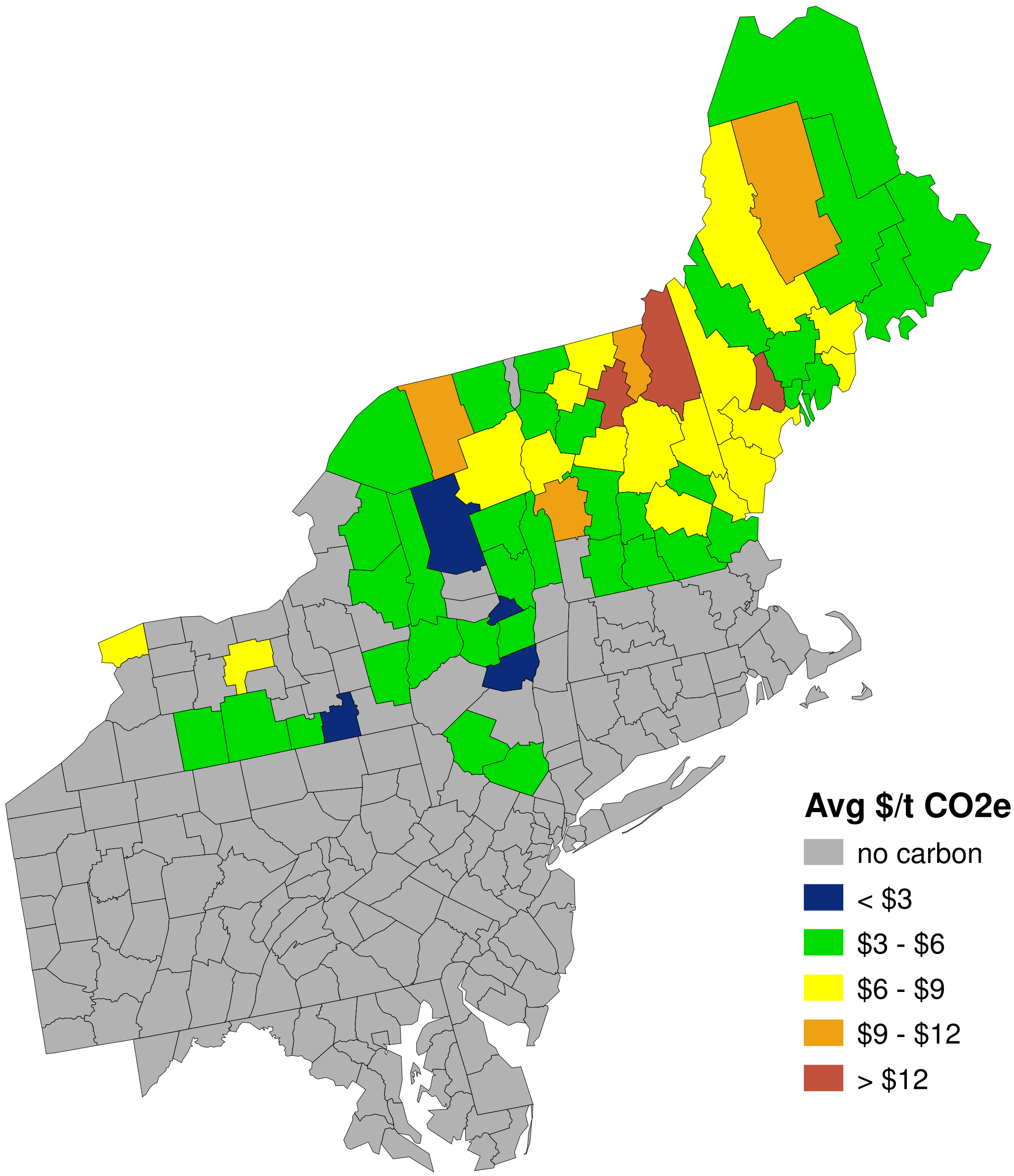

Figure 4-3. Average cost per t CO_2e for sequestering carbon in 5 year rotation extensions in softwoods of four northeastern states (Maine, New Hampshire, New York, and Vermont). (Permanent contract; private lands only; discounted carbon over 300 years; r=6%).

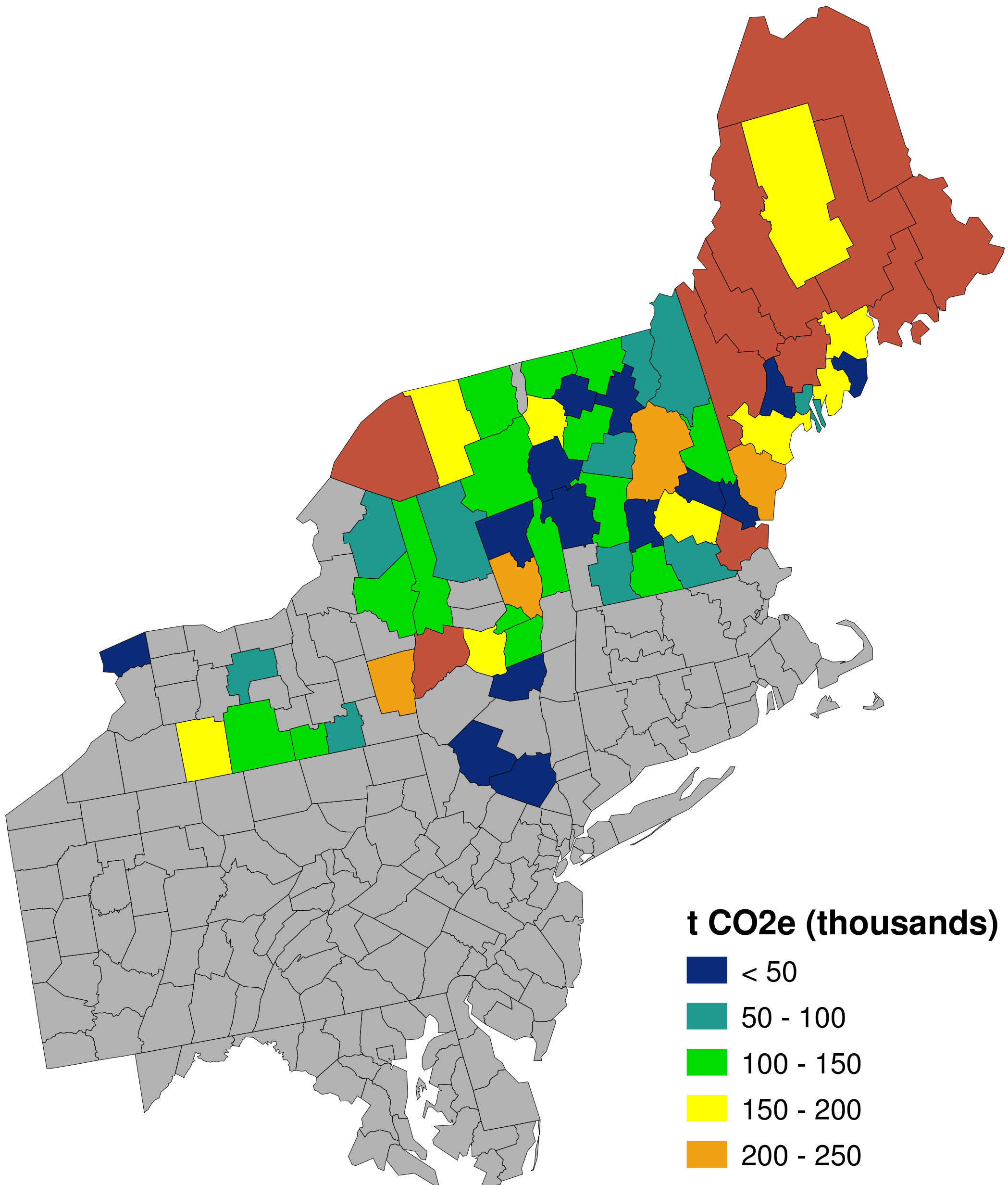

Figure 4-4. Total carbon potentially sequestered by county in four northeastern states only (Maine, New Hampshire, New York, and Vermont) for aging forests 5 years where marginal costs are <$10/t CO_2e. (Permanent contract; private lands only; discounted carbon over 300 years; r=6%).

When carbon is not discounted and summed over a period of 10 years, it appears that substantial carbon can be sequestered in northeastern forests (Table 4-10). Up to 14.9 million t C with 10 or 15 year rotation extensions could be sequestered within 10 years for an average cost of $23/t CO_2e. However, when 20 year contracts are considered, total sequestration in the region is negative for 5 and 10 year rotation extensions (Table 4-11). Sequestration is positive in a 20 year period for 15 year rotation extensions. For the 40 year rotation extensions, the results switch. There is positive carbon in the 5 and 10 year rotation extensions and negative carbon in the 15 year rotation extensions.

This switching between positive and negative sequestration illustrates the complexity of evaluating short-term contracts. The discounted estimates of Table 4-9 show clearly that extending rotations would provide benefits to the atmosphere, and that there are low cost opportunities available. The discounted carbon estimate in Table 4-9 for a 10 year rotation extension, for example, is 4.8 million t C at \$23/t CO_2e. This number represents the carbon offset *today* at a carbon price of \$23/t CO_2e that makes a firm indifferent between sequestration in forests and undertaking the same 4.8 million t C of energy emission reductions today. Thus, if the company can make or buy elsewhere 4.8 million t C of energy emissions reductions *today* for less than \$23/t CO_2e, they should do that. If the firm's cost of reducing 4.8 million t C of energy emissions *today* is greater than \$23/t CO_2e, engaging foresters to make the 10 year rotation extension would provide them with benefits that exceed the costs.

The present value carbon is separate from the issue of how much carbon a firm or company can use as an offset each year of a project, and how much they actually pay for holding those offsets each year they have them. Suppose that a utility company signs 10 year contracts for a 10 year rotation extension. By Table 4-10, they would have 14.9 million t of carbon in the first 10 years that could be used as offsets during that period only. The price (\$/t) is shown as \$23/t CO_2e. This is the price for "permanence," or the price the company would have to pay to buy the project in perpetuity (forever). Companies, however, recognize that this carbon is not permanent. By year 20, for example, the same projects would have emitted 1.9 million t C, for a net loss during the period 10 – 20 of 16.8 million t C. To account for this lack of permanence, the company would only be willing to pay the rental value over the first 10 years. The rental value (average) for the tons sequestered is \$1.38 per t CO_2e per year (\$23*0.06).

Relationship between estimates presented in Tables 4-9 to 4-12:

<u>Present Value Carbon</u> = Discounted value of carbon sequestered over 300 years, or permanent sequestration potential. This is equivalent to the tons of carbon that could be offset *today* at the given cost per ton. The cost per ton is the cost that would make the firm indifferent between energy emissions at that price and sequestering carbon forever in forestry rotation extension projects.

<u>Undiscounted Carbon</u> = Total undiscounted tons that are sequestered (or emitted) by a given time period.

<u>\$/t CO_2e</u> = Present value cost per ton CO_2e for a project that provides permanent sequestration = P^C

<u>Rental Value of Carbon</u> = Annual payment for renting accumulated tons of carbon in a project. Calculated as the interest rate times the present value cost per ton = (0.06) X (P^C) = R^C.

<u>Total Cost of Permanent Project</u> = (Present Value Carbon) X (3.67 to convert C to CO_2e) X (P^C)

<u>Total Cost of 10, 20, or 40 Year Project</u> = Present value of a stream of annual values, where the annual value is the rental value times the accumulated carbon in each year of the project = $\sum_{1}^{X}(R_t^C)CS_t(1+r)^{-t}$, where CS_t is the carbon stock accumulated by time t and X is the time period of the project. Note that if CS_t becomes negative, total rental value is simply \$0.

Consider the following example. Suppose the company contracts for 14.9 million t C over 10 years in 10 year rotation extensions (Table 4-10). The results indicate that this amount of carbon is possible. The company then uses the 14.9 million t C as offsets in a carbon market, in which they guarantee that the 14.9 million t C will be permanently sequestered. Since they have only contracted the tons for the first 10 years, they only pay for the 10 years they hold the tons. At year 10, they will have to rent some tons somewhere else for a time because these particular projects will be emitting carbon for some time. We don't account for the costs of this additional rental that must occur after year 10. We only count the rental costs over the first 10 years of the project in the total cost column of Table 4-10.

For longer term contracts of 20 and 40 years, it is clear that cumulative carbon by the end of the time period can be negative in some cases. This does not mean that carbon has not been stored and been useful during the project period. In fact, tons were available for companies to use during the period. For example, during the first 10 years, the company would have gotten positive storage in all rotation extensions. The total costs of the longer term projects are the present value of the rental on tons stored during the time period, reflecting the value of the earlier storage of carbon. Any emissions of course will have to be matched with additional offsets elsewhere.

The question then is what should the companies use as their measure of the carbon contained in these projects? The recommendation of the authors is that the companies use the present value calculations of Table 4-9. Those numbers (Table 4-9) show the present value of the costs of permanent storage, and the present value of tons permanently stored over the life of the project. Those numbers should be compared to the present value of the costs of other options and the present value of the tons obtained by the other options. In other words, if a company makes a projection and decides it needs 320,000 tons C of abatement each year for the next 40 years, and they think it would cost them \$40/t CO_2e to avoid these emissions with other methods, then the forestry options are cheaper and should be explored. How do we know this? The present value of 320,000 t C over 40 years is 4.8 million t C, and the relevant cost of providing this in forestry is \$23/t CO_2e.

Table 4-10. Summary of C sequestration opportunities from softwoods for 5, 10, and 15 year extensions in rotation ages in Maine, New Hampshire, New York, and Vermont. 10 year contract (undiscounted carbon) and private land only.

	Total Tons 1000 tons C	Total Cost Million \$[1]	Cost per ton Avg. \$/tCO_2e[2]
5 Year Extension			
White-Red Jack Pine Site Class 3	210.3	\$1.7	\$9.69
White-Red Jack Pine Site Class 4	1,044.0	\$7.1	\$8.32
White-Red Jack Pine Site Class 5	1,652.7	\$6.5	\$4.86
White-Red Jack Pine Site Class 6	1,108.9	\$5.1	\$5.64
Spruce-Fir Site Class 3	106.5	\$0.5	\$5.45
Spruce-Fir Site Class 4	628.5	\$3.0	\$5.93
Spruce-Fir Site Class 5	995.4	\$3.5	\$4.35
Spruce-Fir Site Class 6	1,048.8	\$8.8	\$10.25
Total	6,795.0	\$35.8	\$6.48
10 Year Extension			
White-Red Jack Pine Site Class 3	438.7	\$16.5	\$46.11
White-Red Jack Pine Site Class 4	2,214.5	\$58.0	\$32.20
White-Red Jack Pine Site Class 5	3,449.1	\$41.0	\$14.61
White-Red Jack Pine Site Class 6	2,267.9	\$33.7	\$18.26
Spruce-Fir Site Class 3	224.4	\$2.3	\$12.76
Spruce-Fir Site Class 4	1,371.1	\$15.2	\$13.64
Spruce-Fir Site Class 5	2,187.5	\$16.3	\$9.17
Spruce-Fir Site Class 6	2,337.2	\$92.2	\$48.48
Total	14,490.4	\$267.7	\$22.70
15 Year Extension			
White-Red Jack Pine Site Class 3	438.7	\$26.2	\$73.31
White-Red Jack Pine Site Class 4	2,214.5	\$128.3	\$71.18

	Total Tons 1000 tons C	Total Cost Million $[1]	Cost per ton Avg. $/tCO_2e$[2]
White-Red Jack Pine Site Class 5	3,449.1	$74.7	$26.62
White-Red Jack Pine Site Class 6	2,267.9	$54.5	$29.54
Spruce-Fir Site Class 3	224.4	$5.4	$29.80
Spruce-Fir Site Class 4	1,371.1	$36.4	$32.65
Spruce-Fir Site Class 5	2,187.5	$32.4	$18.21
Spruce-Fir Site Class 6	2,337.2	$127.6	$67.08
Total	14,490.4	$468.1	$39.69

[1]Cost of the short term project is the rental value of the carbon held during the period. See "Total Cost of 10,20, 0r 40 year project" above.
[2] Cost per ton is estimated based on equation 4 above.

Table 4-11. Summary of C sequestration opportunities from softwoods for 5, 10, and 15 year extensions in rotation ages in Maine, New Hampshire, New York, and Vermont. 20 year contract (carbon not discounted), private land only.

	Total Tons 1000 tons C	Total Cost Million $[1]	Cost per ton Avg. $/tCO2e[2]
5 Year Extension			
White-Red Jack Pine Site Class 3	-62.2	$2.4	$9.69
White-Red Jack Pine Site Class 4	-352.2	$10.0	$8.32
White-Red Jack Pine Site Class 5	-363.6	$9.5	$4.86
White-Red Jack Pine Site Class 6	-54.5	$7.8	$5.64
Spruce-Fir Site Class 3	-29.3	$0.7	$5.45
Spruce-Fir Site Class 4	-309.1	$4.2	$5.93
Spruce-Fir Site Class 5	-464.4	$4.9	$4.35
Spruce-Fir Site Class 6	-509.8	$12.0	$10.25
Total	-2,145.0	$51.1	$6.48
10 Year Extension			
White-Red Jack Pine Site Class 3	-37.6	$24.9	$46.11
White-Red Jack Pine Site Class 4	-293.8	$86.6	$32.20
White-Red Jack Pine Site Class 5	-113.2	$63.1	$14.61
White-Red Jack Pine Site Class 6	299.1	$54.8	$18.26
Spruce-Fir Site Class 3	-16.2	$3.5	$12.76
Spruce-Fir Site Class 4	-402.2	$21.8	$13.64
Spruce-Fir Site Class 5	-649.8	$23.4	$9.17
Spruce-Fir Site Class 6	-695.6	$132.0	$48.48
Total	-1,909.2	$399.6	$22.70
15 Year Extension			
White-Red Jack Pine Site Class 3	144.6	$45.5	$73.31
White-Red Jack Pine Site Class 4	610.5	$219.0	$71.18
White-Red Jack Pine Site Class 5	1,335.4	$132.3	$26.62
White-Red Jack Pine Site Class 6	1,301.4	$102.2	$29.54
Spruce-Fir Site Class 3	77.6	$9.5	$29.80
Spruce-Fir Site Class 4	117.0	$58.3	$32.65
Spruce-Fir Site Class 5	149.6	$51.6	$18.21
Spruce-Fir Site Class 6	180.5	$203.7	$67.08
Total	3,916.7	$797.8	$39.69

[1]Cost of the short term project is the rental value of the carbon held during the period. See "Total Cost of

10,20, 0r 40 year project" above.
[2] Cost per ton is estimated based on equation 4 above.

Table 4-12. Summary of C sequestration opportunities from softwoods for 5, 10, and 15 year extensions in rotation ages in Maine, New Hampshire, New York, and Vermont. 40 year contract (carbon not discounted), private land only.

	Total Tons 1000 tons C	Total Cost Million $[1]	Cost per ton Avg. $/t$CO_2$e[2]
5 Year Extension			
White-Red Jack Pine Site Class 3	-29.6	$2.4	$9.69
White-Red Jack Pine Site Class 4	-130.3	$10.0	$8.32
White-Red Jack Pine Site Class 5	-192.0	$9.5	$4.86
White-Red Jack Pine Site Class 6	-173.3	$7.8	$5.64
Spruce-Fir Site Class 3	-16.3	$0.7	$5.45
Spruce-Fir Site Class 4	-18.0	$4.2	$5.93
Spruce-Fir Site Class 5	675.0	$5.4	$4.35
Spruce-Fir Site Class 6	-31.2	$12.0	$10.25
Total	84.4	$51.1	$6.48
10 Year Extension			
White-Red Jack Pine Site Class 3	-146.8	$24.9	$46.11
White-Red Jack Pine Site Class 4	-708.1	$86.6	$32.20
White-Red Jack Pine Site Class 5	-1,039.3	$63.1	$14.61
White-Red Jack Pine Site Class 6	-696.6	$55.7	$18.26
Spruce-Fir Site Class 3	-74.1	$3.5	$12.76
Spruce-Fir Site Class 4	-375.7	$21.8	$13.64
Spruce-Fir Site Class 5	201.7	$23.5	$9.17
Spruce-Fir Site Class 6	-624.6	$132.0	$48.48
Total	-3,463.6	$399.6	$22.70
15 Year Extension			
White-Red Jack Pine Site Class 3	-296.6	$47.2	$73.31
White-Red Jack Pine Site Class 4	-1,453.0	$225.5	$71.18
White-Red Jack Pine Site Class 5	-2,099.5	$139.3	$26.62
White-Red Jack Pine Site Class 6	-1,303.1	$111.8	$29.54
Spruce-Fir Site Class 3	-146.5	$9.9	$29.80
Spruce-Fir Site Class 4	-868.7	$58.5	$32.65
Spruce-Fir Site Class 5	-527.4	$51.9	$18.21
Spruce-Fir Site Class 6	-1,428.1	$204.2	$67.08
Total	-8,122.9	$823.4	$39.69

[1]Cost of the short term project is the rental value of the carbon held during the period. See "Total Cost of 10,20, 0r 40 year project" above.
[2] Cost per ton is estimated based on equation 4 above.

4.3.4 Sensitivity Analysis

Two sensitivity analyses are conducted here. First, a lower discount rate for both the financial and carbon analysis was examined by setting the discount rate for both to 3%. Second, the possibility that no credits are given for residuals used in energy production and that decomposition of slash occurs immediately upon harvest were examined.

Lower discount rates, as expected, increase carbon sequestration costs (Table 4-13). There are a number of reasons for this. First, lower discount rates increase optimal rotation periods in the baseline. This extension of the rotation age in the baseline reduces the scope for carbon benefits through aging timber since the aging occurs in the baseline. Second, lower discount rates increase the value of land

and consequently the opportunity costs of carrying timber for additional periods. Third, higher discount rates increase the value of future periods. These future periods include times when the baseline rotation contains more carbon than the alternative, extended rotation. In effect, the increase in rotations reduces the relative benefits that are conferred immediately by holding timber off the market and extending the rotation. As a consequence, lower discount rates reduce the carbon gains and increase the costs of sequestering carbon.

The sensitivity analysis where no carbon credits for residues are provided and there is immediate decomposition of slash substantially increases total potential carbon gains, and reduces the costs of carbon sequestration (Table 4-14). The rationale for this difference in costs is that lengthening rotations in this scenario provides immediate benefits in terms of avoiding emissions associated with residues used in energy and decomposition of slash. This near-term benefit, when discounting is considered as it is in this case, has large effects on the overall calculation of the benefits.

Table 4-13. Sensitivity Analysis with lower discount rate (r=3%) for financial and carbon analysis. Summary of C sequestration opportunities in Maine, New Hampshire, New York, and Vermont softwoods for 5, 10, and 15 year extensions in rotation ages. Private land only.

	1000 tons C	Million $	Avg. $/t$CO_2$e
5 Year Extension			
White-Red Jack Pine Site Class 3	19.2	$4.9	$69.03
White-Red Jack Pine Site Class 4	56.8	$12.0	$57.73
White-Red Jack Pine Site Class 5	226.0	$19.2	$23.11
White-Red Jack Pine Site Class 6	218.9	$16.6	$20.64
Spruce-Fir Site Class 3	13.2	$0.4	$7.64
Spruce-Fir Site Class 4	91.2	$2.5	$7.38
Spruce-Fir Site Class 5	164.9	$4.5	$7.48
Spruce-Fir Site Class 6	136.3	$6.7	$13.34
Total	*926.5*	*66.7*	*$19.61*
10 Year Extension			
White-Red Jack Pine Site Class 3	22.6	$10.8	$130.26
White-Red Jack Pine Site Class 4	59.4	$18.0	$82.64
White-Red Jack Pine Site Class 5	340.7	$36.1	$28.90
White-Red Jack Pine Site Class 6	354.0	$35.0	$26.95
Spruce-Fir Site Class 3	15.9	$0.7	$11.23
Spruce-Fir Site Class 4	109.9	$6.0	$14.94
Spruce-Fir Site Class 5	172.7	$6.5	$10.33
Spruce-Fir Site Class 6	142.3	$17.2	$32.92
Total	*1,217.3*	*130.4*	*$29.18*
15 Year Extension			
White-Red Jack Pine Site Class 3	21.6	$3.5	$43.50
White-Red Jack Pine Site Class 4	45.4	$17.2	$102.92
White-Red Jack Pine Site Class 5	410.3	$54.5	$36.18
White-Red Jack Pine Site Class 6	449.7	$57.5	$34.82
Spruce-Fir Site Class 3	16.0	$1.4	$23.51
Spruce-Fir Site Class 4	112.0	$8.2	$19.90
Spruce-Fir Site Class 5	165.8	$11.2	$18.41
Spruce-Fir Site Class 6	141.2	$34.1	$65.73
Total	*1,362.0*	*187.4*	*$37.48*

Table 4-14. Sensitivity Analysis assuming no carbon credits for residues used in energy and immediate decomposition of slash. Summary of C sequestration opportunities in Maine, New Hampshire, New York, and Vermont softwoods for 5, 10, and 15 year extensions in rotation ages. Private land only; permanent carbon; discounted; r=6%).

	1000 tons C	Million $	Avg. $/t$CO_2$e
5 Year Extension			
White-Red Jack Pine Site Class 3	168.3	$2.5	$4.10
White-Red Jack Pine Site Class 4	809.2	$12.6	$4.25
White-Red Jack Pine Site Class 5	1,250.6	$14.4	$3.15
White-Red Jack Pine Site Class 6	814.0	$11.3	$3.77
Spruce-Fir Site Class 3	88.1	$1.2	$3.77
Spruce-Fir Site Class 4	493.7	$6.8	$3.73
Spruce-Fir Site Class 5	795.9	$10.1	$3.45
Spruce-Fir Site Class 6	859.9	$17.7	$5.60
Total	*5,279.7*	*76.6*	*$3.95*
10 Year Extension			
White-Red Jack Pine Site Class 3	274.5	$12.1	$11.97
White-Red Jack Pine Site Class 4	1,323.8	$66.1	$13.60
White-Red Jack Pine Site Class 5	2,074.7	$73.3	$9.63
White-Red Jack Pine Site Class 6	1,367.5	$57.9	$11.53
Spruce-Fir Site Class 3	143.8	$4.3	$8.14
Spruce-Fir Site Class 4	805.5	$24.4	$8.26
Spruce-Fir Site Class 5	1,298.2	$33.5	$7.03
Spruce-Fir Site Class 6	1,403.4	$84.2	$16.35
Total	*8,691.5*	*355.8*	*$11.15*
15 Year Extension			
White-Red Jack Pine Site Class 3	353.4	$32.1	$24.76
White-Red Jack Pine Site Class 4	1,708.2	$149.4	$23.83
White-Red Jack Pine Site Class 5	2,694.8	$164.8	$16.66
White-Red Jack Pine Site Class 6	1,788.0	$113.8	$17.34
Spruce-Fir Site Class 3	184.4	$12.1	$17.86
Spruce-Fir Site Class 4	1,033.0	$70.0	$18.46
Spruce-Fir Site Class 5	1,663.7	$81.7	$13.38
Spruce-Fir Site Class 6	1,805.9	$203.2	$30.65
Total	*11,231.4*	*827.0*	*$20.06*

4.4 Increasing the Stocking of Under-stocked stands

This section describes analysis conducted to estimate the costs of increasing the stocking density of under-stocked stands in forests of the Northeast. The analysis considers only stands that are greater than 40 years only, and classified as poorly stocked or not stocked according to growing stock volume by the USDA Forest Service FIA (2006). Stands younger than this and classified as poorly stocked or not stocked according to growing stock volume could be regenerating naturally and to provide a conservative estimate here, only the older forest classes were analyzed.

Poorly- and under-stocked forests greater than 40 yr of age encompass approximately 4.6 million acres in the Northeast region. Under current levels of stocking, there are approximately 77.7 million t C on poorly and non-stocked stands (17 t C/acre). Full stocking of these stands could in the future bring the total carbon stored in these forests to 171 million t C (37 t C/acre) over a 300 year period. There are consequently substantial potential C benefits associated with increasing the stocking density. This section provides an examination of the potential to convert these poorly- and non-stocked stands from their current conditions to fully stocked conditions.

4.4.1 Methodology and Data

For this analysis, the following **assumptions** were made that lead to increased stocking density:

1. Landowners would be paid to remove existing biomass, and to then replant the natural potential vegetation type consistent with the site.
2. Landowners harvest the growing stock and extract value from merchantable components at current market prices.
3. Residual slash components remain on the site and decompose.
4. To enhance stocking density, landowners replant forests with seedlings rather than to rely on natural regeneration processes. The rationale for replanting efforts is that poorly- and non-stocked forests have been designated by the USDA Forest Inventory and Analysis crews to be capable of producing more growing stock volume on the sites under analysis, but they have not achieved significant stocking naturally, despite the fact that all the stands considered here are older than 40 years of age. Thus, removal of existing biomass, and additional planting effort could improve future stocking conditions.
5. The direct use of the growing stock volume for biomass energy is not considered in this analysis, although biomass as a residual from the wood production process is incorporated. The rationale for not considering biomass as an alternative to traditional sawnwood and pulpwood at this time is that current prices place biomass energy and pulp markets at about the same price (roughly \$26 - \$27 per m^3 of wood across the region on average). The analysis assumes that wood flows to pulp markets as these markets have been in existence longer, and more mills are available across the region to handle pulp.

The revenue and cost streams analyzed are:

(1) Harvest existing stock and market merchantable component and current prices and costs

- Occurs in the first period.

(2) Replant potential natural vegetation on the site, assuming it is the same as the current forest type. Pay replanting costs.

- Occurs in the first time period.

(3) Harvest forests in the future at 45 year intervals, extracting marketable products at current market prices and costs.

All revenue and cost components in the analysis in this section were discounted at a rate of 6% to determine the present value of revenues or costs associated with the proposed removal of existing material and re-stocking of the stands. For the analysis, it was assumed that removing merchantable timber from low stocked stands would be more expensive on average than typical harvesting operations because there is less merchantable timber available, and the distribution of material for markets is likely to be lower quality. Stumpage prices for step (1) above, therefore, were assumed to differ from the stumpage prices used in step 3. Stumpage prices for step (3) were shown in Table 4-1 above.

To estimate stumpage prices applicable to the removal of the existing stock (step 1), where lower value material on average is contained in the sites, stumpage prices from the various data sources were converted to delivered log prices by adding in logging costs (assumed to be \$16.42/m^3) and hauling costs for a 60 mile haul (\$6.42/m^3). Then, the costs of logging poorly stocked stands was assumed to be 30% more expensive on average than logging typical stands in the Northeast, or \$21.34/m^3 (Table 4-15). Stumpage prices for poorly stocked stands were then estimated based on the locally determined delivered log price minus the logging and hauling costs. The same hauling costs were used for poorly stocked stands since it is presumed that only full loads would be hauled.

Regeneration costs were assumed to be \$405/acre. Hersey and Kittredge (2005) report values for planting seedlings at a rate of 486 seedlings/acre as \$257/acre. Additional costs of replanting, as well as competition suppression, animal management, and other factors were added to this value to determine overall planting costs of \$405/acre.

As with the aging analysis above, applicable cost and revenue streams in this section were discounted assuming a 6% real interest rate. All prices and costs were assumed to be constant throughout the time period. A 300 year time horizon was used for the analysis. Timber rotations obviously can vary substantially across the region, however, future timber rotations were assumed to be 45 years. This value came closest to optimizing land value across the various types and timber prices, and was therefore used throughout the analysis.

Table 4-15. Costs associated with analysis of harvesting and re-stocking currently under-stocked stands in the Northeastern U.S.

Type	Costs	Source
Replanting	\$405/acre	Hersey and Kittredge (2005)
Logging (Full Stocked)	\$16.42/m^3	Mooney, J. (2001); Greene et al. (2004); Fight et al. (2003)
Logging (Poorly Stocked Stands)	\$21.34/m^3	Mooney, J. (2001); Greene et al. (2004); Fight et al. (2003)
Hauling Costs	\$0.11/m^3/mile	Fight et al. (2003), Mooney, J. (2001).
Management Plans	\$0.81/acre/yr	Hersey and Kittredge (2005)
Monitoring Costs	\$0.60/t CO_2e	Winrock Sampling Calculator (http://www.winrock.org/ecosystems/tools.asp)

Based on the yield equations for poorly stocked sites in Table 4-3, the future path of growing stock volumes was estimated for each county and site class. To accomplish this, poorly stocked forests in the region older than 40 years of age were identified. A default age of 60 years as the initial age was chosen for forests older than 40 years of age. The future potential path of carbon (i.e., the baseline) was then calculated for each hectare of poorly stocked stands in each county and each site class in the region. As an example, the baseline path of carbon assumed for mature, site class 4, white-red-jack pine is shown in Fig. 4-5 (lowest line in graph). Carbon inventories are projected to rise from approximately 47 t C/ha to 50 t C/ha over the next 300 years if the forest is left alone—i.e. baseline case.

A newly planted, fully stocked forest that is not harvested in the future is shown as the middle line in Figure 4-5. The fully stocked white-red-jack pine forest on site class 4 could achieve about 130 t C/ha over the next 300 years if the planting is successful and growth occurs according to the fully stocked yield functions shown in Table 4-3.

More importantly for this analysis, the top line in Figure 4-5 shows the carbon in an under-stocked stand that is harvested, regenerated by planting, and then harvested at 45 year intervals in the future. Harvested products were sent to market, and residuals from the wood milling or pulping process were assumed to be used as residuals in biomass energy production processes. These residuals used in energy production are assumed to generate immediate carbon credits when they occur, hence the green line continues to increase over time. Slash was assumed to be left on-site and to decompose. Under the scenario examined in this study, there was some initial carbon loss associated with decomposition of the slash left over, but over the long run the stand is assumed to be harvested at 45 year intervals (note that these same assumptions were used in the aging analysis in section 4.2). The top line captures the net effects from harvesting, milling, energy production, forest growth, and decomposition of slash. Substantially more carbon is sequestered in this scenario than in the baseline because the biomass produced from residuals is counted as a permanent carbon gain.

The specific analysis conducted in this study compares the carbon associated with the top line in Figure 4-5 with the baseline carbon shown by the bottom line. Different forest types will have different levels of carbon sequestered, and this example shows only one forest type, one initial growing stock volume, and one site class. The full analysis below considers four different site classes, and poorly stocked forests that are older than 40 years initially, as well as a number of forest types (see Table 4-3). These lead to different levels of potential carbon sequestration associated with harvesting and replanting poorly stocked stands in each of the forest types and site classes.

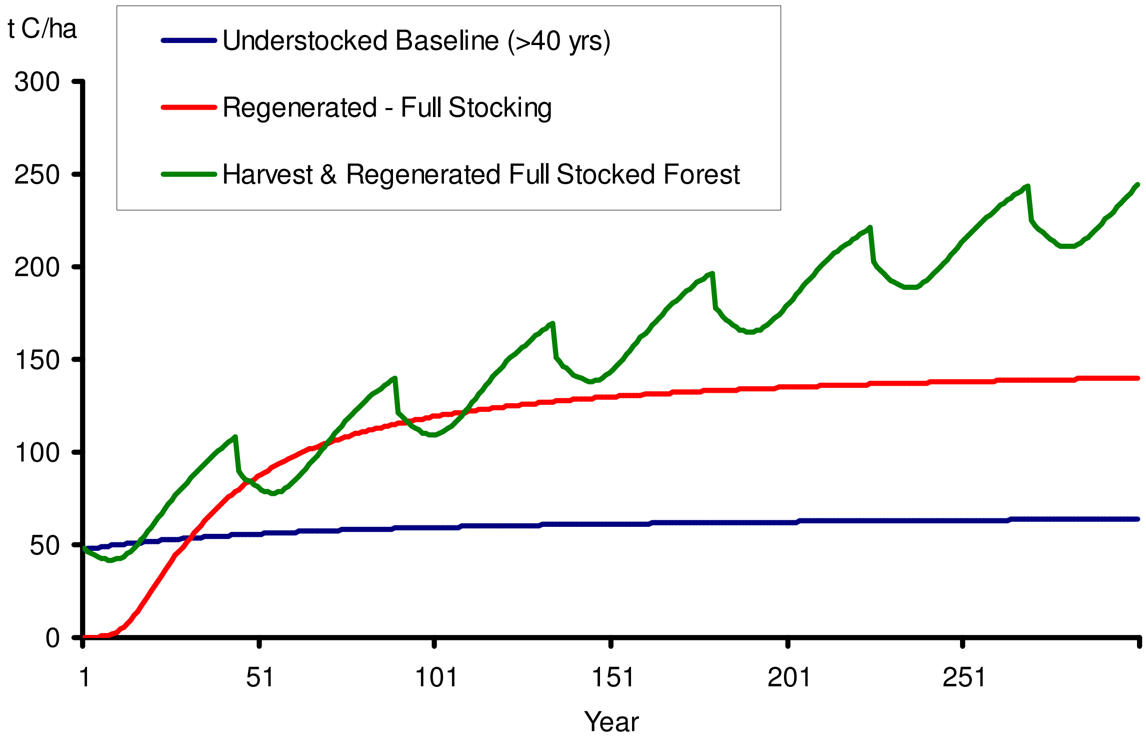

Figure 4-5. Baseline (bottom line) carbon stocks in forest and forest product components for >40 years of age white-red-jack pine forests on site class 4, carbon stocks for regenerated forests that are not harvested (middle line), and carbon stocks for the scenario where poorly stocked forests are harvested initially, replanted, and at 45 year intervals thereafter (top line).

Table 4-4 above illustrated the base assumptions about the disposition of wood products upon harvest. For the under-stocked stands, several adjustments were made to these parameters (Table 4-16). In particular, they are adjusted so that there is less total merchantable wood, and more pulpwood, due to lower quality.

Table 4-16. Disposition of growing stock upon harvest and turnover or decomposition rates for wood products and slash.

	Mature Poorly Stocked (>40)		Fully Stocked		Turnover/ Decomposition
	Softwood	Hardwood	Softwood	Hardwood	
	Proportion of Growing Stock				%/yr
Sawtimber	0.37	0.24	0.49	0.32	0.5
Pulpwood	0.25	0.16	0.12	0.08	0.1
Biomass	0	0	0	0	0
Mill Residues	0.15	0.1	0.15	0.1	0
Slash Left	0.23	0.5	0.23	0.5	10
Fuelwood	0	0	0	0	0

The change in carbon with an effort to improve stocking conditions can be broken down into several effects. First, there is the effect of harvesting the existing poorly stocked forest and monitoring the decomposition of slash and the turnover of wood products. Second, there is the effect of regenerating a well stocked forest, and harvesting in the future (with attendant decomposition effects in slash and turnover rates in wood products). Finally, the baseline carbon must be deducted from the potential gains caused by these two effects. This break down of effects for the sample white-red-jack pine stand is shown in Figure 4-6.

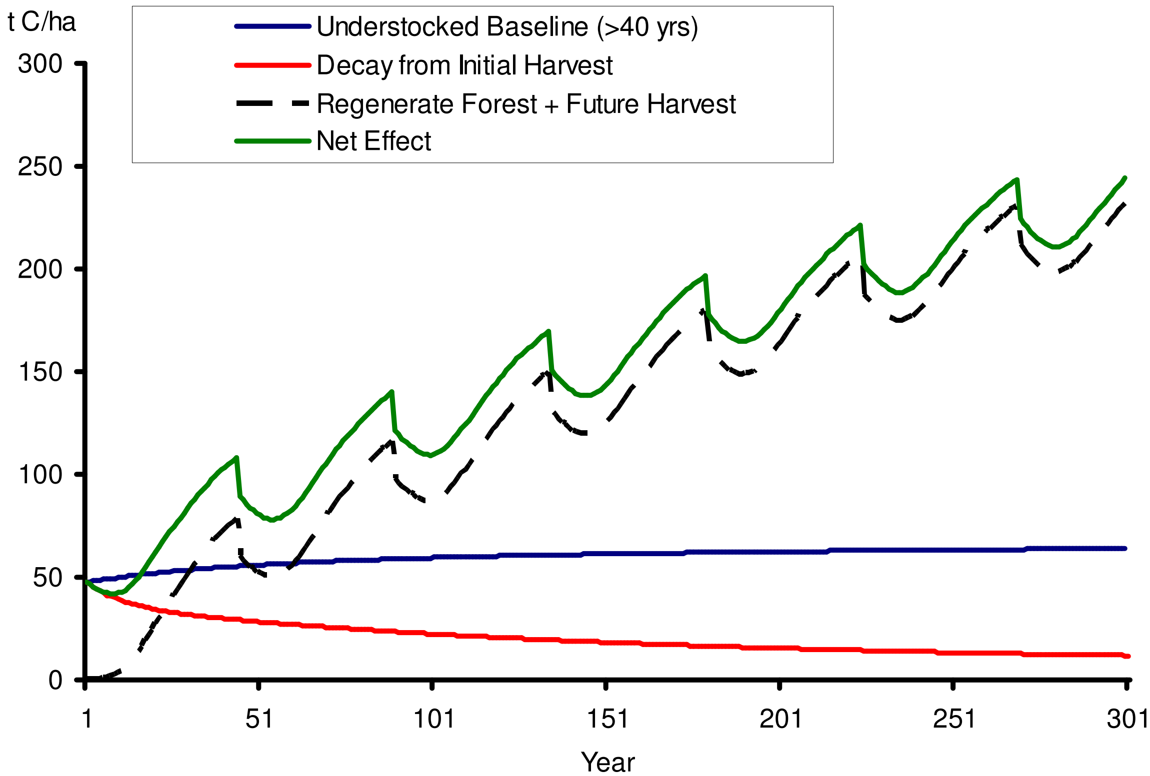

Figure 4-6. Break down of effects of harvesting poorly stocked, mature, white-red-jack pine stands, site class 4.

Figure 4-6 presents, for a representative stand, the full analysis conducted in this section. The blue line is the baseline condition that exists if existing under-stocked stands are left alone. The red bottom line represents the stock of carbon in wood products initially plus slash, plus biomass energy production from milling residues, plus the future turnover of products and decay of slash. The hatched line represents the re-growth of the newly planted, fully stocked stand. The top green line is the net carbon associated with the harvesting and regeneration operation. The difference between the blue line and top green line is the carbon benefit.

In reality, stands have a range of existing conditions. It is important to account for these initial conditions, particularly when considering the potential wood product component of harvested stands. To account for site specific conditions, information and data on the actual growing stock volume for each site class and forest types in mature (>40 years) forests by county in the Northeast was downloaded from the USDA FIA website. The data were used to determine initial quantities allocated to the wood products sector and to slash when poorly stocked forests are harvested using the parameters discussed above. Figure 4-6, therefore, presents a specific condition for a single individual stand. When aggregating the data, however, this analysis accounts for the average condition of the initial growing stock (and consequently the amount of carbon going into forest products and slash components) in each site class, forest type, and county.

Table 4-17 presents the average break down of the different carbon effects in the Northeast. These are averages and do not apply to specific sites or counties. They give an approximation of the effect of harvesting and regenerating poorly stocked stands. Negative numbers imply net discounted emissions over a 300 year period, and positive numbers indicate net discounted sequestration. A comparison of the regenerated stands to the baseline results in negative carbon in each case. This makes sense. In terms of Figure 4-6, it is the comparison of the blue line (baseline) to the black hatched line, which is the carbon in the regenerated stand. In contrast, storing carbon in wood products and slash, even allowing for decomposition and wood products turnover, results in sequestration. This is the red line Figure 4-6. The net effect can be positive or negative, depending on which of these two components is larger (the green line in Figure 4-6 is the net effect).

Table 4-17. Break down of the effects of harvesting poorly stocked stands and regenerating in the Northeast. Effects averaged across site classes and forest types in the region. The values are discounted carbon over a 300 year period (permanent), assuming that the discount rate is 6%.

		WRJ Pine[1]	SF[1]	OP[1]	OH[1]	OCG[1]	EAC[1]	MBB[1]	AB[1]
		t C/ha							
S3 Mature	Regenerate - Baseline	-33.9	-30.1	-24.2	-37.0	-17.7	-17.9	-26.8	-13.5
	Wood Products + Decomp/TO	19.2	26.0	23.5	13.7	0.0	11.7	18.8	0.0
	Net Effect	*-14.8*	*-4.1*	-0.7	-23.4	-17.7	-6.2	-8.0	-13.5
S4 Mature	Regenerate - Baseline	-29.0	-23.0	-24.2	-17.2	-17.7	-14.8	-25.5	-25.5
	Wood Products + Decomp/TO	32.6	28.4	25.1	17.4	10.7	20.5	22.2	16.8
	Net Effect	*3.6*	*5.4*	0.9	0.2	-7.1	5.6	-3.3	-8.7
S5 Mature	Regenerate - Baseline	-27.7	-26.3	-23.2	-13.6	-17.7	-10.3	-23.7	-14.8
	Wood Products + Decomp/TO	24.5	27.6	19.7	19.2	17.2	16.2	18.8	13.0
	Net Effect	*-3.2*	*1.3*	-3.5	5.6	-0.6	5.9	-4.9	-1.8
S6 Mature	Regenerate - Baseline	-15.3	-18.5	-25.4	-15.3	-17.7	-21.5	-24.8	-21.7
	Wood Products + Decomp/TO	23.4	24.1	16.8	16.6	17.7	16.6	18.2	11.8
	Net Effect	*8.1*	*5.6*	-8.5	1.2	-0.1	-5.0	-6.6	-9.9

([1]) WRJ Pine = White, Red, and Jack Pine; SF = Spruce and Fir; OP = Oak-Pine; OH = OakHickory; OCG = Oak-Gum-Cypress; EAC= Elm-Ash-Cottonwood; MBB = Maple-Beech-Birch; AB = Aspen and Birch. ([2]) decomposition of slash and turnover of wood products (Decomp/TO).

The results in Table 4-17 are average effects for the region. They give a first cut approximation of the net effects of the stocking policy described above. They are averaged across the entire 12 state region. Wood product storage and its turnover/decomposition plus decomposition of slash will vary tremendously across the region depending on the actual growing stock in site class, forest type, and county. The results section below presents the cost and carbon estimates based on the more disaggregated data. *The averages in Table 4-17 are presented only to help readers understand the components of the carbon flows considered in this study, and the relative scales of these carbon flows across the entire region.*

4.4.2 Analysis and Results

For the analysis, the data on growing stock volume and area in poorly stocked mature forests was downloaded from the USDA Forest Inventory and Analysis website for each county and each site class in the Northeast. There are a total of 244 total counties in the region, 8 forest types, and 4 site classes, for a total of 7,808 units analyzed, encompassing 4.6 million acres of poorly stocked stands. Prices for timber products in each county were estimated based on the most locally available data available, as discussed above. County level millage rates for land taxes were also applied.

Several analyses were developed for this section. The first analysis examined a permanent 300 year contract with 6% discounting. The other analyses considered shorter contract periods of 10, 20, and 40 years. For these contract lengths, total carbon gains were calculated without discounting. Costs, however, were calculated and presented as discounted costs per discounted ton to provide readers with a clearer sense of the types of carbon prices that would need to be observed over the contract period to make the contract cost effective. The specific analyses conducted for this section were:

- Permanent 300 year contracts, discounted carbon (r=6%)
- 10 year contracts, undiscounted carbon
- 20 year contracts, undiscounted carbon
- 40 year contracts, undiscounted carbon

Permanent 300 Year Contract

The resulting marginal cost curve for the permanent 300 year contracts with discounted carbon are shown in Figure 4-7. The marginal cost curve gives readers a general sense of the scale and cost of changing stocking conditions. The marginal cost curve shows a large range of essentially "free" carbon, that is, sites where it appears economically feasible to remove the existing growing stock and make enough money to pay for the regeneration costs, and to benefit from future timber harvests. This exceedingly low cost carbon amounts to around 2.0 million t C. The total potential from currently mature, but under-stocked, stands is around 3.9 million t C, although some of this is very expensive carbon.

To give a sense for the potential sequestration across the states and forest types, Table 4-18 presents average \$/t CO_2e, total potential t C, and total potential area with positive sequestration for each forest type, for the 300 year permanent contract with carbon discounted at r=6%. The results suggest that the lowest cost options exist with Maple Beech Birch (MBB), Oak Pine (OP), and Oak-Hickory (OH). Maple Beech Birch in particular has high values for some of the maple types (Sugar Maple), and thus there are strong values associated with regenerating well stocked stands. On about 403,900 acres, around 0.7 million t C could be sequestered in the MBB type, and on 534,300 acres, 1.4 million t C could be sequestered in Oak-Hickory types for relatively low or no cost. The states with the least average cost are Pennsylvania, Delaware, New Jersey, and New York.

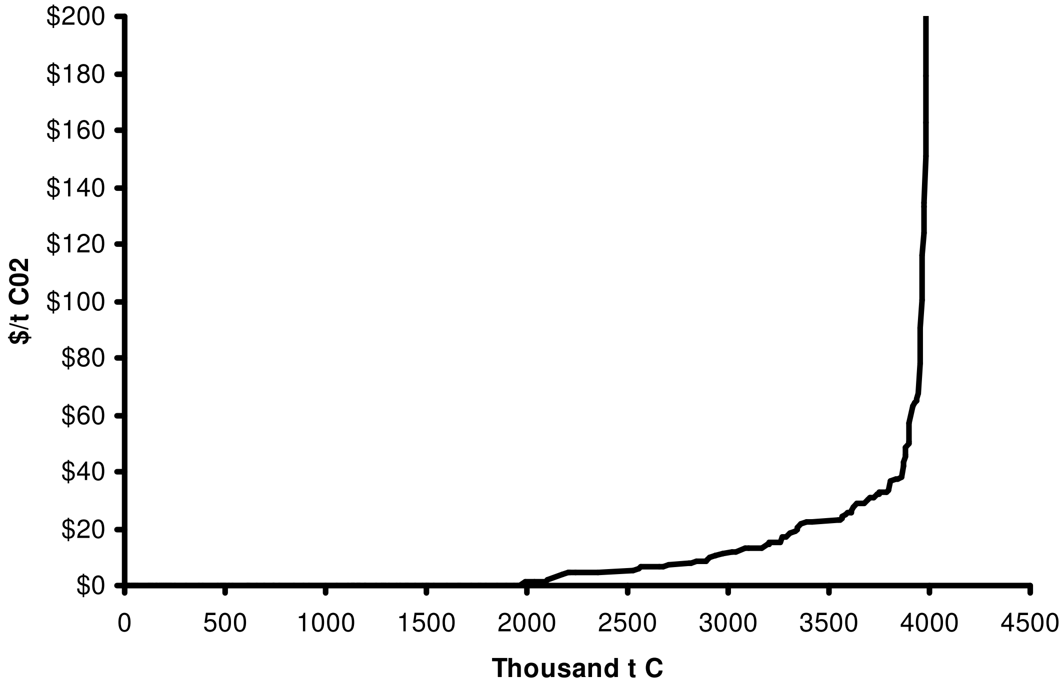

Figure 4-7. **Marginal costs of sequestering carbon through harvesting and re-stocking poorly stocked forests in the Northeast for forests that currently are >40 yr-old. Carbon gains are discounted (r=6%) and calculated over a 300 year period.**

Table 4-18. **Carbon sequestration potential, average costs, and acres in program from harvesting and regenerating poorly stocked stands in The Northeast. Estimates are for permanent 300 year contracts, and carbon changes are discounted (r=6%) over the entire time period. Estimates only include acres for which there are positive carbon benefits. Numbers in parentheses indicate that the projects would potentially generate profits of the indicated values over the cycle.**

	WRJ Pine[1]	SF[1]	OP[1]	OH[1]	OCG[1]	EAC[1]	MBB[1]	AB[1]	Total
					Average $/t CO_2e				
CT	$124	--	--	($2)	--	$235	$179	--	$76
DE	--	--	--	($12)	--	$2	--	--	($9)
ME	($6)	$13	($159)	($25)	--	$13	--	--	$6
MD	--	--	--	--	--	--	--	--	--
MA	$50	--	($21)	($3)	--	$163	--	--	$23
NH	$38	--	--	--	--	$5	($14)	--	$9
NJ	--	--	--	($9)	--	$10	($73)	--	($24)
NY	$14	--	($37)	($18)	--	$13	($271)	--	($50)
PA	$25	$6	($469)	$2	$12	$6	($128)	$281	($35)
RI	--	--	--	$31	--	$151	--	--	$57
VT	$15	$10	--	--	--	($6)	($160)	--	$3
Total	$8	$12	($51)	($2)	$12	$12	($142)	$281	($21)

	WRJ Pine[1]	SF[1]	OP[1]	OH[1]	OCG[1]	EAC[1]	MBB[1]	AB[1]	Total
				Average $/t CO_2e					
Potential Tons Stored in State (permanent 300 year contract – discounted carbon)									
				Thousand t C					
CT	2.7	--	--	12.7	--	5.0	0.7	--	21.1
DE	--	--	--	49.5	--	12.4	--	--	61.9
ME	210.9	647.8	7.3	20.1	--	45.1	--	--	931.3
MD	--	--	--	--	--	--	--	--	--
MA	14.0	--	1.8	32.9	--	4.1	--	--	52.9
NH	17.5	--	--	--	--	32.1	17.3	--	66.9
NJ	--	--	--	85.0	--	58.9	65.2	--	209.0
NY	122.6	--	60.9	178.9	--	153.7	107.9	--	623.9
PA	29.9	16.6	0.3	979.5	20.6	138.8	496.8	2.5	1,685.1
RI	--	--	--	10.1	--	2.8	--	--	12.8
VT	45.8	210.0	--	--	--	60.0	8.9	--	324.7
Total	443.4	874.4	70.4	1,368.6	20.6	512.9	696.8	2.5	3,989.6
Acres Potentially in Program									
				Thousand Acres					
CT	3.5	--	--	1.7	--	11.1	6.6	--	23.0
DE	--	--	--	7.6	--	3.5	--	--	11.1
ME	65.8	292.4	5.7	5.7	--	11.7	--	--	381.3
MD	--	--	--	--	--	--	--	--	--
MA	6.5	--	0.9	6.6	--	6.3	--	--	20.3
NH	6.8	--	--	--	--	7.8	31.1	--	45.7
NJ	--	--	--	25.9	--	19.5	18.6	--	64.0
NY	27.4	--	30.4	73.6	--	42.5	116.1	--	289.9
PA	6.5	1.8	1.6	407.2	7.6	35.5	224.6	6.5	691.1
RI	--	--	--	6.0	--	3.7	--	--	9.8
VT	11.9	45.7	--	--	--	7.1	6.8	--	71.5
Total	128.3	340.0	38.5	534.3	7.6	148.6	403.9	6.5	1,607.6

([1]) WRJ Pine = White, Red, and Jack Pine; SF = Spruce and Fir; OP = Oak-Pine; OH = OakHickory; OCG = Oak-Gum-Cypress; EAC= Elm-Ash-Cottonwood; MBB = Maple-Beech-Birch; AB = Aspen and Birch.

It is useful also to consider the distribution of carbon sequestration potential across the site classes (Tables 4-19 and 4-20). The largest potential exists in the lower site classes (site classes S5 and S6). This is not surprising because the largest overall share (85%) of poorly stocked stands exists in these two site classes. These lower site classes also appear to have substantial low cost opportunities (Table 4-20). Mature forests will have a higher proportion of mature trees that can be used for merchantable timber, which offsets the costs of regeneration. There are some fairly low cost opportunities in the mature higher site classes (S3 and S4), although the overall potential area and tons that can be sequestered in these higher site classes is limited.

Table 4-19. Proportion of total carbon storage potential by site class. Estimates for the permanent 300 year contract, with discounted carbon.

	Site 3	Site 4	Site 5	Site 6
		Proportion		
CT	0.00	0.13	0.03	0.84
DE	0.00	0.36	0.64	0.00
ME	0.01	0.19	0.24	0.56

	Site 3	Site 4	Site 5	Site 6
		Proportion		
MD	0.00	0.00	0.00	0.00
MA	0.00	0.08	0.03	0.89
NH	0.00	0.26	0.00	0.74
NJ	0.00	0.25	0.44	0.31
NY	0.00	0.08	0.60	0.32
PA	0.02	0.10	0.39	0.49
RI	0.00	0.00	0.21	0.79
VT	0.00	0.21	0.39	0.40
Total	0.01	0.14	0.38	0.47

Table 4-20. Average costs across site classes and age. Estimates are for the permanent 300 year contract, with discounted carbon. Numbers in parentheses indicate that the projects would potentially generate profits over the cycle.

	Site 3	Site 4	Site 5	Site 6
		Average $/t CO_2e		
CT	--	$124	$179	$65
DE	--	($2)	($13)	--
ME	($136)	$1	$5	$11
MD	--	--	--	--
MA	--	$163	($21)	$13
NH	--	($14)	--	$16
NJ	--	($28)	($30)	($11)
NY	--	($47)	($61)	($29)
PA	($184)	($21)	($34)	($34)
RI	--	--	$151	$31
VT	--	$12	$4	($3)
Total	($173)	($10)	($31)	($14)

Average costs by county are plotted in Figure 4-8. The figure shows that there are numerous counties with essentially "negative" costs for carbon sequestration (<$0/t CO_2e). These counties have forest types, site classes, and growing stock conditions that lead to net gains in revenues when existing poorly stocked forests are harvested and replanted. There are also a number of counties with no carbon costs given because there are no positive opportunities to sequester carbon within those counties. For these counties, the types of forests, and the existing growing stock levels are such that harvesting the stands and replanting them would lead to negative carbon.

The results indicate that up to 2.9 million t C (10.6 million t CO_2e) could be sequestered for less than $10/t CO_2e, with many of these project activities generating net benefits. The regional distribution of the carbon opportunities with costs less than $10/t CO_2e is shown in Figure 4-9. The largest opportunities appear to occur in Maine, followed by Pennsylvania and by New York. This is not surprising as these states have the most total forestland area.

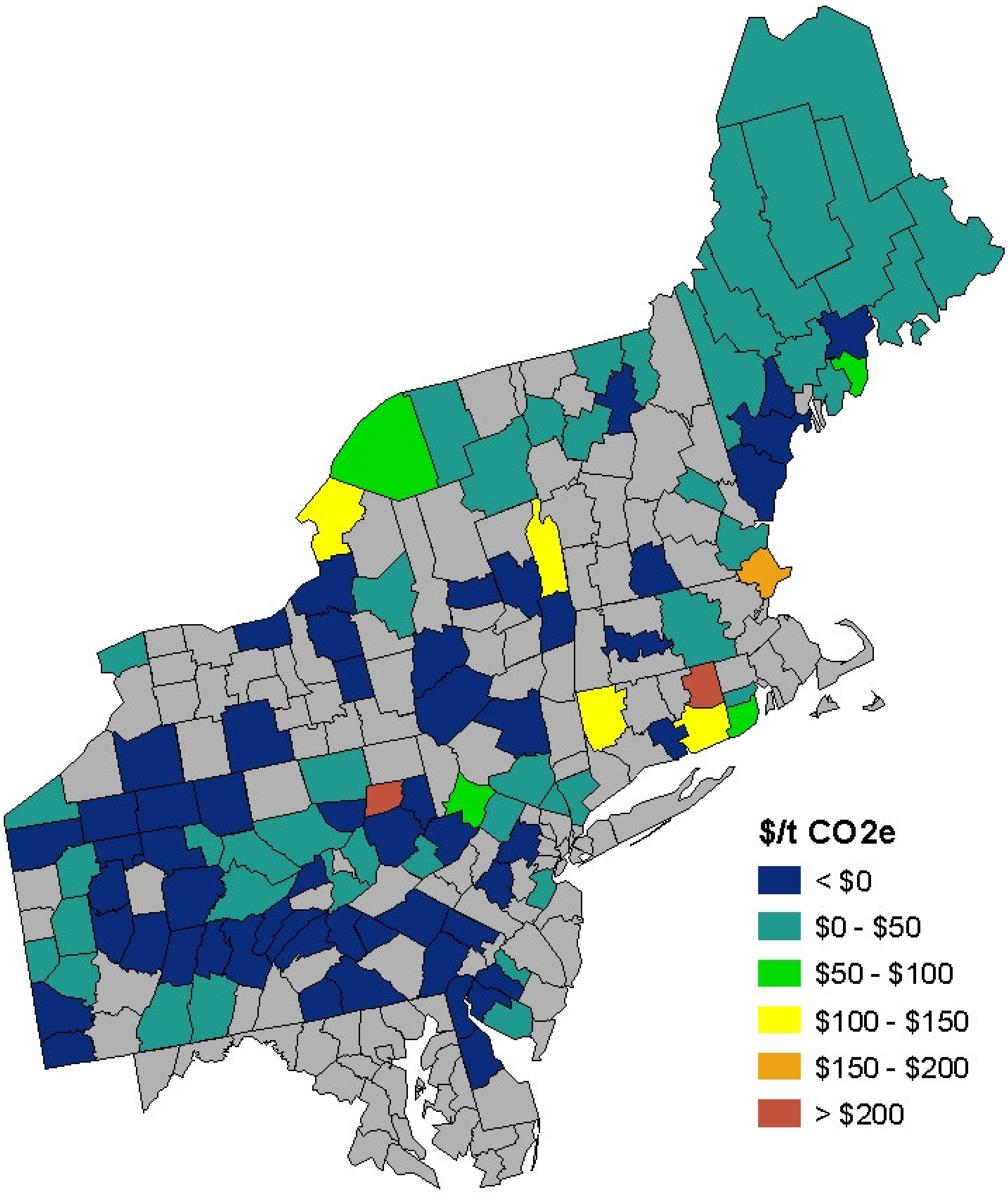

Figure 4-8. **Average cost of carbon sequestration in each county from improving stocking conditions in poorly stocked forests. Estimates for permanent 300 year contract with discounted carbon (r=6%)**

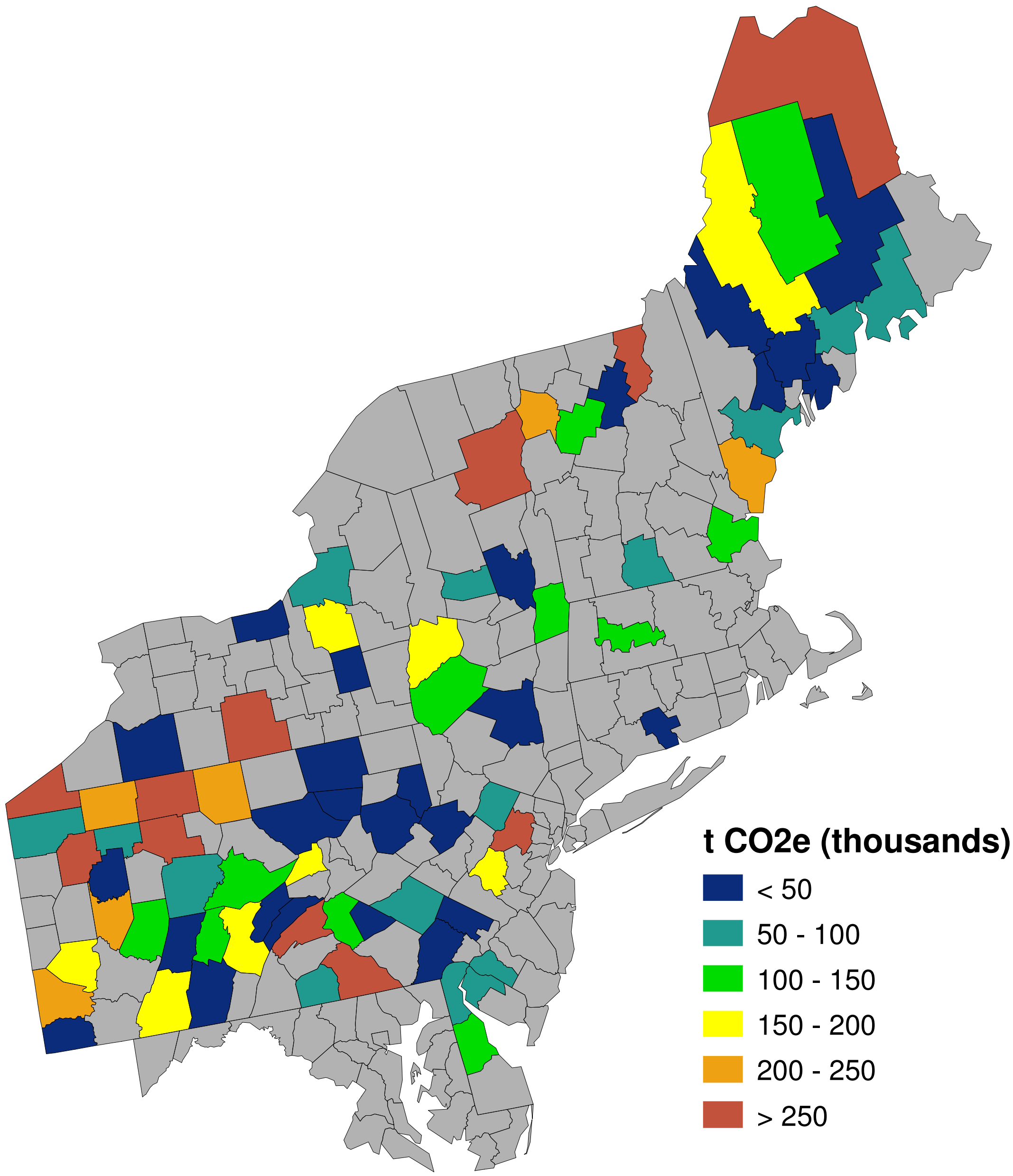

Figure 4-9. Total carbon potential for poorly- and under-stocked stands by county at marginal costs of less than \$10/t CO_2e. Estimates are for permanent 300 year contract with discounted carbon (r=6%).

Contracts of 10, 20, and 40 Years

For shorter term contracts, costs of carbon sequestration are estimated as the present value of costs divided by the present value of carbon, both discounted and assuming that the interest rate is 6%. This provides readers with an idea about what the carbon price needs to be on average over the time period of the contract for the landowner to breakeven. Total carbon for these contracts, however, is calculated without discounting. This tells readers the total amount of carbon that is expected to be obtained over the time period.

As expected, the costs tend to decrease, and the total carbon increases as contract period increases. Costs decline because most costs occur in the initial period, and for longer contracts they are amortized over more carbon. Total acres with positive carbon also increase as the contract period expands. As can be see in Figure 4-7 above, carbon is initially negative (the first 5-10 year periods). Over time, the replanted stand has more carbon than the baseline. Thus, longer contracts will allow more area to enter the program with positive carbon.

The results indicate that over 10 years, 0.4 million t C could be sequestered on 195 thousand acres (2.1 t C/acre) (Table 4-21). Over 20 years, 7.5 million t C could be stored on 2.3 million acres (3.3 t C/acre) (Table 4-22). For the 40 year contract, up to 57 million t C can be sequestered in the region on 4.5 million acres of land (12.7 t C/acre) (Table 4-23).

Table 4-21. Carbon sequestration potential, average costs, and acres in program from harvesting and regenerating poorly stocked stands in the Northeast. Estimates are for 10 year contracts.

Estimates only include acres for which there are positive carbon benefits. Numbers in parentheses indicate that the projects would potentially generate profits of the indicated values over the cycle.

	WRJ Pine[1]	SF[1]	OP[1]	OH[1]	OCG[1]	EAC[1]	MBB[1]	AB[1]	Total
				Average $/t CO_2e[2]					
CT	--	--	--	($5)	--	--	--	--	($5)
DE	--	--	--	($29)	--	--	--	--	($29)
ME	($43)	($6)	--	--	--	--	--	--	($30)
MD	--	--	--	--	--	--	--	--	--
MA	--	--	--	($23)	--	--	--	--	($23)
NH	--	--	--	--	--	$9	--	--	$9
NJ	--	--	--	($57)	--	--	($107)	--	($82)
NY	$20	--	--	($91)	--	--	--	--	($29)
PA	$97	$13	--	($67)	$49	($9)	($227)	--	($84)
RI	--	--	--	--	--	--	--	--	--
VT	--	$11	--	--	--	($16)	--	--	$3
Total	$4	$8	--	($64)	$49	($6)	($194)	--	($49)
Potential Tons Stored in State (10 years, undiscounted carbon)									
				Thousand t C					
CT	--	--	--	5.0	--	--	--	--	5.0
DE	--	--	--	16.5	--	--	--	--	16.5
ME	14.8	9.2	--	--	--	--	--	--	24.0
MD	--	--	--	--	--	--	--	--	--
MA	--	--	--	3.7	--	--	--	--	3.7
NH	--	--	--	--	--	12.3	--	--	12.3
NJ	--	--	--	14.8	--	--	11.7	--	26.6
NY	32.0	--	--	30.1	--	--	--	--	62.1
PA	3.3	6.8	--	99.6	1.3	26.7	28.5	--	166.2
RI	--	--	--	--	--	--	--	--	--
VT	--	41.3	--	--	--	22.7	--	--	64.0
Total	50.1	57.2	0.0	169.8	1.3	61.8	40.2	0.0	380.4

	WRJ Pine[1]	SF[1]	OP[1]	OH[1]	OCG[1]	EAC[1]	MBB[1]	AB[1]	Total
Acres Potentially in Program									
					Thousand Acres				
CT	--	--	--	1.7	--	--	--	--	1.7
DE	--	--	--	4.1	--	--	--	--	4.1
ME	13.6	9.2	--	--	--	--	--	--	22.9
MD	--	--	--	--	--	--	--	--	--
MA	--	--	--	6.6	--	--	--	--	6.6
NH	--	--	--	--	--	7.8	--	--	7.8
NJ	--	--	--	10.5	--	--	5.8	--	16.3
NY	16.2	--	--	13.9	--	--	--	--	30.1
PA	5.0	1.8	--	35.5	7.6	14.4	20.3	--	84.6
RI	--	--	--	--	--	--	--	--	--
VT	--	13.5	--	--	--	7.1	--	--	20.6
Total	34.8	24.6	0.0	72.3	7.6	29.3	26.1	0.0	194.7

([1]) WRJ Pine = White, Red, and Jack Pine; SF = Spruce and Fir; OP = Oak-Pine; OH = OakHickory; OCG = Oak-Gum-Cypress; EAC= Elm-Ash-Cottonwood; MBB = Maple-Beech-Birch; AB = Aspen and Birch.

Table 4-22. Carbon sequestration potential, average costs, and acres in program from harvesting and regenerating poorly stocked stands in the Northeast. Estimates are for 20 year contracts.

Estimates only include acres for which there are positive carbon benefits. Numbers in parentheses indicate that the projects would potentially generate profits of the indicated values over the cycle.

	WRJ Pine[1]	SF[1]	OP[1]	OH[1]	OCG[1]	EAC[1]	MBB[1]	AB[1]	Total
	Average $/t CO_2e[2]								
CT	--	--	--	($3)	--	--	--	--	($3)
DE	--	--	--	($17)	--	$6	--	--	($14)
ME	($10)	$23	--	($69)	--	$24	--	--	$12
MD	--	--	--	--	--	--	--	--	--
MA	--	--	($121)	($4)	--	--	--	--	($6)
NH	$419	--	--	--	--	$7	--	--	$35
NJ	--	--	--	($19)	--	$15	($53)	--	($21)
NY	$16	--	--	($50)	--	$26	($511)	--	($38)
PA	$52	$8	--	($10)	$29	($1)	($204)	--	($51)
RI	--	--	--	$43	--	--	--	--	$43
VT	$9	$16	--	--	--	($7)	--	--	$9
Total	$11	$20	($121)	($17)	$29	$10	($205)	--	($25)
Potential Tons Stored in State (20 years, undiscounted carbon)									
	Thousand t C								
CT	5.6	--	--	30.3	--	0.1	12.1	--	48.1
DE	--	--	--	61.5	--	33.6	--	--	95.1
ME	219.2	1,011.1	31.7	41.9	--	112.3	6.8	--	1,422.9
MD	--	--	--	--	--	--	--	--	--
MA	12.3	--	4.9	49.3	--	42.4	--	--	108.9
NH	15.7	--	--	3.8	--	26.3	68.1	--	113.8
NJ	--	--	13.5	192.2	--	146.3	92.5	--	444.5
NY	115.3	--	209.1	436.9	--	338.1	376.4	--	1,475.8
PA	28.2	21.3	26.6	2,027.1	10.7	259.2	942.5	--	3,315.7
RI	--	--	--	25.0	--	16.8	--	--	41.9
VT	48.2	277.9	--	--	--	86.5	42.2	--	454.9
Total	444.3	1,310.3	285.7	2,868.1	10.7	1,061.7	1,540.7	0.0	7,521.6
Acres Potentially in Program									
	Thousand Acres								
CT	3.5	--	--	8.9	--	6.1	13.7	--	32.3
DE	--	--	--	7.6	--	3.5	--	--	11.1
ME	65.8	324.2	14.2	16.3	--	20.7	17.2	--	458.4
MD	--	--	--	--	--	--	--	--	--
MA	6.5	--	0.9	6.6	--	6.3	--	--	20.3
NH	6.8	--	--	3.7	--	7.8	46.0	--	64.3
NJ	--	--	6.2	49.2	--	19.5	20.1	--	95.0
NY	27.4	--	59.5	178.7	--	50.3	213.4	--	529.2
PA	6.5	4.7	7.9	526.7	7.6	42.7	350.1	--	946.1
RI	--	--	--	6.0	--	3.7	--	--	9.8
VT	11.9	61.9	--	--	--	7.1	39.5	--	120.4
Total	128.3	390.8	88.6	803.7	7.6	167.7	700.0	0.0	2,286.8

([1]) WRJ Pine = White, Red, and Jack Pine; SF = Spruce and Fir; OP = Oak-Pine; OH = OakHickory; OCG = Oak-Gum-Cypress; EAC= Elm-Ash-Cottonwood; MBB = Maple-Beech-Birch; AB = Aspen and Birch.

Table 4-23. Carbon sequestration potential, average costs, and acres in program from harvesting and regenerating poorly stocked stands in the Northeast. Estimates are for 40 year contracts.

Estimates only include acres for which there are positive carbon benefits. Numbers in parentheses indicate that the projects would potentially generate profits of the indicated values over the cycle.

	WRJ Pine[1]	SF[1]	OP[1]	OH[1]	OCG[1]	EAC[1]	MBB[1]	AB[1]	Total
				Average $/t CO_2e[2]					
CT	$98	--	--	($2)	--	$187	$49	--	$63
DE	--	--	--	($11)	--	$2	--	--	($9)
ME	($6)	$15	($145)	($23)	--	$12	($213)	--	$8
MD	--	--	--	--	--	--	--	--	--
MA	$47	--	($18)	($3)	--	$116	--	--	$21
NH	$36	--	--	--	--	$5	($9)	--	$7
NJ	--	--	--	($6)	--	$9	($67)	--	($21)
NY	$14	--	($32)	($16)	--	$12	($259)	--	($55)
PA	$25	$29	($928)	$3	$11	$6	($119)	$191	($33)
RI	--	--	--	$27	--	$105	--	--	$47
VT	$14	$10	--	--	--	($5)	($165)	--	$2
Total	$8	$14	($55)	($1)	$11	$11	($136)	$191	($21)
Potential Tons Stored in State (40 years, undiscounted carbon)									
				Thousand t C					
CT	68.5	--	--	113.7	--	164.5	251.2	--	597.9
DE	--	--	--	177.4	--	80.4	--	--	257.9
ME	1,262.2	4,915.3	361.2	304.3	52.4	514.3	5,864.0	664.8	13,938.2
MD	--	--	--	--	--	--	--	--	--
MA	101.6	--	13.9	200.2	--	127.1	235.1	--	677.9
NH	321.0	--	338.5	112.1	--	102.7	2,530.5	--	3,404.7
NJ	--	--	179.7	710.2	15.2	414.6	445.2	--	1,764.8
NY	1,052.0	373.5	1,259.7	2,649.1	99.8	1,207.9	8,171.6	110.6	14,924.1
PA	179.0	77.7	168.8	8,204.3	121.1	849.6	8,455.0	94.6	18,150.2
RI	--	--	--	81.5	--	57.5	82.8	--	221.9
VT	233.0	1,016.2	--	--	--	202.3	1,382.5	18.5	2,852.5
Total	3,217.4	6,382.7	2,321.8	12,552.8	288.4	3,720.9	27,417.8	888.4	56,790.2
Acres Potentially in Program									
				Thousand Acres					
CT	3.5	--	--	8.9	--	20.2	20.6	--	53.2
DE	--	--	--	7.6	--	3.5	--	--	11.1
ME	66.5	333.9	31.5	19.8	6.6	58.7	535.2	130.0	1,182.2
MD	--	--	--	--	--	--	--	--	--
MA	6.5	--	0.9	12.4	--	6.3	22.1	--	48.2
NH	22.2	--	34.0	9.1	--	11.5	213.5	--	290.3
NJ	--	--	21.8	51.4	3.0	30.0	26.5	--	132.6
NY	68.3	35.2	99.0	215.3	15.7	99.6	702.7	26.3	1,262.1
PA	14.6	4.7	19.8	548.7	11.0	64.4	636.1	14.1	1,313.4
RI	--	--	--	6.0	--	3.7	8.6	--	18.3
VT	11.9	61.9	--	--	--	13.7	119.2	3.6	210.4
Total	193.5	435.7	207.0	879.3	36.2	311.5	2,284.5	174.0	4,521.8

([1]) WRJ Pine = White, Red, and Jack Pine; SF = Spruce and Fir; OP = Oak-Pine; OH = OakHickory; OCG = Oak-Gum-Cypress; EAC= Elm-Ash-Cottonwood; MBB = Maple-Beech-Birch; AB = Aspen and Birch. [2] Negative numbers in average cost estimates indicate that the projects would potentially generate profits over the cycle.

4.4.3 Important Sensitivities

The results in this section suggest that substantial carbon can be sequestered in poorly- and under-stocked forests in the Northeast for literally nothing, i.e. for no cost at all. This type of result confounds economists, but is often found in "bottom-up" analyses, like the one conducted here, which use detailed, site-specific data in some respects, but which do not model market phenomenon like supply and demand directly. There are several explanations for these results.

First, many forest landowners in the U.S. are observed to act "sub-optimally" with respect to traditional economic incentives, such as the price of timber. Other considerations, such as ecological benefits, game management, or other factors, undoubtedly influence landowner behavior and cause them to behave differently from the traditional financial model that includes only the costs and benefits of timber management. It is difficult to incorporate these other factors into the type of economic analysis conducted in this study, however, it is likely that including these other factors would increase the cost estimates. That is, if landowners are holding poorly stocked lands for other reasons important to them, one can reasonably expect that they will not adjust their management plans simply because someone tells them they can make more money by harvesting trees and regenerating well stocked forests. The incentives will have to be larger for landowners in this category.

Second, the analysis is static, and does not account for price adjustments. The scale of potential land that could enter this program is fairly large – 4.6 million acres. Total removals of growing stock associated with this could be around 50.2 million m^3, which is 62% more than the current estimated removals each year of around 31 million m^3. This analysis has assumed that these projects would be implemented over a short period of time, and such large influxes of wood onto the market would have substantial impacts upon prices. Specifically, prices would be depressed, and consequently the costs estimated above would increase. Elasticity estimates for U.S. stumpage markets indicate that the price elasticity is around 0.25. Each 10% increase in quantity within a given year could depress prices by an additional 40%. A sensitivity analysis conducted for this study found that a 40% reduction in timber prices could almost double the costs (about a 92% increase).

In section 4.2, additional scenarios were considered related to the decomposition of slash and the use of milling residues as biomass energy. The base assumption in this model is that decomposition rates for slash are 10%, and that milling residues are used for biomass energy. Sensitivity analysis on these alternatives was not conducted in this section. However, it is possible to describe the effects on carbon sequestered, and costs. First, if biomass credits are ignored, then carbon gains would be lower and costs would be higher. Second, if slash decomposition rates are 100% (or in other words, if slash is ignored in carbon calculations), then carbon gains will also be lower and costs would be higher. Carbon gains would be lowest and costs highest if both biomass is ignored and slash decomposition is assumed to be 100%.

4.5 Conservation Areas Along Streams

This section examines the potential for riparian zone management to increase carbon sequestration. For this analysis, it was assumed that landowners are contracted to maintain a 100 foot riparian buffer (could be additional if regulations already require this—the analysis is the same) along streams on all forestland in the Northeast (50 feet on each side of the stream). The opportunity costs associated with excluding this timber from harvesting for the indefinite future were calculated. New riparian zones were treated as set-asides.

The costs calculated in this analysis pertain only to the timber value associated with the land. That is, the costs are those that would be incurred if a contract with a landowner was made to avoid harvesting timber in the riparian area, and the costs assume that there are no other better opportunities with the land. Thus, the cost estimates do not account for potential development value associated with the land. Substantially more extensive analysis would need to be conducted with actual land sale data to determine the development value of land in each county, and that type of analysis has not been done here. As a consequence, the values estimated here are appropriate for rural areas in the region, but are likely biased downward for regions experiencing substantial land use change from undeveloped to developed land.

The potential carbon credits when riparian land is set-aside result from deferring initial emissions that occur when a stand is harvested. Over the long-run in the Northeast, total carbon storage will be greater if stands are harvested because products provide storage, some residue is likely to be used in biomass energy, and slash decomposes slowly (Figure 4-10). If decomposition rates are faster or if less of the residue from the milling process is used for biomass energy, then there are larger benefits associated with setting aside riparian zones. Figure 4-10 illustrates the difference between two assumptions. In the top line, more milling residue is used for biomass energy, and decomposition rates are 10%. In the middle line, no milling residues are used for biomass energy, and slash is assumed to decompose immediately.

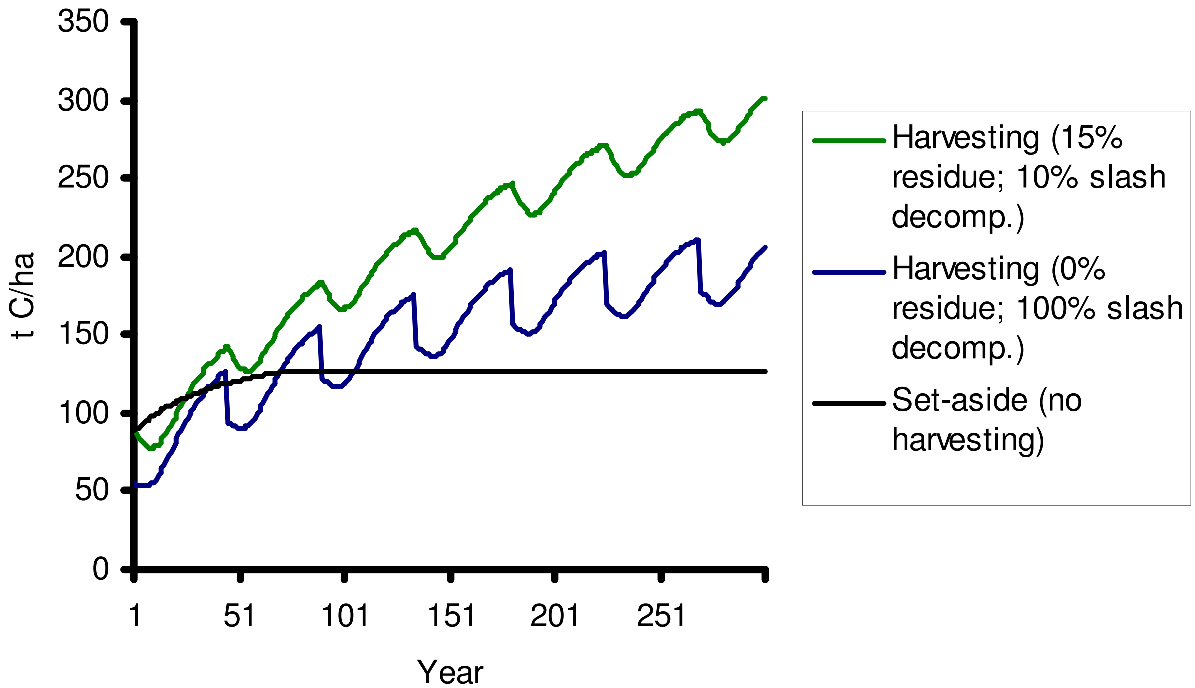

Figure 4-10. White-red-jack pine site class 3, tons carbon per hectare stored in above-ground biomass and products for the set-aside (bottom line) and harvesting under two assumptions about the use of residue in biomass energy production (0% and 15%), and the decomposition of slash (100% and 10% decomposition per year; 100% simulates immediate decomposition).

Figure 4-10 illustrates two important points about conservation set-asides. First, in the long run, harvesting of forests in this region appears to provide more carbon sequestration due to the conversion of harvested material to products and milling residues. This raises the apparent cost of this opportunity relative to the other opportunities examined in this chapter.

Second, in the shorter run, i.e. in 10, 20, or 40 year contracts, set-asides can provide positive carbon sequestration, however, simply counting the carbon during the first 10, 20, or 40 years of the set-aside and ignoring the future (beyond that) would ignore permanence issues. That is, even if carbon has been sequestered in the first 10 years, and companies count those benefits, they will still be held responsible for future liabilities that accrue when in the baseline the stands would have been accruing more carbon through the harvesting regimes. Discounting the carbon over a longer time-frame (e.g., 300 years) allows companies to account for the fact they may gain some short-term advantages from set-asides (e.g., the carbon sequestered in the first 10 -20 years). In consideration of these two points, firms should carefully consider using this option for carbon sequestration.

Table 4-24 shows the permanent (300 year) discounted carbon, as well as the undiscounted tons sequestered in 10, 20, and 40 year time periods. If permanent discounted carbon is negative, costs are very high (for example, oak-pine types), whereas if permanent discounted carbon is positive, companies can potentially gain from the short term benefits of set-asides. Across all the forest types examined, set-asides would lead to carbon gains in the first 10 years. Over the first 20 years, some types exhibit negative carbon gains (or net emissions relative to the baseline), and over the first 40 years, nearly all types exhibit losses relative to the baseline.

Table 4-24. Carbon gains in forests and costs associated with setting aside riparian zones in the Northeast. Decomposition of slash occurs at 10%/yr, and milling residues are used for biomass energy.

		300 yr (r=6.0%)	10 year (r=0.0%)	20 year (r=0.0%)	40 year (r=0.0%)
	$/acre	t C/ha	t C/ha	t C/ha	t C/ha
White Red Jack Pine SC3	$560	5.7	20.7	9.3	-19.0
White Red Jack Pine SC4	$483	10.0	22.2	17.6	-9.2
White Red Jack Pine SC5	$440	1.5	14.0	1.3	-19.5
White Red Jack Pine SC6	$329	12.9	20.0	22.7	3.8
Spruce Fir SC3	$457	5.4	17.8	9.6	-15.3
Spruce Fir SC4	$374	4.7	15.3	8.0	-12.6
Spruce Fir SC5	$548	2.5	12.2	3.7	-13.5
Spruce Fir SC6	$410	2.0	10.8	2.8	-12.5
Aspen Birch SC 3	$365	5.3	11.1	9.1	-2.9
Aspen Birch SC 4	$466	9.4	15.6	16.1	1.3
Aspen Birch SC 5	$413	7.1	13.1	12.1	-1.3
Aspen Birch SC 6	$313	4.6	9.6	7.9	-2.7
Maple Beech Birch SC 3	$981	5.5	17.2	9.2	-13.2
Maple Beech Birch SC 4	$882	-0.8	10.1	-2.5	-20.0
Maple Beech Birch SC 5	$874	3.2	14.0	4.8	-14.6
Maple Beech Birch SC 6	$728	2.8	12.1	4.4	-12.3
Oak Pine SC 3	$1,081	-2.4	11.7	-5.2	-26.3
Oak Pine SC 4	$851	-2.7	9.0	-4.2	-22.9
Oak Pine SC 5	$729	-7.5	2.1	-12.0	-26.4
Oak Pine SC 6	$433	-0.6	5.9	1.0	-11.8
Oak Hickory SC 3	$1,417	18.9	26.1	34.1	10.1
Oak Hickory SC 4	$1,461	3.2	15.6	5.3	-17.6
Oak Hickory SC 5	$1,305	-1.4	9.8	-3.4	-21.6
Oak Hickory SC 6	$842	-4.4	2.7	-7.9	-18.9

It is also important to recognize that these results are sensitive to the assumed proportion of milling residues used for biomass energy and the slash decomposition rate, following figure 4-10. If fewer residues are converted to biomass energy production, and decomposition rates are greater, then relatively more carbon is stored in set-asides. Both these factors are likely to be location specific, for example they will depend on local climatic conditions and technology employed at nearby mills. White-red-jack pine has the largest storage potential, followed by aspen-birch and spruce-fir in general. Oak-pine and Oak-hickory have smaller storage potential (negative if slash decomposition rates are slower and milling residue is used for biomass).

The total costs per hectare of setting aside timberland were estimated as the current stumpage value of mature timber on each hectare, assuming the timber is near the optimal rotation age, plus the present value of bare land. If timber is the best alternative for the land, these estimates provide a lower bound estimate of what it would cost individuals interested in purchasing set-asides to negotiate with landowners for the rights to hold the timber on the land indefinitely. However, as noted above, if the alternative land use is development, these estimates do not account for development values and therefore are likely to be lower than the actual costs. The total costs per hectare of setting aside timberland are shown in table 4-24 (and repeated in table 4-25). Costs per ton ($/t) are estimated by dividing total tons gained into the total costs (Table 4-25).

Table 4-25. Costs and carbon gains in forests associated with permanently setting aside riparian zones in the Northeast. Carbon gains are present value of carbon over 300 years, and $/t CO_2e are permanence costs.

	10%/yr decomposition of slash Milling residue used for biomass energy[1]			100%/yr decomposition of slash No milling residue used for biomass energy[1]		
	$/acre	t C/ha	$/t CO_2e	$/acre	t C/ha	$/t CO_2e
White Red Jack Pine SC3	$560	5.7	$65.90	$560	27.6	$13.65
White Red Jack Pine SC4	$483	10.0	$32.47	$483	29.8	$10.88
White Red Jack Pine SC5	$440	1.5	$198.16	$440	20.1	$14.72
White Red Jack Pine SC6	$329	12.9	$17.12	$329	28.1	$7.87
Spruce Fir SC3	$457	5.4	$56.57	$457	23.4	$13.14
Spruce Fir SC4	$374	4.7	$53.20	$374	20.6	$12.23
Spruce Fir SC5	$548	2.5	$146.14	$548	17.0	$21.66
Spruce Fir SC6	$410	2.0	$136.40	$410	15.4	$17.97
Aspen Birch SC 3	$365	5.3	$45.98	$365	16.4	$15.02
Aspen Birch SC 4	$466	9.4	$33.53	$466	22.6	$13.90
Aspen Birch SC 5	$413	7.1	$39.35	$413	19.1	$14.53
Aspen Birch SC 6	$313	4.6	$46.06	$313	14.4	$14.61
Maple Beech Birch SC 3	$981	5.5	$119.02	$981	24.1	$27.42
Maple Beech Birch SC 4	$882	-0.8	--	$882	16.4	$36.13
Maple Beech Birch SC 5	$874	3.2	$185.58	$874	20.3	$29.02
Maple Beech Birch SC 6	$728	2.8	$172.26	$728	17.9	$27.41
Oak Pine SC 3	$1,081	-2.4	--	$1,081	19.0	$38.20
Oak Pine SC 4	$851	-2.7	--	$851	15.7	$36.46
Oak Pine SC 5	$729	-7.5	--	$729	9.1	$54.02
Oak Pine SC 6	$433	-0.6	--	$433	10.9	$26.78
Oak Hickory SC 3	$1,417	18.9	$50.57	$1,417	37.9	$25.18
Oak Hickory SC 4	$1,461	3.2	$306.30	$1,461	22.6	$43.44
Oak Hickory SC 5	$1,305	-1.4	--	$1,305	16.5	$53.24
Oak Hickory SC 6	$842	-4.4	--	$842	8.8	$64.66

[1]The two scenarios in Figure 4-10—top and middle lines

It is also useful to estimate how much land is available in forested riparian areas for potential protection. To accomplish this, stream lengths through different types of land uses in each county in the northeastern states were estimated in a GIS. The stream lengths through forested areas were extracted from these data, and used to estimate the total area of land in a set-aside encompassing 50 feet of land on each side of the stream (Table 4-26). The data included information on the types of forests, allowing the economic value and carbon sequestration estimates from Table 4-25 to be attached to the total area of forests in the riparian zone.

The estimated area is 2.8 million acres of forestland in 50 foot buffers along streams currently in the northeastern region. Of this, about 25% is in currently economically mature age classes, or around 693 thousand acres. For economic maturity, forests between 40 and 60 years old only were used. Older forests are assumed to already be preserved and to provide little additional sequestration potential if they are not contracted for carbon sequestration. As can be seen from Table 4-24, some forest types sequester negative "permanent" present value carbon. Based on the calculations, only about 470,000 acres could be set aside and provide net sequestration (Table 4-26). The total carbon sequestration potential (assuming permanent contracts with carbon discounting) associated with taking the economically mature land with positive carbon potential and setting it aside in buffers is estimated to be 700 thousand t C (2.6 million t CO_2e), and the costs are estimated as $308 million in total. The average cost across all species is $441 per t C for discounted, permanent sequestration, or $656 per acre (Table 4-26).

For the 10 year contract, nearly all of the mature forests currently estimated to be along streams could be set-aside to produce positive, undiscounted, carbon equaling 3.28 million t C (Table 4-26). As one only needs to rent the acres for 10 years, total costs are lower than the total costs of the permanent contract. Average costs per acre are also lower because rather than buying the land, the land is just rented for 10 years. When moving to a 20 year contract, less land will produce positive carbon by year 20, however, during the 20 year period, all of the land included in the evaluation of the 10 year period will have produced positive sequestration during the first 10 years of the contract. For the 20 year contract, therefore the same acres as evaluated in the 10 year contract were evaluated. Because negative carbon is produced by the 20th year in a large number of stands, total carbon storage at year 20 is less than total carbon storage at year 10 (Table 4-26). Total costs are higher because the land now must be rented for 20 years. For the 40 year contracts, very few stands have positive carbon at the 40th year, although all of the stands sequestered carbon through year 10 and many sequestered positive carbon through year 20. Total costs and average costs per acre are higher because the land is rented for 40 years rather than 10 or 20 years. Total costs for the 20 and 40 year contracts, in particular, are greater than the total costs of the permanent contract because more hectares are assumed in that program.

The average cost per ton presented in Table 4-26 are the present value costs over the time period divided by the present value carbon. With the shorter time periods, however, the actual expenditures per ton are actually not all that substantial. For instance, with the 10 year contract, total present value costs are $238 million, and total tons stored are 3.28 million t C, for an apparent cost of about $20/t CO_2e. This looks substantially cheaper than the permanent 300 year contract, however in reality all that has occurred is the use of the tons over a 10 year period. Similarly for the 20 and 40 year contracts, tons are just used over the given period of time. An estimate of the present value average cost per ton is given for each of the shorter contracts. For the 10 and 20 year contracts, the costs are lower than the average cost per ton for the permanent contract in part because different land is included (as also seen in the average cost per acre calculation).

Table 4-26. Estimated total area of riparian zones and total cost of protecting mature forests in a 100 foot buffer zone along streams in the Northeast.

	300 yr (r=6.0%)	10 yr (r=0.0%)	20 yr (r=0.0%)	40 yr (r=0.0%)
Total Potential Area (acres)	2,750,688	2,750,688	2,750,688	2,750,688
Mature Potential Area (acres)	692,661	692,661	692,661	692,661
Total Carbon (million tons)	0.70	3.28	1.14	0.01
Total Cost (million $$)	$308	$238	$346	$372
Average Cost per Ton ($ /t CO_2e)[1]	$120	$20	$83	$13,322
Average Cost per Acre ($ /acre)	$656	$343	$499	$538
Total Potential Acres Contracted	469,577	692,266	692,266	692,266

[1] The average cost per ton is the total cost divided by the total carbon.

4.6 Case Study: Thinning Management

This section considers the potential to utilize pre-commercial thinning in forests, combined with the use of the material derived from the pre-commercial thinning operation in biomass energy production. Credits would be obtained from the biomass energy production. Net carbon benefits would arise from permanent offsets provided by the reduction in traditional energy sources utilized in the region, such as coal and natural gas, or fuel oil for heating. Additional carbon credits could potentially arise from changes in the residual growth of stands, and the changes in the distribution of merchantable products derived from the production.

A recent review of the literature by Wagner et al. (2004a) indicates that herbicide treatments, in combination with pre commercial thinning, in northern forests can increase wood production by 50 - 450%. The C implications of these treatments, however, are not clear. The studies described in the review mainly report increases in merchantable wood, or increases in specific species of interest (hence the large increases in wood production). Research by Daggett and Wagner (2002) indicates that pre-commercial thinning alone does not enhance volume growth in spruce-fir stands, but when combined with herbicide treatments can increase volume growth and improve the proportion of spruce and fir in stands. Depending on the ultimate use of these species, overall C sequestration may increase or decrease (i.e., if the carbon in a larger proportion of products has longer residence time).

This case study focuses on pre-commercial thinning (PCT). Wagner et al. (2003) suggest that widespread use of PCT could substantially enhance annual harvests (30%) over the next 30 - 50 years. As shown in the appendix, however, widespread adoption of PCT could reduce carbon stocks in the near term, as large areas of forestland are thinned. Long-term inventories would increase, but these increases may not offset the earlier losses.

As an example, consider the possibility of taking a stand that is currently 20 years old, and applying a PCT operation to it. Typically, thinned material is left onsite as slash because it is not commercially viable to remove the material, however, for this example, the possibility that all of the material is removed and used in biomass energy production is considered. The biomass energy production results in credits from biomass energy. Final harvest is assumed to occur at age 45. The baseline in this scenario involves leaving the stand alone and conducting final harvests every 45 years. Replanting costs are not included.

Baseline and the thinning regime carbon are shown over 300 years in Fig. 4-11 for a representative spruce fir stand in the region. Total carbon sequestered increases over the time period under the thinning regime, mainly due to credits from biomass energy production. Over the entire 300 year period, the net gain is about 25 t C/ha for the high site class forest shown in the figure. When considered in net present value terms, however, the net gain is relatively small -- only 0.37 t C/ha. The initial C gains are small, and consequently the net present value of the gains is small.

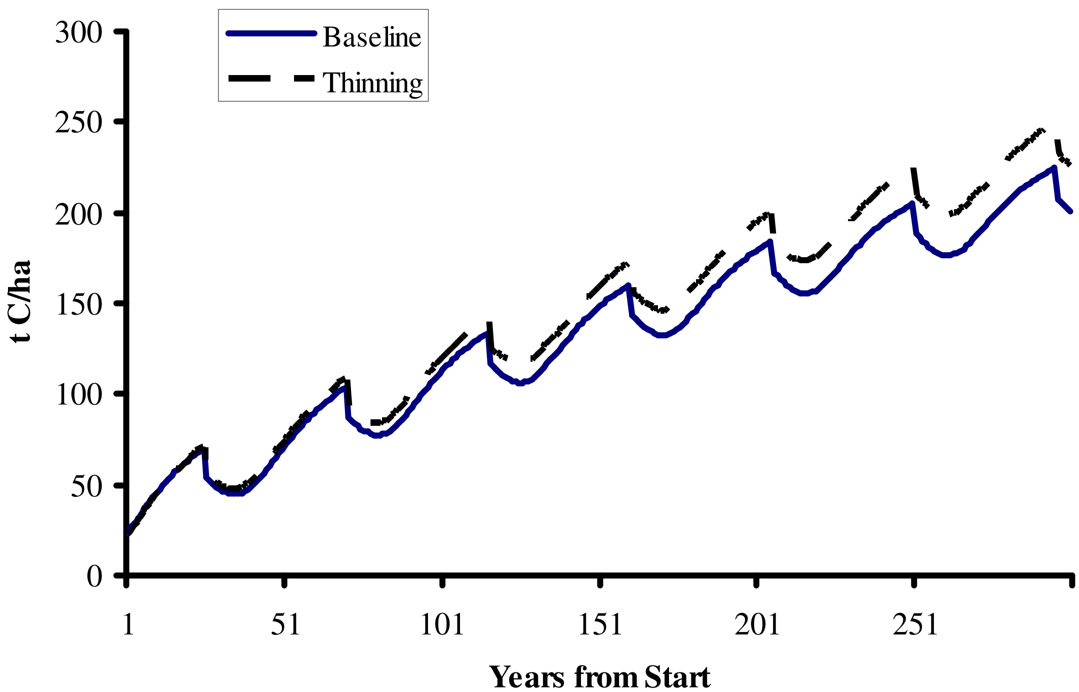

Figure 4-11. Comparison of baseline carbon (no PCT) to carbon with PCT for Spruce-Fir stands, site class 3. Under the thinning regime, 100% of the material from thinning operations is used in biomass energy.

Under the assumptions of this analysis, the net present value of carbon gains over all of the site classes and forest types considered is relatively small, and in some cases, net present value is negative (Table 4-27). Although there are overall gains over 300 years in undiscounted terms, these gains occur far in the future, and therefore have a relatively small effect on the net present value of the gains. For example, in table 4-27, carbon gains tend to be negative over the first 10 years, with the exception of a few species and site classes. Over 20 years, more site classes have positive carbon gains from thinning, and over 40 years, most species and site classes have positive carbon gains. Because most of the gains result from the use of the material as biomass, any reduction in the proportion of thinned material used for biomass would reduce the net carbon gains.

Economic analysis on the potential thinning option is conducted using net present value analysis. The analysis begins by assuming a 20 year old, un-thinned spruce-fir stand. In the baseline, this stand would be left un-thinned and harvested at 45 years. At that time, the overall proportion of merchantable timber in a typical spruce-fir stand that is sawtimber is estimated to be 43% (Table 4-28). The remaining merchantable wood is assumed to be used for pulp. The forest type spruce-fir in the Northeast is predominately spruce and fir, but not entirely. Using USDA Forest Service FIA data, the average allocation of different types of species in the spruce-fir stands is shown in Table 4-28 (Final Cut Proportion). Around 73% of the average stand is spruce-fir, or other softwood, with 23% of the material being spruce-fir sawtimber, 14% being pine sawtimber, and 50% being softwood pulpwood quality. The remainder is scattered among different hardwood types.

The analysis is conducted for Piscataquis county, and the prices for sawtimber stumpage, pulp stumpage, and biomass delivered material (chipped and hauled) are shown (note that biomass stumpage prices are $5.01/m^3$). In the baseline, revenues at harvest time (in 25 years when the currently 20 year old stand is 45 years old) are calculated as the growing stock volume times the proportion of material in different uses times the price for those uses. No planting costs are assumed, and similar forest compositions are assumed to be harvested at the same price in the future in the baseline.

For the alternative scenario, PCT occurs in the initial period (when the stand is 20 years old), and then the final harvest occurs at year 45 (25 years hence). Beyond this first cycle, it is assumed that pre-commercial thinning continues at 20 years, and that final harvest occurs at 45. When pre-commercial thinning occurs, it is assumed that 100% of the thinned material is extracted, chipped, and sent to biomass energy facilities 60 miles away. The value of the delivered biomass material for Piscataquis county is \$30.39 per m^3. Harvesting costs are assumed to be \$21.34 per m^3, which is the same cost used above in the thinning analysis of section 4.3. Chipping and hauling costs are assumed to \$8.42/m^3 (\$1.80 for chipping and \$6.62 for hauling), per section 4.3.

Table 4-27. Net present value of carbon gains, and undiscounted net gains over 10, 20, 40, and 300 years for PCT at 20 years and harvesting at 45 years versus final harvest at 45 years only. 100% of material from PCT is assumed to convert to biomass.

	t C/ha							
	WRJ Pine	SF	OP	OH	OCG	EAC	MBB	AB
Net Present Value of All Gains								
Site 3	0.14	0.37	0.59	0.42	0.78	1.39	0.39	0.05
Site 4	0.07	0.31	0.59	0.3	0.78	1.54	0.23	0.35
Site 5	-0.06	0.18	0.85	0.42	0.78	0.73	0.28	0.32
Site 6	-0.03	0.1	0.21	0.55	0.78	0.6	0.3	0.24
Net Gain from all Sources over 300 years (Undiscounted)								
Site 3	26.89	25.03	33.44	33.44	18.61	8.72	50.47	30.68
Site 4	25.15	23.83	33.44	33.44	23.73	8.72	52.11	23.28
Site 5	18.15	20.43	36.69	36.69	29.18	8.72	36.53	25.7
Site 6	13.5	17.6	15.48	15.48	27.43	8.72	8.66	24.16
Net Gain from all Sources over 10 years (Undiscounted)								
Site 3	-0.81	-0.45	-0.44	-0.44	-0.09	0.69	-0.01	-0.58
Site 4	-0.82	-0.47	-0.44	-0.44	-0.43	0.69	0.13	-0.5
Site 5	-0.71	-0.5	-0.2	-0.2	-0.46	0.69	-0.34	-0.53
Site 6	-0.5	-0.49	-0.26	-0.26	-0.22	0.69	0.49	-0.44
Net Gain from all Sources over 20 years (Undiscounted)								
Site 3	0.22	0.49	0.29	0.29	0.4	1	0.83	-0.01
Site 4	-0.02	0.24	0.29	0.29	0.01	1	0.9	-0.12
Site 5	-0.2	0.04	0.32	0.32	-0.12	1	0.1	-0.12
Site 6	-0.17	-0.09	0.01	0.01	-0.07	1	0.62	-0.17
Net Gain from all Sources over 40 years (Undiscounted)								
Site 3	3.67	3.52	4.75	4.75	2.43	1.2	7.2	4.26
Site 4	3.39	3.31	4.75	4.75	3.16	1.2	7.38	3.15
Site 5	2.33	2.78	5.16	5.16	3.97	1.2	5.08	3.51
Site 6	1.67	2.34	2.04	2.04	3.71	1.2	1.14	3.28

At final harvest time when pre-commercial thinning occurs, a larger proportion of merchantable wood is available for sawtimber purposes, although total volume declines (Daggett and Wagner, 2002; Wagner et al., 2004a). For the purposes of this analysis, it is assumed that there is a 9% reduction in total volume at harvest time, but that 60% of the merchantable timber is available for sawtimber purposes (see column "Final Cut w/ PCT" in Table 4-28). In addition, a larger proportion is spruce fir (48% of the sawtimber).

Table 4-28. Basic data for economic analysis of Pre-commercial Thinning (PCT) option in Spruce-Fir stands in Maine. Prices are for Piscataquis county only.

	Price	Final Cut Proportion	PCT Proportion	Final Cut w/ PCT Proportion
Overall Proportion[1]				
Sawtimber		0.43	0	0.6
Pulp		0.57	0	0.4
Biomass		0	1	0
Sawtimber Allocation[2]		Proportion of material		
Pine stumpage price ($/m3) & proportion[3]	$29.20	0.14	0.00	0.06
Spruce stumpage price ($/m3) & proportion	$26.15	0.11	0.00	0.24
Fir stumpage price ($/m3) & proportion	$26.15	0.12	0.00	0.24
Oak stumpage price ($/m3) & proportion	$23.60	0.00	0.00	0.00
Hickory stumpage price ($/m3) & proportion	$18.68	0.00	0.00	0.00
Elm-Ash-Cottonwood stumpage price ($/m3) & pr.	$22.24	0.00	0.00	0.00
Maple stumpage price ($/m3) & proportion	$41.17	0.02	0.00	0.03
Beech stumpage price ($/m3) & proportion	$14.60	0.00	0.00	0.00
Aspen stumpage price ($/m3) & proportion	$12.22	0.01	0.00	0.01
Birch stumpage price ($/m3) & proportion	$31.49	0.02	0.00	0.02
Pulp				
Pulp ($/t) - HW stumpage price ($/m3) & pr.	$18.68	0.07	0.00	0.04
Pulp ($/t) - SW stumpage price ($/m3) & pr.	$9.82	0.50	0.00	0.36
Biomass				
Proportion		0.00	1.00	0.00
Biomass Price $/m3 (Delivered material)	$30.39[4]			
Harvest Cost $/m3			$40	
Chipping & Hauling Cost $/m3			$8.42	

[1] Overall proportion determined by estimating the proportion of merchantable wood that is sawtimber size from USDA Forest Service FIA data. [2] The proportion of the spruce-fir stand in different species is derived from USDA Forest Service FIA data, averaged for Maine. [3] Prices discussed in section 6.3 above. [4] The delivered biomass price is estimated as the biomass stumpage price ($5.10/m^3) plus the harvesting cost for a final cut ($16.87/m^3) plus the chipping and hauling cost ($8.42/m^3).

The present value calculations for the baseline are given as follows:

Baseline PV: $$\left[\mathrm{Re}\,venueFHB + \frac{\mathrm{Re}\,venueFHB * (1+r)^{-45}}{1-(1+r)^{-55}}\right](1+r)^{=25}$$

where RevenueFHB = $\left(\sum_i P_i \tau_i\right)V$, and P_i is the stumpage value for the output (type of sawtimber, pulpwood, or biomass), τ_i is the proportion of the stand volume allocated to the type, and V is the merchantable volume. For the scenario, the present value calculations are:

Scenario PV: $$\mathrm{Re}\,venueT + \left[\mathrm{Re}\,venueFHS + \frac{\mathrm{Re}\,venueFHS * (1+r)^{-45}}{1-(1+r)^{-55}}\right](1+r)^{=25}$$

where RevenueFHS = $\left(\sum_i P_i \tau_i^S\right) V^S$, where τ^S_i is the proportion of the stand volume allocated to the type in the thinning scenario, and V^S is the merchantable volume in the thinning scenario. The difference between the scenario PV and the baseline PV represents the net gain from the project. Taxes and other management/overhead costs are the same regardless of the management, and so are not included in the calculations because the net difference between them will be $0.

The baseline revenue at harvest time ranges from $538 - $862 per acre, depending on the site quality (Table 4-29). In present value terms, the value of the stand (20 years old at the start) ranges from $129 - $206 per acre. Thinning and removing material are assumed to cost of $40 per m^3 removed, or around $81 per acre in this analysis. With those costs, there is a loss from thinning, ranging from $30-$41 per acre. The losses are lower for the lower site classes because less material is removed. Revenues at harvest time with thinning are higher, but these gains are not enough to offset the costs of the thinning operation, thus there are net losses associated with the thinning operation when considered in net present value terms. These range from $28 - $39 per acre. Given that there are 0.10 - 0.37 t C/ha stored, in net present value terms, the marginal costs range from $65/t CO_2e to $187/t CO_2e.

Table 4-29. Economic calculations for pre-commercial thinning versus baseline (no thinning) case.

	SC3	SC4	SC5	SC6
	$/acre			
Baseline				
RevenueFHB	$862	$731	$627	$538
PV Net Revenue - all years	$206	$175	$150	$129
Thinning				
RevenueT	($41)	($41)	($35)	($30)
RevenueFHS	$897	$751	$645	$553
PV Net Revenue - all years	$171	$136	$117	$100
Net PV Gain (Loss)	($36)	($39)	($33)	($28)
Cost of Carbon ($/t CO_2e)	$65	$85	$124	$187

Several sensitivity analyses are of interest as well. First, it has been assumed that thinning occurs at year 20, and that 20% of the growing stock volume is removed at thinning time. Potentially, by increasing the time to thinning or by increasing the proportion thinned, there may be increases in carbon storage and changes in costs. For the analysis, we look at increasing the timing of the thinning to 30 years, and we consider increasing the proportion of growing stock removed to 30% (Table 4-30). Both alternatives increase the carbon sequestered in net present value terms and they reduce the costs relative to the baseline. However, it is interesting to note that while thinning more material at 20 years reduces costs, if thinning is already slated to occur at age 30, then thinning additional material provides little additional benefit. The reason for this is that we continue to assume that the starting point is age 20, thus when the thinning age is 30, the first thinning will occur in 10 years. The additional discounting reduces the benefits of thinning 30% of 30 year old stands. In general,

Overall, the sensitivity results suggest that thinning more material (and converting that material to biomass energy), and thinning at a later date (beyond 20 years) will provide larger carbon benefits. However, across the range of thinning possibilities, thinning 30-40% of the material provides the lowest cost carbon. One other issue to note is that if carbon discounting is ignored, these cost estimates would be substantially less. As noted in table 4-26, undiscounted carbon gains for spruce fir stands over 300 years could be 27 - 30 t C per hectare. Using these undiscounted numbers would make the costs look substantially lower.

Table 4-30. Sensitivity analysis of the costs of carbon sequestration for pre-commercial thinning spruce-fir stands. All carbon gains for the sensitivity analysis are estimated with 6% discounting over a 300 year period.

	SC3	SC4	SC5	SC6
Baseline (thin at 20, 20%)				
t C/ha	0.37	0.31	0.18	0.10
Cost of Carbon ($/t CO_2e)	$65	$85	$124	$187
Thin at 30, 20%				
t C/ha	1.80	1.52	1.25	1.04
Cost of Carbon ($/t CO_2e)	$24	$26	$27	$28
Thin at 20, 30%				
t C/ha	1.28	1.16	0.90	0.73
Cost of Carbon ($/t CO_2e)	$33	$39	$42	$45
Thin at 30, 30%				
t C/ha	2.91	2.48	2.07	1.76
Cost of Carbon ($/t CO_2e)	$24	$26	$27	$27

4.7 CONCLUSION

The results indicate that for less than $20/t CO_2e, it is possible to sequester up to 4.5 million t of discounted carbon (r=6%; 16.5 million t CO_2e) in the northeastern U.S. through increasing the rotation age of forests (Table 4-31). The aging analysis focused only on softwoods in the states of New Hampshire, Maine, New York, and Vermont. The lowest cost options for the aging analysis were found to occur with 5 year extensions of the rotation age, where average costs of sequestration in the region are around $6/t CO_2e. For 10 year extensions, average costs rise to $22/t CO_2e, and for 15 year extensions they rise to $39/t CO_2e on average.

Shorter term contracts of 10, 20, and 40 years were also examined in the study, and undiscounted carbon estimates for these contract periods were calculated (see tables 4-6 to 4-8 in text). Not surprisingly, 10 year contracts provide the largest increase in carbon. Up to 14.5 million t C can be sequestered over a 10 year period. The average cost of this carbon is $7.34/t CO_2e, calculated by dividing the total discounted cost over a 300 year period by the undiscounted carbon over a 10 year period. The costs thus account for the liability that is assumed when offsets are used. There are two important points here. First, if the entire 14.5 million t C were purchased for 10 years, then when these contracts expire at the end of 10 years, the companies would still be responsible either for providing actual emissions reductions, or for holding offsets somewhere else in their overall portfolio, either of them equal to 14.5 million t C. Second, the 10 year contracts do not actually provide 14.5 million t C in permanent offsets because the land will emit carbon in future periods. The present value calculations of table 4-5 and 4-28 provide estimates of the actual permanent carbon storage.

The 20 year contracts illustrate the liability associated with shorter-term contracts: Carbon storage is negative by year 20 with aging contracts. Aging of forests provides temporary additional storage for a period of time, but these contracts will have periods of emissions eventually. By year 20, the 5 and 10 year aging contracts will have net emissions in undiscounted terms. The 15 year aging contracts have net sequestration, but it is relatively expensive.

Table 4-31. Total potential carbon for \$10 and \$20 per t CO_2e for aging and re-stocking understocked stands. Both assuming permanent contracts with discounted carbon over 300 years (r=6%).

\$/t CO_2e	Aging		Re-stocking		Riparian Set-Asides	
	Million t C	Million t CO_2e	Million t C	Million t CO_2e	Million t C	Million t CO_2e
\$10	3.6	13.3	2.9	10.8	0.03	0.09
\$20	4.5	16.5	3.3	12.3	0.05	0.17

With the 10 year contracts, achieving 1 million t CO_2e would take approximately 80,944 acres of land. This amounts to 12.4 t CO_2e per acre, or 8.3 t C per hectare (Table 4-32). Within 10 years, the carbon gains are fairly substantial, and so it does not take much land to achieve substantial carbon sequestration. The 20 year contracts take more land to achieve similar carbon levels, not surprisingly, because 20 year contracts are less efficient. The 40 year contracts take fewer hectares than the 20 year contracts in general.

Table 4-32. Total area of holding timber beyond the optimal rotation age to sequester a given amount of undiscounted carbon by 10, 20, or 40 years (minimum cost).

	Estimated area needed (acres)		
ton CO_2	10 years	20 years	40 years
10,000 t	9,240	1,310,772	36,284
50,000 t	9,240	1,522,234	195,180
100,000 t	9,240	1,522,234	195,180
1 million t	80,944	1,787,157	762,566

Harvesting and re-stocking mature forests that currently are under-stocked is estimated to have the potential to provide up to 2.9 million t C for less than \$10/t CO_2e, and up to 3.3 million t C for less than \$20/t CO_2e (Table 4-31). Within 10 years, it is estimated that the total potential storage is 0.4 million t C, or 1.5 million t CO_2e. Within 20 years, total potential is 7.5 million t C (27.5 million t CO_2e), and within 40 years, total potential is 57 million t C (209 million t CO_2e). To obtain 1 million t CO_2e (undiscounted) within 10 years, one would need to treat 142,734 acres of land in the region (Table 4-33). To obtain 1 million t CO_2e within 20 years, one would need 126,465, and to obtain this amount within 40 years, one would only need 15,600 acres. With the stocking scenarios, there are some short-term negative consequences of removing existing forestland and replanting that reduce the efficiency of shorter-term contracts.

Table 4-33. Total acres of harvesting and restocking needed to sequester a given amount of undiscounted carbon by 10, 20, or 40 years (minimum cost).

	Estimated area needed (acres)		
ton CO_2	10 years	20 years	40 years
10,000 t	1,740	10,311	10,311
50,000 t	14,678	10,311	10,311
100,000 t	20,322	15,600	10,311
1 million t	142,734	126,465	15,600

Riparian zone management in the region is fairly expensive by comparison (Table 4-31). Although it is estimated that there are around 690,000 acres available in mature forests in 50 foot buffer strips around streams in the region, very little carbon can be sequestered for \$10 or \$20 per t CO_2e. One reason for this is that the carbon gains are smaller per acre than for the aging or re-stocking scenarios. Setting aside timberland provides temporary carbon benefits, but in the long-term, harvesting of forests in the region (with or without mill residues being used for energy production) stores more carbon.

To sequester 1 million tons CO_2e over 10 years, around 162 thousand acres would be needed to be set-aside in riparian zones (Table 4-34). Over a 20 year period, more land would be needed, which is not surprising given that the amount of carbon in stands declines from year 10 to 20. Over 40 years, it is not possible to sequester 1 million t C with riparian zone set-asides.

Table 4-34. Total area of riparian set-asides (100 foot buffers) needed to sequester a given amount of undiscounted carbon by 10, 20, or 40 years (minimum cost).

	Estimated area needed (acres)		
ton CO_2	10 years	20 years	40 years
10,000 t	1,313	1,771	NA
50,000 t	7,210	12,226	NA
100,000 t	15,218	21,906	NA
1 million t	162,461	447,810	NA

The thinning case study indicates that under the assumptions that were used, thinning would lead to net sequestration in the region. In present value terms over 300 years, the net gains range from 0.07 t C/ha to 1.54 t C/ha. In undiscounted terms, the gains over the same 300 years could be as much as 52 t C/ha on Maple-Beech-Birch stands. These gains largely occur far in the future, as the undiscounted gains in 40 years range from 1.14 t C/ha to 7.38 t C/ha. The potential the costs of sequestration in the single county of Maine were found to be relatively high, ranging from \$65 - \$187 per t CO_2e. These costs could be reduced, however, by thinning more heavily and waiting additional years to thin. Costs for the representative county were found to decline to \$24 - \$27 per t CO_2e if thinning occurred at year 30 and 30% of the material was thinned.

4.8 Chapter References

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APPENDIX 1: TRENDS IN FORESTRY

There were approximately 72.9 million acres of forestland in the Northeastern U.S. in 2002 (Table A4-1). Since the turn of the century, the area of forest land has increased by around 0.4% per year, however, since the 1960's, the total area of forestland has been fairly constant. The trends are consistent across the states in the region. Maine, New York, and Pennsylvania have the greatest forestland area, not surprisingly, because they are the largest states.

Table A4- 1: Forestland area in Northeastern U.S.: 1953 – 2002. Source: Smith et al. (2003a).

	2002	1997	1987	1977	1963	1953
	Total forestland area (Thousand Acres)					
Connecticut	1,859	1,863	1,815	1,861	1,910	1,990
Delaware	383	389	398	392	392	454
Maine	17,699	17,711	17,713	17,718	17,425	17,088
Maryland	2,566	2,701	2,632	2,653	2,920	2,920
Massachusetts	3,126	3,264	3,097	2,952	3,070	3,288
New Hampshire	4,818	4,955	5,021	5,014	5,019	4,848
New Jersey	2,132	1,991	1,985	1,928	2,371	2,098
New York	18,432	18,581	18,775	18,380	15,865	14,450
Pennsylvania	16,905	16,905	16,997	16,826	16,486	14,805
Rhode Island	385	409	399	404	434	434
Vermont	4,618	4,607	4,509	4,512	4,230	3,860
Total	72,923	73,376	73,341	72,640	70,122	66,235

In 2002, there were approximately 3.1 billion m^3 of timber on forestland in the region (Table A4-2). Most of this, 2.9 billion m^3, is growing stock, and 71% of the growing stock is hardwood. On average, growing stock volume increased by 0.4% per year between 1997 and 2002. Hardwood volume increased the most during that time period, or about 0.5% per year. In the 1960's, net growth rates for hardwoods were approximately 1.7% per year, suggesting that net growth has slowed considerably in the recent 2 – 3 decades. Softwood net growth rates have similarly declined since the 1960's, but they have remained relatively constant since the 1980's. There are important regional differences in the distribution of growing stock among species. Maine has a large proportion of growing stock in softwood types (55%), while all the other states have larger proportions of hardwood growing stock. There was little increase in growing stock volume in Maine between 1997 and 2002.

One reason for the relatively slow net growth rates in forests in the Northeastern U.S. is that the area of older stands is increasing, while the area of younger stands is declining. For example, since 1997, the area of softwood forests 60 years and older has increased, whereas the area of softwood forests younger than 60 years old has declined (Figure A4-1). Since younger forests typically have higher growth rates, net growth rates have declined. Similar results are found for hardwoods (Figure A4-2), although there are smaller reductions in forest area in younger age classes for hardwood forests.

Table A4-2: Timber and Growing Stock Volume in 2002 and Annual Percentage Change between 1997 and 2002 in Northeastern U.S. Source: Smith et al., (2003a).

	All timber			Growing stock		
	All	Softwoods	Hardwoods	All	Softwoods	Hardwoods
	2002 Million m3 (Annual % change 1997 - 2002)					
Connecticut	96 (2.9%)	14 (2.1%)	81 (3%)	90 (2.9%)	13 (1.2%)	77 (3.2%)
Delaware	20 (1.3%)	3 (-8.1%)	17 (3.8%)	19 (1.6%)	3 (-7.6%)	16 (4.2%)
Maine	631 (0%)	348 (0%)	283 (0%)	591 (0%)	330 (0%)	260 (0%)
Maryland	148 (1.9%)	23 (-0.3%)	125 (2.4%)	144 (2.4%)	22 (-0.3%)	121 (2.9%)
Massachusetts	173 (2.9%)	63 (5.4%)	110 (1.6%)	162 (3.2%)	59 (5.3%)	102 (2.2%)

	All timber			Growing stock		
	All	Softwoods	Hardwoods	All	Softwoods	Hardwoods
	2002 Million m3 (Annual % change 1997 - 2002)					
New Hampshire	273 (0%)	114 (0%)	159 (0%)	255 (0%)	107 (-0.1%)	147 (0%)
New Jersey	84 (3.5%)	17 (3.1%)	66 (3.6%)	79 (3.3%)	16 (2.1%)	63 (3.7%)
New York	652 (0%)	158 (0%)	493 (0%)	618 (0%)	152 (0%)	465 (0%)
Pennsylvania	729 (0%)	67 (0%)	662 (0%)	705 (0%)	65 (0%)	639 (0%)
Rhode Island	15 (4.2%)	3 (18.8%)	11 (1.4%)	14 (4.6%)	3 (18.5%)	10 (1.8%)
Vermont	268 (0.1%)	86 (-0.1%)	182 (0.2%)	246 (0%)	80 (-0.1%)	165 (0.1%)
Total	3094 (0.4%)	901 (0.4%)	2193 (0.4%)	2926 (0.4%)	855 (0.3%)	2070 (0.5%)

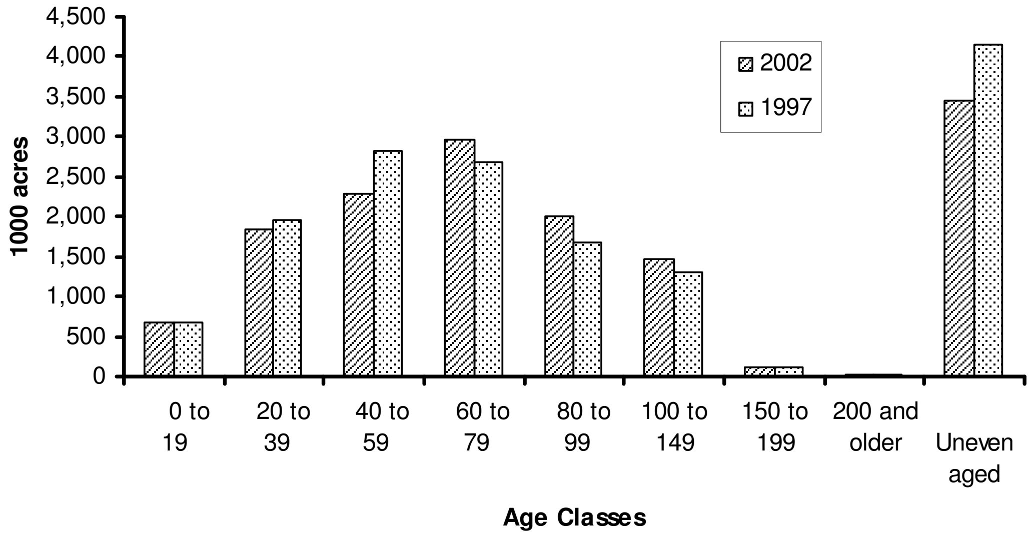

Figure A4- 1 Softwood Age Class Distributions in northeastern forests, 1997 & 2002. Note that these estimates include West Virginia. Source: Smith et al. (2003a).

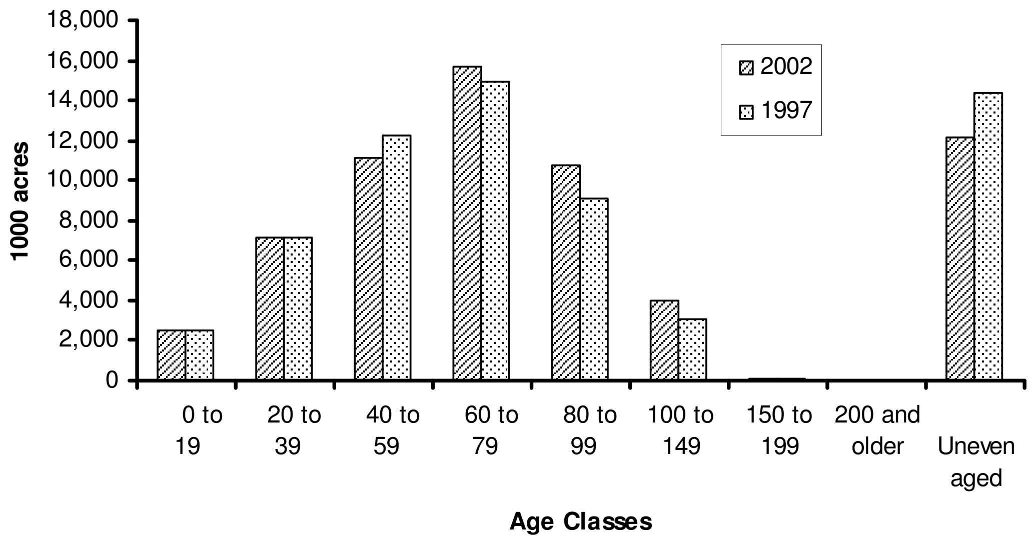

Figure A4-2: Hardwood Age Class Distributions in northeastern forests, 1997 & 2002. Note that these estimates include West Virginia. Source: Smith et al. (2003a).

Looking more specifically at the distribution of forest types in the Northeastern U.S., nearly 69% of the forestland area is Maple-Beech-Birch and Oak-Hickory (Figure A4-3). Spruce-Fir and White-Red-Jack Pine account for another 18% of the forestland area. In volume terms, Maple-Beech-Birch, Oak, and Hickory account for only about 51% of the total volume, while White-Red-Jack pine and Spruce-Fir forests account for about 21% of total volume (Figure A4-4). This suggests that hardwood forests, particularly the higher value hardwood forests, may be relatively under-stocked in comparison to the higher value softwood forests.

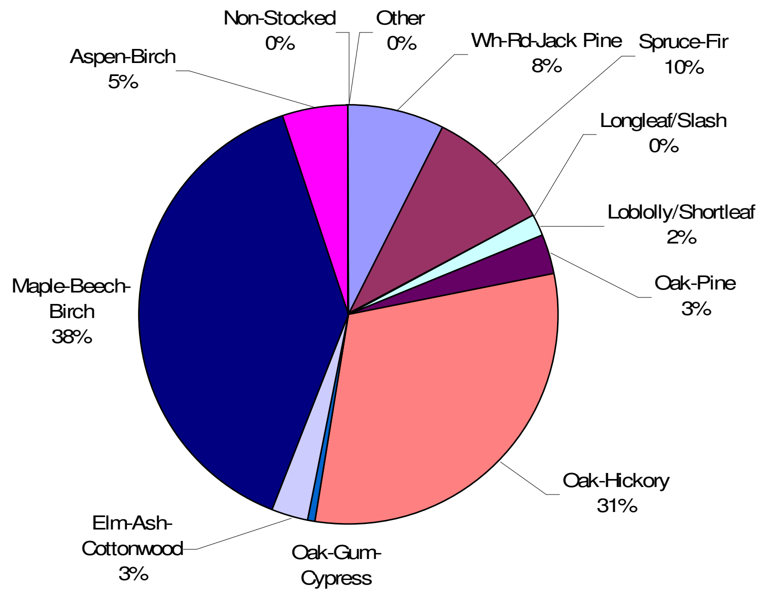

Figure A4-3: Distribution of FIA Forest Types (percentage, by acres) in the Northeastern U.S., 2002. Source: Smith et al. (2003a).

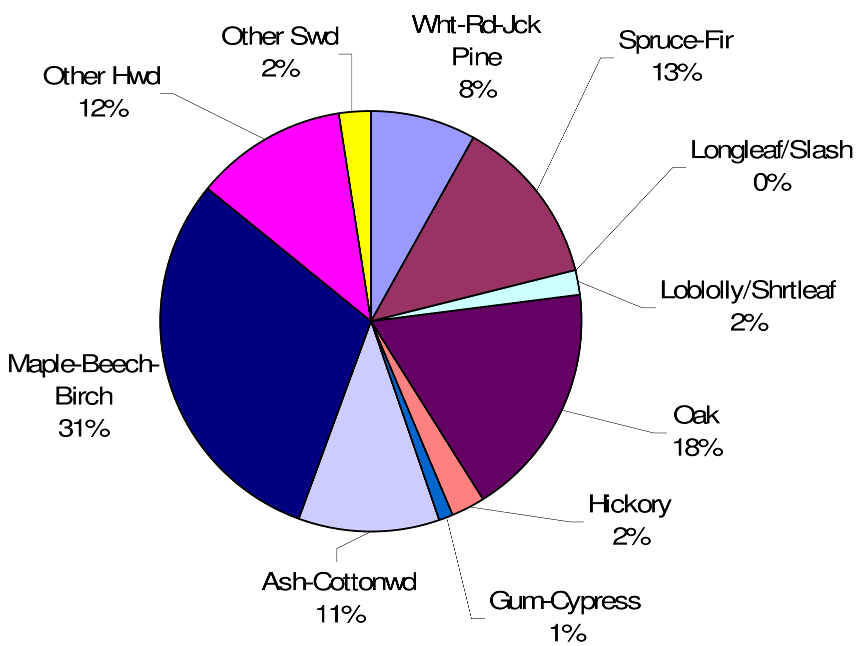

Figure A4-4: Distribution of FIA Forest Types by Volume in the Northeastern U.S., 2002. Source: Smith et al. (2003a).

Timber harvesting represents a substantial use of the land in this region. Lumber production in the region fell during the 1950's and 1960's, but has rebounded since then (Figure A4-5). From 1970 to present times, lumber production has risen by around 1.4% per year. Comparable estimates over the same time period for pulpwood are not available, but it is likely that similar trends have occurred. The increase in timber harvesting has followed the increase in growing stock volume that occurred over the same time period.

The most recent estimates of removals from the US Forest Service Timber Products Output database (USFS TPO data, 2006) indicate that total removals for sawtimber and pulpwood were around 31.5 million m^3 in 2002. Fuel wood is a substantial use of forests in the region, accounting for an additional 13.1 million m^3 of removals. Around 58% of the removals for industrial (non-fuelwood) uses occur in hardwoods, and 42% in softwoods. Softwoods are much more intensively managed in this region, given that only 30% of the growing stock volume in the region is in softwoods.

Estimates of growing stock removals for industrial purposes by state are shown in Table A4-3. Around 1.3% of the softwood growing stock is removed annually, while around 1.0% of the hardwood growing stock is harvested each year. Harvests were largest in Maine, followed by Pennsylvania, and New York. The largest proportion of total growing stock was removed in Maine, 2.2%. New York and Pennsylvania, by contrast, have lower harvests as a proportion of total growing stock.

These results can be used to estimate gross growth rates in the region. Gross forest growth rates are estimated as the net annual growth in growing stock volume plus the percentage of annual growing stock removed for all purposes (industrial wood and fuel wood). The gross growth for the Northeast is estimated to be 2.0% per year, with gross growth slightly higher in softwood species (Table A4-4).

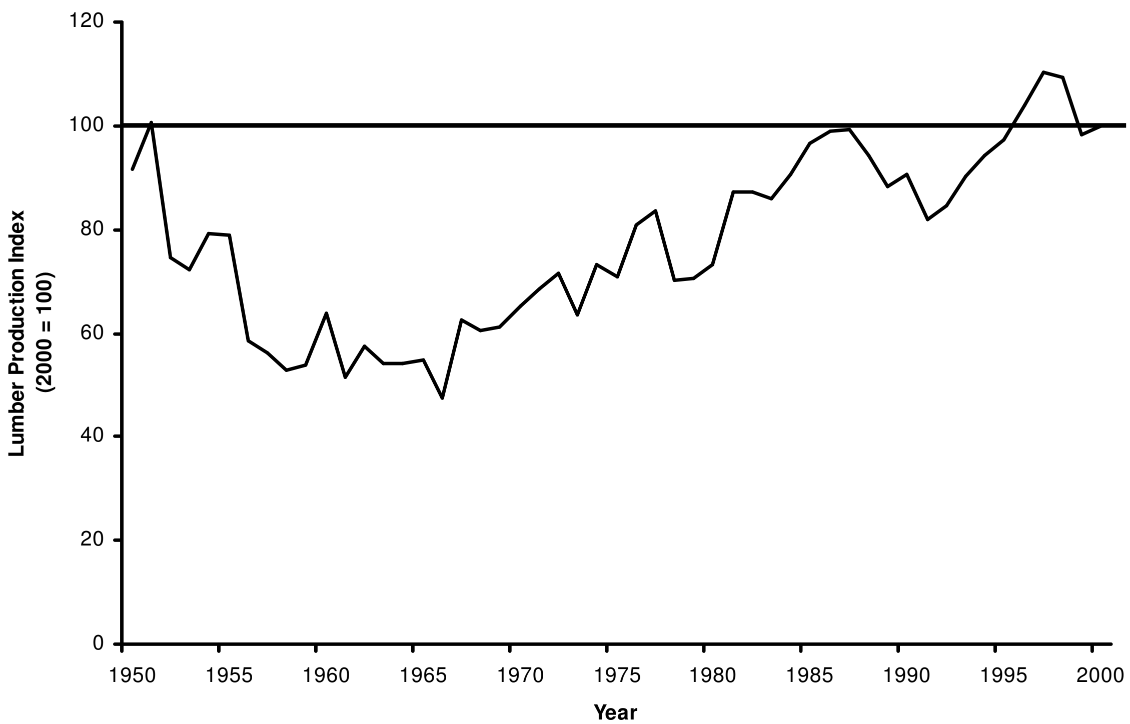

Figure A4-5: Lumber Production index for the Northeastern U.S., 1950 – 2000. Production is indexed to year 2000, which is normalized to equal 100. Data obtained from personal communication with Richard Haynes, U.S. Forest Service, Pacific Northwest Forestry Sciences Laboratory.

Table 4-3: Growing stock removals for industrial wood purposes, 2002 (USDA Forest Service TPO data, 2006)

	Sawtimber/Pulpwood Removal per Year			Percent of Growing Stock Removed per Year		
	Total	SWD	HWD	Total	SWD	HWD
	Million m3					
Connecticut	0.30	0.04	0.26	0.3%	0.3%	0.3%
Delaware	0.24	0.12	0.11	1.2%	4.1%	0.7%
Maine	13.29	7.04	6.25	2.2%	2.1%	2.4%
Maryland	1.08	0.21	0.87	0.8%	1.0%	0.7%
Massachusetts	0.40	0.17	0.23	0.2%	0.3%	0.2%
New Hampshire	3.83	1.27	2.57	1.5%	1.2%	1.7%
New Jersey	0.11	0.00	0.11	0.1%	0.0%	0.2%
New York	4.07	0.97	3.10	0.7%	0.6%	0.7%
Pennsylvania	5.86	0.58	5.28	0.8%	0.9%	0.8%
Rhode Island	0.03	0.00	0.03	0.2%	0.1%	0.3%
Vermont	2.30	1.02	1.27	0.9%	1.3%	0.8%
Total	31.51	11.43	20.08	1.1%	1.3%	1.0%

Table A4-4: Calculation of Gross Growth in Northeast over the Period 1997-2002.

	% Removed	Net Growth	Gross Growth
Softwoods	1.7%	0.4%	2.1%
Hardwoods	1.4%	0.5%	2.0%
Total	1.5%	0.5%	2.0%

Based on the growing stock volumes provided in Table A4-2 above, there are approximately 1.8 billion tons C in live above-ground biomass in the Northeastern U.S. (Smith et al., 2003a). Based on the growth calculations presented in Tables A4-2 and A4-4, carbon is accumulating in the region at a rate of about 0.5% per year currently, or around 8.9 million tons C per year. Maryland, Massachusetts, and New Jersey have the largest annual carbon increments, whereas states with the largest stocks (Maine, New York, and Pennsylvania) have the smallest annual carbon increments.

Table A4-5: Carbon Stock and Annual Carbon Growth based on net annual increment in growing stock volume.

	Stock	Annual Growth
	Million t C	
Connecticut	53	1.5
Delaware	12	0.2
Maine	380	0.0
Maryland	83	2.0
Massachusetts	89	2.9
New Hampshire	144	-0.1
New Jersey	54	1.8
New York	370	0.0
Pennsylvania	448	0.0
Rhode Island	9	0.4
Vermont	139	0.1
Total	1,782	8.9