Technical Progress Report on Application and Development of Appropriate Tools and Technologies for Cost-Effective Carbon Sequestration

Quarterly Report
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ABSTRACT

The Nature Conservancy is participating in a Cooperative Agreement with the Department of Energy (DOE) National Energy Technology Laboratory (NETL) to explore the compatibility of carbon sequestration in terrestrial ecosystems and the conservation of biodiversity. The title of the research project is "Application and Development of Appropriate Tools and Technologies for Cost-Effective Carbon Sequestration".

The objectives of the project are to: 1) improve carbon offset estimates produced in both the planning and implementation phases of projects; 2) build valid and standardized approaches to estimate project carbon benefits at a reasonable cost; and 3) lay the groundwork for implementing cost-effective projects, providing new testing ground for biodiversity protection and restoration projects that store additional atmospheric carbon. This Technical Progress Report discusses preliminary results of the six specific tasks that The Nature Conservancy is undertaking to answer research needs while facilitating the development of real projects with measurable greenhouse gas reductions. The research described in this report occurred between April 1st and July 30th 2006. The specific tasks discussed include:

- Task 1: carbon inventory advancements
- Task 2: emerging technologies for remote sensing of terrestrial carbon
- Task 3: baseline method development
- Task 4: third-party technical advisory panel meetings
- Task 5: new project feasibility studies
- Task 6: development of new project software screening tool

Work is being carried out in Brazil, Belize, Chile, Peru and the USA. Partners include the Winrock International Institute for Agricultural Development, The Sampson Group, Programme for Belize, Society for Wildlife Conservation (SPVS), Universidad Austral de Chile, Michael Lefsky, Colorado State University, UC Berkeley, the Carnegie Institution of Washington, ProNaturaleza, Ohio State University, Stephen F. Austin University, Geographical Modeling Services, Inc., WestWater, Los Alamos National Laboratory, Century Ecosystem Services, Mirant Corporation, General Motors, American Electric Power, Salt River Project, Applied Energy Systems, KeySpan, NiSource, and PSEG.

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EXECUTIVE SUMMARY

The Nature Conservancy, partners and collaborators had a productive quarter conducting research under this cooperative agreement.

SPVS and TNC submitted a report on the results of work under tasks 1 and 3. Under task 1 this report provided the methodologies and results from research on soil-vegetation stratification, minimum diameter range selection, and destructive sampling for refining allometric equations. Under task 3 this report provided the methodologies and results from an evaluation of GEOMOD for reforestation and avoided deforestation baselines and a comparison of the results from using simple land use change detection and GEOMOD.

In California (Task 2) final calculations were produced for the aboveground biomass and measurement and statistical error of the 36 North Yuba carbon plots, along with draft allometric equations for the 40 inventory plots in the Mailliard Redwoods State Reserve and the Garcia River forest. The LIDAR date for the North Yuba area was further analyzed and an equation of the LIDAR-derived height to field-measured aboveground biomass was derived.

A baseline study (Task 3) on the effects of sea level rise on the terrestrial carbon storage on North Carolina's Albemarle Peninsula was completed and delivered.

In the Northeast study (Task 5), a draft of Part III examining the potential of afforestation on cropland and pasture lands has been completed. Upon invitation, the study team briefed the Northeast Regional Greenhouse Gas Initiative (RGGI) staff working group on the preliminary results of Part III of this study. A draft of Part IV examining opportunities for improving carbon storage and management on forest lands has also been completed.

EXPERIMENTAL

Task 1 Carbon Inventory Advancements

Carbon Inventories can be increased and costs lowered through improved techniques. Forest Inventories have been carried out for a number of reasons; to use for M3DADI calibration (task 2), for use in carbon baseline development (task 3) and for development of new regression equations and improved estimates of biomass for different terrestrial systems.

Atlantic Rainforest Restoration Project

Stratification study

Stratified sampling was used for the carbon inventory, which helped to make the estimates more precise and cost-effective. Two different approaches for stratification were tested and compared. The first one was based on vegetation map where, from 13 vegetation classes, 5 forest classes (Submontane Forest, Lowland Forest, Medium / Advanced Secondary Forest, Medium Secondary Forest and Young Secondary Forest) were assumed to be under threat and therefore were used during the carbon inventory work to estimate the carbon stock benefits to be generated at the project area.

In addition to those forest strata, other non-forest classes such as pasture, herbaceous vegetation and shrubs were also included as part of the carbon inventory, but temporary plots were used for those strata.

The second approach was conducted using a stratification which combines soil and vegetation and can reduce the biomass variation within each stratum and, thereby, makes carbon inventory better in terms of precision and cost-effectiveness. Seventeen strata were distinguished in this case, where the strata were formed by overlay forest and soil classes (Dystrochrept – “háplico”, “gleico”, “flúvico”; Paleudult, Haplaquept, Humaquept, Tropofluvent and Udorthent)

Fifty eight nested permanent plots were installed in seventeen forest strata (4 to 8 per strata). An Excel spreadsheet was used to estimate the number of permanent and clip plots required for each stratum. Once the permanent plots were installed the spreadsheet was updated with the information from the inventory and the final number of plots for all strata could be calculated. The methodology chosen for the carbon inventory was the one developed by Winrock International (MacDicken, 1997) and adapted to the project conditions. A Standard Operating Procedure (SOP) was developed for the project.

Four nested permanent plots were used to measure aboveground biomass; a 1 meter radius to measure saplings with DBH <5 cm; a 4 meters radius (0.005 ha) for trees between 5-19.9 cm DBH; a 14 meters radius (0.06 ha) for trees between 20-69.9 cm DBH; and a 20 meters radius for trees with ≥ 70 cm DBH.

Diameter Range Study
ARRP uses a nested permanent plot design to quantify forest carbon stocks. The three nested plots are 4, 14, and 20 meters in radius. In the small plots all trees greater than 5 cm in diameter breast height (DBH) are measured, in the medium plots all trees greater than 20 cm, and in the large plot all trees greater than 70 cm. It was suspected that the minimum diameter in the large plots was too high for the forested stands and that reducing the minimum diameter would significantly decrease variability between plots and uncertainty in carbon inventories. Therefore a study was implemented during the 2003 inventory to assess the impact of minimum diameters on estimates, and uncertainties related to carbon stocks. During the field work, the DBH and distance from the plot center of all trees >35 cm in the large plot were measured. This data allowed for the estimation of carbon stocks using different minimum diameters for trees in the large plot. In the first analysis all trees that were more than 14 m from the plot center, and greater than 35 cm were included in the analysis.

The analysis included trees with 35 to 70 cm DBH (with 5 cm intervals), comparing mean, coefficient of variation and lower end of confidence interval. The purpose of this analysis was:
1) To investigate whether there are any significant differences in the C stock estimates when changing the minimum DBH of the large plot,
2) To see whether decreasing the minimum diameters and thereby increasing the number of trees measured would significantly decrease the variation coefficient.

Destructive Sampling
A total of 23 trees (DBH>20 cm) were measured and weighed to check the accuracy of the biomass regression equation that were used to estimate forest carbon tree stocks. Using the destructive sampling data we compared the measured biomass with estimates of biomass using wet and moist equations.

In order to calculate the volume of the bole, the diameter was measured in the base, medium and below the first branch. In addition the total and the bole height were measured as were, crown extension and DBH. The branches and leaves were weighed with a dynamometer.

Task 2 Emerging technologies for remote sensing of terrestrial carbon

Multispectral 3-D Aerial Digital Imagery
Multispectral 3-D Aerial Digital Imagery (M3DADI) studies will be conducted by Winrock International. M3DADI uses GPS-base mosaicing techniques and off-the-shelf equipment with camera mounts that can be attached to any Cessna aircraft to generate accurate raster-based photomaps. After the videography is flown, 3-dimensional (3D) reconstruction are developed from video that identifies terrain features and vegetation types and measures the height and mass of individual trees. The measurements from the videography are then calibrated with the carbon inventory data and regression equations from Task 1 to estimate carbon remotely.

Research in California*: *Monitoring Forest Carbon and Impacts of Climate Change with Forest Inventories, High-Resolution Satellite Images, and LIDAR

Emerging remote sensing technologies, including high-resolution satellites such as QuickBird and Light Detection and Ranging (LIDAR), provide potential tools to scale up carbon estimates from hectare-scale forest inventory plots to landscapes of hundreds of square kilometers. The project tests the capabilities of three technologies, QuickBird 0.6 m resolution imagery, LIDAR, and digital videography to quantify aboveground forest carbon at three sites in the United States.

The project employs QuickBird and LIDAR in an applied research project "Monitoring Forest Carbon and Impacts of Climate Change with Forest Inventories, High-Resolution Satellite Images, and LIDAR." The project is a collaboration of the California Department of Parks and Recreation, Carnegie Institution of Washington, the Conservation Fund, Colorado State University, the Nature Conservancy, Stanford University, USDA Forest Service, U.S. Department of Energy, and the University of California, Berkeley.

The project establishes permanent forest inventory plots to provide independent estimates of species composition, tree sizes, and above-ground biomass and to furnish the data to assess the accuracy of QuickBird-derived crown diameter and LIDAR-derived tree height and crown diameter. In the Tahoe National Forest, the team uses a 1.25 km resolution grid to establish a systematic sample of 36 plots using the USDA Forest Service Forest Inventory and Analysis (FIA) design. In the Garcia River forest and the Mailliard Redwoods State Reserve, the project uses the California Department of Forestry and Fires Protection vegetation map to establish a sample of 40 FIA plots stratified by trunk diameter. In the FIA plots, the inventory team is identifying the species of every live tree of diameter ≥ 20 cm at a height of 1.37 m, tagging each tree, and measuring the height, trunk diameter, and crown diameter. In addition, the inventory team is measuring a sub-sample of small trees, dead wood, and litter and estimates one, ten, and 100 hour fire fuel loads.

Using species-specific allometric equations of biomass as a function of trunk diameter, the project will directly calculate aboveground biomass for each analysis area. In addition, the project will develop equations of trunk diameter as a function of height and crown diameter together and as a function of crown diameter alone in order to calculate biomass from LIDAR and QuickBird data.

For the Sierra Nevada transect, the inventory team is establishing eight sets of four permanent 20 m x 50 m Whittaker plots in late seral stands with a southwest aspect at approximately 200 m elevation intervals. The team selected areas with no significant timber, livestock grazing, or fire management history. In each Whittaker plot, the team is identifying the species of and measuring the height and trunk diameter of every tree of diameter ≥ 20 cm at a height of 1.37 m. In addition, the inventory team is measuring a sub-sample of small trees, dead wood, and litter and estimates one, ten, and 100 hour fire fuel loads. The team also plans to take cores of a sample of trees to estimate ages and growth rates of measured trees.

LIDAR is an airborne laser system that can measure the height of individual trees and produce a three-dimensional profile of the interior of a forest canopy. The basic measurement that a LIDAR device makes is the distance between the sensor and a target, derived from the time that elapses between the emission of a laser pulse towards the target and the return of the pulse's reflection to the sensor. Equipped with global positioning system (GPS) receivers and inertial navigation systems, LIDAR devices make georeferenced digital elevation measurements at discrete sample points along a flight path. Merging of point samples from a series of flights generates a single spatial data layer. The team is employing a discrete LIDAR system that records the intensities of first and last return while an integrated differential global positioning system (GPS) receiver establishes the coordinates of the detector. The system creates digital elevation data layers for the ground surface and the canopy.

The LIDAR spatial resolution of 1 m is finer than the size of many trees, so the team will process LIDAR data to give multiple indices of canopy height within raster cells with a spatial resolution of 15 m, the diameter of an FIA annular plot. The team will then develop regression equations of LIDAR-derived height indices at 15 m spatial resolution to the aboveground carbon calculated in the forest inventory plots. Application of the regression equation to non-inventoried areas will allow calculation of aboveground carbon per unit area.

The team will also use an alternate method of calculating aboveground carbon from LIDAR data by delineating individual tree crowns and calculating crown diameter and height of individual trees. The inventory-derived equations of trunk diameter as a function of crown diameter and height will allow the team to estimate the biomass of each tree and calculate aboveground carbon per unit area. The team will also compare LIDAR height and crown estimates with forest inventory measurements and test the ability of LIDAR-derived crown estimates to improve estimates of trunk diameter.

The QuickBird satellite captures photographic-quality images at 0.6 m panchromatic resolution and 2.4 m multi-spectral resolution in five spectral bands of 11 bit data depth. QuickBird captures data across a swath of 16.5 km on the ground. The satellite circles the Earth every 94 minutes at an altitude of 450 km, in a sun-synchronous orbit with the descending node crossing the Equator at approximately 10:30 AM local solar time. The owner of QuickBird, DigitalGlobe, Inc., allows users to purchase data at times and locations specified by the user.

The team is using orthorectified QuickBird scenes with a geographic location root mean square error of 6.2 m. The team is developing automated programs that combine iterative local maxima and minima filtering with analysis of extracted ordinate data to detect crown perimeters and crown diameters. The team will compare these crown estimates with forest inventory crown measurements. The inventory-derived equations of trunk diameter as a function of crown diameter will allow the team to estimate the biomass of each tree and calculate aboveground carbon per unit area. The QuickBird spatial resolution of 0.6 m is finer than the size of many trees, so the team will calculate the aboveground carbon density at a resolution of 15 m, the diameter of the FIA annular plot.

Task 3 Carbon Baseline Method Development

The task involves developing and refining spatially explicit methods for estimating the carbon sequestration baseline for proposed forest conservation and reforestation projects at three sites in the United States and five sites in Latin America. The methods project possible future deforestation and reforestation trends and permit the calculation of carbon offsets from project activities.

Evaluation of GEOMOD for avoided deforestation and reforestation baselines in the Guaraqueçaba Environmental Protection Area

The software used for analysis was the following: IDRISI's Kilimanjaro (GEOMOD), ERDAS 8.6, image analyst and ArcView 3.2, Spatial Analyst extension. The steps of the modeling effort are listed in table 1.

Table 1: Steps used to run GEOMOD and generate the simulations - the classification and evaluation of images were made with Image analyst and ERDAS 8.6 software. For all remaining stages, the Idrisi's Kilimanjaro program was used.

Step	Function utilized	Objective
Classification and evaluation of the images	Supervised and Non-supervised classification	To get two land use classes for future analyses (Forest and deforest)
Overlay vegetation maps (86x02, 75x86, 75x02)	Crosstab	Verify the rate of deforestation for the analyzed period
Reclassification of the overlay maps	Reclass	Exclusion of the deforested and regenerated areas in the next steps
Generation mask or desert map	Multiply	Image of EPA with the deforested and regenerated areas excluded in the previous step
Preparation of the "drivers"	Distance (Idrisi) or Search (Erdas)	Generation of distance images (roads, rivers, deforestation and communities)
Reclassification of the Distance	Reclass	Reclassification to get a total of 255 classes of distance to be analyzed in the next step
selection of drivers	PCA (principal component analyze)	Selection of the most important drives related to deforestation and / or regeneration rate
Attribution of the weights	Multiple Linear Regression	To verify the influence of each driver in the deforestation and / or regeneration rate
Stratification of image	Watershed & Crosstab	Generation of the image with sub-region (strata)
Simulation	GEOMOD	Start the simulation with the classified anddistance images and also with the attributed weights for each driver

Assessment of the results	Validate	To assess the precision of the simulation
Generation of tables	Histogram	Generate tables that will be used to estimate carbon offsets

Local drivers and physical characteristics influence the deforestation and regeneration rates in different ways, For example, flat land is easy to work and probably will be deforested before areas found on a slope. In other words some areas are more likely to be deforested because they would be more profitable in economic terms.

For the Guaraqueçaba EPA region, the drivers considered were the following: 1) paved and unpaved roads; 2) distance from deforested areas; 3) rivers; 4) communities; 5) altitude; 6) slope; 7) aspect; 8) soil and 9) watershed.

In some cases, a large number of drivers may lead to difficulties in establishing which of these parameters were the most important to assess land use change. One of the most widely used techniques to define the factors more relevant to explain the variance is through analysis of the Principal Component Analysis (PCA). Through this analysis it is possible to have a smaller number of variables, increase the accuracy and have a better picture of the variation occurring between those factors. Therefore, the following drivers were selected: distance from deforested area, distance from roads, distance from communities, and slope.

Evaluation of Simple Land Use Change Detection in Guaraqueçaba Environmental Protection Area

To perform the multitemporal study, images from Landsat Thematic and Enhanced Thematic Mapper have been used. As the studies involving the Guaraqueçaba EPA were started in 2000, the following scenes from INPE (National Institute for Space Research) were used:

- Sep/1986 and Jul/1994 - Landsat TM 5, bands 3 (visible), 4 and 5 (infra-red ray), resolution 30 m, path 220, row 078.
- Sep/1999 - Landsat ETM 7, bands 3 (visible), 4 and 5 (infra-red ray), resolution 30 m and band 8, resolution 15 m, path 220, row 078.

Based on a supervised and non supervised classification and also a visual interpretation the land cover was separated into different stratums and the following land use classes were defined:

- Urban area
- Planted forest
- Pasture / open areas
- Mangroves (“manguezais” and “marisma”)
- Coastal plain vegetation (“Restinga”)
- Forested wetland (“várzea” and “caxetal”)
- Lowland Forest (primary altered)
- Submontane Forest (primary altered)
- Medium / advanced secondary forest (riparian)

- Medium secondary forest
- Young secondary forest

In order to verify the deforestation dynamics and analyze land use the team geoprocessed images of the EPA area from the years 1986, 1994 and 1999. The vegetation maps were overlaid through the Image Analyst Cross tab function in Image Analyst software.

Terrestrial Carbon Storage on Albemarle Peninsula, North Carolina: Baseline Estimates in the Face of Sea Level Rise

This study looks at projected sea level rise for the Albemarle Peninsula in northeastern coastal North Carolina, and examines the likely effect on terrestrial carbon storage. Present and past trends in land cover on the peninsula were examined through analysis of the National Land Cover Data (NLCD). Current carbon stocks in the biomass on the land were quantified as well as carbon stored in the peat deposits, and their likely fate with land inundation from sea level rise.

Spatial models of projected sea level rise were created using the Hadley 3 General Circulation Model and based on the A1F1, A2 and B1 storylines of the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios. An additional scenario of the most extreme flooding was modeled; this was a combination of the A1F1 scenario coupled with a breaching of the Outer banks; barrier islands currently shielding the Albemarle Peninsula from lunar tides.

A review of the scientific literature shows that considerable uncertainty exists over the biochemical processes that are likely to occur when peatlands become inundated with saline water. As such three scenarios were modeled which assumed 0, 50 and 100 % loss of carbon from the peat when flooded. From a further literature review it was concluded that the constant and saline nature of flood water, combined with its depth will lead to the dead and decay of even the most flood and salt tolerant woody plants.

Task 4 Third-Party Technical Advisory Panel Meetings

Standardizing measurement procedures and methods for carbon monitoring is a major step in the demonstration that land use projects should be creditable under any future regulatory mechanism. The Technical Advisory Panel (TAP) gathers a group of experts to evaluate existing methods and to develop standardized carbon offset measurement guidelines for use in all land-use change and forestry projects.

Task 5 New Project Feasibility Study

While there seem to be a variety of project ideas that would lead to cost-effective sequestration and biodiversity projection, there has been little work accomplished to explore the feasibility of these ideas. Within the United States, we have yet to develop sound knowledge of the potential for implementing specific forestry and agricultural carbon sequestration projects. By assessing the cost and potential carbon benefits of different domestic projects we can learn more about how conservation and carbon sequestration projects may or may not be compatible.

Northeast Study

The work proposed to be carried out in the Northeast region, seeks to provide:

- Historical trend of sinks and sources for carbon emissions and/or sequestration in the land-use and forestry sector for the period about 1987-1997;
- Classification of the land conservation and management activities that represent the major opportunities for carbon storage on the land for each state by county within the Northeastern U.S.;
- Improved data on the quantity and costs of carbon storage for major classes of land-use and forest-based projects in the Northeast in a format that allows comparison with opportunities in other regions;
- Greater confidence within the Northeast region on how land-use and forestry projects that reduce emissions or sequester carbon can fit into State energy and natural resource planning goals; and
- Potential environmental co-benefits from carrying out the projects that reduce emissions or sequester carbon.

The following are goals for each section of this project.

Stakeholder Outreach and Input
The goal under this task is to involve and invite input from various stakeholders including state regulatory land use and natural resources staff in the Northeast states, non governmental organizations (NGOs), and industry representatives throughout the project. The Team will seek their input and feedback as to our scope of work, the datasets to be used, assumptions regarding implementation of land use changes, and the methodology for determining carbon creation potential and costs.

I*dentify and estimate carbon sources and sinks in the Northeast region.*
The goal for this phase is to identify and quantify the key sources and sinks of carbon in the land-use and forestry sector of the Northeast region at the county level, for the period of about 1987-1997[1] (in other words measure the carbon emission or sink trend over the most recent decade of data available.)

Classify the Carbon Storage Opportunities
The goal is to identify the existing classes of lands in the region and then to identify a suite of land use changes that could take place to increase carbon sequestration.

Quantify the carbon benefit
The goal is to quantify the costs of changing the use of land for carbon sequestration, including opportunity costs, conversion costs, maintenance costs, and measuring and monitoring costs.

Identify Environmental Co-Benefits from Changes in Land Use

[1] If we can get the 2002 NRI data broken down by county, we plan on using that data instead of the 1997 data.

The Team's goal is to identify the potential environmental and economic co-benefits of implementing certain land-use change activities and to map these benefits along with the carbon supply and cost curves.

Summary Maps and Report
Finally, the Team will prepare county scale summary maps of quantities of carbon and their associated costs for the major classes of potential land-use and forest-based activities in the Northeast region in a format that allows comparison with opportunities in other regions in the U.S. The Team will work to produce a written report containing summarizing the background, methodology, findings, and recommendations of the study.

<u>*Part III. Opportunities for Improving Carbon Storage and Management on Agricultural Lands*</u>
Information about current land use (based on state level land cover maps), potential changes in land use and the incremental carbon resulting from the change, opportunity costs, conversion costs, annual maintenance costs, and measurement and monitoring costs were obtained and used in the analyses. The analyses are performed in a geographic information system (GIS) to include the diversity of land uses, rates of carbon sequestration, and costs. As a result, not only are more realistic estimates of the potential supply of carbon produced, but the use of GIS shows where the least to most expensive carbon credits will most likely be found. The general approach was to identify and locate classes of land where there is potential to change the use to a higher carbon content, estimate the cost of changing land use practices, estimate rates of carbon accumulation for each major potential land-use change activity for each land class, and then estimate the cost per unit potential carbon dioxide sequestered at a county scale.

The analyses take the following steps to assess the quantity and cost of potential carbon sequestration through land use change:

- Classify lands found in the region by harmonizing existing state-level land cover maps.
- Identify the major land cover types with potential for carbon sequestration.
- Estimate the area available for each potential land use change.
- Identify the major land use change categories with a potential for significant climate mitigation
- Estimate the total costs associated with land use conversion (opportunity, conversion, maintenance, and measuring and monitoring).
- Estimate the quantities of carbon per unit area that could be sequestered for the change in land use over a given time period.
- Combine the estimated sequestered carbon per unit area with corresponding land cover class to estimate the total quantity of carbon at the county scale that could be sequestered using each land use category for a given range of costs in \$/ton CO_2[2].
- Determine the geographic distribution of available carbon at various prices.

The total cost associated with afforestation of agricultural land has three components: conversion and maintenance costs; monitoring costs, and opportunity cost. The conversion and maintenance

[2]All values given in metric tons. To convert from metric tons to short tons, multiply by 1.102. (If tons in denominator, e.g. \$/ton, divide value by 1.102)

costs are those associated with land preparation, planting, and land management. Data on 'conversion cost' was obtained state by state for the region through surveys of entities involved in afforestation activities. Costs differed within each state, with higher costs in Pennsylvania, Connecticut, and Maryland due mainly to measures needed to protect seedlings from deer herbivory.

'Monitoring costs' vary with size of the area being monitored, whether the total area is one large block or disaggregated into smaller parcels, the expected variation in the carbon stocks, the pools being monitored, and the frequency of monitoring.

The third component is the 'opportunity costs' associated with loss of income from the current activity. For this section of the analysis, data were collected on the major crops grown in each state, and the respective areas planted over the past 5 years. The dominant agricultural land uses for the region as a whole are corn, hay/pasture, and soybeans. With corn and hay comprising about 3 and 4 million acres respectively; soybeans are a distant third with just over 1.3 million acres harvested annually. Wheat and oats each occupy less than 300,000 acres throughout the region. These data were collected from the USDA National Agricultural Statistics Service (NASS) via their website. In addition, data were compiled on the average (over recent years) prices, production costs, and yields for these dominant crops. Using this information, the average annual profitability per unit area for each crop was calculated. Yields are generally available at the county level and can provide spatial variation on the opportunity costs within each state. The average profitability per crop was weighted by the area that each crop represents within each county/state. This provides a representative opportunity costs for land within each county. Adding the conversion costs, monitoring costs, and opportunity costs together forms the total costs associated with converting agricultural land to forest land.

The carbon sequestration potential of lands found in the region was investigated using the USDA Forest Service's FIA data sources. The FIA contains the largest database of forest biomass and growth and the database encompasses the entire region. County level data on the carbon stocks of FIA plots were downloaded for all forest types and site productivities. Based on these data, growth curves were developed for each forest type and site productivity class. These growth curves of above and belowground biomass were then used to estimate the carbon sequestration potential for each county. The productivity class dominant in the county within the FIA database was assigned to each county. Using an NRI-based database of the land which moved from non-forest in 1987 to a particular forest type in each county in 1997, a forest type was assigned to each county. The appropriate forest type and carbon growth curve was then used to estimate the potential carbon sequestered per area of land converted to forest land. Carbon levels were then also discounted by 6% to present more clearly the net present value of the carbon stocks to be sequestered. The discounting of the future flow of carbon offsets is important to account for uncertainty regarding future offset alternatives and the rules that will govern carbon offset trading programs. Discounting the carbon reduces carbon levels by 26% at 10 years and 60% at 40 years.

The final stage in the analysis is to combine the costs associated with ceasing agricultural activities and afforesting with the projected carbon dioxide to be sequestered from this land use action. By dividing the costs per acre by the t CO_2 per acre, this creates the cost associated with each ton of carbon dioxide sequestered. Calculating the cost per CO_2 allows the various land management practices to be compared with other mitigation options. Prices per ton of CO_2 will vary dependent on both the costs associated with conversion and the potential carbon sequestration capacity.

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

Increasing the Stocking of Under-stocked stands

For this analysis, it is assumed that to increase stocking density, landowners would be paid to remove existing biomass when there is growing stock available, and to then replant the natural potential vegetation type consistent with the site. Landowners are assumed to harvest growing stock and extract value from merchantable components at current market prices. Residual slash components are assumed to remain on the site and decompose. 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 volumes on the sites under analysis, but they have not achieved significant stocking naturally. Thus, additional regeneration effort could improve future stocking conditions, although this effort must occur with the assistance of replanting efforts.

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 sawwood 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 since 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 are 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. Stumpage prices were obtained from a variety of sources. Stumpage prices are delivered log prices minus the costs of logging and hauling wood. Stumpage price estimates contain a range of sale types, and consequently harvesting costs associated with them. 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, are assumed to differ from the stumpage prices used in step 3. The stumpage prices obtained from the data sources are applicable to harvests in step 3.

In order to estimate stumpage prices applicable to the removal of the existing stock, 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 $\$21.34/m^3$. 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.

In addition to prices and logging costs, annual costs of developing management plans for forests were included, amounting to $2/ha/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.

Regeneration costs were assumed to be $1000/hectare. Hersey and Kittredge (2005) report values for planting seedlings at a rate of 1200 seedlings/hectare as $634/hectare. 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 $1000/hectare.

A final important cost issue involves accounting for the effects of taxation. 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 of the Northeast impose a yield tax, which is applied on a percentage basis to the value of the stumpage harvested.

For the economic analysis of the costs and benefits of harvesting timber on poorly stocked stands and regenerating them, present value analysis is used. Applicable cost and revenue streams are discounted assuming a 6% real interest rate. All prices and costs are assumed to be constant throughout the time period. A 300 year time horizon is used for the analysis. Timber rotations obviously can vary substantially across the region, however, for the analysis, future timber rotations are 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.

To assess the carbon benefits associated with removing vegetation from poorly stocked sites and regenerating well stocked forests, one must first determine the baseline. The baseline begins with the current level of carbon in a poorly stocked stand, and assumes that carbon on that site grows as the forest matures. Stands that are initially poorly stocked are assumed to remain poorly stocked stands in the baseline. Two sets of growth and yield functions for growing stock volume have been estimated based on USDA Forest Inventory and Analysis data -- the yield of poorly stocked stands and the yield of fully stocked stands.

Yields are estimated for eight forest types and four site classes for the eleven 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 is used to determine parameters for yield functions with the following functional form:

(1) $$\text{Yield } (m^3/ha) = a - b/\text{age}.$$

The terms "a" and "b" are estimated parameters. Yield is given in m^3/ha. 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.

To determine carbon content, estimates from Table 5 in Smith et al. (2003b) are applied. These estimates provide information on the above-ground biomass density per hectare, 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).

Based on the equations for poorly stocked sites, the future path of growing stock volumes was estimated for each county and site class. To accomplish this, poorly stocked forests in the region were classified as younger than 40 years of age, and older than 40 years of age. A default value of 20 years old was chosen to calculate initial growing stock in forests younger than 40 years of age, and a default age of 60 years 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.

Extending the Rotation Age in Softwood forests

Previous estimates of carbon sequestration costs through aging timberland have been developed for Winrock International for several southern and western states (Sohngen, 2003, 2004a, 2004b). The methods used to estimate the costs of carbon sequestration through aging in this report follow the methodologies developed in those earlier reports, although they most closely follow the methods described in the most recent reports on aging timber in California (Sohngen, 2004b).

Several important assumptions underlie the analysis of extending rotation ages. First, prices for all products and carbon are assumed to be constant over time. Second, for financial analysis, the value of carbon sequestration is discounted. When calculating potential carbon storage, additional tons gained over time are also discounted. The issue of carbon discounting is discussed in more detail below.

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:

(2) Stand Value = W(a) =

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

Where:

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

The first part of Eq. 2 represents the value of harvesting the stand and selling products in markets, (PSφS + PPφP)*V(a)e-ra. The second part of Eq. 2 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 decay (or replacement rate of products):

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

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 [ ] accounts for the value of carbon sequestered on the stump. Carbon on the stump is rented annually at the rate of rPC. 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. 2. 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. 2 is solved numerically for each timber type and pricing region in the two states over a set of constant carbon prices (ranging from \$0 - \$270 per t CO2). This allows us to determine the optimal rotation age, given timber prices and carbon prices. The carbon price, as shown in Eq. 2, 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, a 300 year period is used to assess carbon gains. Carbon stocks are calculated across this 300 year period for the baseline, and for each increment in rotation ages. The carbon benefit calculated for aging timber 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:

(3a) $$CSD_t = CS_t^{ER} - CS_t^{B}$$

where CS^{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:

(3b) $$S_t = CSD_t - CSD_{t-1}$$

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:

(3c) $$NPV(Carbon) = \sum_{0}^{300} S_t (1+r)^{-t}$$

If discounting is ignored, then r = 0. In cases where discounting is ignored, conducting the analysis within the 300 year time period will result in no clear positive or negative effect. 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.

While most economists recognize the importance of discounting monetary flows over time, equations (3a – 3c) above discount a non-monetized flow of carbon, rather than carbon values. Discounting carbon flows like this is appropriate for benefit cost analysis under the following conditions. Suppose a company considers investing in a project that has a stream of costs, Ct, a stream of annual carbon sequestration, St, and a stream of the benefits of sequestering a ton of carbon in each year, Pct. Pct is the price of carbon that would evolve in a carbon market, thus it represents the marginal costs of abating carbon in the next best alternative for the company, i.e. it is the opportunity cost for sequestering carbon. A company would choose to invest in projects where the following condition holds (where r is the discount rate):

(4) $$\sum_{0}^{X} C_t (1+r)^{-t} < \sum_{0}^{X} P_t^c S_t (1+r)^{-t}$$

Assuming that the price of carbon rises at a rate of "g" over time, this equation becomes:

(4a) $$\sum_{0}^{X} C_t (1+r)^{-t} < \sum_{0}^{X} P_0^c (1+g)^t S_t (1+r)^{-t}$$

(4b) $$\sum_{0}^{X} C_t (1+r)^{-t} < P_0^c \sum_{0}^{X} S_t \left(\frac{(1+g)}{(1+r)} \right)^t$$

Under this assumption, one would invest in the project if the discounted costs divided by the net discounted carbon gains are less than the current price of carbon.

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

Note that for this analysis, no salvage value is assumed, thus the landowner retains the rights to the carbon. Further, the company that purchased the sequestration over the period of time in question must continue to hold sequestered tons beyond the project period, X, equal to the undiscounted stream of St. Companies may choose to renegotiate their contracts with existing landowners, purchase new contracts, or abate carbon on their own, depending on the relative costs of other alternatives, at the end of the term of the contract.

As can be seen in Eq. 5, if g is 0, carbon flows can be discounted at financial discount rates and the costs per ton can be compared to the current opportunity costs of carbon sequestration. Alternatively, one could assume that carbon is discounted with social discount rates to determine the present value of carbon. Social discount rates for carbon could be appropriate for long term problems like climate change where damages occur in the very far distant future. The carbon analysis uses a social discount rate of 6% for carbon. Costs are discounted at 6%.

Task 6 Development of new project software screening tool

Carbon measurement and monitoring costs are unique transaction costs for forest-based carbon sequestration projects. Project developers need to weigh the costs of carbon measurement and monitoring against the potential benefits of the sale of carbon offsets (carbon revenue). Carbon benefit data from USDA Forest Service inventories will be combined with carbon measurement and monitoring variables in a spreadsheet-based tool to allow users to compare potential carbon costs and revenues on a project level.

RESULTS AND DISCUSSION

Task 1: Carbon Inventory Advancements

Atlantic Rainforest Reforestation Project

Stratification Study
The total carbon pool (excluding carbon soil) in Atlantic Rainforest Restoration Project, based on vegetation stratification was 782,200 t C (Table 2). This amount includes the pasture pools, which represents 0.6% of the total t C.

Table 2. Mean of carbon (t C ha^{-1}) content by soil-forest strata for the 2003 inventory in the ARRP project area.

Strata code	Area (ha)	Above ground biomass	Root	Standing dead wood	Fallen dead wood	**Woody Biomass < 5cm DBH**	Total mean (t C/ha)	Total biomass
Arg - M	423.4	59.5	11.9	2.7	4.4	2.5	81.0	34,307
Arg - M/A	221.3	96.2	19.2	1.8	6.1	0.9	124.2	27,482
Camb - I/A	46.5	44.0	8.8	1.3	0.5	16.1	70.8	3,293
Camb - M	475.7	75.0	15.0	1.6	3.7	2.4	97.8	46,504
Camb - M/A	1271.3	90.0	18.0	2.9	5.7	1.2	117.9	149,847
Camb - SM	1121.5	132.4	26.5	2.5	7.9	1.0	170.3	191,010
Camb_fluv - M/A	109.5	120.7	24.1	0.0	6.7	0.5	152.0	16,645
Camb_glei - M	555.0	70.2	14.0	1.1	2.0	2.7	90.0	49,924
Camb_glei - M/A	338.3	121.5	24.3	0.4	3.7	2.1	152.1	51,447
Glei - I/A	94.7	43.1	8.6	0.9	1.9	7.7	62.2	5,895
Glei - M	320.5	73.4	14.7	0.7	1.9	2.5	93.2	29,873
Glei - M/A	66.4	90.8	18.2	1.9	6.9	2.3	120.0	7,967
Glei_Mel - M	81.2	55.9	11.2	0.0	4.9	3.1	75.0	6,090
Glei_Mel - M/A	232.7	59.1	11.8	2.6	5.9	0.7	80.1	18,639
Neo_Fluv - M/A	422.3	88.1	17.6	1.4	0.7	0.5	108.4	45,767
Neo_Fluv - TB	498.4	79.7	15.9	0.1	1.1	0.8	97.7	48,687
Neo_Lit - SM	385.5	94.9	19.0	2.5	8.2	2.1	126.7	48,825
Weighted mean(CI*)		92.6 (5.6)	18.5 (1.1)	3.3 (0.5)	5.0 (0.9)	4.2 (0.5)	119.7	782,200

Arg: Paleudult
Camb: Dystrochrept
Camb_fl: Dystrochrept “flúvico”
Camb_gl: Dystrochrept “gleico”
Glei: Haplaquept
Glei_Mel: gleissolo melânico
Neo_fl: Tropofluvent
Neo_Lit: Udorthent
IA: Young Secondary Forest;
M: Medium secondary forest
TB: Lowland forest
SM: Submontane forest
M/A: Medium/advanced Secondary forest

As a result of the carbon inventory conducted in the Atlantic Rainforest Restoration Project it was possible to quantify the amount of carbon stored with a good level of precision (p=0.05).

The inventory was used to estimate the differences between the with- and without-project carbon pools and is the primary basis for determination of project GHG benefits. Through ongoing carbon inventory work, several aspects of the carbon inventories that could be improved or significantly strengthened were identified.

The data sets are extensive and complex but currently no customized database programs to track and compare inventory data exist. The method for analysis to date has been to use Excel spreadsheets, but improvements could be made using a database program to increase analysis efficiency.

The results of stratification based on the combination of vegetation and soil maps were significant because there was a reduction of 16% in the total sampling size, for the same precision level, and it makes the estimates of the inventory more cost effective.

Diameter Range Study

It was proposed to use 35 cm as a minimum diameter for tree measurement in the large plots. But these results indicate that the improvement in stock estimates is negligible and thus would not be worth the extra field work required during inventory events since a lower minimum diameter will lead to more trees being measured per plot. Even assuming that projects will report carbon stocks at the lower end of the 95% CI range (as has been proposed by IPCC Good Practice Guidelines), using the 35 cm minimum diameter would not increase reportable carbon stocks.

The minimum DBH for the large plot is currently set at 70 cm. After examining the ARRP inventory and analyzing carbon stocks using 35 to 70 cm as a minimum DBH for the large plot, no significant differences were found. The results indicate that using 70 cm as a minimum large plot diameter does adequately sample the forest strata. Switching to 35 cm as a minimum DBH for the large plot will only add to the overall costs of measuring and monitoring over time.

Destructive Sampling

Table 3: Brazil destructive sampling data; Total measured biomass and estimated biomass using the wet and moist equations

Species	Tree dbh (cm)	Height (m)	Total measured biomass(kg)	Wet equation biomass(kg)	Moist equation biomass(kg)
Talauma ovata	54.6	19.0	1,765	1,848	2,896
Schizolobium parahybum	64.0	28.0	4,000	2,607	4,293
Machaerium sp	21.3	24.4	239	209	275
Brosimum lactescens	77.0	27.0	7,478	3,873	6,778
Vochysia bifalcata	83.5	24.1	4,899	4,600	8,277
Cryptocaria aschersoniana	41.8	25.5	1,749	1,024	1,490
Ficus insipida A	70.0	26.0	4,259	3,161	5,357
Pterocarpus violaceus	70.0	26.0	3,293	3,161	5,357
Myrcia sp2	29.3	17.3	1,450	453	613

Ficus insipida	92.0	30.0	7,832	5,645	10,507
Hyeronima alchorneoides B	53.6	24.0	3,114	1,775	2,766
Hyeronima alchorneoides A	52.8	23.0	2,545	1,717	2,665
Machaerium hritum	54.5	24.5	3,778	1,840	2,883
Myrcia sp1	28.0	24.0	897	407	547
Pseudopiptadenia warmingii	84.0	31.0	10,570	4,659	8,400
Ocotea catharinensis	81.0	31.0	6,865	4,313	7,680
Myrtaceae 4	50.9	20.3	2,876	1,585	2,433
Calycorectes australis	33.0	27.4	844	598	826
Bauhinia forficata	25.6	13.0	231	328	437
Calyptranthes cf. grandifolia B	64.0	21.0	4,058	2,607	4,293
Talauma ovata	48.0	23.0	1,663	1,393	2,103
Calyptranthes cf. grandifolia A	35.4	17.0	1,133	702	984
Matayba guianensis	58.5	17.0	2,094	2,147	3,436

Most of the trees analyzed fell between the predicted results for moist and wet equations but in some cases the measured biomass was higher than even the predicted biomass of the moist equation. On average, the analysis revealed that the coastal Atlantic Rainforest are somewhere between the moist and wet equations (Figure 1).

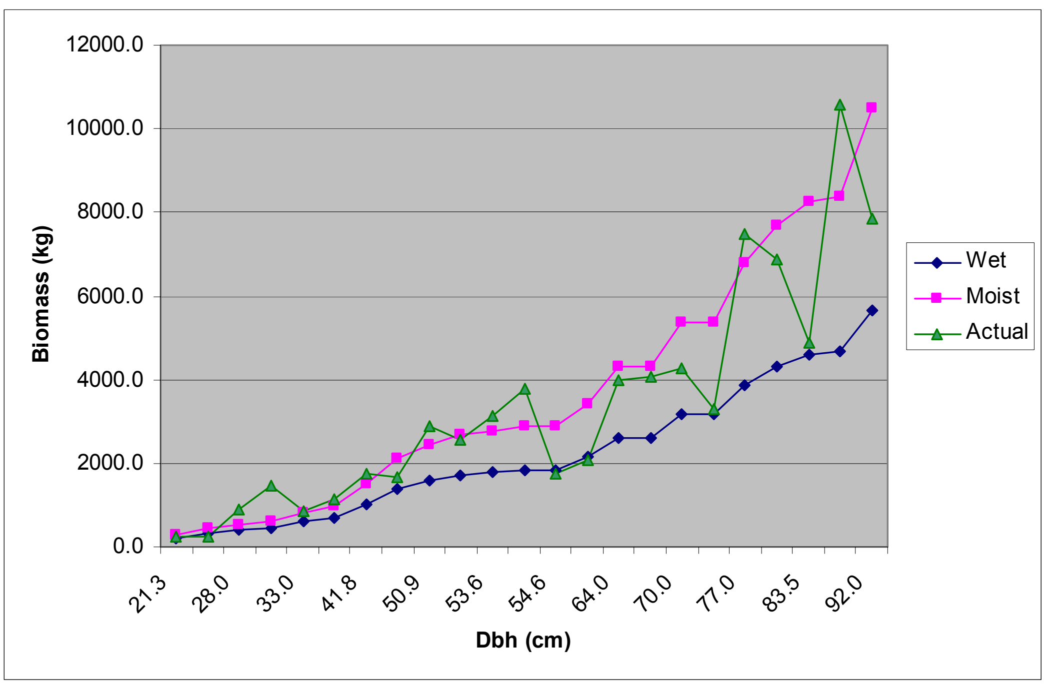


Figure 1: Comparison of estimated biomass with general moist and wet equations compared to actual measured biomass.

A new biomass equation was also developed using the actual measured biomass for the 23 destructively sampled trees. This curve fit slightly below the moist equation prediction, in most cases (Figure 2).

To date, carbon stocks in the three project areas have been estimated using the wet equation. The results of the destructive sampling study indicate that forests in the project areas are closer to the general moist equation. For estimating carbon stocks there are three options: 1) reanalyze the data using the moist equation, 2) use a new equation based on the results from the 23 trees, or 3) continue to use the wet equation.

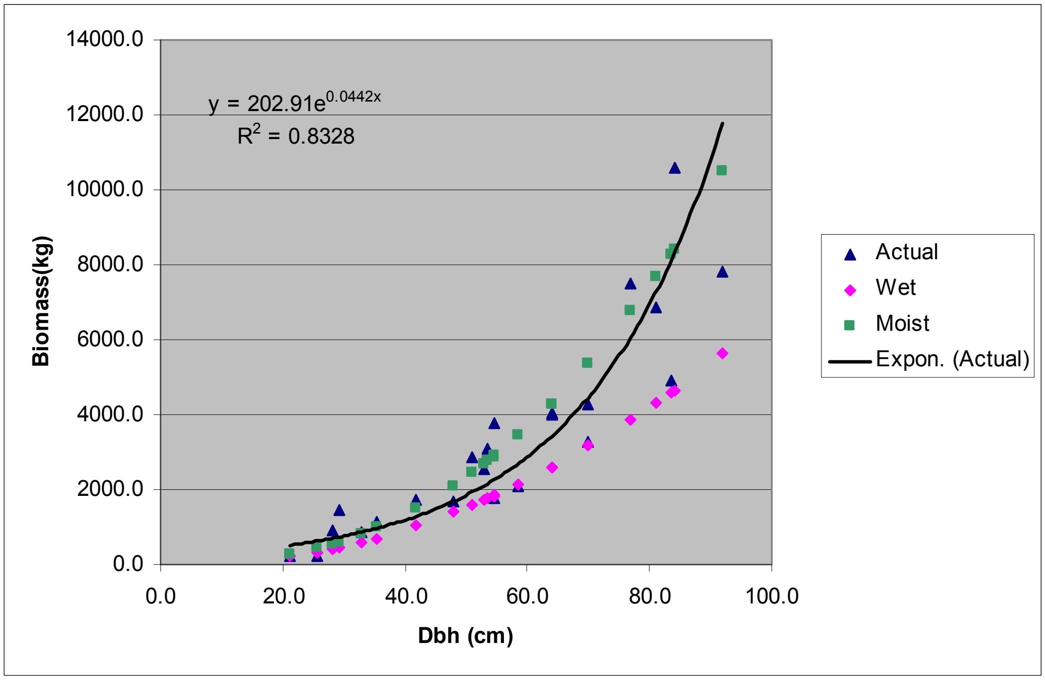


Figure 2: Best fit curve for the 23 destructively sampled trees in Brazil. The best fit curve is applied for the actual results only. The moist and wet predictions points are shown for illustration.

The preliminary results suggested that biomass for trees in the Atlantic Forest fall somewhere between the general wet biomass equation and the general moist biomass equation (Brown, 1997), that the wet equation currently used in the project may be underestimating the total biomass and carbon stock of the project and that, apparently, the moist equation might be more appropriate to estimate biomass for trees.

Using the moist equation can make a great impact in the estimation of the carbon stock in the project; it will increase from 34 to 47 % (Table 4).

Table 4: Mean of carbon per strata for Atlantic Rainforest Restoration Project using the Wet and Moist equation

Vegetation	Wet equation Mean TC ha-1	Moist equation Mean TC ha-1	Increase of Carbon using Moist equation %
IA	43.7	68.2	36
M	67.0	101.4	34
MA	91.7	141.5	35

SM	132.9	236.3	44
TB	94.8	180.8	47

IA: Young secondary forest; M: Medium secondary forest
MA: Medium/advanced forest SM: Submontane forest
TB: Lowland forest

In order to confirm the tendency found in this study or even increase the data set to develop a new equation for the project it is recommend that more trees need to be destructively sampled.

Task 2: Emerging technologies for remote sensing of terrestrial carbon

Research in California: *Monitoring Forest Carbon and Impacts of Climate Change with Forest Inventories, High-Resolution Satellite Images, and LIDAR*

The University of California team, led by Professor John J. Battles, has produced final calculations of the aboveground biomass and measurement and statistical error of the 36 North Yuba carbon plots (Table1.) Measured aboveground biomass ranges from 80 ± 40 t ha^{-1} to 1300 ± 740 t ha^{-1}.

Table 5. Aboveground biomass and measurement and statistical error of the North Yuba carbon area.

Plot	Aboveground biomass (t ha^{-1})	Confidence interval (p =0.05) ± (t ha^{-1})	plot	Aboveground biomass (t ha^{-1})	Confidence interval (p =0.05) ± (t ha^{-1})
B4	320	140	F3	140	180
B5	550	290	F4	380	110
B6	470	180	F5	330	200
B7	420	150	F6	220	130
C2	100	50	F7	1100	430
C3	260	160	F8	260	90
C4	1300	140	G2	570	120
C5	150	60	G3	280	100
C6	480	300	G4	720	190
C7	80	40	G5	210	100
D2	220	50	G6	480	160
D3	380	280	G7	240	170
D4	120	40	G8	1300	740
D5	130	90	H4	580	100
D6	220	70	H5	420	270
D7	360	150			
E3	230	270			
E4	590	320			
E5	450	170			
E6	410	250			
E7	240	130			

The team has also produced draft allometric equations of biomass vs. height and biomass vs. crown diameter for the 40 inventory plots in the Mailliard Redwoods State Reserve and the Garcia River forest (Table 6)

Table 6. Allometric equations for mixed secondary coast redwood-oak forest (Garcia) and old-growth coast redwood forest (Mailliard).

Area	allometric equation	sample	negative log likelihood	AIC
Mailliard	$\log(b) = 10.916+0.0919\ h$	103	-121.86	249.71
Mailliard	$\log(b) = 8.82*d^{0.2217}$	102	-149.41	304.83
Garcia	$\log(b) = 10.243+0.1122\ h$	274	-367.21	740.43
Garcia	$\log(b) = 8.573*d^{0.2078}$	261	-312.88	631.75
AIC = Akaike's Information Criterion				

b = aboveground biomass (g) d = crown diameter h = height (m)

The Colorado State University team, led by Professor Michael A. Lefsky, has further analyzed the LIDAR data for the North Yuba carbon area. Using a progressive morphological filter to determine bare ground elevation and first-return LIDAR signal to determine canopy elevation, the team calculated canopy height at a spatial resolution of 25 m, equivalent to the footprint of the forest inventory plots. Mean maximum canopy height was 38 m ± 11 m (Figure 3).

Using stepwise multiple regression, the team derived an equation of LIDAR-derived height to field-measured aboveground biomass. Estimates of confidence intervals for the total aboveground biomass stored in the North Yuba area required propagation of the errors from the field data through the regression equations linking LIDAR-derived height and field estimates of aboveground biomass. Therefore, the team used a two-step Monte-Carlo analysis to incorporate the errors in the field data into the goodness-of-fit statistics from the regression analysis and to estimate the uncertainty in the landscape biomass estimates of aboveground biomass from the combination of field data and regression analyses. Mean aboveground biomass was 400 t ha^{-1} ± 100 t ha^{-1}. The spatial distribution of biomass shows higher values in lower parts of the watersheds (Figure 4). LIDAR estimated the biomass of the field plots to a high level of statistical significance (Figure 5).

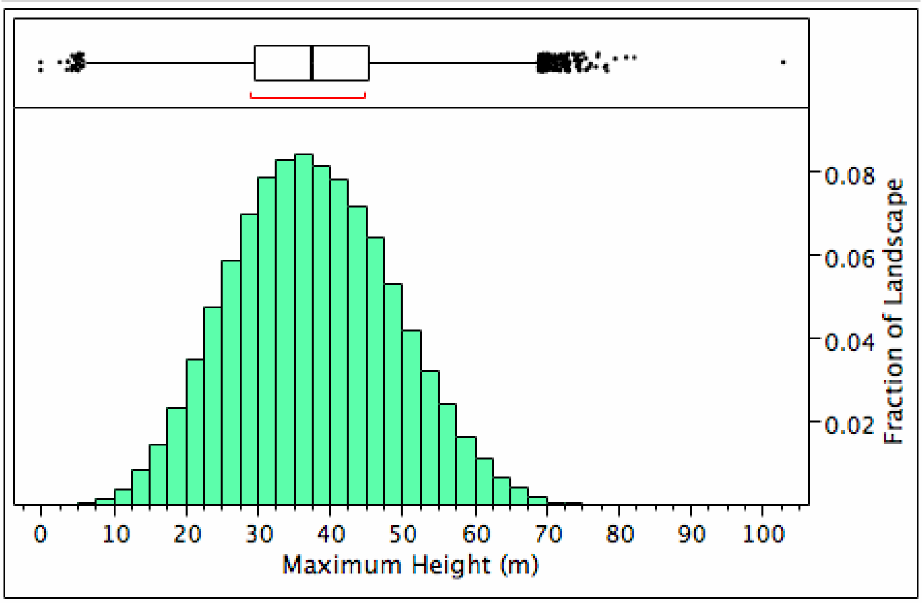


Figure 3. Distribution of mean maximum canopy height.

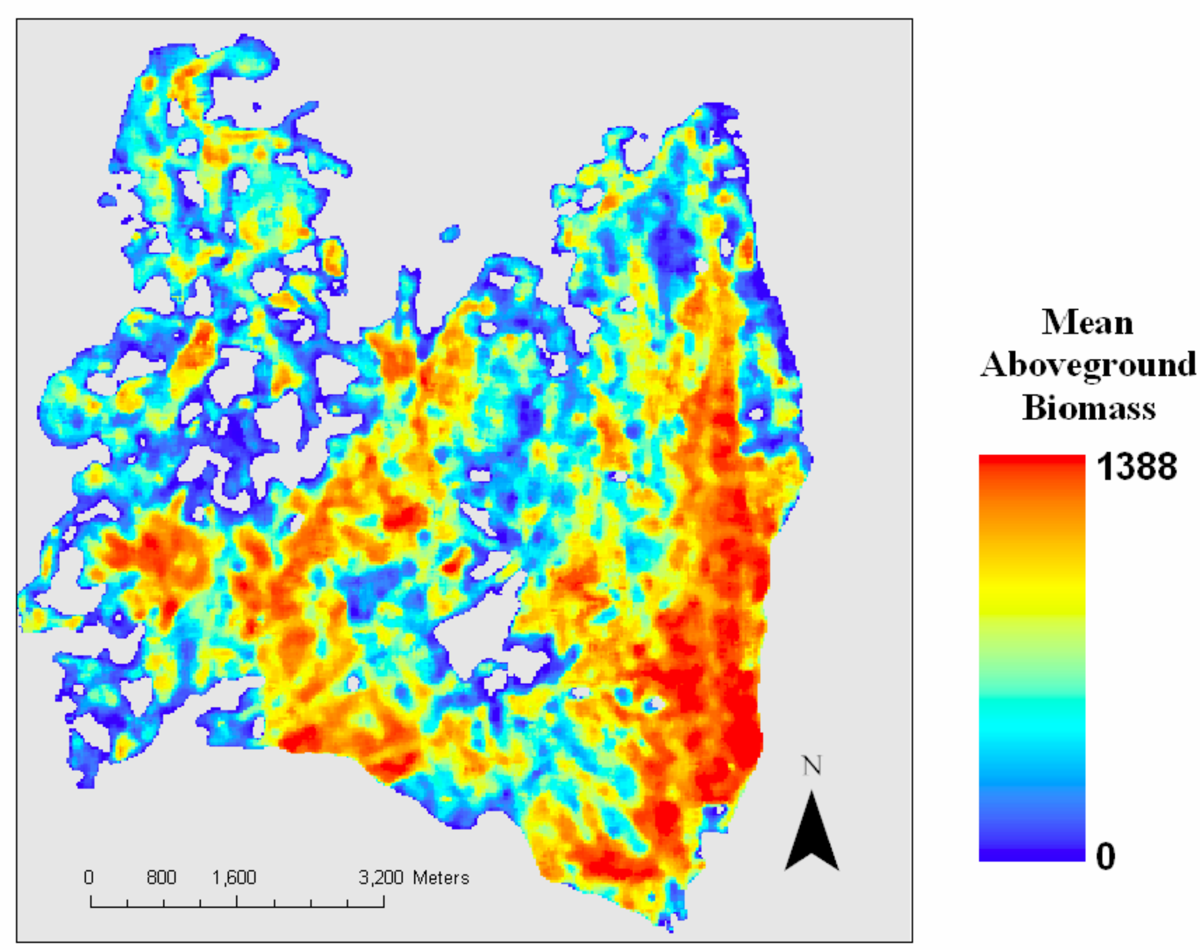


Figure 4. LIDAR-derived spatial estimate of aboveground biomass in the North Yuba area.

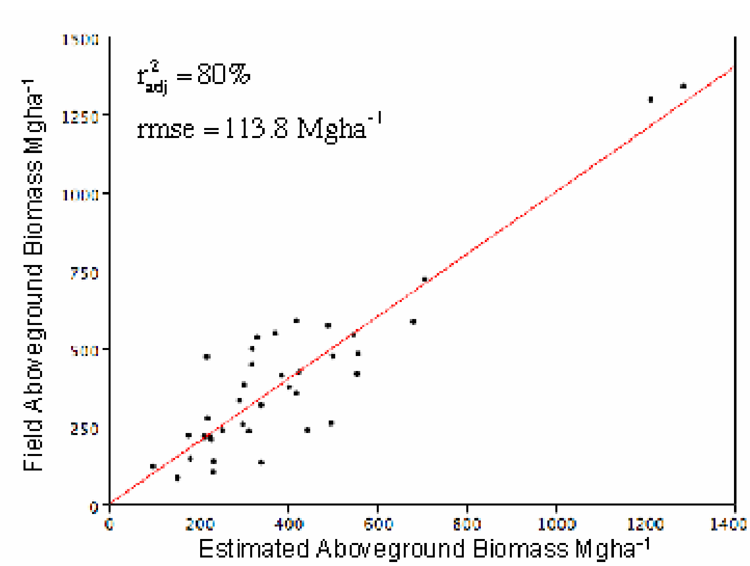


Figure 5. Field-measured biomass vs. LIDAR-estimated biomass.

Task 3: Baseline Method Development

Evaluation of GEOMOD for avoided deforestation and reforestation baselines in the Guaraqueçaba Environmental Protection Area

GEOMOD allowed us to evaluate the land use change dynamics in the Guaraqueçaba Environmental Protected Area (EPA) and also provided the means to projects future land use/land cover change types over time and determine where on the landscape deforestation and reforestation are most likely to occur.

In the Guaraqueçaba EPA regions below 100 feet in elevation were projected to lose 7,100 hectares to deforestation over the 40 years, but also benefit from natural regeneration on 3,000 ha. Overall this means a net loss of 4,100 ha showing a clear trend of deforestation in the region.

Approximately 170,300 t C are expected to be generated at the Atlantic Rainforest Restoration Project through regeneration/restoration (120,900 t C) and avoided deforestation (49,400 t C) over 40 years. Only 32 ha were predicted to regenerate without the project.

Guaraqueçaba Climate Action Project will generate a total of 120,120 t C (440,400 CO2) through natural regeneration/restoration (86.300 t C) and avoided deforestation (37,500 t C).

The Antonina Pilot Reforestation Project is expected to generate 27,531.1 t C through natural regeneration/restoration and 17,900 t C through avoided deforestation, totaling 45,300 t C or 166,100t CO2, over the 40 years.

Evaluation of Simple Land Use Change Detection in Guaraqueçaba Environmental Protection Area

Approximately 173,100 t C are expected to be generated at the Atlantic Rainforest Restoration Project through regeneration/restoration (634,700 t CO2) and avoided deforestation (67,400 t C) over the 40 years. Only 96 ha were predicted to regenerate without the project, which represents a total amount of 11,500 t C.

The Guaraqueçaba Climate Action Project will generate a total of 111,000 t C through natural regeneration/restoration (80,800 t C) and avoided deforestation (40,100 t C).

The Antonina Pilot Reforestation Project is expected to generate 28,700 t C and 8,300 t C through natural regeneration/restorationand avoided deforestation, totaling 35,500 t C over the 40 years.

Comparative analysis between GEOMOD and Simple Land Use Change Detection methods

When GEOMOD and the Land Use Change methods were compared the following differences were found: (Table 7):

Table 7: Data set from GEOMOD and Land Use Change (LUC) methods for the three projects in Guaraqueçaba EPA

	ARRP		GCAP		APRP	
	LUC	GEOMOD	LUC	GEOMOD	LUC	GEOMOD
Deforested area (ha)	421	262	238	218	52	87
Avoided deforestation(t C)	67,400	23,300	40,100	30,700	8,300	12,300
Regeneration/reforestation (t C)	117,200	158,400	80,800	86,700	28,700	17,700
Benefit	184,600	181,700	120,900	116,400	37,000	30,000

GEOMOD indicates that there are fewer areas predicted to be deforested in ARRP and GCAP than in the Land Use Change method. GEOMOD is a model that works with the trends of the deforestation, using different rates according to the trend of a specific area. Land Use Change just considers the deforestation rates through the years; meaning that an area more likely to be deforested (such as flat land) has the same deforestation rate as other less threatened areas (such as slope areas).

The Land Use Change method demands previous vegetation studies, digital geoprocessing and extensive field work. During the process, mistakes as the delimitation of the polygons, the location of attributes can reduce the precision of the work and can give an unrealistic estimate of land use change of a region.

Terrestrial Carbon Storage on Albemarle Peninsula, North Carolina: Baseline Estimates in the Face of Sea Level Rise

The results of the sea level rise spatial modeling show that between 1260 km2 and 3020 km2 of the land area of the Peninsula will be flooded by the year 2100 (Figure 6 and Table 8).

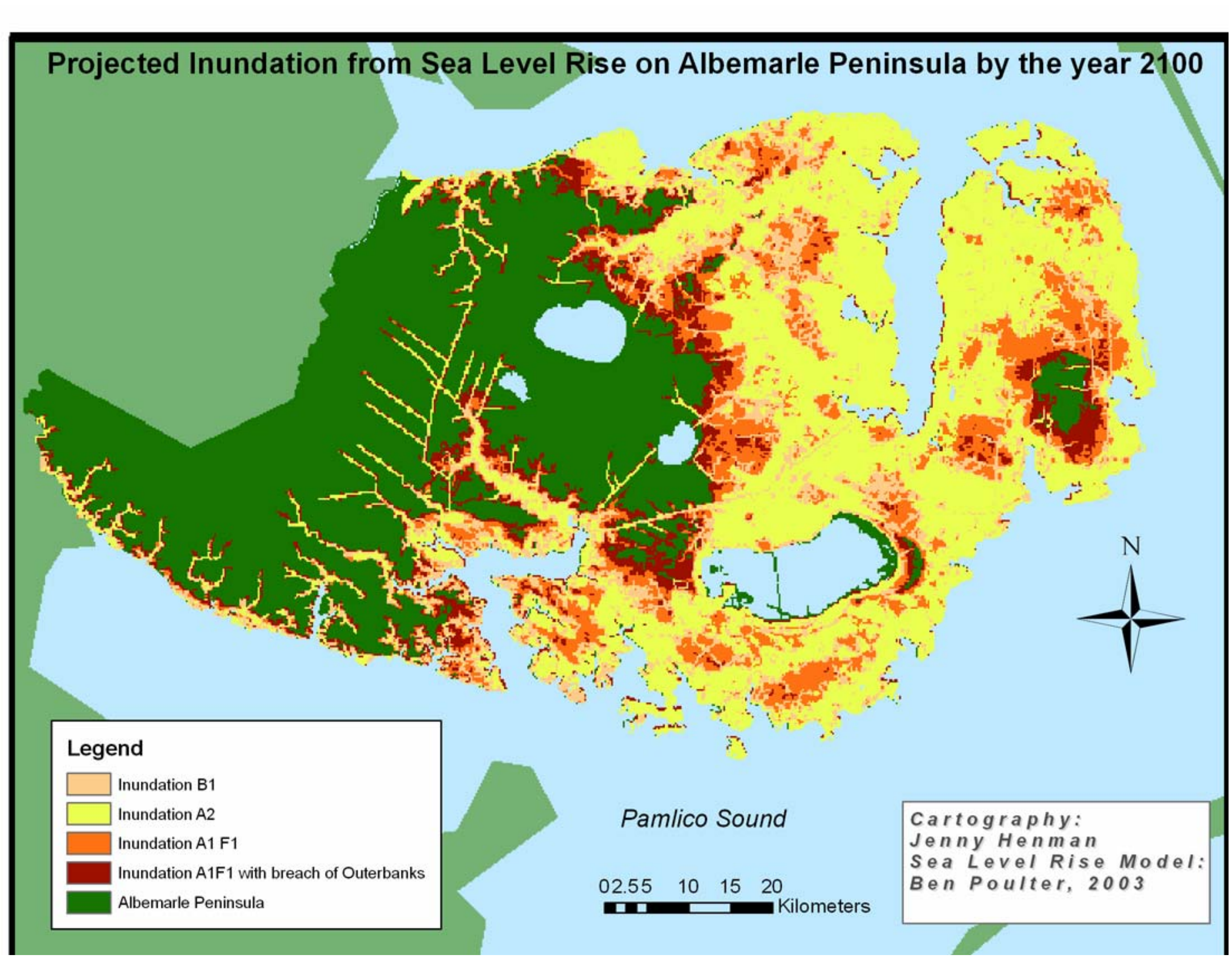


Figure 6: Projected flooding of Albemarle Peninsula by the Year 2100 under the 4 different sea level rise scenarios. (B1, A2, A1F1 and A1F1 with a breach of the outer banks)

Table 8 lists the carbon storage (and loss potential) in vegetation types across the Albemarle Peninsula. Table 9 lists the surface area and carbon storage in peat deposits in flood prone areas.

Table 8: Carbon lost from vegetation under sea level rise flooding scenarios on Albemarle Peninsula. (assuming 100% loss of carbon from vegetation stocks as a result of constant flooding, irrespective of flooding depth)

	Land Area Flooded Under A1F1 "with breach of outerbanks" Scenario (Ha)	Carbon Loss Under A1F1" with breach of outerbanks" Scenario (Tg C)	Land Area Flooded Under A1F1 Scenario (Ha)	Carbon Loss Under A1F1 Scenario (Tg C)	Land Area Flooded Under A2 Scenario (Ha)	Carbon Loss Under A2 Scenario (Tg C)	Land Area Flooded Under B1 Scenario (Ha)	Carbon Loss Under B1 Scenario (Tg C)
Water	5037.8	0.0	4999.9	0.0	4835.6	0.0	4288.7	0.0
Urban/ Developed	7914.8	0.0	5257.4	0.0	3809.4	0.0	2177.5	0.0
Barren	35.6	0.0	31.8	0.0	29.8	0.0	20.9	0.0
Deciduous Forest	3017.4	0.5	1842.1	0.3	1322.5	0.2	811.1	0.1
Evergreen Forest	22208.7	2.4	14469.3	1.5	10494.8	1.1	5900.3	0.6
Mixed Forest	2293.9	0.3	1682.8	0.2	1308.9	0.2	728.3	0.1
Shrub/ Scrub	8012.2	0.2	5943.6	0.2	4623.4	0.1	2782.6	0.1
Grasslands/Herbaceous	10229.4	0.1	7412.4	0.1	5440.2	0.0	3128.6	0.0
Pasture Hay	973.2	0.0	541.6	0.0	351.1	0.0	164.9	0.0
Croplands	42759.2	0.6	27941.9	0.4	19222.5	0.3	10461.3	0.1
Woody Wetlands	168335.2	10.9	143432.2	9.3	121115.0	7.9	79401.1	5.2
Emergent Herbaceous We	30511.0	0.9	29211.3	0.9	25817.8	0.8	16148.4	0.5
Total	301328.4	15.9	242766.3	12.9	198370.9	10.6	126013.9	6.8

Table 9: Surface area of and carbon storage in peat deposits predicted to be flooded under the four different carbon storage scenarios.

Surface Area of Peat Flooded Under A1F1 "with breach of outerbanks" Scenario (Ha)	Carbon stored in area flooded under A1F1" with breach of outerbanks" Scenario (Tg C)	Surface Area of Peat Flooded Under A1F1 Scenario (Ha)	Carbon stored in area flooded under A1F1 Scenario (Tg C)	Surface Area of Peat Flooded Under A2 Scenario (Ha)	Carbon stored in area flooded under A2 Scenario (Tg C)	Surface Area of Peat Flooded Under B1 Scenario (Ha)	Carbon stored in area flooded under B1 Scenario (Tg C)
1066	98	967	84	728	67	431	40

This study concluded that carbon losses resulting from predicted flooding from sea level rise (by year 2100) on the Albemarle Peninsula lie between 7 Tg C and 114 Tg (Table 10). If a median value was assumed then even this would constitute a considerable positive feedback, contributing to further exacerbation of GHG emissions, especially when considering extrapolation of these findings to the entire Eastern and Southern seaboards of the United States.

Table 10: Twelve different scenarios of total loss of Carbon (Mg) on Albemarle Peninsula as a result of inundation from sea level rise

	A1F1 w/h a breach of the Outer Banks	A1F1	A2	B1
Loss of C from Vegetation + 100 % loss of C from Peat Deposits (Mg C)	114	111	78	27
Loss of C from Vegetation + 50 % loss of C from Peat Deposits (Mg C)	65	70	44	7
Loss of C from Vegetation + 0 % loss of C from Peat Deposits (Mg C)	16	28	11	7

The estimate of carbon emissions which will result from the predicted flooding of the Albemarle Peninsula from sea level rise show a fairly large positive climate feedback. The estimates of the carbon emissions under different scenarios span a large range. The most conservative estimate is 7 Tg C when considering the B1 SRES, and assuming no loss of carbon from peat deposits when inundated. In contrast the highest estimate of projected emissions of carbon from the A1F1 scenario assuming a breach of the Outer Banks, and 100 % loss of carbon the peat deposits is 114 Tg C. The annual carbon emissions for the state of North Carolina are about 50 Tg C. Over 100 years, sea level rise on the Albemarle Peninsula alone could add an additional 1 Tg C of carbon to atmosphere from activities based in North Carolina.

Further field research is needed into the effects of flooding of coastal peat deposits on release of carbon stocks, in addition to research into the ability of tree species to survive in saline and flooded conditions. Climate adaptation research and strategies are being developed by the Nature Conservancy in collaboration with partners to minimize the negative impact that sea level rise will have on Albemarle Peninsula.

Task 5 New Project Feasibility Studies

Northeast Study

Project Management

The team continues to hold monthly team calls to discuss progress and issues related to the completion of the project. In addition, other team meetings are being held to go over methodology related to execution of the study.

In addition, ongoing outreach and communication to stakeholders related to this project continues. Below is a summary of the most significant stakeholder outreach activities during this quarterly report time period.

On May 25, 2006, the study team was invited to brief the Northeast Regional Greenhouse Gas Initiative (RGGI) staff working group (SWG) on the preliminary results of Part III of this study. The RGGI SWG was interested in the estimates being generated from the study of the availability of carbon for the region and the estimated cost per ton of CO_2. A general conclusion that was presented was that the cost per ton of CO_2 appeared to be far greater than the estimates for an allowance (the price per ton CO_2 under the cap) under the RGGI regulatory cap and trade scheme being considered. The team urged them to allow afforestation offsets from outside of the RGGI region to be counted the same as afforestation offsets from inside the RGGI region.

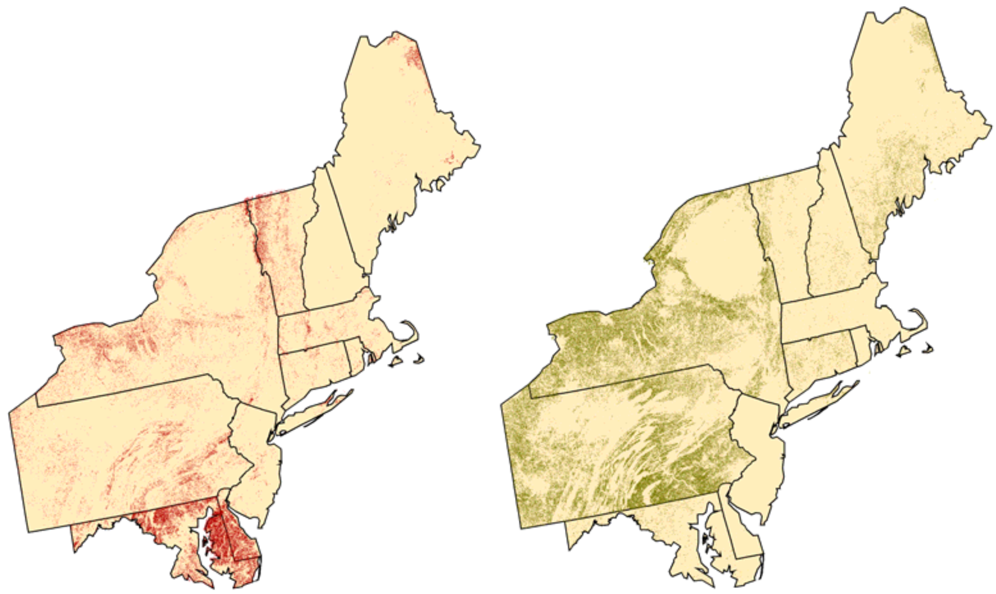
On July 5, 2006, the team sent out a draft of Part III (the same version as was submitted as our most recent milestone report) to the stakeholder list, for comment and feedback. The team received some comments and will continue to collect and respond to comments prior to submitting our final report.

Part III. Opportunities for Improving Carbon Storage and Management on Agricultural Lands

A draft of Part III examining the potential of afforestation on cropland and pasture lands has been completed. For the final report this Part will also include an examination of cropland management and biomass energy crop production. The $/ton of CO_2 is presented and analyzed at a county level. The analysis identifies the areas for potential lower costs per carbon dioxide for afforestation.

The results are summarized and displayed in carbon supply curves and corresponding maps. Although this study will investigate afforestation, cropland management and biomass energy crop production, the current report only present's results of afforestation on crop and pasture lands.

This report presents the findings of research and analysis conducted to describe where, how much, and at what cost in the region it would be economically attractive to alter land use to increase carbon storage.



Cropland Pasture

Figure 7. Land cover of cropland and pasture in the northeast region

This analysis shows the costs related to converting agricultural land to forest land to be variable across the region but averaged $1600/acre and $2300/acre for a ten year time period for pasture land and cropland respectively. Costs increase as the length of time increases, with opportunity costs making up a higher proportion of the costs. At ten years, opportunity costs account for an average of 62% of the costs, but by forty years they account for almost 80% of the costs (Figure 8).

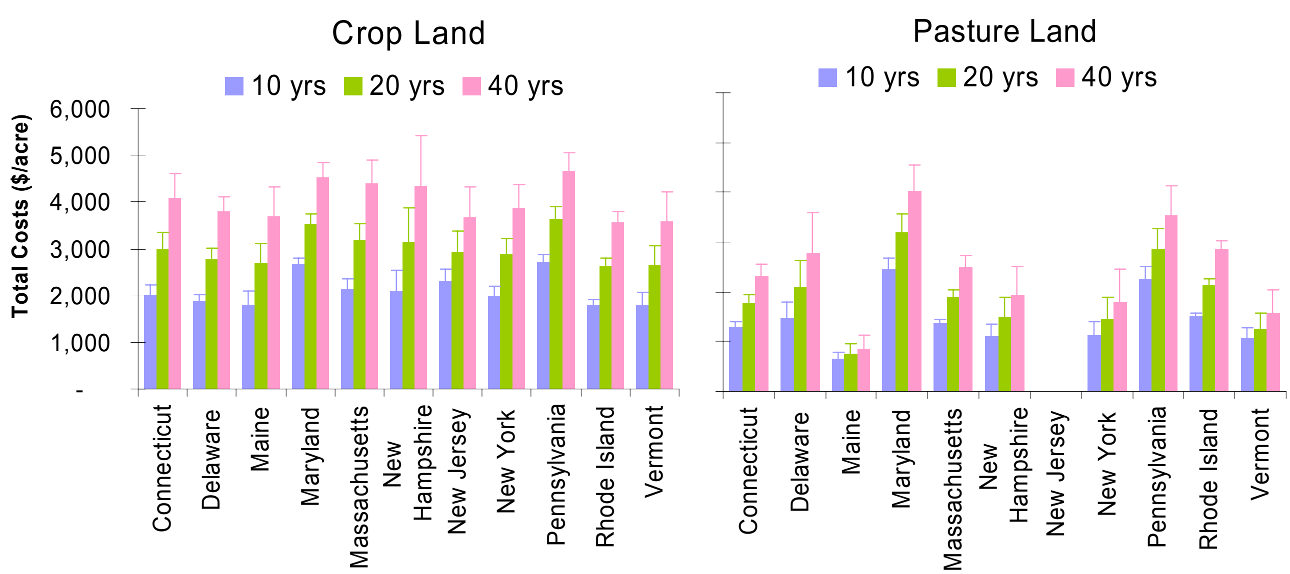


Figure 8. Total costs associated with land use change from agriculture to afforestation.

The estimated carbon sequestration potential of lands found in the region averages 31 tons CO_2/acre after ten years up to 100 tons CO_2/acre after 40 years (Table 11, Figure 9). Therefore, an area of 1,600 acres would accumulate over 50,000 tons of CO_2 in ten years (Table 12).

Table 11. Range of estimated carbon dioxide sequestered over different time periods per unit area.

	tons of CO_2/acre					
	10 years		20 years		40 years	
	0% dis	6% dis	0% dis	6% dis	0% dis	6% dis
Weighted Mean	31	23	57	33	100	41
Minimum	16	12	23	14	49	20
Maximum	41	30	74	44	120	52

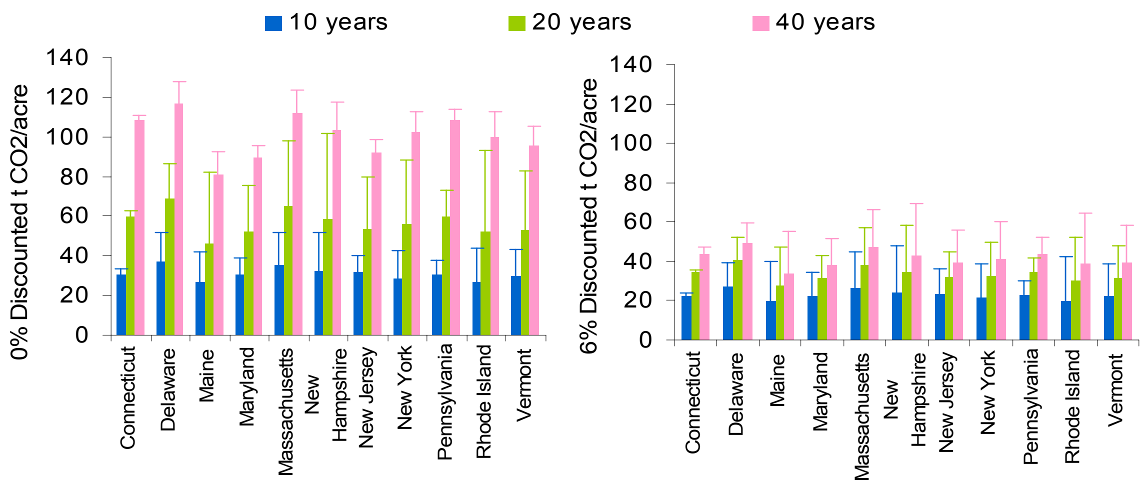


Figure 9. Mean estimated carbon dioxide sequestered per area in each state.

Table 12. Estimated afforestation area needed to sequester given amounts of carbon dioxide.

	Estimated area needed (acres)					
ton CO_2	10 years		20 years		40 years	
	0% dis	6% dis	0% dis	6% dis	0% dis	6% dis
10,000 t	327	444	177	303	100	242
50,000 t	1,635	2,221	885	1,513	498	1,212
100,000 t	3,270	4,443	1,770	3,027	996	2,424
1 million t	32,700	44,429	17,695	30,268	9,962	24,242

Prices per ton of CO_2 are lower in pasture land due to the lower opportunity costs (Table 13, Figure 10). Discounting carbon levels increases the costs per ton of CO_2 substantially; however these costs will be a more accurate representation of the economic attractiveness of afforestation. Cropland only becomes available for afforestation when prices have reached \$40/ton CO_2 (Table

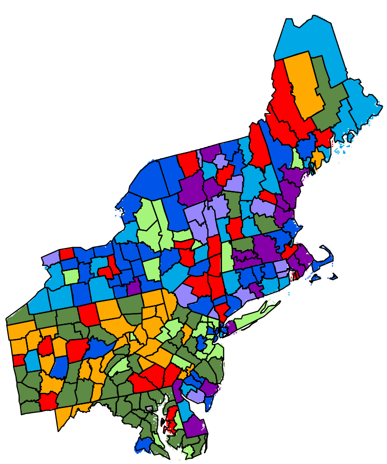
3-4). Some pastureland will be available at a price of \$15/ton CO_2, and the amount of land available increases dramatically as the time interval is extended (Table 14).

Table 13. Weighted mean cost per ton of CO_2 sequestered in all Northeastern states on crop and pasture land.

	0% Discounted CO_2			6% Discounted CO_2		
	10 years	20 years	40 years	10 years	20 years	40 years
	Cropland - \$/ton CO_2					
Weighted mean	\$79	\$61	\$44	\$107	\$103	\$107
Minimum	\$29	\$21	\$16	\$39	\$36	\$38
Maximum	\$173	\$159	\$92	\$235	\$254	\$233
	Pasture Land - \$/ton CO_2					
Weighted mean	\$56	\$37	\$25	\$76	\$64	\$62
Minimum	\$14	\$7	\$4	\$18	\$13	\$10
Maximum	\$179	\$166	\$88	\$243	\$265	\$244

Table 14. Estimated potential tons of CO_2 that could be sequestered and area of land that would be available at various prices per ton of CO_2.

	Cropland			Pasture land		
	10 years	20 years	40 years	10 years	20 years	40 years
	6% Discounted Carbon					
	Estimated potential tons CO_2					
\$10/t CO_2	0	0	0	0	0	121,000
\$15/t CO_2	0	0	0	66,000	242,000	1.7 million
\$20/t CO_2	0	0	0	66,000	5.6 million	10.5 million
\$40/t CO_2	45,000	67,000	81,000	13.8 million	38 million	51.5 million
	Estimated potential area (acres)					
\$10/t CO_2	0	0	0	0	0	75,000
\$15/t CO_2	0	0	0	75,000	75,000	185,000
\$20/t CO_2	0	0	0	75,000	350,000	645,000
\$40/t CO_2	1,600	5,400	1,600	1.26 million	3.3 million	3.7 million



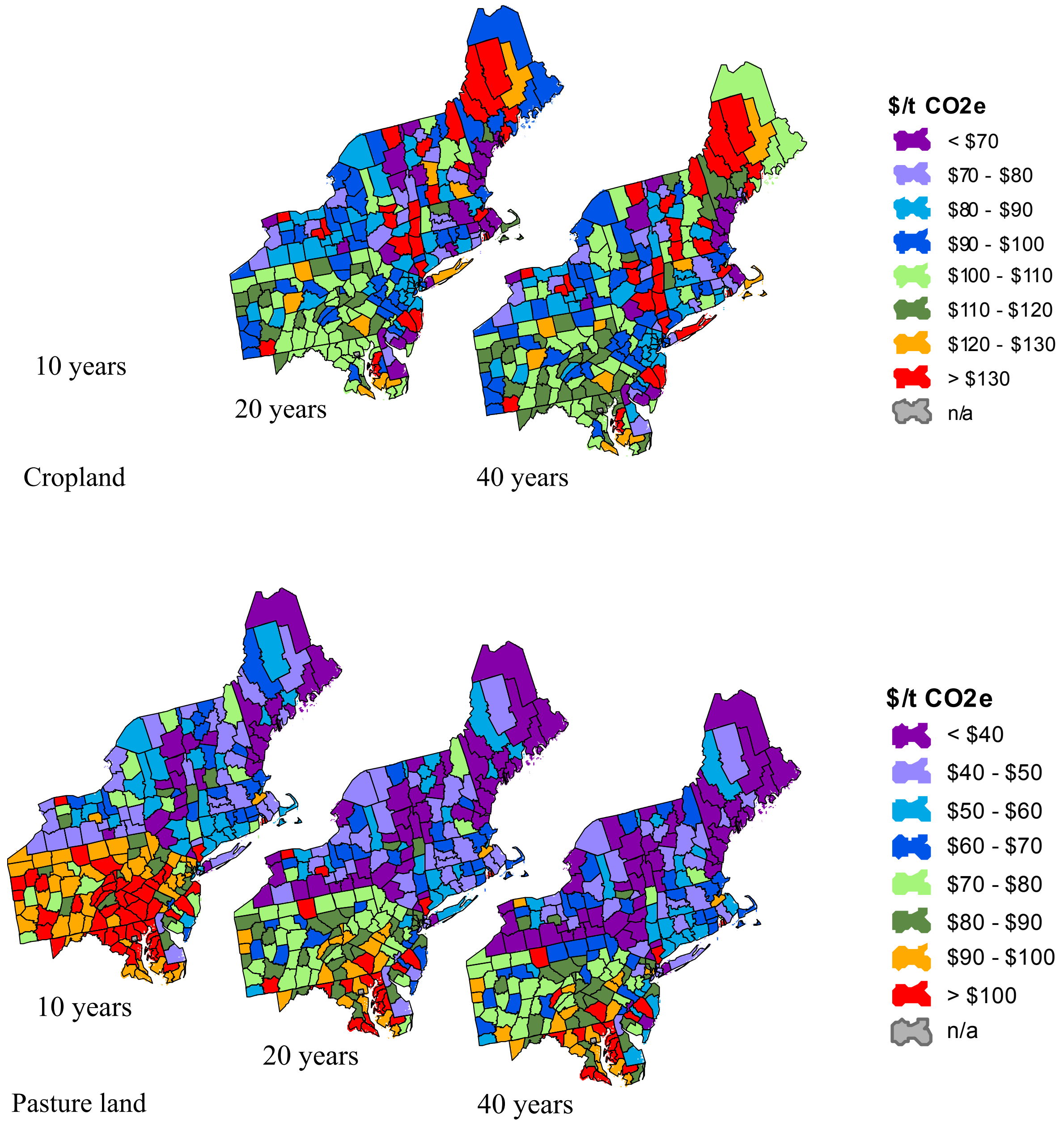


Figure 10. Estimated cost per ton carbon dioxide sequestered of 6% discounted carbon in both cropland and pasture land.

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

Improved stocking of under-stocked stands

For the analysis, the data on growing stock volume and hectares in poorly stocked young and mature forests is downloaded from the USDA Forest Inventory and Analysis website for each county and each site class in the Northeast region. There are a total of 244 total counties in the region, 8 forest types, 4 site classes, and 2 general age classes (younger than 40 years and older than 40 years), for a total of 15,616 units that were analyzed. The analysis encompasses 3.2 million hectares of poorly stocked stands in the Northeast region. 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.

The resulting marginal cost curves for the stocking analysis are shown in Figure 11. The marginal cost curves show 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 2.7 million t C, 2.0 million t C of which comes from currently mature, but poorly stocked stands. In general, costs for converting mature stands tend to be lower, although there are fewer hectares of mature poorly stocked stands, and consequently fewer total opportunities with these stands. The total potential from currently mature stands is around 4.5 million t C, although some of this is very expensive carbon. The potential for the currently young stands is around 5.4 million t C.

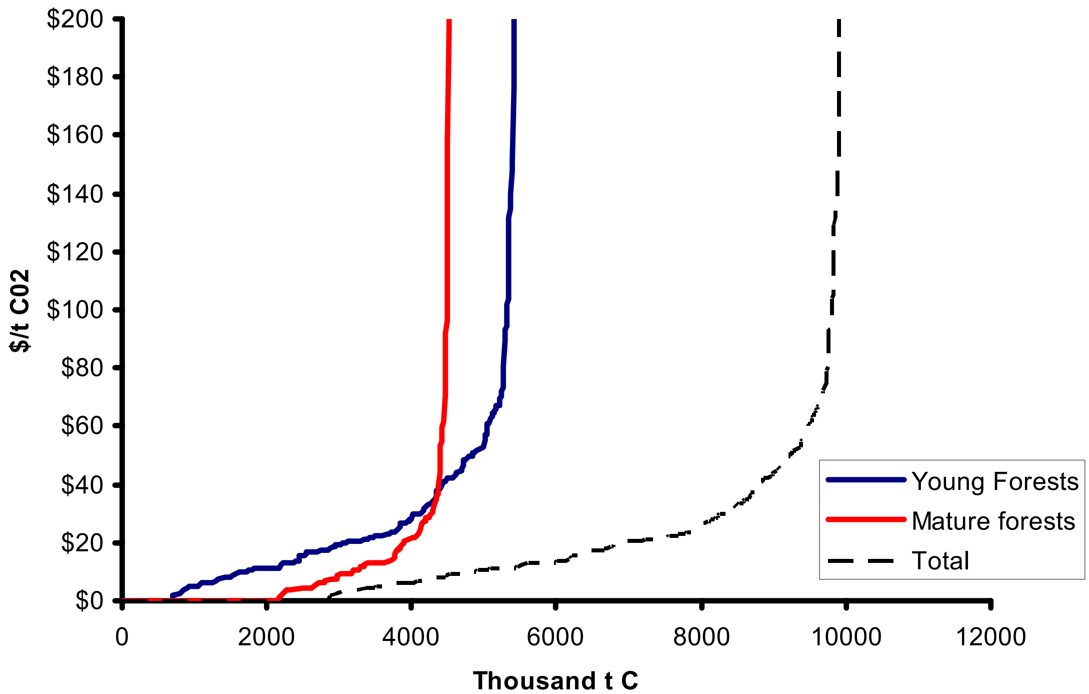


Figure 11: Marginal costs of sequestering carbon through harvesting and re-stocking poorly stocked forests in the Northeast region for forests that currently are young and those that are currently mature.

To give a sense for the potential sequestration across the states and forest types, Table 14 presents average \$/t CO2, total potential t C, and total potential hectares with positive sequestration for each forest type. The results suggest that the lowest cost options exist with the

Maple Beech Birch types (MBB). This forest type 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 346,000 hectares, around 1.6 million t C could be sequestered in the MBB type.

There are also a number of low cost opportunities associated with oak pine (OP) types in Maine, Massachusetts, and New York; oak hickory (OH) types in Delaware, Maine and Massachusetts; and elm-ash-cottonwood (EAC) types in many states. The states with the least average cost are Pennsylvania, Delaware, New Jersey, and New York. Overall average costs are only about $2 per t CO2, owing to the relatively low costs (high benefits) and large C quantities for MBB.

It's useful also to consider the distribution of carbon sequestration potential across the age and site classes. 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, particularly the mature forests (Table 16). 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 16, however, clearly points out that mature stands represent the bulk of the lower, or no, cost opportunities for carbon sequestration through increasing the stocking condition.

Average costs by county are plotted in Figure 12. The figure shows that there are numerous counties with essentially "negative" costs for carbon sequestration (<$0/t C). 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.

Table 14: Carbon sequestration potential, average costs, and hectares in program from harvesting and regenerating poorly stocked stands in Northeast region. Estimates only include hectares for which there are positive carbon benefits.

	WRJ Pine	SF	OP	OH	OCG	EAC	MBB	AB	Total
				Average $/t CO2[1]					
CT	$119	--	--	$24	--	$33	$14	$81	$30
DE	--	--	--	($12)	--	$1	$28	--	($9)
ME	($3)	$13	($3)	$9	$289	$17	$5	$93	$10
MD	--	--	--	--	--	--	--	--	--
MA	$26	--	($22)	$10	--	$157	--	--	$24
NH	$55	$50	--	$11	--	$4	($1)	--	$11
NJ	--	--	$102	$12	--	$8	($70)	--	($1)
NY	$40	$45	$8	$19	$23	$16	($105)	$94	$6
PA	$38	$13	$23	$13	$17	$5	($90)	$62	($11)
RI	--	--	--	$29	--	$146	--	--	$54

VT	$20	$9	$19	--	--	$1	($27)	$32	$8
Total	$19	$15	$11	$15	$24	$14	($69)	$65	$2
Potential Tons Stored in State									
					Thousand t C				
CT	2.7	--	--	70.9	--	64.4	31.2	10.7	179.9
DE	--	--	--	49.5	--	12.4	1.4	--	63.3
ME	411.1	878.1	65.6	69.4	2.0	47.0	114.7	35.0	1,622.9
MD	--	--	--	--	--	--	--	--	--
MA	49.8	--	1.8	41.6	--	4.1	--	--	97.4
NH	33.2	33.3	--	102.7	--	32.1	219.6	--	421.0
NJ	--	--	5.1	290.8	--	74.0	69.6	--	439.4
NY	217.4	71.9	93.8	1,495.4	46.3	486.9	333.6	38.5	2,783.9
PA	166.7	19.8	57.7	1,797.9	57.9	138.8	789.0	60.4	3,088.2
RI	--	--	--	10.1	--	2.8	--	--	12.8
VT	57.8	208.5	26.8	--	--	77.9	62.6	62.8	496.5
Total	938.8	1,211.6	250.8	3,928.3	106.2	940.4	1,621.7	207.5	9,205.2
Hectares Potentially in Program									
					Thousand Hectares				
CT	1.4	--	--	7.3	--	7.8	4.6	3.1	24.1
DE	--	--	--	3.1	--	1.4	0.6	--	5.0
ME	32.1	140.5	8.9	7.9	1.9	6.2	37.2	13.9	248.6
MD	--	--	--	--	--	--	--	--	--
MA	4.6	--	0.3	4.7	--	2.5	--	--	12.2
NH	8.2	5.7	--	6.0	--	3.2	48.9	--	71.9
NJ	--	--	2.4	30.0	--	8.5	7.6	--	48.5
NY	38.4	12.1	26.9	189.0	5.1	43.6	98.4	13.6	427.2
PA	23.1	1.3	11.1	263.2	7.9	14.4	137.1	13.9	471.8
RI	--	--	--	2.4	--	1.5	--	--	3.9
VT	6.7	18.5	2.5	--	--	5.0	12.2	8.5	53.4
Total	114.4	178.1	52.2	513.6	15.0	94.0	346.6	52.9	1,366.7

[1] Negative numbers in average cost estimates indicate that the projects would potentially generate profits over the cycle.

Table 4-13: Proportion of total carbon storage potential by site class and age. S3 = "yng" stands for the young age classes and "mat" stands for mature.

	S3 yng	S3 mat	S4 yng	S4 mat	S5 yng	S5 mat	S6 yng	S6 mat
				Proportion				
CT	0.06	0.00	0.01	0.02	0.33	0.00	0.48	0.10
DE	0.00	0.00	0.00	0.35	0.00	0.62	0.02	0.00
ME	0.03	0.01	0.08	0.11	0.08	0.18	0.19	0.32
MD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MA	0.00	0.00	0.00	0.04	0.00	0.02	0.46	0.48
NH	0.18	0.00	0.00	0.04	0.00	0.04	0.62	0.12
NJ	0.00	0.00	0.00	0.12	0.12	0.21	0.40	0.15
NY	0.05	0.00	0.11	0.02	0.25	0.13	0.37	0.07

PA	0.03	0.01	0.08	0.06	0.13	0.21	0.22	0.27
RI	0.00	0.00	0.00	0.00	0.00	0.21	0.00	0.79
VT	0.09	0.00	0.13	0.14	0.02	0.25	0.11	0.26
Total	0.05	0.00	0.08	0.06	0.15	0.17	0.28	0.20

Table 4-14: Average costs across site classes and age. S3 = "yng" stands for the young age classes and "mat" stands for mature.

	S3 yng	S3 mat	S4 yng	S4 mat	S5 yng	S5 mat	S6 yng	S6 mat
	Average $/t CO2							
CT	$81	--	$189	$119	$17	$146	$19	$62
DE	--	--	--	($3)	--	($13)	$28	--
ME	($4)	($141)	$5	($0)	$17	$2	$28	$10
MD	--	--	--	--	--	--	--	--
MA	--	--	--	$157	--	($22)	$26	$12
NH	($18)	--	--	($20)	--	$75	$16	$15
NJ	--	--	--	($29)	$5	($31)	$26	($12)
NY	$16	--	$31	($50)	$2	($62)	$36	($31)
PA	($16)	($186)	$33	($22)	$15	($36)	$23	($36)
RI	--	--	--	--	--	$146	--	$29
VT	$10	--	$17	$11	($112)	$4	$46	($3)
Total	$1	($175)	$26	($11)	$7	($30)	$29	($16)

The results indicate that up to 3.6 million tons could be sequestered for less than $10/t CO2, with many of these projects generating net benefits. The regional distribution of the carbon opportunities with costs less than $10/t CO2 is shown in Figure 13. The largest opportunities appear to occur in Maine, followed by New York and Pennsylvania. This is not surprising since these states have the most total forestland area.

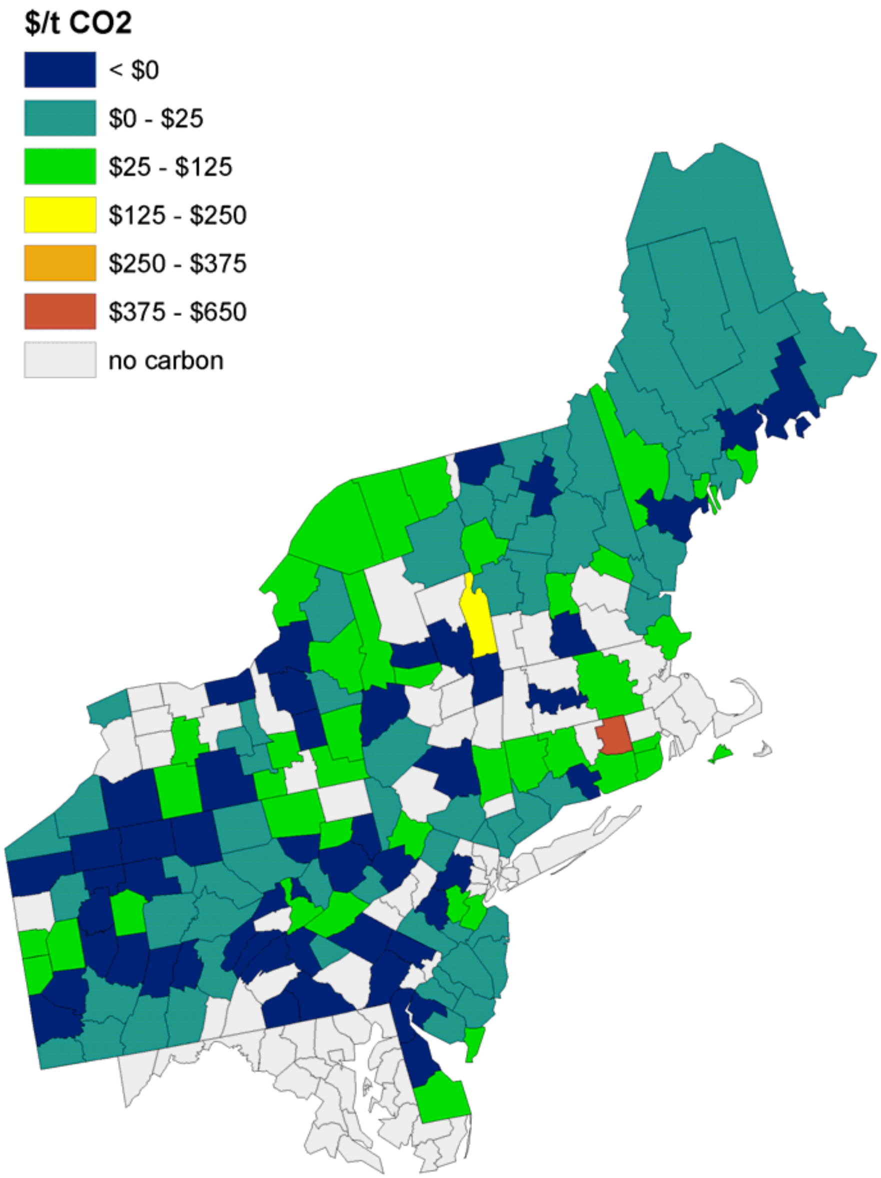


Figure 12: Average cost of carbon sequestration in each county from improving stocking conditions in poorly stocked forests.

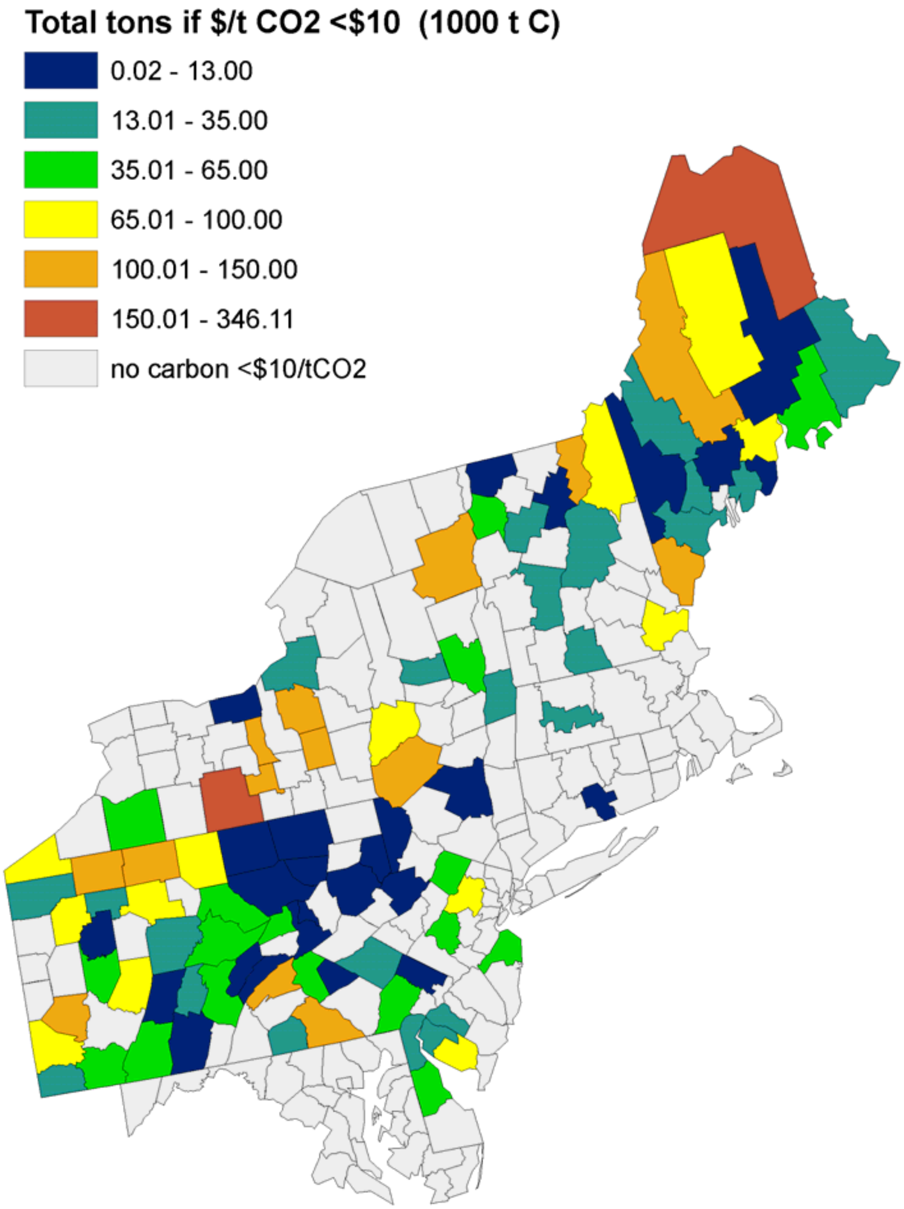


Figure 13: Total carbon potential by county for projects that cost less than $10/t CO2.

Important Sensitivities

The results in this section suggest that substantial carbon can be sequestered in the Northeast region 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 found to act sub-optimally with respect to traditional economic incentives, such as the price of timber. We currently have no way of incorporating these other factors that motivate individual landowners, such as ecological benefits, game management, or other factors, into economic analysis. These other considerations 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.

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 larger for landowners in this category. It is not possible with datasets available today to estimate the scale of these additional costs, however.

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 - nearly 1.4 million hectares. Total removals of growing stock associated with this could be around 71.5 million m^3, which is more than double the current estimated removals each year of around 31 million m^3 (see discussion in the section of this report titled, *Trends in Forestry*). 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%, and 40% reduction in prices increases costs by around 92%!

Third, the analysis has assumed that carbon should be discounted. Discounting carbon is important for businesses considering alternatives for mitigating carbon emissions because often must make trade-offs among current time periods and future time periods. However, we have used the full financial rate for discounting the carbon, 6%. It is not clear what the effect of reducing the discount rate for carbon will be because as Figures 4-8 and 4-9 show, a number of different future carbon paths enter the total carbon picture. For example, discounting reduces the value of the future gains in carbon due to improved stocking, but it also reduces the gains that would occur in the baseline.

Reducing the discount rate for carbon sequestration to 3% is found to reduce the average cost of sequestration by around 40%. However, and this is an important caution, reducing the discount rate for carbon sequestration accounting does not have consistent effects in all regions and for all species. Some states, and age classes experience increased costs as a result of changing the discount rate.

Extending the Rotation Age in Softwood forests

The results of the analysis indicate that there are potentially substantial opportunities for increasing carbon sequestration through aging in Northeast softwood forest (Table 15). For 5 year rotation extensions, around 2.9 million t C could be sequestered for around \$6/t CO2. The lowest cost opportunities appear to be site class 5 for both white-red-jack pine and spruce-fir forests. This amounts to around 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 CO2. 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. 17. The results indicate that about 1.5 million t C could be sequestered for less than \$5/t CO2, and that 3.3 million t C could be sequestered for less than \$10/t CO2. 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 CO2, 98% of the carbon would arise with 5 year extensions; and for projects with marginal costs <\$10/t CO2, 83% of the carbon would arise with 5 year extensions.

Table 15: 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. $/tCO2
5 Year Extension			
White-Red Jack Pine Site Class 3	95.5	$3.2	$9.15
White-Red Jack Pine Site Class 4	417.5	$11.7	$7.61
White-Red Jack Pine Site Class 5	720.8	$11.5	$4.36
White-Red Jack Pine Site Class 6	496.0	$9.3	$5.12
Spruce-Fir Site Class 3	48.9	$0.9	$4.84
Spruce-Fir Site Class 4	280.8	$5.6	$5.40
Spruce-Fir Site Class 5	453.1	$6.4	$3.88
Spruce-Fir Site Class 6	463.9	$16.9	$9.94
Total	*2,976.6*	*$65.5*	*$6.00*
10 Year Extension			
White-Red Jack Pine Site Class 3	140.1	$23.4	$45.57
White-Red Jack Pine Site Class 4	608.0	$68.3	$30.60
White-Red Jack Pine Site Class 5	1,096.5	$57.8	$14.37
White-Red Jack Pine Site Class 6	776.9	$51.2	$17.94
Spruce-Fir Site Class 3	71.1	$3.1	$11.99
Spruce-Fir Site Class 4	407.1	$19.6	$13.10
Spruce-Fir Site Class 5	659.6	$21.5	$8.89
Spruce-Fir Site Class 6	672.8	$132.1	$53.48
Total	*4,432.0*	*$376.9*	*$23.17*
15 Year Extension			
White-Red Jack Pine Site Class 3	168.5	$84.6	$136.86

White-Red Jack Pine Site Class 4	730.5	$184.9	$68.97
White-Red Jack Pine Site Class 5	1,348.1	$131.8	$26.64
White-Red Jack Pine Site Class 6	970.9	$104.2	$29.25
Spruce-Fir Site Class 3	84.1	$8.9	$28.77
Spruce-Fir Site Class 4	480.6	$57.5	$32.61
Spruce-Fir Site Class 5	780.5	$53.1	$18.55
Spruce-Fir Site Class 6	801.6	$348.6	$118.50
Total	*5,364.8*	*$973.7*	*$49.45*

To get a sense for the spatial distribution of these potential projects, the average costs for 5 year rotation extensions are shown in Fig 4-18. 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 that can be sequestered in each county for <$10/t CO2 is plotted by county in Fig. 4-19. The largest potential appears to occur in Maine, but of course, this partly results from the relatively large counties in that state.

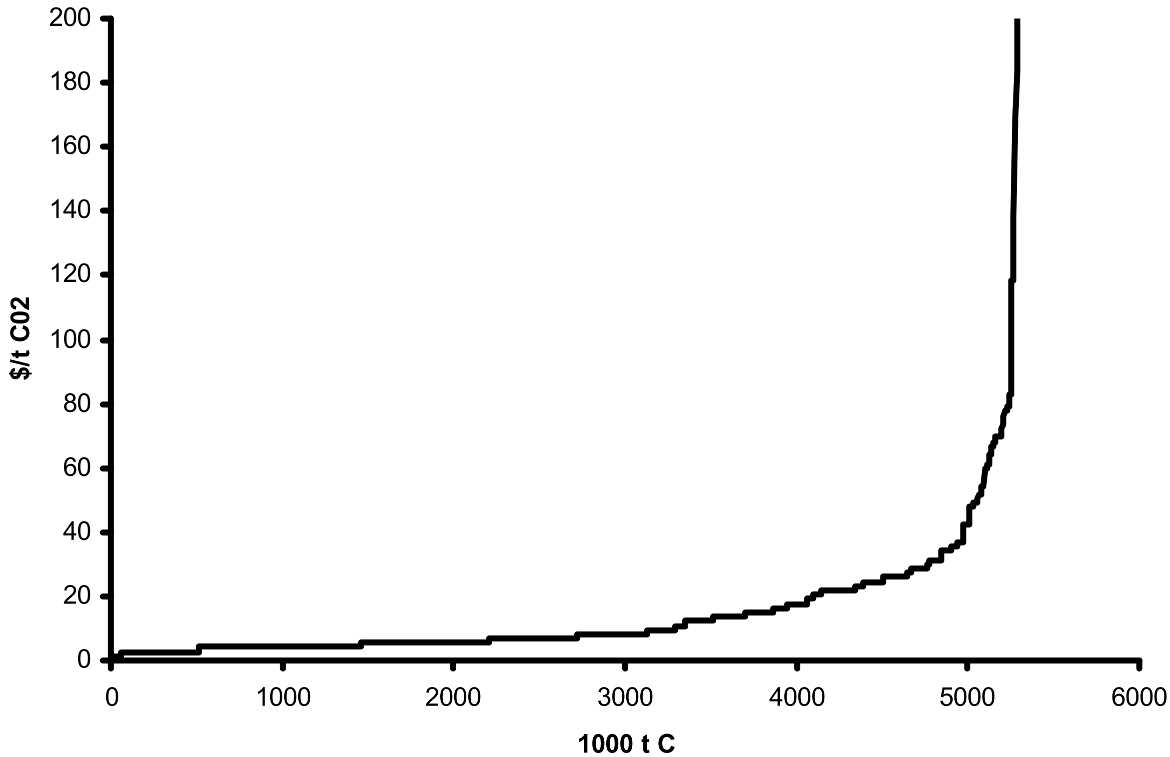


Figure 17: Marginal costs of sequestration through aging softwood forests Maine, New Hampshire, New York, and Vermont.

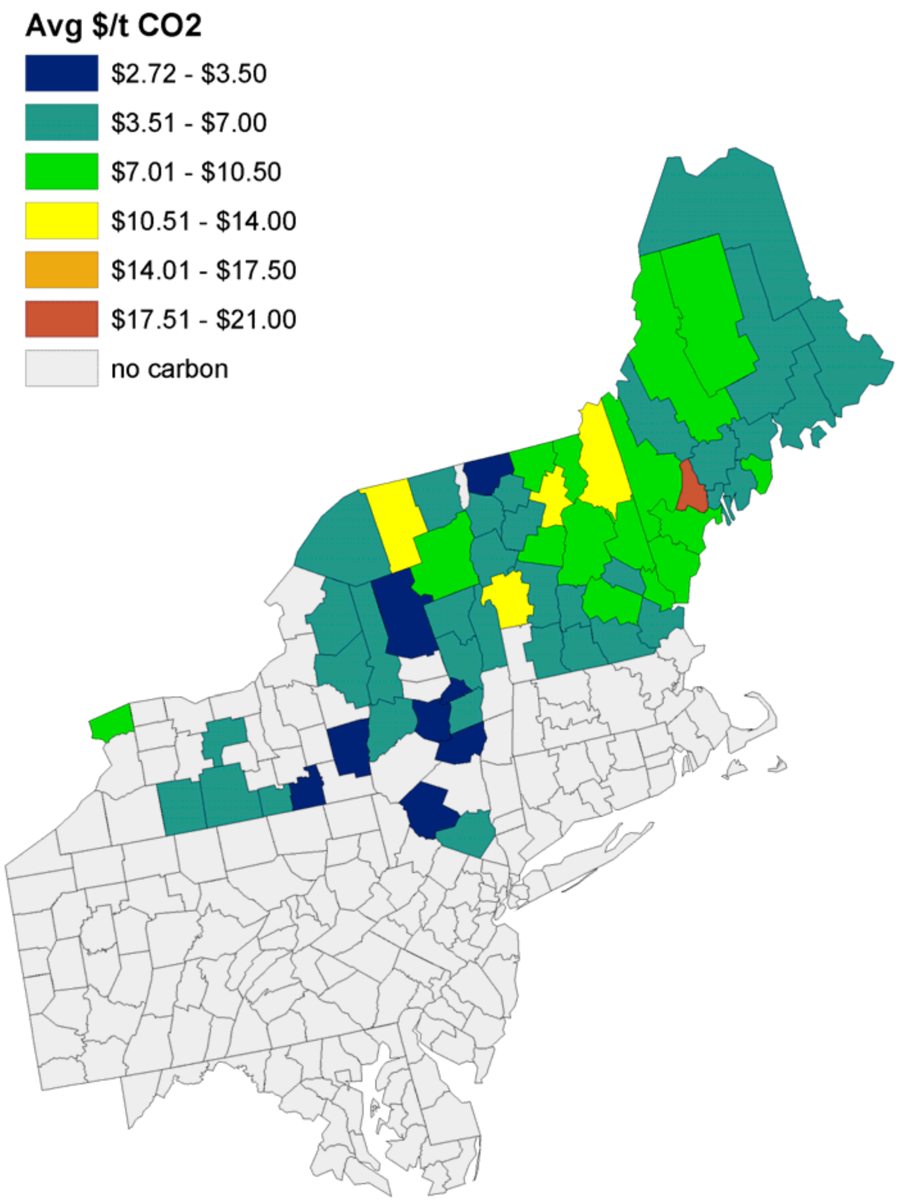


Figure 18: Average cost per t CO2 for sequestering carbon in 5 year rotation extensions in softwoods of four Northeast states (Maine, New Hampshire, New York, and Vermont).

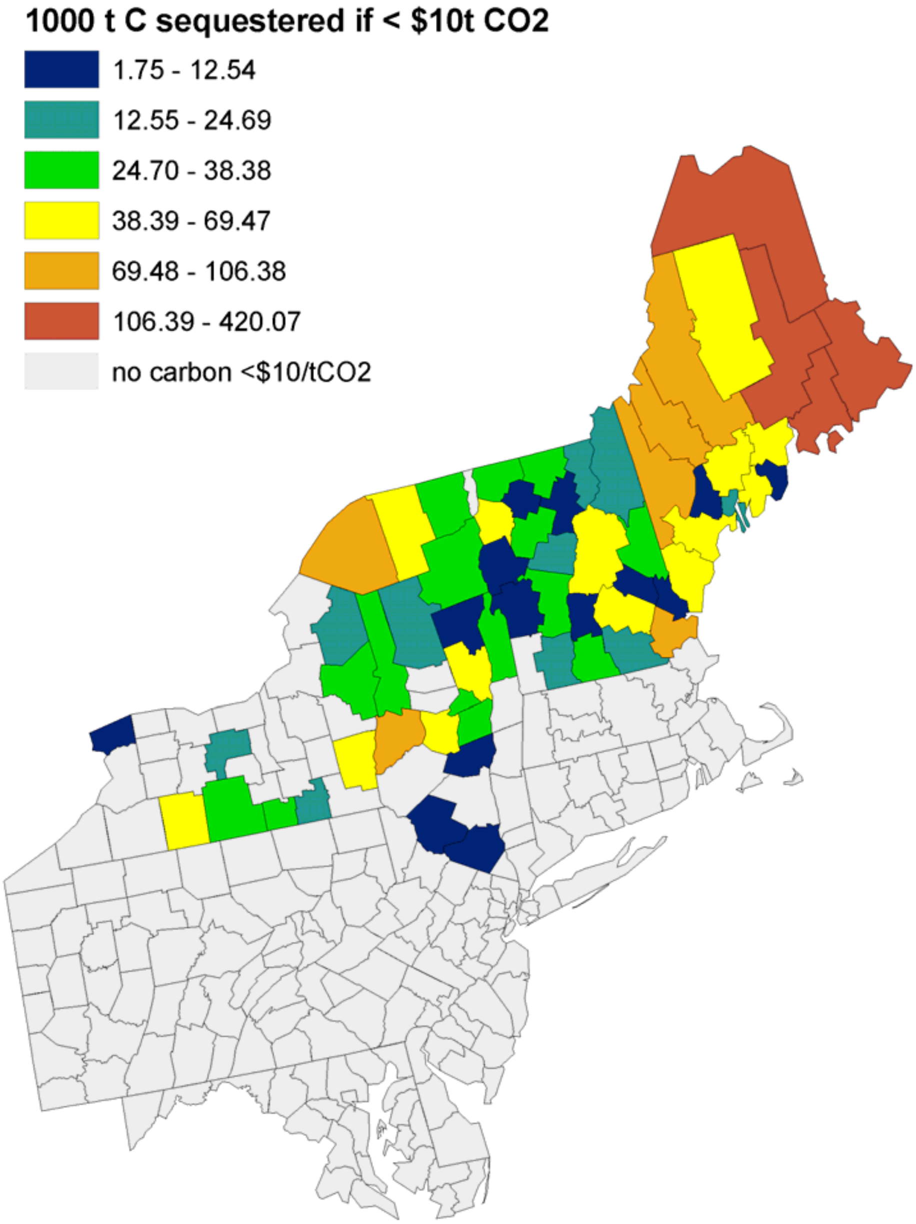

1000 t C sequestered if < $10t CO2
1.75 - 12.54
12.55 - 24.69
24.70 - 38.38
38.39 - 69.47
69.48 - 106.38
106.39 - 420.07
no carbon <$10/tCO2

Figure 19: Total carbon potentially sequestered by county for aging forests 5 years where marginal costs are <$5/t CO2. Four Northeast states only (Maine, New Hampshire, New York, Vermont).

Sensitivity Analysis

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

Table 16: 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. $/tCO2
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*

Lower discount rates, as expected, increase carbon sequestration costs (Table 16). 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 17). 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 17: 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.

	1000 tons C	Million $	Avg. $/tCO2
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*

CONCLUSIONS

Interesting and practical findings have resulted from the work accomplished in the April to June 2006 quarter.

Under Task 1 work in Brazil has resulted in the demonstration of more cost effective measurement techniques utilizing vegetation and soil stratification, the determination that reducing the minimum diameter for tree measurement would not improve stock estimates but would increase overall measurement costs, and the finding that biomass in coastal Atlantic Rainforest likely falls between moist and wet allometric equations.

Under Task 2 an equation of LIDAR-derived height to field-measured aboveground biomass was derived. It was found that LIDAR estimated the biomass of the field plots to a high level of statistical significance.

Under Task 3 a comparison was made of GEOMOD and simple land use change detection, resulting in GEOMOD indicating that there are fewer areas predicted to be deforested in the study areas compared to the results from simple land use change detection.

Also under Task 3 the baseline estimates of terrestrial carbon storage on the Albemarle Peninsula in the face of sea level rise were estimated, with estimates ranging from 7 to 114 Tg of carbon (25.6 to 418 Tg of CO_2 equivalent).

Under Task 5, a draft of Part III examining the potential of afforestation on cropland and pasture lands in the Northeast was completed. Preliminary results indicate that the Northeast region has variable amounts of available land for afforestation, with agricultural land covering 20% of the land area. The nature of forest growth causes carbon dioxide accumulation to be minimal in the first 10 years. Over longer time periods, carbon accumulation through afforestation is substantial. The costs associated with changing land use management to afforestation are large in the region due to the high opportunity costs, high estimated conversion costs, and slower carbon accumulation. However, a large amount of pasture land in many states could be available at relatively lower prices and provides the best opportunity for economically attractive afforestation.

Also under Task 5, a draft of Part IV examining the opportunities for improving carbon storage and management on forest lands in the Northeast was completed. Improved stocking of under-stocked stands and extending the rotation age in softwood forests were explored in detail. Preliminary results indicate that there is a large range of very low cost carbon potential in under-stocked stands and there are potentially substantial opportunities for increasing carbon sequestration through aging in softwood forest, with lower cost opportunities existing with 5-year rotation extensions.

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