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

Quarterly Report
October - December 2006

Principal Authors:
Bill Stanley
Sandra Brown
Patrick Gonzalez
Brent Sohngen
Neil Sampson
Mark Anderson
Miguel Calmon
Sean Grimland
Zoe Kant
Dan Morse
Sarah Woodhouse Murdock
Arlene Olivero
Tim Pearson
Sarah Walker
Jon Winsten
Chris Zganjar

Date Issued: January 2007

Cooperative Agreement No. DE-FC-26-01NT41151

Submitting Organization:
The Nature Conservancy
4245 North Fairfax Drive
Suite 100
Arlington, Virginia 22203

Primary Subrecipients:
Winrock International
1611 North Kent Street
Arlington, VA 22209

DISCLAIMER

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 October 1st and December 31st 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.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

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

Under task 2 Colorado State University presented results at the Annual Meeting of the American Geophysical Union on the error propagation analysis used to quantify the uncertainty of forest carbon estimates in Tahoe National Forest and Garcia River forest, California.

Under Task 3 data collection was initiated in November 2006 for a baseline forest cover change analysis for the Cordillera Central of the Dominican Republic. Anecdotal information on land use trends and the motivations (national policy, customs) driving them was collected in consultation with representatives of FORESTA, the Dominican forest service. Furthermore, maps of the areas of influence of existing rural development projects promoting reforestation were acquired to further delimit spatially the influence of these ongoing initiatives to trends in forest cover change. Forest carbon stock data was additionally collected in the field to eventually assign biomass carbon estimates to coarse forest cover types identified from the satellite imagery consulted in the forest area change analysis.

For the Northeast study (Task 5), this quarterly report contains an update on the status of Part 4 titled, “Opportunities for Improving Carbon Storage and Management on Forest Lands,” which was previously submitted but is now undergoing revisions. This section examines the potential to increase carbon sequestration in Northeastern forests through alternative forestry management activities. The activities investigated include extending rotation ages of softwood forests beyond their economically optimal rotation age, harvesting and re-stocking currently under-stocked forests, conserving forests in riparian zones, and additional thinning. The first three of the analyses are conducted across the region, while the final analysis (the potential for increasing thinning to enhance carbon sequestration) is done as a case study. This report also contains work completed on Part 5, “Environmental Co-Benefits of Carbon Sequestration Opportunities.” Part 5 analyzes the environmental co-benefits, which could be achieved in the study region through efforts to increase terrestrial carbon sequestration. Analysis is completed on the environmental co-benefits of afforestation activities in identified priority conservation areas. Analysis remains to be done on restocking of understocked forests on identified priority conservation areas and is awaiting revised data on this activity which in process of being completed. Finally, this report contains work completed to date on Part 6, “Comparison of Opportunities,” which compares all the various sequestration opportunities analyzed in the previous parts of the report and summarizes opportunities based on quantity and cost. A final Part 7 of the report is also planned. Part 7 will be a summary for decision makers and will consist of a brief concise summary of the entire report. This section is meant to be presented in non technical terms and be easily understood by a broad audience of stakeholders interested in the findings of the report.

In addition to drafting sections of the report, we held our final stakeholder meetings on December 5th in Durham, NH and on December 6th in Newark, NJ. Approximately 25 people attended the meeting in Durham, NH and 12 attended the meeting in Newark, NJ. The goal of the final stakeholder meetings was to present the findings of the report and to allow time for questions, discussions and comment. The discussion and feedback was significant. Due to questions posed at these meetings, revisions are being made to the restocking of understocked forests covered in Part 4 of the report.

EXPERIMENTAL

Task 1 Carbon Inventory Advancements

Carbon Inventories can be enhanced 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.

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

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.

Madre de las Aguas, Dominican Republic Baseline Study

Data collection was initiated in November 2006 for a baseline forest cover change analysis for the Cordillera Central of the Dominican Republic. The region encompasses the Madre de las Aguas project currently in development. The altitude range of 500 to 1,500 meters above sea level was chosen to frame the geographic scope of the analysis, representing a more or less homogeneous ecoregion of Hispaniola and all within the political confines of the Dominican Republic.

The Nature Conservancy has previously classified from ground-truthing a time series of satellite imagery of the Cordillera Central to be used in the forest change analysis. Anecdotal information on land use trends and the motivations (national policy, customs) driving them was collected in consultation with representatives of FORESTA, the Dominican forest service. Furthermore, maps of the areas of influence of existing rural development projects promoting reforestation were acquired to further delimit spatially the influence of these ongoing initiatives to trends in forest cover change.

Forest carbon stock data was additionally collected to eventually assign biomass carbon estimates to coarse forest cover types identified from the satellite imagery consulted in the forest area change analysis. Forest measurements collected from sample plots in the field were acquired from an ongoing biomass quantification activity coordinated by The Nature Conservancy, totaling 22 plots from broadleaf and pine forest ecosystems. Local forest inventory data to compliment the measurements above were generously provided by representatives of FORESTA.

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

"Part 4: Opportunities for Improving Carbon Storage and Management on Forest Lands,"
After further discussions with stakeholders and US Forest Service, it was determined that an adjustment needed to be made in the analysis on the restocking of under-stocked forest stands. These revisions are currently being finalized and will result in the reduction, from analysis reported in the previous quarterly report, of the area of land available and the maximum potential quantity of carbon sequestered via this management option.

"Part 5, Environmental Co-Benefits of Carbon Sequestration Opportunities"
The Nature Conservancy (the Conservancy) identified land in 11 states in the Northeast US where the potential exists to enhance conservation through afforestation activities on pasture and croplands. To carry out this analysis we have used conservation prioritizations developed by the Conservancy. We analyzed potential afforestation activities in forest habitat and buffer areas as well as for buffer areas to streams and watersheds that were selected for their conservation value.

The Nature Conservancy has prioritized the conservation status of forest habitat in the Northeast into a system of forest matrix blocks selected for their size, natural land cover, and diversity of features, both biotic and abiotic. The conservation portfolio of forest matrix blocks was developed to identify those places that are the most critical to conserve. The Nature Conservancy's process of identifying priority conservation areas is a thorough process involving the analysis of extensive biotic and abiotic features as well as threats to the landscape. Figure 1 shows the current forest matrix block map that was used to carry out the co-benefits analysis for this part of the report. The potential to enhance conservation through afforestation was quantified based on the forest block area plus a 10 km buffer around the forest block.

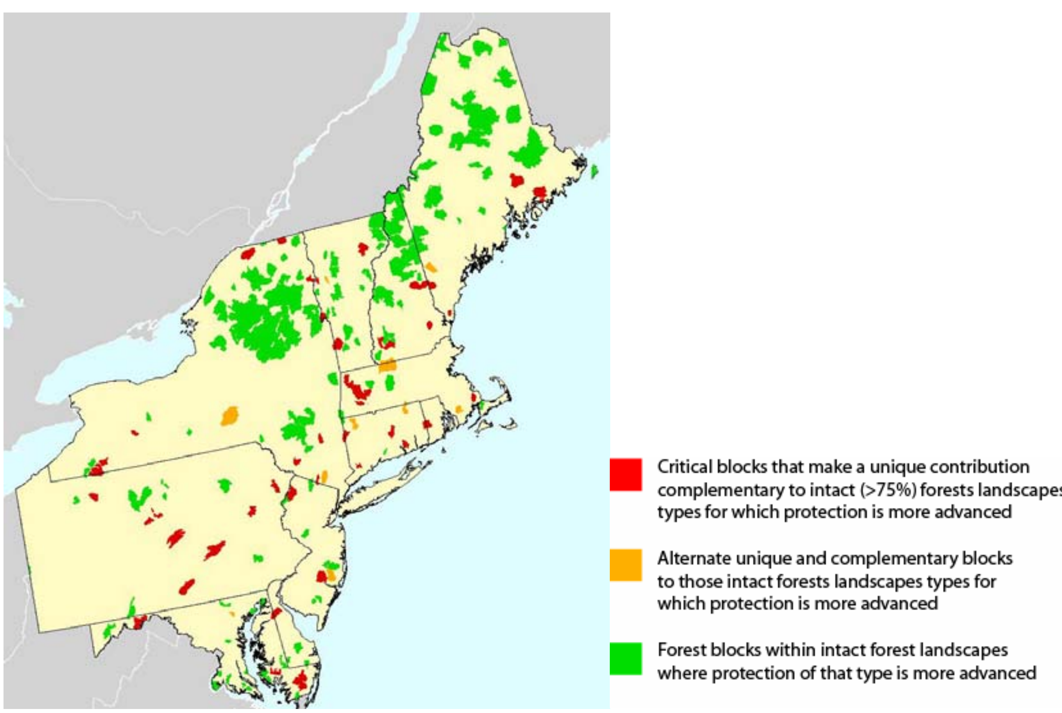

Figure 1. Eastern United States Forest Conservation Regions Matrix Blocks

Freshwater is a critical resource to terrestrial species and ecosystems in the Northeast. With hundreds of millions of miles of streams in the region, it is unlikely that we can protect them all. Thus it becomes important to identify those stream systems that, if protected, will have the greatest positive impact on maintaining biodiversity throughout the region.

By converting the cropland and pasture lands in the riparian and watershed buffer areas to trees, numerous benefits are known to occur. Natural vegetated buffers along streams and water bodies provide a suite of benefits to aquatic systems such as bank stabilization, water temperature moderation, nitrogen removal, sediment removal, flood mitigation, and wildlife habitat. Natural cover throughout the watershed also provides important wildlife habitat and contributes to maintaining intact hydrologic, sediment, and nutrient regimes in streams and lakes. Figure 2 shows the priority stream map that was used to carry out the co-benefits analysis for this part of the report.

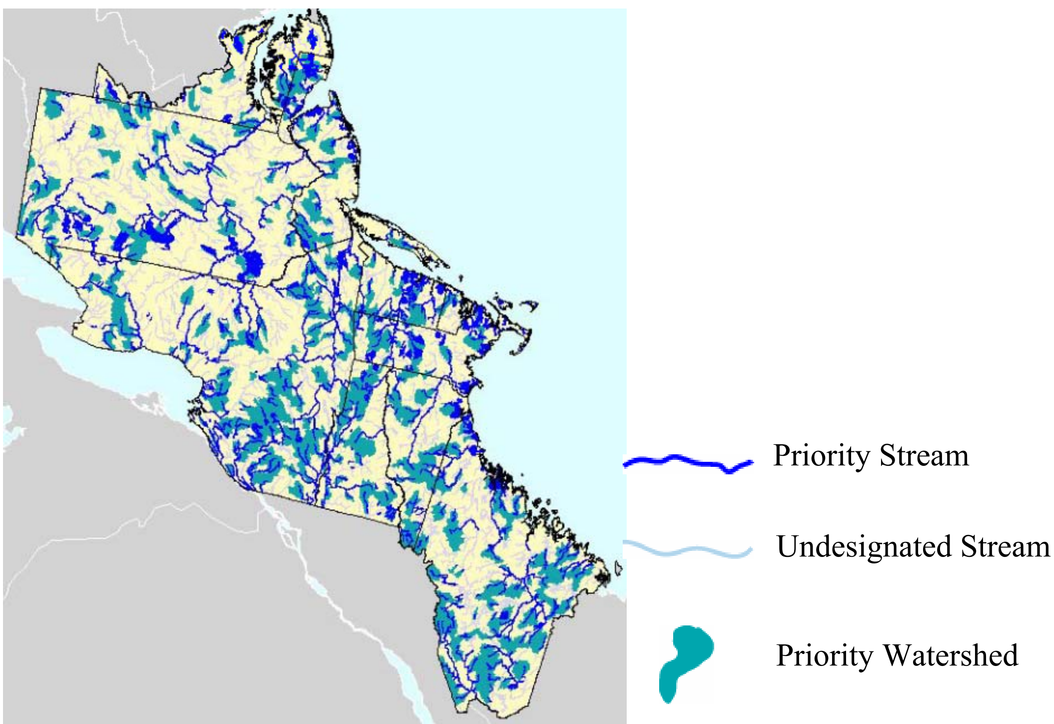

Figure 2. Eastern United States Freshwater Biodiversity Areas

The Nature Conservancy ranked the conservation value of forest and aquatic assemblages within study area and prioritized their level of ecological importance and threat. We then identified the amount of crop and pasture lands in each of the priority ranked conservation areas to demonstrate how afforestation activities can result in a net increase of potential habitat thereby enhancing the conservation value of the lands through carbon sequestration activities.

We used spatial data on the quantity and cost of carbon from afforestation to determine the amount and cost of carbon in areas that yield a conservation and biodiversity benefit.

For the purposes of this report, we are assuming all afforestation efforts will result in forest habitat, suitable to effectively supplement existing forest matrix blocks and areas of hydrologic priority. We intersected cropland and pasture land spatial data with spatial data representing Conservancy derived forest matrix blocks with a surrounding 10k buffer area and priority aquatic systems with a 200 meter (100 meter on each side) buffer. These intersected crop and pastured polygon areas were considered viable land units on which afforestation activities would have a high degree of conservation benefit. Using county scale per acre totals of tons CO2e, we calculated the total potential tons of CO2e that could be gained on all crop and pasture land within forest matrix blocks and priority aquatic areas as well as the associated costs. The carbon accumulation measurements were calculated for 10, 20, and 40 years of growth.

"Part 6, Comparison of Opportunities"
Before initiating a particular sequestration strategy, each land management option should be evaluated in comparison to all other strategies. This part of the report summarizes the potential CO_2e gain, available land area, and marginal costs of each of the land management strategies and creates tables and figures that compare the various strategies. This objective approach allows for an unbiased presentation of the potentials.

The CO_2e potential of afforestation of crop and grazing lands is evaluated against converting to no-till, permanent vegetation, or moving to biomass energy crops. On forest lands, the CO_2e potential of extending current forestry rotations, restocking understocked stands, and riparian buffers is compared with each other and, where appropriate, with land management options on current agricultural lands. Each of the land management options is compared in total and spatially across the region. Potential sequestration and associated costs vary substantially spatially, and therefore by comparing each option on a county level, the most cost effective approach for a region can be elucidated. In the proceeding sections of the report, land management options on current agricultural lands were examined at various points in time, however, in the presented comparison, only data for a 20 year period are shown. Due to the nature of forestry land management, data presented are assuming a long term land management alteration.

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 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

A two-stage 1000-iteration Monte Carlo error propagation analysis produced confidence intervals of calculated biomass that accounted for field measurement error and statistical uncertainty in inventory sampling, species-specific allometric equations, the LIDAR biomass regression equation, and landscape variation. For the 4722 ha of forest in the Tahoe National Forest research area, average aboveground biomass was 320 t ha^{-1} with a standard deviation of only 0.6 t ha^{-1} (Sherrill et al. 2006).

Task 4 Third-Party Technical Advisory Panel Meetings

The final TAP meeting has been scheduled for April 3-4, 2007 in The Nature Conservancy's Worldwide Office in Arlington, Virginia. Invitations will be sent out in February 2007.

Task 5 New Project Feasibility Studies

Northeast Study

"Part 5, Environmental Co-Benefits of Carbon Sequestration Opportunities"
The following is a summary of the results and discussion completed on the analysis of environmental co-benefits of afforestation activities. Additional tables and figures will be included in the actual report. Co-benefits analysis of restocking understocked forests is forth coming.

Table 1 summarizes the total tons CO2e sequestered for each ranked conservation priority system through afforestation of both cropland and pasture land.

	Carbon Sequestration Potential of Cropland and Pasture Land Depicted by Habitat Type and Priority Ranking (tons CO2e at 20yrs)									
	FM 1	FM 2	FM 3	FM 4	FM Total	SB 1	SB 2	SB 3	SB 4	SB Total
CT	153,832	4,128,125	1,953,475	800,141	7,035,574	311,426	4,087,376	2,752	0	4,401,553
DE	1,897,005	1,269,756	0	9,778,573	12,945,335	511,999	10,824,034	0	0	11,336,033
MA	54,760	1,822,153	1,933,971	2,184,364	5,995,249	424,809	4,329,672	12,524	0	4,767,006
MD	5,585,597	3,640,905	1,414,905	16,687,318	27,328,725	551,248	12,288,949	0	0	12,840,196
ME	0	2,667,129	766,873	9,694,258	13,128,260	382,442	7,005,693	93,469	35,878	7,517,483
NH	0	1,438,634	250,057	2,244,814	3,933,505	214,218	1,482,019	36,294	95,173	1,827,705
NJ	548	545,516	3,166	343,738	892,968	0	0	0	0	0
NY	977,782	12,168,681	5,119,687	31,982,776	50,248,926	78,439	909,583	2,491	0	990,514
PA	1,745,168	20,824,582	0	12,039,132	34,608,882	2,413,498	48,565,789	11,521	0	50,990,808
RI	0	241,318	15,921	0	257,239	1,767,868	42,341,608	92,422	0	44,201,898
VT	587,015	4,180,492	834,896	10,937,276	16,539,679	17,513	411,926	0	0	429,439
Total	11,001,708	52,927,293	12,292,951	96,692,391	172,914,341	6,673,459	132,246,649	251,474	131,051	139,302,633

FM= Forest matrix
1= priority ranking
SB = Stream buffer

Table 1. Carbon Sequestration Potential of Cropland and Pasture Land Depicted by Habitat Type and Priority Ranking (tons CO2e)

The following maps show the potential total tons of CO2e in each county for the areas of highest ranked priority of both forest conservation enhancement through afforestation of cropland (Figure 3a) and afforestation of pasture land (Figure 3b) in the study region.

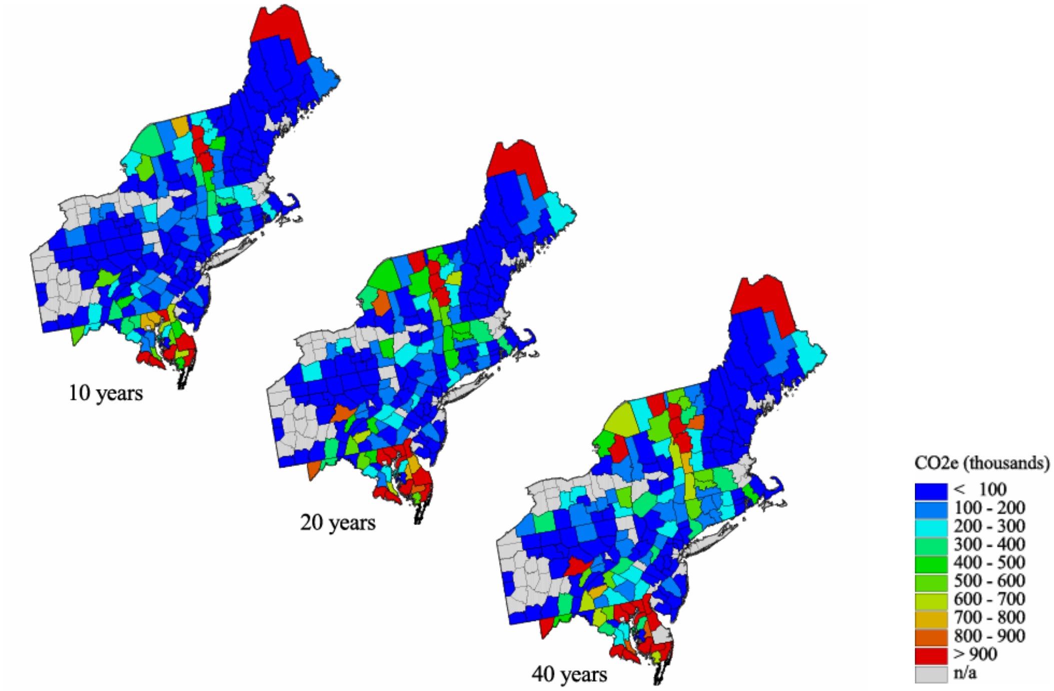

Figure 3a. Estimated CO2e in thousand tons sequestered in areas of highest ranked priority through afforestation of cropland in forest matrix areas reported by county

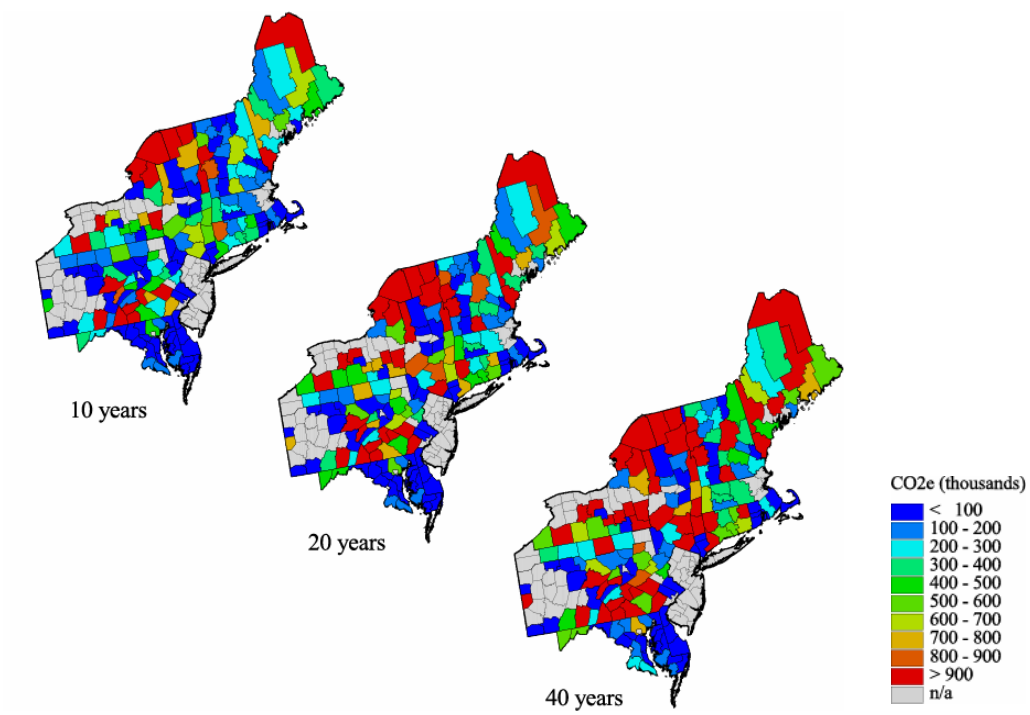

Figure 3b. Estimated CO2e in thousand tons sequestered in areas of highest ranked priority through afforestation of pasture land in forest matrix and buffer areas reported by county.

Tables 2a and 2b show the total potential tons of CO2e that could be sequestered through afforestation of cropland and pasture land respectively at various costs: $7; $10; $20; $40; $50/ton CO2e. The various price points were determined by summing the potential CO2e of the counties with prices at or below the stated price level. Totals are reported for areas of highest ranked priority in both forest and aquatic conservation areas.

Table 2a.

Estimated Total Potential tons of CO2e From Afforestation of cropland						
	Forest Matrix			Stream Buffer		
	10 years	20 years	40 years	10 years	20 years	40 years
$7/ton CO2e	0	0	0	0	0	0
$10/ton CO2e	0	0	0	0	0	0
$20/ton CO2e	0	0	0	0	0	0
$40/ton CO2e	14000	21000	26000	13000	20000	24000
$50/ton CO2e	16000	73000	82000	14000	58000	65000

Table 2b.

Estimated Total Potential tons of CO2e From Afforestation of Pastureland						
	Forest Matrix			Stream Buffer		
	10 years	20 years	40 years	10 years	20 years	40 years
$7/ton CO2e	106000	3.2 mil	3.9 mil	2000	1.0 mil	1.3 mil
$10/ton CO2e	106000	3.2 mil	4.7 mil	2000	1.0 mil	1.7 mil
$20/ton CO2e	2.5 mil	4.2 mil	7.0 mil	850000	2.3 mil	4.3 mil
$40/ton CO2e	10.1 mil	33.4 mil	50.7 mil	6.6 mil	21.0 mil	31.2 mil
$50/ton CO2e	10.1 mil	50.4 mil	59.2 mil	17.7 mil	35.0 mil	44.0 mil

"Part 6, Comparison of Opportunities"

The following describes a summary of the results to date for this section of the report. A sampling of results is provided here to capture the how information is being summarized and compared. The report will contain additional figures and tables that are not included in this quarterly report. At this moment, Part 6 has not yet been completed due to some revisions taking place in Part 4 Forest Management as mentioned previously. Results from Part 5, the environmental co-benefits analysis, have not been included as well.

Altering the land management on croplands to afforestation has the potential to accumulate a large amount of carbon per unit land area through the growth of trees (Table 3). Changes in other carbon pools such as soil, litter, and deadwood were not included in the analysis but are expected to increase or not decline significantly over time (as in the case of soil carbon on grazing lands converted to afforestation). Estimated carbon emission reductions through the conversion to no-till or to permanent vegetation in the analysis include carbon emission changes through altered farming practices and soil carbon accumulation. As can be see, accumulation on a per unit area basis is small. Estimates of the emission reductions associated with converting to biomass energy production include the growth of the biomass, the displacement of fossil fuels, and the increase belowground carbon. Production of biomass energy has high carbon emission reduction potential per unit area, however, due to the scarcity of data on biomass production potential, the applicability of this estimate across the region is not well known.

Table 3: Area weighted average carbon emission reduction equivalence (t CO_2e/acre) for 20 year time period for each land management option on agricultural lands

	Afforestation t CO_2e/acre	No-till	Permanent Vegetation	Biomass Energy
Connecticut	60	11	15	201
Delaware	69	9	12	201
Maine	46	16	19	201
Maryland	52	9	12	201
Massachusetts	65	15	18	201
New Hampshire	58	16	22	201
New Jersey	53	9	9	201
New York	56	11	13	201
Pennsylvania	60	10	14	201
Rhode Island	52	10	14	201
Vermont	53	14	20	201
All States	57	11	14	201
Minimum	23	7	0	201
Maximum	74	19	27	201

The presented potential carbon dioxide emission reduction equivalence per unit area can then be used to estimate the amount of land needed for a certain level of CO_2e (Table 4). Because the carbon sequestered per unit area for afforestation and biomass energy production is relatively high, the area of land needed to result in certain t CO_2e is small compared to other land management styles. Altering forest lands requires the most land to reach a given t CO_2e.

Table 4: Estimated area of land required to result in a given amount of CO_2e emission reductions for each land management option

	Agricultural Lands				Forest Lands	
ton CO_2e	Afforestation	No-till	Permanent Vegetation	Biomass Energy	Restocking Understocked Stands	Extending Rotation Age
	10 years - in acres					
10,000 t	327	2,206	1,490	48	1,740	3,741
50,000 t	1,635	11,028	7,450	240	14,680	8,637
100,000 t	3,270	22,056	14,900	480	20,320	14,690
1 million t	32,700	220,563	148,998	4,804	157,310	116,372
	20 years - in acres					
10,000 t	177	1,103	749	24	12,300	183,808
50,000 t	885	5,514	3,747	118	49,630	247,959
100,000 t	1,770	11,028	7,495	235	66,220	283,178
1 million t	17,695	110,281	74,946	2,353	359,520	514,521
	40 years - in acres					
10,000 t	100	N/A	N/A	12	1,980	79,020
50,000 t	498	N/A	N/A	61	12,300	79,020
100,000 t	996	N/A	N/A	123	12,300	96,460
1 million t	9,962	N/A	N/A	1,227	66,220	790,490

The maximum potential estimated CO_2e emission reductions for the region through afforestation or biomass energy production is substantial, due to both the high sequestration per unit area and the large area of agricultural land. If all the agricultural land in the region was afforested, the potential estimated CO_2e sequestered over 20 years would equal 17% of the 2005 greenhouse gas emissions of the United States (Energy Information Administration, DOE 2006). The maximum potentials are significantly lower for other land management options. A scenario in which all agricultural land or forest land is converted to one land management strategy is highly unlikely, and so the total possible maximum is presented only to illustrate the management style's overall maximum capacity. Because afforestation has the greatest per unit area potential (if biomass energy is excluded), afforestation is the land management option with the largest potential within each county as well (Figure 4).

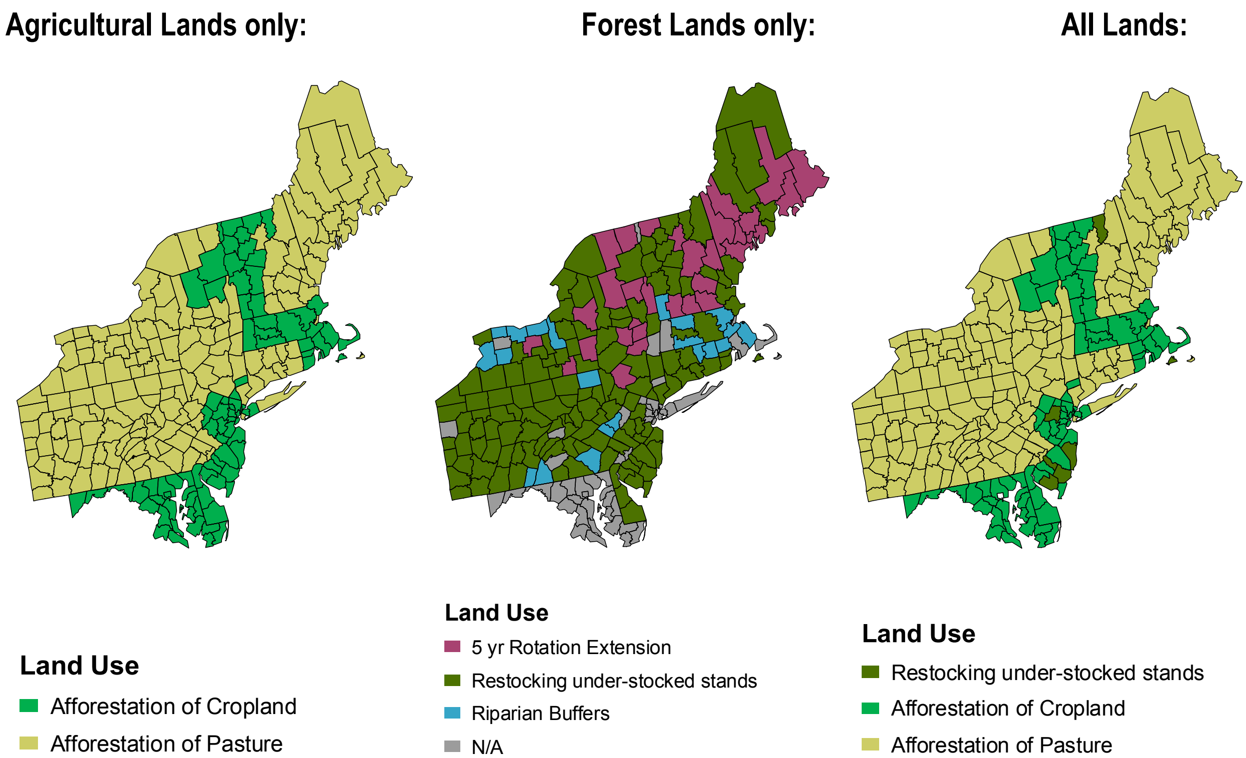

Figure 4: Land management option with largest potential t CO_2e in a county

Assuming 20 year period on agricultural lands, and permanent land management change in forest lands

Although afforestation and biomass energy produce the greatest quantity of t CO_2e, they are not the lowest land management strategy with the lowest marginal costs. Although the costs vary substantially by county, restocking understocked forest stands and forest rotation extension both provide the option with the lowest overall marginal costs (Figure 5). As a reminder, the analysis on extending rotations only took place in Maine, New Hampshire, New York, and Vermont. Because the land use activity does not need to alter, converting to no-till agricultural, on average, presents the management type with the lowest marginal costs on agricultural lands. For some counties in the more southeasternly area, conversion to permanent vegetation is the most cost effective management style.

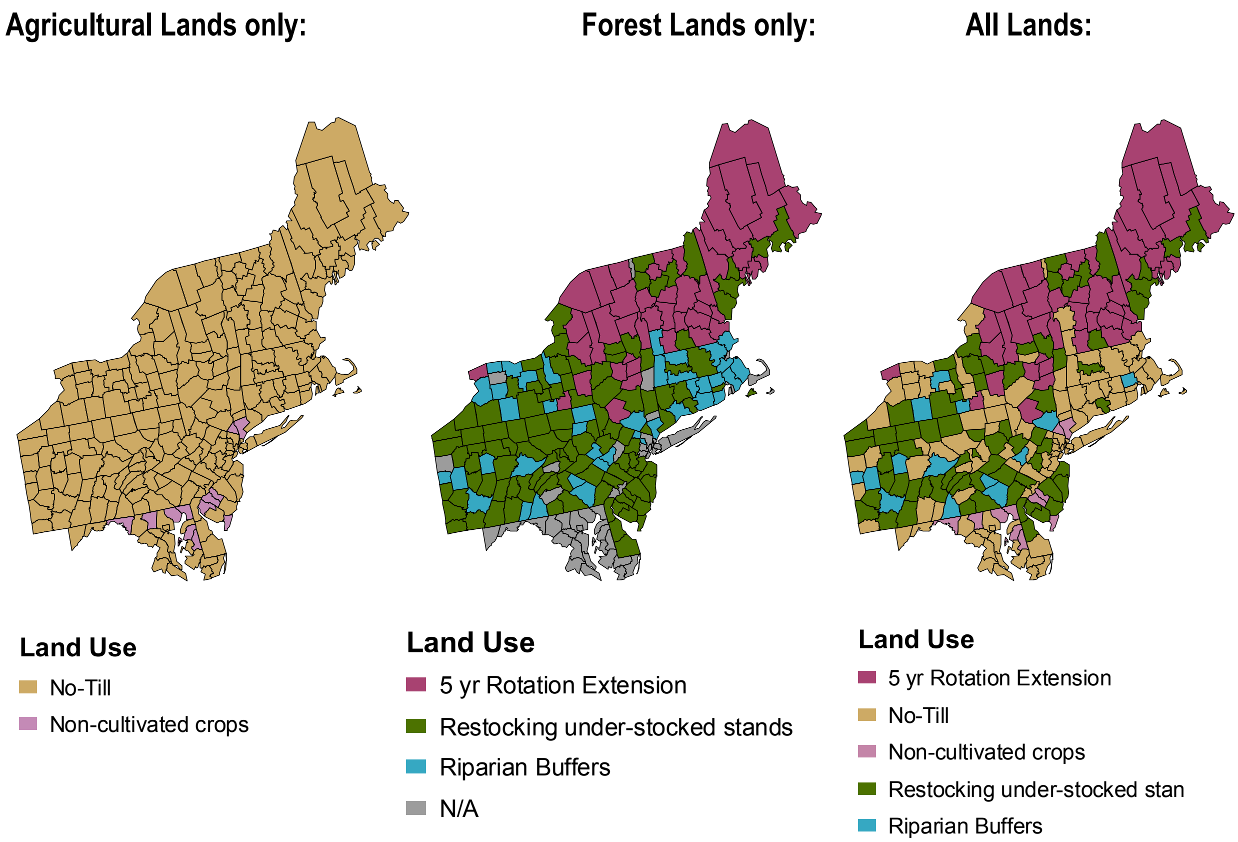

Figure 5: Land management option with lowest marginal cost (\$/ton CO_2e)

Assuming 20 year period on agricultural lands, and permanent land management change in forest lands

At specified price points, the maximum amount of land available and the total potential t CO_2e resulting from a land management strategy can be calculated (Table 5). As a result of the high marginal costs, very little area is available or potential CO_2e sequestered for afforestation until higher prices levels. However, conversion to permanent vegetation and all forest management options are economically attractive land management strategies on some lands even at prices as low as \$7/t CO_2e.

Table 5: Summary of potential area and amount of emission reductions available at various price points for all land management options

Assuming 20 year period on agricultural lands, and permanent land management change in forest lands

	Afforestation		Crop Management			Forest Management		
	Cropland	Pasture	No-till	Permanent Vegetation	Biomass Energy	Restocking Understocked Stands	5 yr Rotation Extension	Riparian Buffers
	potential t CO_2e							
< $7/t CO_2e		8 million		6.6 million		tbd	8.4 million	137,000
< $10/t CO_2e		8 million	1.2 million	6.6 million	6.9 million	tbd	11 million	143,000
< $20/t CO_2e		21 million	32 million	7.6 million	9.7 million	tbd	11.6 million	201,000
< $40/t CO_2e	116,000	215 million	33 million	13 million	1.4 billion	tbd	11.8 million	489,000
	potential area (acres)							
< $7/t CO_2e		169,000		550,000		tbd	389,000	104,000
< $10/t CO_2e		169,000	110,000	550,000	35,000	tbd	524,000	109,000
< $20/t CO_2e		351,000	5.7 million	636,000	48,000	tbd	556,000	180,000
< $40/t CO_2e	2000	3.6 million	5.7 million	1 million	7 million	tbd	563,000	295,000

CONCLUSIONS

Interesting and practical findings have resulted from the work accomplished in the October to December 2006 quarter.

Under task 2 work in California, overall, this large-scale operational test showed that LIDAR is suitable for spatial estimation of forest carbon, although QuickBird is unsuitable under conditions of high shadows and steep topography. This research has provided data on forest species, tree density, biomass, and fuels to assist in the management of a priority natural resource conservation area. The network of permanent forest inventory plots will allow long-term studies of old-growth forest. The allometric relationships derived can be applied to the estimation of forest carbon in other California forests of similar species composition and structure. The research results also contribute to the Department of Energy National Energy Technology Laboratory goal to "develop instrumentation and protocols to accurately measure, monitor, and verify both carbon storage and the protection of human and ecosystem health."

Under task 3, the data collected in November 2006 will be applied in a forest cover change analysis of the Cordillera Central to be completed in April 2007.

Under task 5, Northeast Study, *"Part 5, Environmental Co-Benefits of Carbon Sequestration Opportunities",* as the analysis for all co-benefit opportunities has not yet been completed, conclusions are preliminary. Yet, presented here are some conclusions based on the work to date.

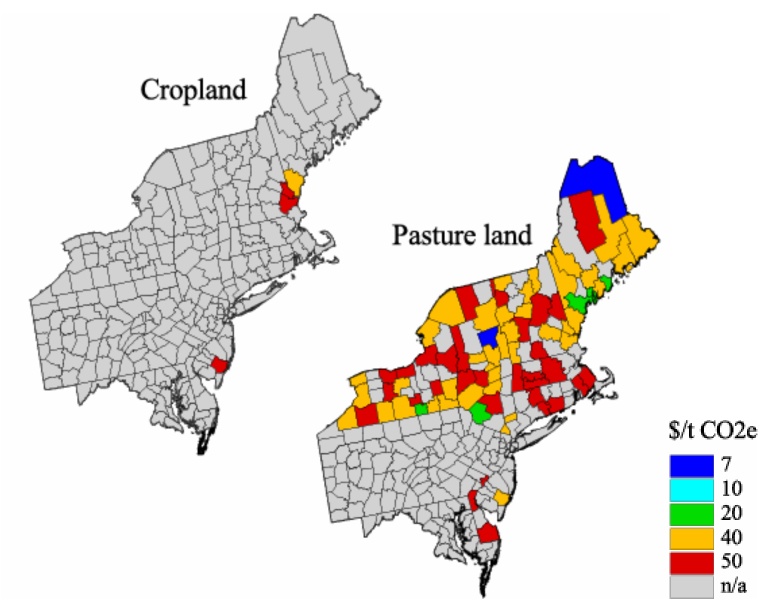

Figure 6. Counties where afforestation to benefit high priority forest conservation is economically attractive at lower prices of $/ton CO2e.

The northeast region has over 9 million acres of agriculture land available for afforestation that would directly enhance The Nature Conservancy's forest and hydrologic conservation efforts. We have presented a sample of the work completed to date. When planning afforestation activities with environmental co-benefits it is important to realize that forest growth causes carbon dioxide accumulation to be minimal in the first 10 years. However 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 providing the best opportunity for economically attractive afforestation to enhance conservation.

Also under task 5, Northeast Study, *"Part 6, Comparison of Opportunities", d*ue to some data still lacking from Part 4 of the study, the conclusions for this section have yet to be completed.

REFERENCES

Anderson, M. G., A. Olivero, C. Ferree, D. Morse, S. Khanna, in collaboration with the Eastern Region Conservation Measures Team. 2006. Conservation Status of the Northeastern U.S. and Maritime Canada. The Nature Conservancy.

Forest Inventory and Analysis Data Center, USDA Forest Service http://ncrs2.fs.fed.us/4801/fiadb/

Sherrill, K., M. Lefsky, J. Battles, K. Waring, and P. Gonzalez. 2006. An error propagation analysis of estimates of aboveground biomass estimates from Lidar remote sensing. Eos, Transactions, American Geophysical Union 87: Fall Meeting Supplement, Abstract B43D-07.

2006. *Emissions of Greenhouse Gases in the United States 2005.* Energy Information Administration, Office of Integrated Analysis and Forecasting, U.S. Department of Energy. Washington, DC.