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

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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 , 2005 and June 30th, 2005. 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 last quarter of 2005 saw considerable progress in many areas of the research being carried out under this cooperative agreement. A number of topical reports were completed, namely; the baseline study using the Forest Restoration Carbon Analysis in the Selva Central of Peru and the finding of the research on Multispectral 3-D Aerial Digital Imagery (M3DADI) and its capacity to estimate carbon stocks in the closed canopy forest of Belize was completed. The completion of all the topical reports on M3DADI by Winrock International also allowed the topical report comparing the cost of carbon estimates from M3DADI and from ground inventories to be completed. Although automated delineation of crowns is not possible currently using the M3DADI imagery, the use of M3DADI still proved cheaper that traditional ground inventory approaches. Costs differentials between the two approaches varied between field location, vegetation cover and conditions.

Work in California on both field inventories and analysis of LIDAR and Quickbird imagery is moving along well. Results of on ground field inventories in the North Yuba River area and Tahoe National Forest are now being used to develop regression equations as a function of height and a function of crown diameter to calculate biomass density for Quickbird and LIDAR analyses. Work on parts one to four of the North East Feasibility Study are underway. Chapter one characterizing the North East Region was completed by The Sampson Group and reviewed by the project team. It has now been released to stakeholder for their review. Chapter 2 is nearing completion by The Sampson Group. Both Chapters 3 and 4 which are being led by Winrock International are in their data collection/ analysis phases.

Arrangements for the Technical Advisory Panel proceed as planned with a number of leading experts coming to give presentation. The meeting will be held in The Nature Conservancy head quarters in Arlington, Virginia on March 6th and 7th 2006.

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. Some calibration of Laser Induced Breakdown Spectroscopy (LIBS) calibration has also been carried out using soils collected during TNC research in Indiana and in association with a workshop in Brazil.

Task 2 Emerging technologies for remote sensing of terrestrial carbon

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. We will test 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.

We will employ 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.

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

We are establishing 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, we used 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, we used 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, we will directly calculate aboveground biomass for each analysis area. In addition, we 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. We 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. We also plan 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. We are 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 we 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. We 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.

We 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 us to estimate the biomass of each tree and calculate aboveground carbon per unit area. We 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 (Figure 1) 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.

We are using orthorectified QuickBird scenes with a geographic location root mean square error of 6.2 m. We are developing automated programs that combine iterative local maxima and minima filtering with analysis of extracted ordinate data to detect crown perimeters and crown diameters. We 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 us 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 we 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

We will develop and refine 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.

Baseline work in Chile We are using the following data from previous work:

1. Allometric equations, temperate rainforest, Chile
2. Above- and belowground biomass in forest, woodland, and grassland, Decima Región, Chile
3. Land cover, Valdivia and Osorno Provinces, 1986, 1999
4. Projection of forest cover, five comunas, 2012

We are using the previous data and new data to conduct a Forest Restoration Carbon Analysis (FRCA) along the following steps:

1. Acquire Landsat scene for Path 233, Row 88 for February 1, 2002
2. Geographically register 2002 scene to the registered 1986 scene.
3. Delineate the ecological boundary of coastal temperate rainforest (bosque humido templado de la cordillera de la costa) using national land cover data. The area of analysis will be the section of coastal temperate rainforest between the Rio Calle Calle and the Rio Huevelhue.
4. Combine detailed forest types into a set of forest classes of similar ecology, botany, and biomass.
5. Conduct supervised classification of Landsat scenes into the defined forest classes.
6. Estimate 1988-2004 changes in forest cover and carbon
7. Develop biomass growth curves
8. Compile deforestation and reforestation factors:
    a. distance to non-forest
    b. distance to forest

c. land ownership (empresa = 1, non-empresa = 0)
d. distance to roads
e. distance to rivers
f. distance to population centers
g. elevation
h. slope
i. aspect

9. Conduct principal components analyses to determine weight of factors
10. Develop equations of deforestation and reforestation vs. factors
11. Calculate probability of deforestation and reforestation
12. Project future native forest cover
13. Estimate carbon storage due to proposed project

Baseline work in Peru The team from ProNaturaleza is measuring the diameter at a height of 1.3 m of all trees of in the plots where this diameter is greater than or equal to 10 cm. The team is identifying each measured tree to the lowest possible taxonomic level. The team is tagging each measured tree with an aluminum tags at a height of 1.4 m.

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) will gather 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.

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
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.

Task 6 Development of new project software screening tool

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

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

Tasks 1 and 2: Carbon Inventory Advancements and Remote Sensing for Carbon Analysis

California

The University of California team has applied 32 allometric equations developed for individual conifer and broadleaf tree species in Sierra Nevada and Cascade Mountain forests to the forest inventory data from 36 plots in the North Yuba River area of the Tahoe National Forest. Aboveground biomass of trees of diameter ≥ 19.5 cm at a height of 1.37 m ranges from 120 t ha^{-1} to 1200 t ha^{-1}; the mass of dead trees ranges from 0 to 160 t ha^{-1}; total aboveground mass ranges from 150 to 1300 t ha^{-1} (Table 1). The plots are 1000 m^2 circles.

We are developing regression equations of biomass as a function of height and biomass as a function of crown diameter to calculate biomass density from QuickBird and LIDAR data.

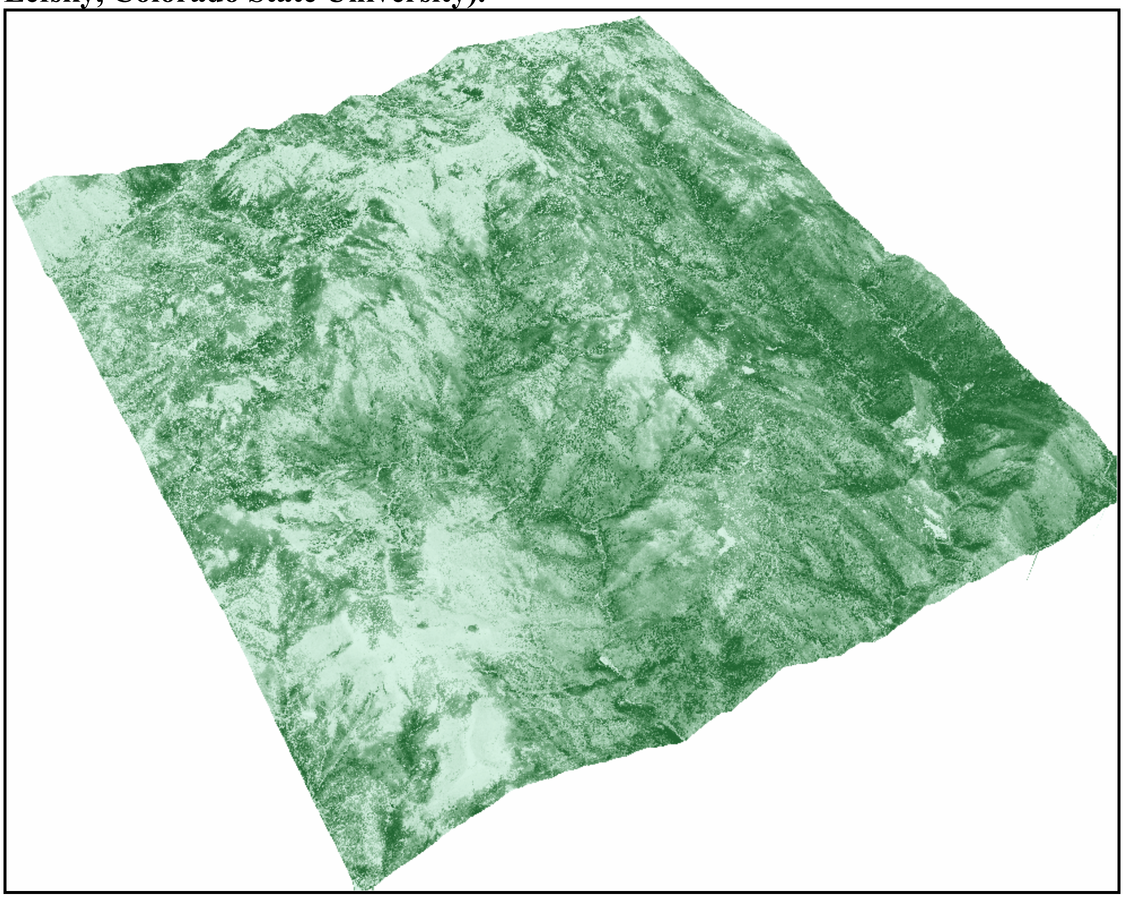
Table 1. Coordinates, biomass, and dead tree mass in 36 forest inventory plots in the North Yuba River area of the Tahoe National Forest (analysis J.J. Battles, K. Waring, UC Berkeley).

plot	N	E	live	dead	total	plot	N	E	live	dead	total
B4	4392252	684267	245	51	296	E5	4391000	688001	634	24	657
B5	4390998	684243	731	14	746	E6	4389751	688002	410	15	425
B6	4389895	684254	332	49	381	E7	4388504	688003	83	0	83
B7	4388504	684250	254	80	334	F3	4393524	689147	455	16	471
C2	4394636	685484	172	163	335	F4	4392261	689193	519	177	697
C3	4393508	685503	260	52	312	F5	4390997	689250	441	0	441
C4	4392249	685500	1247	97	1345	F6	4389220	689271	354	0	354
C5	4391001	685502	171	0	171	F7	4387939	689303	341	33	374
C6	4389747	685501	603	100	703	F8	4387289	689260	271	17	288
C7	4388506	685214	150	2	152	G2	4394677	690516	634	159	793
D2	4394713	686723	265	2	267	G3	4393500	690505	116	15	131
D3	4393497	686854	884	16	900	G4	4392182	690523	628	29	657
D4	4392251	686750	120	53	173	G5	4391006	690505	302	3	305
D5	4391014	687022	203	3	207	G6	4389745	690500	498	53	552
D6	4389745	686749	144	12	156	G7	4388501	690498	94	101	195
D7	4388495	686743	279	0	279	G8	4387286	690690	500	7	507
E3	4393664	688024	683	7	690	H4	4392246	691754	427	0	427
E4	4392248	687996	444	1	445	H5	4390996	691739	844	116	960

The Colorado State University team has analyzed all of the LIDAR data for the North Yuba River area, the Garcia River Forest, and the Mailliard Redwoods State Reserve. They have derived the ground level and the height of the canopy for each site. Preliminary results for the North Yuba River area (Figure 1) indicate canopy heights of up to 60 m, clustering along the river valleys and other low spots. After calibrating the LIDAR height data with a precisely-located and measured set of individual trees, the team will develop a spatial estimate of carbon for the entire area.

The team from Carnegie Institution of Washington and Stanford University have analyzed the QuickBord scene from the North Yuba River area and derived coordinates and tree crown polygons for over 65 000 individual trees. After calibrating the data with a precisely-located and measured set of individual trees, the team will develop a spatial estimate of carbon for the entire area separate from the LIDAR estimate.

Figure 1. LIDAR-derived digital elevation of the ground surface and the forest canopy across the North Yuba River area of the Tahoe National Forest. Area is approximately 30 km square. Canopy height ranges from 0 (white) to 60 m (dark green) (analysis M.A. Lefsky, Colorado State University).



The reports "Application of Multispectral 3-Dimensional Aerial Digital Imagery for Estimating Carbon Stocks in a Closed Tropical Forest" and "Cost Comparison of the M3DADI System and Conventional Field Methods for Monitoring Carbon Stocks in Forests" were reviewed by Zoë Kant, and final versions of these topical report was submitted to John Litynski. A brief summary of the reports is below:

"Application of Multispectral 3-Dimensional Aerial Digital Imagery for Estimating Carbon Stocks in a Closed Tropical Forest"

The M3DADI (Multispectral Three-Dimensional Aerial Digital Imagery) system offers the potential for the accurate, precise and cost effective measurement of carbon stocks. M3DADI collects high resolution overlapping stereo imagery (≤ 10 cm pixels) from which a virtual forest can be created where crown area and height of individual plants and trees can be measured.

The M3DADI system has been tested in highly heterogeneous savanna (Brown et al 2004, 2005) and homogeneous temperate forest (Pearson et al 2005). In the pine savanna of Belize the extreme heterogeneity creates the requirement for high intensity sampling and consequently very high on the ground measurement costs. For M3DADI the highest costs are fixed and the cost of analyzing high numbers of plots is low in comparison to measurements on the ground (Brown et al 2004, 2005). In the homogeneous temperate Delta National Forest in Mississippi, USA the flooded topography makes ground measurements highly problematic, time consuming, expensive and even dangerous, which are problems that are avoided by the use of aerial imagery (Pearson et al 2005). To date, however, there has not been a full test of the ability of M3DADI to determine carbon stocks in closed tropical forest such as exists in the Rio Bravo Conservation Management Area (RBCMA) in Belize, Central America (Figure 1).

The RBCMA is the site of a pilot carbon sequestration study under the United Nations Framework Convention on Climate Change (UNFCCC). In 1997 and 2000 Winrock International carried out on-the-ground measurements of carbon stocks (Brown et al 2001). To test the M3DADI method against the field methods, the goal is to analyze one-third the number of field plots and compare the results against the field measurements – a comparison is made of the means to determine if they overlap and also compare the coefficient of variation and use this to estimate the number of plots needed to be within the targeted precision level.

The image analysis revealed a mean carbon stock of 117.3 t C/ha ± 8.7 (mean ± 95 % confidence interval). This is composed of 109.1 t C/ha ± 8.9 in broadleaf trees and 8.2 t C/ha ± 4.6 in palm trees. The 95 % confidence interval for the total stock is equal to just 7.4 % of the mean.

Abstract: "Cost Comparison of the M3DADI System and Conventional Field Methods for Monitoring Carbon Stocks in Forests"

Given the interest in implementing land-use change and forestry projects for mitigating carbon dioxide emissions, there is potentially a large demand for a system to measure carbon stocks accurately and precisely in a cost-effective manner. To date most methods for measuring carbon stocks in forests accurately and to targeted levels of precision rely of standard field methods. Although the use of standard field techniques is not an expensive operation per se ($4-8/ha for a 1,000 ha tract of land; Mooney et al., 2004), given the potentially large number of forest-based activities that could be implemented in the US, any savings in cost of measuring and monitoring carbon in forests would be advantageous to all stakeholders.

A potential way of reducing costs of measuring the carbon stocks of forests is to collect the key data remotely. Winrock team has designed such a system (a multispectral three-dimensional aerial digital imagery system—M3DADI) that collects high-resolution overlapping stereo imagery (≤ 10 cm pixels) from which we can distinguish individual trees or shrubs. The M3DADI system has been applied to a pine savanna in Belize, a tropical broadleaf forest in Belize, and temperate bottomland forest in the Delta National Forest, US. In each of these

settings, the carbon stocks in trees were measured using both the M3DADI system and conventional field approaches. In this report, we report on the comparison of the costs for monitoring these forests using the M3DADI and field approaches. We collected data only for the time (in person-hours) involved in each of the various steps in preparing, acquiring, interpreting, and entering the data into spreadsheets for the final step in the analysis. The overall goal of this task is to compare the total person-hours needed for both approaches at the three sites to collect the same set of data to achieve a 95% confidence interval (CI) of ±8% of the mean based on the sampling error only.

In all three study sites, the time cost for the field approach is about 2.5 to 3.5 times longer than for the M3DADI approach to achieve the same precision level. The overall time involved in the data-collection preparation phase using the M3DADI approach represented a larger percent of the total time (20-80% of the total time) than the field approach (about 5% or less of the total time). The main reasons for the difference in time costs for the measurements of the plots are: the shorter time needed to measure an image plot versus a field plot and the lower coefficient of variation in carbon stocks among image plots versus field plots, resulting in fewer plots needed for the M3DADI approach to achieve a given precision target.

The image plots are presently interpreted and measured manually—a relatively time consuming step in the process. However, due to the recent advances in high-resolution imagery and sophisticated software, automating these processes may be possible. After reviewing the recent literature and testing four of the commercially available products, we conclude that the existing software products are unable to automatically delineate tree crowns and heights in these forest types.

Task 3: Baseline Method Development

Peru

We completed the milestone report (Gonzalez et al. 2006) of the Forest Restoration Carbon analysis in Selva Central:

Conversion of tropical forest to agricultural land and pasture has reduced forest extent and the provision of ecosystem services, including watershed protection, biodiversity conservation, and carbon sequestration. Forest conservation and reforestation can restore those ecosystem services. We have assessed forest species patterns, quantified deforestation and reforestation rates, and projected future baseline carbon emissions and removal in Amazon tropical rainforest at La Selva Central, Peru. The research area is a 4800 km^2 buffer zone around the *Parque Nacional Yanachaga-Chemillén, Bosque de Protección San Matías-San Carlos,* and the *Reserva Comunal Yanesha.* A planned project for the period 2006-2035 would conserve 4000 ha of forest in a proposed 7000 ha *Área de Conservación Municipale de Chontabamba* and establish 5600 ha of natural regeneration and 1400 ha of native species plantations, laid out in *fajas de enriquecimiento* (contour plantings), to reforest 7000 ha of agricultural land. Forest inventories of seven sites covering 22.6 ha in primary forest and 17 sites covering 16.5 ha in secondary forest measured 17 073 trees of diameter ≥ 10 cm. The 24 sites host trees of 512 species, 267 genera, and 69 families. We could not identify the family of 7% of the trees or the scientific species of 21% of the trees. Species richness is 346 in primary forest and 257 in the secondary forest. In primary forest, 90% of aboveground biomass resides in old-growth species. Conversely, in secondary forest, 66% of aboveground biomass rests in successional species. The density of trees of diameter ≥ 10 cm is 366 trees ha^{-1} in primary forest and 533 trees ha^{-1} in secondary forest, although the average diameter is 24 ± 15 cm in primary forest and 17 ± 8 cm in secondary forest. Using Amazon forest biomass equations and wood densities for 117 species, aboveground biomass is 240 ± 30 t ha^{-1} in the primary sites and 90 ± 10 t ha^{-1} in the secondary sites. Aboveground carbon density is 120 ± 15 t ha^{-1} in primary forest and 40 ± 5 t ha^{-1} in secondary forest. Forest stands in the secondary forest sites range in age from 10 to 42 y. Growth in biomass (t ha^{-1}) as a function of time (y) follows the relation: biomass = 4.09 - 0.017 age^2 ($p < 0.001$). Aboveground biomass and forest species richness are positively correlated (r^2 = 0.59, $p < 0.001$). Analyses of Landsat data show that the land cover of the 3700 km^2 of non-cloud areas in 1999 was: closed forest 78%; open forest 12%, low vegetation cover 4%, sparse vegetation cover 6%. Deforestation from 1987 to 1999 claimed a net 200 km^2 of forest, proceeding at a rate of 0.005 y^{-1}. Of those areas of closed forest in 1987, only 89% remained closed forest in 1999. Consequently, closed forests experienced disruption in the time period at double the rate of net deforestation. The three protected areas experienced negligible deforestation or slight reforestation. Based on 1987 forest cover, 26 000 ha are eligible for forest carbon trading under the Clean Development Mechanism, established by the Kyoto Protocol to the United Nations Framework Convention on Climate Change. Principal components analysis showed that distance to non-forest was the factor that best explained observed patterns of deforestation while distance to forest best explained observed patterns of reforestation, more significant than elevation, distance to rivers, distance to roads, slope, and distance to towns of population > 400. Aboveground carbon in live vegetation in the project area decreased from 35 million ± 4 million t in 1987 to 34 million ± 4 million t in 1999. Projected aboveground carbon in live vegetation would fall to 33 million ± 4 million t in 2006, 32 million ± 4 million t in 2011, and 29 million ± 3 million t in 2035. Projected net deforestation in the research area would total 13 000 ± 3000 ha in the period 1999-2011, proceeding at a rate of 0.003 ± 0.0007 y^{-1}, and would total 33 000 ± 7000 ha in the period 2006-2035. The proposed 7000 ha of forest conservation could prevent gross baseline deforestation of 100 ha (min. 70 ha, max 150 ha) in the period 2006-2035, averting baseline carbon emissions of 10 000 t (min. 6 000 t, max. 18 000 t). Projected gross reforestation in the research area would total 8500 ± 1500 ha in the period 1999-2011, proceeding at a rate of 0.0012 y^{-1} (min. 0.01 y^{-1}, max. 0.014 y^{-1}), and would total 24 000 ± 4000 ha in the period 2006-2035. Gross baseline reforestation for the proposed 7000 ha of reforestation would total 2600 ± 400 ha in the period 2006-2035, representing a baseline removal from the atmosphere of 73 000 t carbon (min. 30 000 t, max. 120 000 t). The proposed reforestation project could sequester 230 000 t carbon (min. 140 000 t, max. 310 000 t) above baseline removal in the period 2006-2035. Through this applied research, we have developed a forest restoration carbon analysis method that quantifies measures of success for forest conservation and projects the future carbon benefit of the restoration of biologically significant forests.

Reference

Gonzalez, P., B. Kroll, and C.R. Vargas. 2006. Forest Restoration Carbon Analysis of Baseline Carbon Emissions and Removal in Tropical Rainforest at La Selva Central, Perú. The Nature Conservancy, Arlington, VA.

Albemarle Peninsula, North Carolina

Jenny Henman, working in collaboration with Ben Poulter at Duke University has completed the estimates of carbon sequestration in fuel grade peat deposits have, as well as GIS analysis of the area of peat which will be inundated under various sea level rise projects. A full literature view of the effects of sea water intrusion on peat deposits proved research carried out to date to be limited and inconclusive. Further research on this topic is needed, with relatively little research having been carried out into the dynamics and processes of coastal peatlands, and saline intrusions. As such, for the purposes of this study hypothetical scenarios are being examined on the likely effect of saline intrusion and carbon dioxide released from projected flooding of deposits from sea level rise.

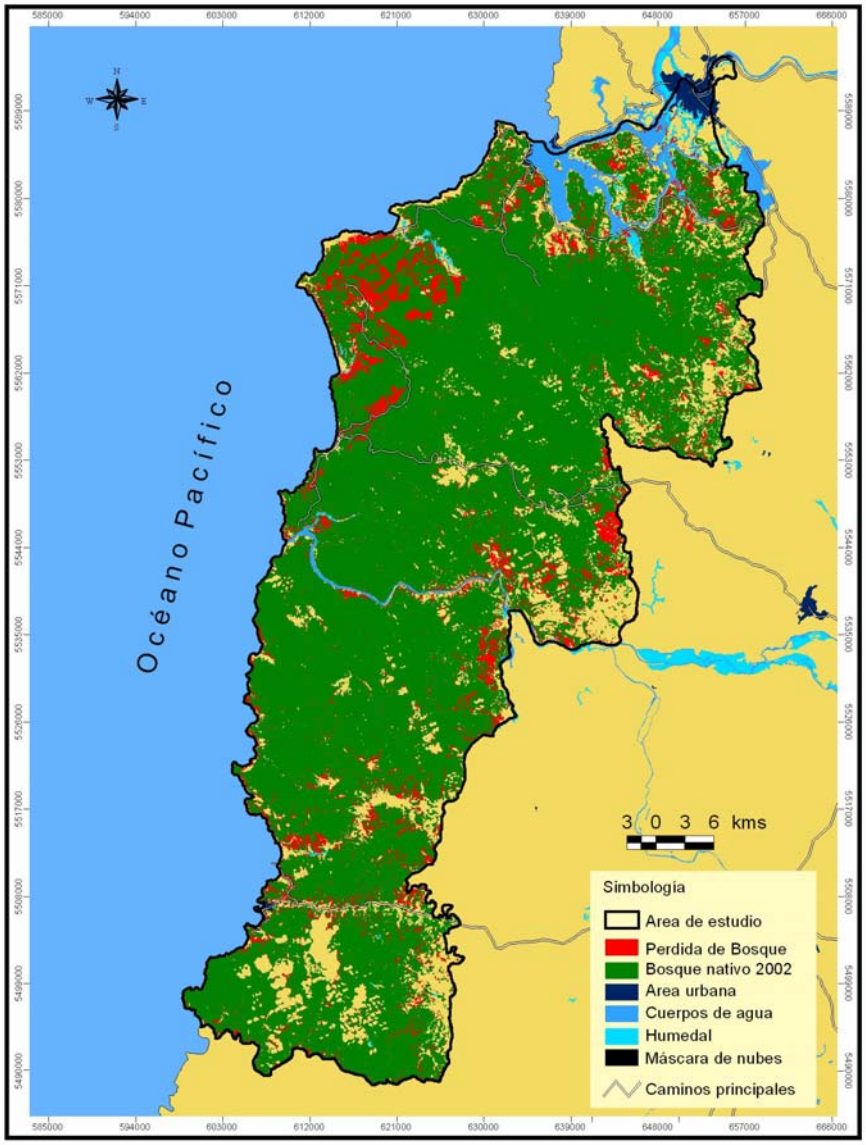
The 1992 and 2001 National Land Cover Database classifications for the peninsula were downloaded, harmonized and then re-classed into new clumped groupings. Trends in land cover between 1992 and 2001 were compared. Between 1992 and 2001 there has been an expansion of urban development on Albemarle Peninsula at the expense of evergreen forest cover. Closer examination of land use trends has revealed the unrealistic assumption of assuming a linear continuation of trends until 2100. With different geographical and anthropogenic factors affecting the Western and Eastern sides of the peninsula, a 'non-business as usual' scenarios likely on the Peninsula with sea level rise because of climatic change and subsidence, and without a spatial model to project future land use change it has been decided that the 2001 land cover maps will form the basis for estimates of changes in carbon sequestration from above ground biomass.

Chile

The Universidad Austral de Chile team has completed atmospheric and terrain correction of the 1986 and 2002 Landsat data for the 3000 km^2 coastal temperate analysis (Figure 3) area and surrounding land. Net deforestation in the period 1986-2002 claimed 13 000 ha of native forest (Figure 4). This resulted from a gross deforestation of 24 000 ha and gross reforestation of 11 000 ha. The team continues the Forest Restoration Carbon Analysis of the area.

Figure 2. Coastal temperate rainforest analysis area (red) in Chile (cartography E. Neira, Universidad Austral de Chile).

Figure 3. Deforestation 1986-2002 in the coastal temperate rainforest of Chile (analysis, cartography A. Lara, E. Neira, and P. Romero, Universidad Austral de Chile).



Task 4: Third-party technical advisory panel meeting

Preparations for the Spring 2006 Technical Advisory Panel are being finalized. The meeting will be held on March 6th and 7th. Currently six speakers have been lined up, namely; Sandra Brown (Winrock International), Patrick Gonzalez (TNC), Bernard Schlamadinger (Joanneum Research), Xiaoquan Zhang (Chinese Forest Academy), Linda Heath (USDA), Joerg Seifert (FAN Bolivia). We are awaiting responses from Greg Ansner from Carnegie Institute of

Washington, and from Antonia Lara from the Universidad Austral de Chile who have also been invited to speak.

Task 5 New Project Feasibility Studies

Task 5 – New Project Feasibility Studies

Project Management

Ongoing stakeholder outreach
On November 1, 2005, Neil Sampson and Sarah Murdock of the Project Team conducted a stakeholder outreach briefing with State of Delaware officials. We met with and briefed Secretary John Hughes of the DE Department of Natural Resources and Environmental Control (DNREC), Secretary Michael Scuse, DE Department of Agriculture and Phil Cherry, Env. Programs Administrator in DNREC. There was a general discussion and agreement that the report will contribute some valuable information to DE to help them explore programs and projects that will encourage carbon sequestration activities. DE officials felt that biomass has the potential for expansion in their state. They also stated that development pressure is the largest issue threatening farming in their state. They also commented that any program that has the potential to increase payments to farmers would be welcome in DE. They also have a forest land protection program in the state for lands 10 acres and up. Any potential funding sources that would bolster that program would be welcome.

Report Part 1: Identify the existing classes of lands in the region.

The Sampson Group has completed the working draft of Part I and it has been reviewed and commented on by the Team which will be sent out to all stakeholders for comment in the next week.

Part I of the report briefly characterizes the Northeast Region to establish the basis for assessing terrestrial carbon sequestration opportunities in the region.

Due to the size of these individual parts of the report, our current plan is to present each part as a separate downloadable file for these initial reviews. At the conclusion of the project, we will edit all the parts so that they flow together for a coherent full report.

Part 2: Recent Trends in Sinks and Sources of Carbon

Work on Part 2 has been proceeding during this period, and an initial draft is nearly ready for team review. A major technical challenge in the analysis is to quantify the impact on carbon stocks and emission/sequestration rates associated with the recent changes in land use and management identified in the region. For example, as pointed out in Part 1, almost 3 million acres were converted from cropland, pasture, and forest into rural and urban development. The impact on carbon stocks in these conversions can range from near-neutral to fairly significant emissions, and we are working to develop the best estimates from the available data.

Agriculture has been declining in the region, and several factors affect carbon stocks on agricultural lands. They include: changing management and crop types, changing cultivation practices (largely adoption of no-till methods), and conversion of cropland to permanent pasture or forest, as well as to development. Estimates are being developed of the extent of these recent changes, as well as the carbon implications of each type of change.

As was done in Part 1, Part 2 will illustrate these changes with tables at the regional, sub-regional, and state levels as appropriate, and provide some county-based map illustrations of the major findings.

The current working outline for Part 2 is:

- Background on Part II
- Overview
- Data used in the analysis
  - The National Resources Inventory (NRI)
  - The Forest Inventory and Analysis (FIA)
  - Conservation Tillage Data
- Methods and Assumptions
  - Geographical Sub-Regions
  - Carbon Dynamics on Forest Lands
    - Forest Growth
    - Change in Forest Area
    - Wood Products
  - Carbon Dynamics on Agricultural Lands
    - Cropland and pasture moving in and out of cultivation
    - Agriculture and forest land moving into development
  - Activity Factors used in calculating carbon sinks and sources
- Results
  - Baselines and carbon change in forests
  - Baselines and carbon change in agricultural lands
    - Land moving in and out of cultivation
    - Changes in cultivation practices
    - Cultivation of organic soils
  - Land use change
- Non-CO_2 Greenhouse gases
- Summary

Part 3: Opportunities for Improving Carbon Storage and Management on Agricultural

Many of the states in the northeast have recently updated their land cover maps. In general, the land cover classification schemes vary among states. For this project, land cover classes were first harmonized and then compiled into five main classes relevant to this project: forest, grazing land, cropland, orchards and other. Most recent land cover data sets for each state in the study region were collected and are being used. Pennsylvania and New York do not have any updated land cover data at this time and therefore for these states the 1992 NLCD map will be used.

The carbon sequestration potential of lands found in the region is being 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. Regionally-specific FIA data will be downloaded and used to estimate carbon sequestration levels over time.

The total cost associated with afforestation of agricultural land has two components. The first component of the total cost is the cost associated with land preparation, planting, and land management for afforestation. This 'conversion cost' is currently being researched for the region through surveys of entities involved in afforestation.

The second component is the opportunity costs associated with loss of income from the current activity. For this section of the analysis, data have been collected on the major crops grown in each state and the respective areas planted over the past 5 years. The next steps are to collect data on the average (over recent years) prices, production costs, and yields for these crops to calculate the average annual profitability per hectare. 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 will be weighted by the area that each crop represents within each state. This will provide a representative opportunity costs for land within each county.

To date progress on Part 3 has been to harmonize all land cover maps for all states, including those for PA and NY using the older 1992 NLCD land cover classification. The area of cropland, grazing land and forested land within the region was calculated. For illustration, the area of agricultural and forested land within Massachusetts is included (Table 1, Figure 1-3)

Table 2: Area of cropland, grazing land, and forested land within Massachusetts

	Acres	hectares
Cropland	222,605	90,088
Grazing land	91,278	36,940
Forest Land	2,965,954	1,200,322

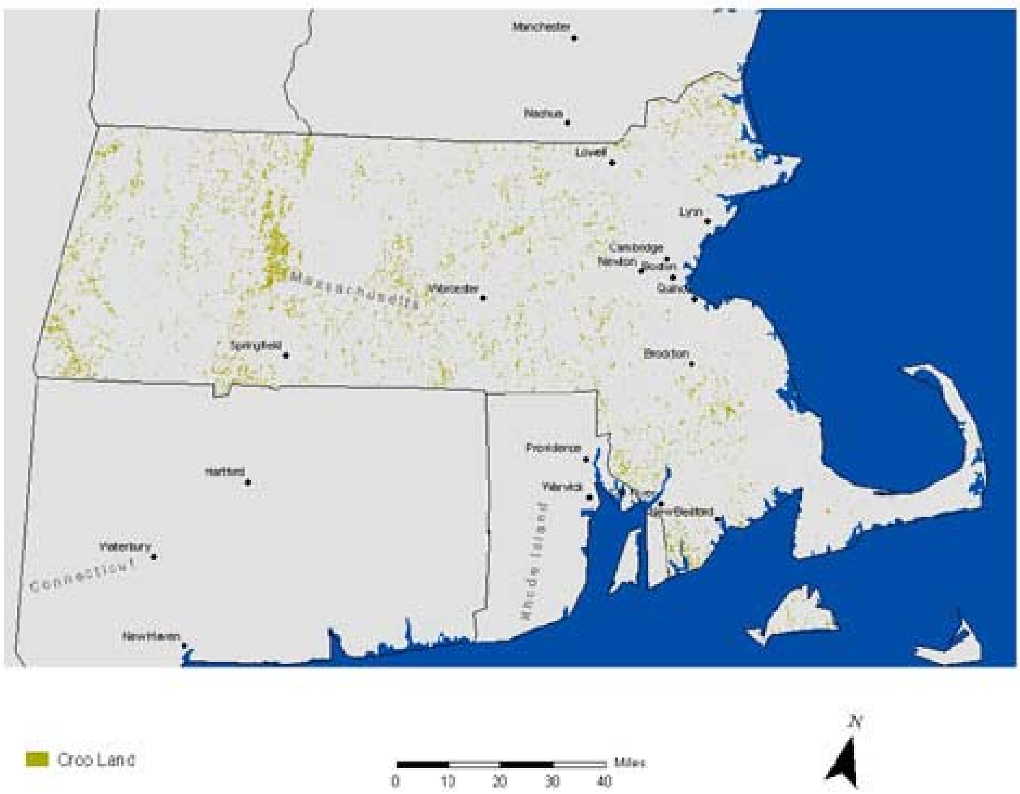


Figure 4. Area of croplands in Massachusetts

Figure 5. Area of grazing land in Massachusetts

Figure 6. Area of forest lands in Massachusetts

During the initial investigation into 'conversion costs' associated with reforestation, costs were found to vary significantly across the region. Effort was made to investigate costs within in all states. A summary of costs compiled at this point is included in Appendix 3-1.

The dominant agricultural land uses for the region as a whole are corn, hay/pasture, and soybeans (Table 2). With corn and hay comprising well over 3 million acres each; soybeans are a distant third with just over 700,000 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. This information along with the profitability data to be collected will be used to asses the opportunity costs associated with afforestation.

Table 3: Preliminary estimates of area of crops currently planted within the 11 state region

Crop	Acres	Hectares
Corn	3,234,000	1,308,800
Hay	3,763,000	1,522,886
Oats	195,000	78,917
Wheat	273,000	110,483
Soybeans	710,000	287,337
Barley	82,000	33,185
Potatoes	37,400	15,136
Tobacco	3,000	1,214

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

Current data on forest inventories, carbon storage, and current practices in forestry that influence carbon stocks is being examined and compiled. A list of the major classes of possible alternate forest land managements within the eleven state region will be developed and assessed for their potential to sequester carbon. Currently, the list of activities includes: improved stocking of understocked stands; and improved forest management that includes extending forest rotation age; expanded streamside management zones (conservation); fertilization; thinning (species balance and stocking control); and conservation of existing forests. As this list is a preliminary, some of these activities may not be relevant for the region and therefore not assessed in the full analysis.

The economic model will utilize methods similar to past research conducted by Winrock in different regions (see, for example, Sohngen, 2003, 2004a and 2004b). However, this region is substantially different than the other regions in which economic analysis has been conducted, thus, it is expected that the earlier used methods will be adapted for use in the Northeastern region.

Conclusions

Through the completion of the research in the Selva Central, Peru, The Nature Conservancy, in collaboration with partners ProNaturaleza have developed a forest restoration carbon analysis method that quantifies measures of success for forest conservation and projects the future carbon benefit of the restoration of biologically significant forests.

Trials and analyses of the effectiveness of the Multispectral 3-D Aerial Digital Imagery (M3DADI) in three different environments has now been completed by Winrock International. Effectiveness, precision levels and prices varied between the Open and Closed Forest locations and the Delta National Forest in Mississippi where this technique for estimating carbon stocks was carried out. An overall cost comparison between field inventory costs versus remote analysis using the M3DADI proved that the use of this remote technique is more cost effective.

The baseline study for North Carolina is nearing completion. Final carbon estimates for different land cover classes have now been researched, and geospatial maps of flooding projections for 2100 based off different sea level rise projections developed by the IPCC. Conclusive research on the effect of flooding of peat with sea water does not to date exist. In the light of lacking scientific research hypothetical scenarios are being modeled to examine the possible effect of sea water flooding on carbon storage and release on Albemarle Peninsula.

Although still in its early stage the new research projects in California and the North Eastern United States are progressing very well. LIDAR and Quickbird imagery is being analyzed for the project sites in California, and carbon estimates derived from field inventories for corresponding locations completed. Part 1 of the North East feasibility study has now been released for stakeholder review, and other parts of the project progress as planned.

REFERENCES

- Birdsey, R.A. 1996. Carbon storage for major forest types and regions in the conterminous United States. In: Sampson, R.N., Hair, D. (eds) *Forests and Global Change, Volume 2: Forest Management Opportunities for Mitigating Carbon Emissions*. American Forests, DC, USA. Pp. 1-26, 275.
- Birdsey, Richard A. 1996. Appendix 2 and Appendix 3, in *Forests and Global Change, Volume 2: Forest Management Opportunities for Mitigating Carbon Emissions*, American Forests: Washington, DC.
- Block, Nadine E., V. Alaric Sample. 2001. Industrial Timberland Divestitures and Investments: Opportunities and Challenges in Forestland Conservation. Pinchot Institute for Conservation Washington DC, USA. Pp 5, 9-11, 15.
- Boyer, W.D. 1993. Long-term development of regeneration under longleaf pine seedtree and shelterwood stands. Southern Journal of Applied Forestry 17: 10-15.
- Boyer, W.D. 2000. Long-term effects of biennial prescribed fires on the growth of longleaf pine. Pages 18-21 in W. Keith Moser and Cynthia F. Moser (eds.). Fire and forest ecology: innovative silviculture and vegetation management. Tall Timbers Fire Ecology Conference Proceedings, No. 21. Tall Timbers Research Station, Tallahassee, FL.
- Brown, S. 1997. Estimating Biomass and Biomass Change of Tropical Forests: A Primer. FAO Forestry Paper 134, Rome, Italy.
- Brown, S., Calmon, M. and Delaney, M. 2000. Development of a Deforestation and Forest
- Brown, S., L. R. Iverson, and A. E. Lugo. 1994. Use of GIS for estimating potential and actual forest biomass for continental South and Southeast Asia, pp. 67-116 in V. H. Dale (Ed.), The effect of land-use change on atmospheric CO_2 concentrations, Springer-Verlag, New York.
- Brown, S., M. Delaney, D. Slaymaker, D. Shoch, W. Sabido, and D. Novelo. 2003. Estimating the Carbon Content of Pine-Savanna Vegetation in the Rio Bravo Carbon Sequestration Pilot Project Using Digital Aerial Imagery. Winrock International, Arlington, VA.
- Brown, S.L. and Schroeder, P.E. 1999. Spatial patterns of aboveground productions and mortality of woody biomass for eastern US forests. *Ecological Applications* 9: 968-980.
- Chomitz, K. 2002. Baseline, leakage and measurement issues: how do forestry and energy
- Dale, V H., R. V. O'Neill, M. Pedlowski, and F. Southworth. 1993. Causes and effects of land-use change in central Rondonia, Brazil. Photogrammetric Engineering and Remote Sensing 59:997-1005.
- Degradation Trend Model for the Guaraqueçaba Climate Action Project. Winrock International,
- Ducks Unlimited. 2003. Forest Change Detection in the Lower Mississippi Valley.
- Ebinger, M. H., D. A. Cremers, D. D. Breshears, P. J. Unkefer, S. A. Kammerdiener, M. J.Ferris.

- Echeverria, C. and A. Lara. 2004. Growth patterns of secondary Nothofagus obliqua-N. Alpina
- Edmisten, J.E. 1963. The ecology of the Florida pine flatwoods. Ph.D. thesis, University of Florida, Gainesville.
- Florida Forever. Website. Dec. 20, 2004 <http://www.dep.state.fl.us/lands/acquisition/FloridaForever/default.htm>
- forests in southern Chile. Forest Ecology and Management 195: 29-43.
- Gagnon, J.L., E.J. Jokela, W.K. Moser and D.A. Huber. 2003. Dynamics of artificial regeneration in gpas within a longleaf pine flatwoods ecosystem. Forest Ecology and Management 172: 133-144.
- Gayoso, J. and B. Schlegel. 2003. Estudio de línea de base de carbono: Carbono en bosques nativos, matorrales y praderas de la Décima Región de Chile. Universidad Austral de Chile, Valdivia, Chile.
- Gholz, H.L. and R.F. Fisher. 1982. Organic matter production and distribution in slash pine plantation ecosystems. Ecology 63:1827-1839.
- Gholz, H.L., Fisher, R.F., and W.L. Pritchett. 1985. Nutrient dynamics in slash pine plantation ecosystems. Ecology 66:647-659.
- Gonzalez, P., B. Kroll, and C.R. Vargas. 2004. Forest restoration carbon analysis in moist tropical forest at La Selva Central, Peru. Abstracts of the 89th Annual Meeting of the Ecological Society of America, August 1-6, 2004. Ecological Society of America, Washington, DC.
- Gonzalez, P., B. Kroll, and C.R. Vargas. 2006. Forest Restoration Carbon Analysis of Baseline Carbon Emissions and Removal in Tropical Rainforest at La Selva Central, Perú. The Nature Conservancy, Arlington, VA.
- Hall, C. A. S., H. Tian, Y. Qi, G. Pontius, J. Cornell and J. Uhlig, 1995a. Spatially explicit models of land use change and their application to the tropics. DOE Research Summary, No. 31. (Ed. by CDIAC, Oak Ridge National Lab); and Hall, C. A. S., H. Tian, Y. Qi, G. Pontius, J. Cornell and J. Uhlig, 1995b. Modeling spatial and temporal patterns of tropical land use change. Journal of Biogeography 22: 753-757.
- Hall, Myrna and Dushku, Aaron. 2002. Spatial modeling of the averted deforestation baseline for the Noel Kempff Mercado Climate Action Project, Bolivia. Winrock International.
- Heyward, F. 1939. Some moisture relationships of soils from burned and un-burned longleaf-pine forests. Soil Science 47: 313-325.
- Heyward, F. 1937. The effects of frequent fires on profile development on long-leaf pine forest soils. Journal of Forestry 35: 23-27.
- Jenkins, J.C., Chojnacky, D.C., Heath, L.S. and R.A. Birdsey. 2003. National-scalebiomass estimators for United States tree species. Forest Science 49: 12-35.
- Kaimowitz, D. And A. Angelsen. 1998. Economic models of tropical deforestation: a review. Center for International Forestry Research, Bogor, Indonesia.
- Kant, Z., D. Gori, C. Enquist & W. Parton. 2003. Carbon Sequestration and Semi-arid Grassland Restoration and Management in the Apache Highlands Ecological Region. The Nature Conservancy, Arlington, VA.

- Kant, Z., W. Parton & M. Ebinger. 2003. Carbon Sequestration and Native Prairie Restoration in Kankakee Sands, Indiana. The Nature Conservancy, Arlington, VA.
- Kreps, Brad. 2003. Establishing Land Cover Baselines and Prioritizing Sites for Reforestation for Carbon Sequestration and Reforestation of Mined Lands in the Clinch and Powell River Valleys. The Nature Conservancy, Arlington, VA.
- Kronrad, G. D., R. Bates, and C. Huang. 2002. Enhancement of Terrestrial Carbon Sinks Through Reclamation of Abandoned Mine Land in the Appalachian Region. Stephen Austin State University, Nagodoches, TX.
- Kush, J.S., W.D. Boyer, R.S. Meldahl and G.A. Ward. 1999. Precommercial thinning intensity in longleaf pine: effect on product volume and value. *In* Longleaf Pine: a Forward Look; Proceedings, Second Longleaf Pine Conference, 1998 November 17-19; Charleston, SC. *Edited by* John S. Kush. Longleaf Alliance Report No. 4 pp. 106-108.
- Laboratory, Los Alamos, NM.
- Laessle, A.M. 1942. The plant communities of the Welaka area with special reference to correlation between soils and vegetational succession. University of Florida, Gainesville.
- Markewitz, D., Sartori, F., and C. Craft. 2002. Soil change and carbon storage in longleaf pine stands planted on marginal agricultural lands. Ecological Applications 12(5): 1276-1285.
- McCulley, R.D. 1950. Management of natural slash pine stands in the flatwoods of south Georgia and north Florida. U.S. Department of Agriculture Circulation No. 845.
- Mooney, S. 2003. Measurement and Monitoring Costs: influence of parcel contiguity, carbon variability, project size and timing of measurement events. Winrock International, Arlington, Virginia. 34 p
- Neira, E., P. Romero, and A. Lara. 2004. Complementación del estudio para el diseño de una línea de base para captura de Carbono en la Xma Región de Chile. Universidad Austral de Chile, Valdivia, Chile.
- Ober, L.D. 1954. Plant communities of the flatwood forests in Austin Cary Memorial Forest. M.S. thesis, University of Florida, Gaineville.
- Outcalt, K. 1993. Southern pines performance on sandhill sites in Georgia and South Carolina. Southern Journal of Applied Forestry 17: 100-102.
- Pearson, T., D. Shoch & S. Brown. 2003. Carbon Sequestration Estimates for Bottomland Hardwood Restoration on Cropland. Winrock International, Arlington, VA
- Pearson, T., D. Shoch & S. Brown. 2003. Feasibility for Carbon Sequestration through Bottomland Hardwood Restoration in Riparian Zones of the Susquehanna Watershed. Winrock International, Arlington, VA.
- Pienaar, L.V. and K.J. Turnbull. 1973. The Chapman-Richards Generalization of Von Bertalanffy's Growth Model for Basal Area Growth and Yield in Even-Aged Stands. Forest Science 19 (1): 2-22.

- Platt, W.J., G.W. Evans and S.L. Rathbun. 1988. The population dynamics of a long-lived conifer (*Pinus palustris*). The American Naturalist. Vol 131 (4): 491-525.
- Pontius, G. 1994. Modeling tropical land use change and assessing policies to reduce carbon dioxide release from Africa. Ph.D. dissertation, State University of New York, Syracuse,New York; Tian, H. 1995. Spatial and temporal patterns of carbon flux and land use/cover at scales from landscape to the biosphere: an empirical study with observation and modeling. Ph.D. dissertation, State University of New York, Syracuse, New York; and Qi, Y. 1994. Human-induced biospheric change and the global carbon cycle: a spatialmodeling approach and its application to tropical Asia. Ph.D. dissertation, State University of New York, Syracuse, New York.
- projects compare? Climate Policy 2(1): 35-49.
- Results from the Field and Implications for Carbon Sequestration. Los Alamos National
- Richards, F.J. 1959. A flexible growth function for empirical use. Journal of Experimental Botany 10(29):290-300.
- RPA (Resources Planning Associates, Inc.) ECOPLOT software, Ithaca, NY
- Sande, Jon Bingen. 2003. Industrial Structures: Who Will Own the Forests? Vaxjo University International Conference on Forest Industry and Markets. 19 – 22 May 2003. Vaxjo, Sweden.
- Schlamadinger, B. and Marland, G. June, 2000. Land Use & Global Climate Change: Forests, Land Management, and the Kyoto Protocol. The Pew Center on Global Climate Change.
- Schriever, J.R. & R.G. Congalton. 1995. Evaluating seasonal variability as an aid to cover-type mapping from Landsat Thematic Mapper data in the Northeast. Photogrammetric Engineering and Remote Sensing 61 (3):321-327.
- Shoch, D, Brown, S., Delaney, M. and Broadwell, R. 2002. An Assessment of Carbon Sequestration Potential of Longleaf Pine Restoration and Conservation in Georgia. A Winrock International Report to Oglethorpe Power Company. Pp. 32.
- Slaymaker, D.M., K.M.L. Jones, C.R. Griffin & J.T. Finn. 1996. Mapping deciduous forests in southern New England using aerial videography and hyperclustered multi-temporal Landsat TM imagery. Pages 87-101 in Gap Analysis: A Landscape Approach to Biodiversity Planning, ASPRS, Bethesda, MD, USA
- Sohngen, B. 2003. Quantifying Carbon Market Opportunities in the United States: A report on the costs of sequestering carbon by changing forest management in Arkansas, Louisiana, and Mississippi. Draft Report Submitted to Winrock, International. May, 2003.
- Sohngen, B. 2004a. Quantifying Carbon Market Opportunities in the United States: A report on the costs of sequestering carbon by changing forest management in Georgia. Draft Report Submitted to Winrock, International. May, 2004.
- Sohngen, B. 2004b. Quantifying Carbon Market Opportunities in the United States: A report on the costs of sequestering carbon by changing forest

management in California. Draft Report Submitted to Winrock, International. February, 2004.
- Spanner, M.A., L.L. Pierce, D.L. Petersen & S.W. Running. 1990. Remote sensing of temperate coniferous forest leaf area index: The influence of canopy closure, understory vegetation and background reflectance. International Journal of Remote Sensing 11(1)95-111
- Stoddard, H. 1969. Memoires of a Naturalist. University of Oklahoma Press. 303 pp.
- Total Carbon Measurement in Soils using Laser-Induced Breakdown Spectroscopy:
- Wahlenberg, W.G. 1946. Longleaf pine: Its use, ecology, regeneration, protection, growth, and management. Charles Lathrop Pack Forestry Foundation and USDA Forest Service. Washington, DC 429 pp.
- Wilent, S.. 2004. Investors Increase Timberland Holdings. The Forestry Source Vol. 9, No.12. Bethesda, MD. Pp1-4.

Appendix

Estimates of the 'conversion costs' for reforestation/afforestation across the northeast region.

State	Cost Variable	$ per acre	Year	Comments
Connecticut	Streamside Restoration and Enhancement	500-1,000	2001	Livestock fencing, streambank stabilization (using bioengineering techniques), and streambank revegetation are techniques used to restore riparian habitat in partnership with private landowners and other partners. Restoration of streamside forest habitats reduces runoff and erosion and improves the water quality in the streams. Forested riparian areas provide habitat for wildlife that depend on these areas for breeding and as a dispersal corridors. Livestock fencing at $1-2 per foot is often combined with tree and shrub planting at $500-$1,000 per acre. Source: Partners for Fish & Wildlife Program Steward B. McKinney National Wildlife Refuge, P.O. Box 1030, Westbrook, CT 06498, 860 399-2513 fax: 860 399-2515
Delaware	Forest restoration	400	2001	Delaware has lost over 60 percent of its forest lands since European settlement in the 1600s. In 2001, the Partners Program began a forest initiative to replant tree seedlings on marginal agricultural lands. With the help of the Natural Resources Conservation Service and the Delaware Forest Service, the Partners Program provided 300,000 native hardwood tree seedlings and the necessary technical assistance to landowners to replant 1,005 acres of agricultural lands. An additional 700 acres were slated to plant in the spring of 2002. Source: Partners for Fish and Wildlife Program, U.S. Fish & Wildlife Service, 177 Admiral Cochrane Drive, Annapolis, MD 21401, 410 573-4500, fax 410 269-0832.

State	Cost Variable	$ per acre	Year	Comments
	Agricultural land set aside for wildlife	70		Delaware Wildlife Habitat Enhancement Program: WHEP provides technical and financial assistance to enhance and/or protect early successional stage wildlife habitat. It offers $70 per acre per year for 5 years to landowners who agree to set aside part of their agricultural land for wildlife. The land must either be left fallow or planted with approved species. Fees are paid in lump sum for 5 years upon signing a contract. Source: Division of Fish and Wildlife, 89 Kings Hwy, Dover, DE 19977, (302) 739-5297, William.Whitman@state.de.us).
Maine	Riparian forest buffers, hand planted	1,600-2,100	2005	Estimated establishment Costs per acre
				Item Site 1 Site 2
				Tree & shrub planting (labor) $358 $550
				Plants $560 $700
				Tree shelters & mats $664 $816
				Total costs $1,582 $2,066
				Per acre costs differ between the two sites primarily because of differences in planting rates. The other major factor was the different labor costs for shrubs. Generally unit costs for the same materials (species of plants, shelters, stakes and mats) at the two sites were identical. Source: Economics and Survival of Hand Planted Riparian Forest Buffers in West Central Maine. NRCS. 967 Illinois Avenue, Suite #3, Bangor, ME 04401 www.me.nrcs.usda.gov
Maryland	Buffer Incentive Program	218-729	2000	Riparian forest buffer panel (Chesapeake Bay area incentive program) One time payments of $300 per acre for planting and maintenance of minimum 50-foot forested buffers along streams/ shorelines. Source: Wye Research & Education Center, University of Maryland. Maryland Cooperative Extension. http://www.riparianbuffers.umd.edu/home.html
Massachusetts	Planting & maintenance	350-400	2005	In Massachusetts site preparation is most expensive because the use of chemicals. Chemicals may cost $12 to $24/acre. Bare root stock: $125 to $230/seedling; and hardwoods seem more tolerant to deer damage Source: Mike Downey, (413) 442-8928 ext. 35 Service Forester District No1 Department of

State	Cost Variable	$ per acre	Year	Comments
				Conservation and Recreation Massachusetts
				Foresters charge for planting: $30-1,000/1,000 seedlings and it is done mostly for Christmas trees Source: David Kittredge, CF, 413 545-2943 Department of Natural Resources, UMass
New Hampshire				
New Jersey	Reforestation project	400	2001	The Partners Program implements reforestation projects particularly in areas where forest areas have been fragmented by development or agriculture. Source: Partners for Fish & Wildlife Program, U.S. Fish and Wildlife Service, New Jersey Field Office
New York	Afforestation/ Reforestation	450-550		Purpose: Site preparation, planting, seeding and practices to ensure forest establishment for timber and fiber production and carbon sequestration. In the cost share FLEP progr. actual costs should not exceed the following rates:
				Softwood tree planting (seedlings & planting) $175/acre
				Hardwood tree planting (seedlings & planting) $200/acre
				Site preparation for tree planting $ 75/acre
				Site preparation for natural seeding $ 150/acre
				Tree shelters $ 150/acre
				Weed barriers $ 50/acre
				Fencing $ 2/foot
				Source: FLEP 2 - Forest Land Enhancement Program Refer to NRCS Conservation Practice Standard 490, Forest Site Preparation. ftp://ftp.ftw.nrcs.usda.gov/pub/nhcp/pdf/490.pdf and Tree/Shrub Establishment 612 New York State Dept. of Environmental Conservation http://www.dec.state.ny.us/website/dlf/privland/flep/flep2.pdf

State	Cost Variable	$ per acre	Year	Comments
Pennsylvania	Riparian Forest Buffer Program	2,500	2005	The federal government provides 75% of the cost to install the buffer, and the landowner is responsible for the remaining 25 %. The budget is based on $2,500 per acre, so the government's share is $1,875 per acre and the landowner's is $625 per acre. The landowner pays all expenses up front, and funds are usually reimbursed within six weeks from the date of installation. Source: Stroud Water Research Center, 920 Spencer Road, Avondale, PA 19311. 610 268-2153, fax:610 268-0490 http://www.stroudcenter.org/research/riparianbuffer.htm
	Large scale plantation forestry		2005	Tree planting, labor cost: 28 to 35 cents/seedling Average plantation density: 600 seedlings/acre Labor cost: 168 to 210 $/acre Source: James Bailey, Pennsylvania Bureau of Forestry Forest Genetics/Regen Specialist, 717-787-2708
				Site prep activities are: vegetation control with herbicides $20/acre, and mechanical site prep. Like mowing to reduce brush: $25-30/acre; Seedling cost: 10-17.5 cents/seedling for non profits; Deer control fencing cost: $1.75/foot - $105/acre, and $1,248/acre without gates, gates cost: $300/2gates but gates are recycled several years. Tree tubes: $4.5/seedling, includes tube, stake & installation. Fencing or tubes are alternatives, they are not used together as these are expensive costs. Fence maintenance: $120/hour two men crew walking the fence for repairs, several times per year, during 3 years Source: Alex Day, Chief, Nursery Operations Section Pennsylvania Bureau of Forestry, Dept. of Conservation and Natural Resources. 814 364-5150 total tree planting per year: 2500 acres
Rhode Island			2005	In Rhode Island tree natural regeneration is more important than tree planting. Cost for NR are: Soil scarification: $240-600/acre Seedlings costs varies by species Source: Bureau of Natural Resources, Forest Div. 401 647-1439

State	Cost Variable	$ per acre	Year	Comments
Vermont	Tree & shrub planting	500-1000	2001	Riparian habitat - Agricultural land clearing and loss of streamside forests have had a detrimental impact on water quality. Loss of forested riparian areas eliminate habitat for wildlife that depend on these areas for breeding and as a dispersal corridors. Livestock fencing at $1-2 per foot is often combined with tree and shrub planting at $500-$1000 per acre. Source: Partners for Fish & Wildlife, US Fish & Wildlife Service, Lake Champlain Fish & Wildlife Resources Complex, 11 Lincoln St., Essex Junction, VT 05452 802 872-0629 http://www.fws.gov/partners/pdfs/VT-needs.pdf
	Forest restoration buffers	1320	2005	Mary Drodge (802) 265-8645 Nature Conservation, West Haven, Vermont Most planting is done trough Federal funding system to a minimum of $220 stems/acre, at 6US$/tree. This value includes: cost of tree species, tree tube, stakes, mat and labor. Right now this system is considering increasing the funds provided as it is not enough to pay labor and using volunteers for planting is not efficient in terms of planting quality.